MAN'S GADGETS *OR* THE MACHINES THAT DO THINGS

TARSICIO PASTRANA SALCEDO

Lacería

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INTRODUCTION

This book has its origin in the research I did for my PhD studies in architecture, at that time it was not easy for me to look for the publication of the work, I was more interested in finishing my studies and continue with my life. Time and chance led me to publish part of that thesis in my first book, however that publication did not cover all the work done so far, so that's what's decided by the editors, leaving out the part of the analysis of the machines and taking only the explanations of hydraulic engineering, mestizo processes and treaties and their analysis, the book published in 2010, two years after obtaining the PhD, represented my debut feature *Hydraulic Engineering in Mexico sixteenth century* and despite the happiness that caused me that first publication had the feeling that there was something that I still need to do. Besides, I never found a clear explanation as to why only half of the thesis had been published, perhaps the number of pages, or the choice of a topic evaluated as being of greater interest, that question had been going around in my head for some time. Why had hydraulic machines been left out?

Machines and their relationship with architecture was one of the main ideas that led me to begin with my research, it was the central topic of my master's thesis and later also in my

doctoral thesis, I needed to analyze the intangible aspects of machines, which was associated; considering that the architectural space is one more piece of a supply chain, these machines produced and architecture is configured to produce, perhaps nowhere do we find a more demolishing argument towards pragmatism than in an architectural space dedicated to produce, the machine requires an adequate surrounding configuration, this is important in the field of conservation since the building is one more piece of that productive process; I think I should clarify that the part that was excluded in that first publication spoke mainly of wooden machines that were moved by water and served in various production processes, in the physical and temporal space of the Viceroyalty of New Spain, these machines were called *ingenious* derived from latin *ingenius* formed by *in* within and *genus* generate, the root refers to creation.

Interesting, actually if we analyze correctly, what would the hydraulic wood machines have to do with architectural conservation? I would say that there's a strong relationship between these elements, as I mentioned, the architectural space is designed so that the machine and the productive process have an optimal operation, then the architecture is the result of these factors, in addition, hydraulic devices exist from millennia before the industrial revolution of the second half of the eighteenth century.

Another characteristic of the hydraulic mills that fits in with several current and current themes is their sustainability when using the hydraulic resource that is later reintegrated into nature. We could think of several industrial revolutions throughout history and something more transcendental, some of those industrial revolutions were more environmentally friendly, this industrial revolution that has lasted for millennia and that is based on the hydraulic inventions was only altered in the 19th century when the volumes of production, new sources of energy and new schemes of organization completely altered the schemes that had worked previously, without a doubt these topics deserve to be considered, now, since this is a singular topic it would be convenient to explain from where this interest arose?

How do things work, how are they built? These questions directly concern a part of the heritage analysis that is not as visible as the artistic, stylistic part or the building itself that we perceive with our senses in a tangible way, even the way of executing the constructive systems that in most cases are not perceived would be in the realm of the intangible, if it is true that with a physical result the same architectural product, however that procedure like the recipe for preparing a *mole poblano* carries the instructions to produce an object, I believe that these aspects, so neglected in the field of conservation, are vital for a solid project. It leads us

to reflect on the compatible techniques and the original techniques. Knowing how it was built and how it worked allows us to propose compatible techniques when intervening in an architectural space. These reflections have always led me to search for the origin of these preferences in my mind.

When I was a child I was interested in both fields, how it is built and how it works, most of my games were to build things, to construct, this was mixed with another field that has given me great satisfaction, that of heritage, particularly architectural heritage and its conservation, this relationship between conceiving an object and creating it, understanding it and in an adult stage conserving it is a process that is implicit in my professional life, the materialized idea, the constructed idea, the tangible of the intangible. Perhaps when I was a child building castles with wooden cubes I did not interpret how those games would become my way of life, many times the hobbies that are awakened in childhood do not survive until adulthood.

That these tastes and interests migrated from my childhood to adulthood, I have to thank my parents, they encouraged my taste for building and construction, my father visited old houses and old buildings in the historic downtown of Mexico City where my father was born and lived the first years of his life, these visits determined my preferences for the conservation of

spaces, my mother gave me the freedom to build as much as I wanted, houses in the garden made with mattresses, blankets and pillows, I also insistently encourage my taste for reading and playing. When I studied architecture with the strong idea of studying monument restoration in mind, my interest moved from the simple object to the story that that object told us, observing those surviving spaces led me to ask questions: How many people had lived there? How many life stories? Dramas, joys and lives, many lives the objects as a testimony of history how many people like us, although it is true that they were other times people in their passions have changed very little, we have only dressed in technology.

The history in the object, the questions that could not be answered, that was my interest, when I was working in the old Jesuit school of Tepotzotlán in Mexico State at the north of the Mexico City, I came across the building that would be the subject of my master's degree in restoration, a few water mills of the viceroyalty a little ruined and in a state of abandonment, the museum that now exists in the old schools had them under its custody and the few living spaces worked as warehouses, the first time I visited them I found it impressive, that air that floats in the building that was once the center of a frenetic activity, the sounds and the people left, leaving only the abandoned spaces, without machines, noise or odors, only the vegetation and

the fauna that have been colonizing the space, the only sounds of silence, the wind among the vegetation and some insects. Another thing that captured my attention immediately was the relationship of the building with the water, where before there were deposits and channels with running water now there was vegetation and in some cases a puddle, these images awakened my imagination and encourage me to investigate to discover, the first time I entered that abandoned space I felt I was on an exploration to find something amazing, without realizing it in a fortuitous way, with the small push of some genius I was joining the tastes of my childhood in a project of adulthood, preserve the heritage and understand how the architectural space works.

Visiting that building was to fill my head with questions such as: what were the machines like? what was the production process like? what was the purpose of that canal? where did the water circulate? how much did they produce? how were they used? the main question that gave rise to the research of mastery had to do with reading the vestige and collecting information contained in the object. would it be possible for the building to speak to us and tell us its history through understanding those vestiges? Becoming someone who investigates the hidden history of the building is something strongly related to the restorer of architecture, even before

deciding how to intervene should be collected as much information as possible, is part of the assessment and the accuracy of the opinions depends largely on the project decisions, hence the importance of developing the necessary and appropriate techniques to read the building.

So, enter the world of hydraulic engineering and its relationship with architecture, deepen the reading of space, in the identification of machines, in the understanding of its operation and above all in a relationship that continues to govern my research, water and architecture, indissoluble factor that leads me to deepen this vital relationship, water where we need it and where we need it, a bad hydraulic engineering design makes it difficult to live and work.

Already in the PhD I worked with several machines, to verify that each type of machine, even if it does not exist, leaves an imprint in the space that can be read and that in this way we can identify the identifiers of different scale that define the objects that we try to preserve. That historical and technical analysis, in which some spaces are analyzed and machines are reconstructed to see their relationship with architecture, is what is contained in this book.

As time passed by, the opportunity was given to publish the material that had been left out of that first book, I reviewed, changed,

updated mainly images, to try to give a fluid reading, I found some mistakes, especially in some of the reconstructions of the machines, in advance I offer an apology, the initial function of these virtual reconstructions was the didactic one so we decided with the editors to keep them as they had been included in the thesis, In my apology I can say that the difference between the publication of the thesis and the opportunity to publish the part that was left out of the first book is 12 years, returning was fun, however the decision was made not to change the texts, only to work some formal aspects the drawings are made by me more in an effort to understand first and then explain the space and its relationship with the machine, that by an artistic inclination, the maps and photographs are of my authorship.

Taking up the work again also brought to my memory the moments in which I was advised to carry out the work, I remembered the director of this work José Manuel Mijares y Mijares, dear professor of the postgraduate course of architecture of the UNAM, also Leonardo Icaza, national specialist in water architecture, Luis Arnal Simón who participated as a reader, the memory is emotional because between that 2008 and this 2020 all three died, also a recognition to a member of that synod that is among us, Mario Carmona who in spite of my inclination towards architecture did not allow me to move away from Engineering. I cannot conclude without thinking about my

brothers, Adela and Daniel, accomplices of my madness and my games helped and are helping to keep these interests turned into a way of life.

I have to say in conclusion that I enjoyed very much what I did for my doctoral thesis and that I have enjoyed the work that has been done for the publication, reaffirms those tastes instilled by my parents, between the operation and construction and the conservation of the object, I personally cannot conceive the historical study of architecture without those analyses and therefore I am a fervent believer that the conservation of the architectural heritage begins in the recording analysis and study of those objects that are testimony to history.

I. THE SUGAR MACHINE

1. Introduction

The sugar was together with mining the most profitable activities from the colonial era. Unlike other processes in which the work was handmade and in a certain way has been adapted to the work from that time, either way the transformation of the production methods and techniques that catapulted to the establishments which more pre-industrial innovations incorporated, the sugar production requested the biggest economical investment and production capability available on that moment; all the improvement principles of production create innovations who place them in the industrial activities scope, the profits relied on the success of implementing these improvements that in most cases were applied as machines.

Because of the driving forces par excellence on that time were the hydraulics those were applied systematically to the sugar production, on those days there were two establishments, there craft one and the industrial one, on the second one all the hydraulic infrastructure were key, from the irrigation process to preparing the product, the difference between one and the other impacted the productivity.

Was not yet conceived a mill without the diving force of the water, thus complexity became more notorious, machines that moves with water in the mills became the heart itself, and water was the second major input just behind the cane itself, not only as diving force but also as input on the production process and also very important for the

high amount of water required by the crops needs to develop properly, that means, the water was not only used as diving force, within the obtaining sugar process and from the irrigation of the fields it was a key input, therefore hydraulic facilities were not only conceived for the movement of the water wheels.

Regarding sugar mills, the required water was even higher than in other mills, that's why their location were always affected by this situation unlike other establishments like the Haciendas de Beneficio that in locations where water was scarce machines were replaced by horse mills, sugar cane dependency from the hot weather areas linked to the vast supply of water rise the water dependency like in any other mills. The dependency to the water and also to the machine who use it to move on the sugar production that this machine gave the name to the whole establishment, this way it was known as sugar mill or just mill that was the name of the machine.

To develop the hydraulic machine topic used in the sugar's production it's important to give a comprehensive view about how complex was the whole process this way it could be analyzed as a whole the use of the hydraulic technology on the building and operation of a sugar mill.

Like I already said before on this thesis I'll bring a comprehensive view about the history of the sugar at New Spain, the operation of establishments, the manufacturing process of the sugar and then remark on the hydraulic technology applied to the sugar manufacturing that is the main topic of this thesis and that is why this will be the most important one.

2. History of Sugar

The origin of the sugar cane, after several researches, relies on Melanesia, Oceania¹, since where it traveled to mainland and kept traveling from west coast to India, where it became widespread the consumption, at the beginning as fruit that was chewed to get its juice, also as ornamental plant.

From this place it took two different paths, on the one hand it rooted on India where they began with large-scale crops, on the other hand it traveled north to China. Sugar cane is mentioned in antiquities mythological texts from this region between 100 to 800 B.C. and then between 200 B.C. and 200 A.C. is reflected on administrative texts, although the oldest text where the sugar cane is reflected is Manu Code, written around year 1000 B.C., and talks about sweet cane and on act 341 from book number 8 it states that: *"The Duijda who travels and whose supplies are so miserly, if takes two or three sugar canes or two small roots from the neighborhood fields, should not pay any tribute"*, in the verse 143, from book 11, they wrote: *"Having died many insects that born from rice and other grains and from liquids like sugar cane juice."*²

The technique of getting sugar from the cane was developed in different ways according to the region where it grows, therefore we may see in ceramic from China part of the milling process, at 51 B.C. King Dario brought sugar crops and production to Persia, the first contact of West with sugar and with a

Figure 1. The route that follows the sugar cane to travel around the world began at Oceania then through the inter-islands bridge to arrive to mainland and keep its journey to West through India and Middle East where it took two different paths, on the first hand across northern Africa all the way to Spain, on the second hand after some centuries with the crusaders to the rest of Europe, from Spain to America across the Atlantic Islands and Antilles. Image Tarsicio Pastrana.

cane was through Alexander the Great expedition from the III century B.C., in both cases there's a reference, Dario's soldiers mentioned the cane who produce honey and Greeks used to call it salt from India, they talked about a plant who produce a honey as sweet as the bee's honey, even though the plant was known at Europe it wasn't used to produce anything.

Egypt produced a low-quality sugar, although they developed systems to clear it up, it is also important to mention that honey followed a similar process used by men with some other plants to obtain its concentrated products, that means, the same technique was used on different plants and improved with time.

Romans and Greeks knew it, it was a very expensive product considered medicinal; it was the Arabs, who invaded Persia at the 600 A.C., the ones who got in touch with sugar crops and with the production method, that is why the path from the sugar within across Europe took two paths, the first hand with the Arabs who took it to the Northern Africa and the Mediterranean

¹ Crespo Horacio (director), HISTORIA DEL AZÚCAR EN MÉXICO TOMO 1, Fondo de Cultura Económica, Mexico 1988, pag.21 y 22.

² G. Bühler translation, SACRED BOOKS OF THE EAST (THE LAWS OF MANU) vol. 25, Oxford, 1886. En <http://www.sacred-texts.com/hin/manu.htm>

Figure 2. Press with 3 vertical grinders represented on Chinese ceramic, can be seen two characters who operated the machine controlled by the shaft, they were placed outside the area by the fence, from inside those two characters who pass the canes between the presses for the milling, on one side the canes are seen and on the floor on the blanket the bagasse of canes already pressed, on the left side collection of juices inside a wood bucket it's a late representation because of the vertical roller mills dates back to the seventeen century. Image: A sweet story of the sugar Carlos Azcoytia. Retrieved to <http://www.historiacocina.com/historia/articulos/azucar.html>

coast from Spain, on all those Arab territories included the Mediterranean islands got the perfect weather for sugar cane corps and production, also the Arabs improved the production methods, let us remember that they are skilled engineers and they apply their techniques to the production.

The second route it's across the species route, they strengthened it during the middle age when the sugar was known as the sweet spice; they transported it on the same caravans along with the rest of the products to Europe. This route transported the sugar but not the production methods, the regions where the sugar cane could grow was under Arab control, after some time the surpluses from the Arab regions where exported to the rest of Europe.

The preferred way to sweeten in Europe was with bee honey, that's why sugar was a rare and expensive product for

a long time. Throughout middle age it was a luxury item, considered as medical, even though in most areas where it was allowed some crops and factories where settled.

Before this proto-industrial process at Spain they used some techniques similar to those we will analyze later on this thesis in the chapter referring to the middle east³, there are some reference about sugar production and the way to get honeys from which the sugar was processed, this technique comes from the first sites where they crop the cane with the purpose of getting the honey, even though getting the sugar it's a complex process, people were used to use honey, natural honey, figs honey, bees honey; it's not strange to think about that the first aim was getting honey from the cane and then process more honeys to get the sugar.

The main regions where the sugar was produced were at the Sicilia and the southern part of the Iberian Peninsula. The increase in the corps doesn't reduce the costs because of the complexity of the process, based on the refinement of the juices from the cane.

During the reconquest the Spanish people were used to accustom to use sugar, so they kept encouraging its production, when the Canary Islands were colonized they took the production there, they took production also to the Atlantic Islands like Madeira and Azores. The process to produce sugar was taken from the Mediterranean to the Atlantic was done by the Spanish

³ We have mention that the process of the plants in order to obtain juices was similar, within time becoming increasingly diversify and specialized, for the cane the ground and the mill for getting the juice and after that the juice concentrated production trough cooking produced honeys and juices. The word trapiche comes from Latin trapetum, it was the name who was given to the olive mills.

and the Portuguese, with all these movements the sugar production on the Mediterranean decreased, this happened also with the corps at America, with this the sugar cane corps and factories started to disappeared.

The cane was widely disseminated in Netherlands Antilles, the main promoter of this campaign was Christopher Columbus during one of his trips in 1494 "We truly are like the work shows, in this land, like the wheat or the wine, it will be born very well; but it's needed to wait for the fruit, which will be, like its show by the promptly born of the wheat and for some cuttings who was set won't get any problem nor at Andalusia nor Sicilia, nor the sugar canes, just some who settled had grown"⁴ referring to the plants who tried to settle on the Spanish island, wheat, vine and cane.

These first samples of canes didn't prosper because of political issues of those years and some years later at the XVI century the first mills were built and started the sugar production at the Netherlands Antilles, being these islands the one who provided plants to the viceroyalties in New Spain from America, on the same way from the Portuguese islands they took the cane to Brazil where the crops became so popular and black slaves became experts on the sugar production, and that is because they were taken from Africa to work on the corps. This situation gradually replaced the native to the islands for black slaves.

Figure 3. Old process to get sugar. In the first plane on the left side we can see the cut of the cane, after the milling on the stone mill, can be seen on the lower part under the hydraulic wheel who moves the stone; behind the mill on the same plane the pressing of the bagasse with beam press, on the right side the process of the juice, after the fill of the forms and at the front of the process to get sugar breads, at the back side its seen cane corps and Gravado harvest from XVI century Juan Stradamus nova reperta.

3. History of sugar in New Spain

On the Netherlands Antilles, mainly at Cuba where Cortes discovered the sugar cane crops, he was the one who brought the plant to Mexico. The first crop dates back to Tuxtla, Veracruz at 1524, at the same time Cortes himself talks about building a mill in 1526⁵. The weather from Mexico was perfect to introduce sugar cane, besides the weather the hydraulic resources were extensive at the zones with good weather, this causes that the sugar corps began to proliferate, Cortes brought the canes and the mills to create productive enterprises. At Cuernavaca Valley, the first mills were Axomulco and Amanalco both dates from 1535.⁶

The biggest crops began to appear, due to the big investments that were needed to create a mill the owners used to be members of the upper classes able to invest high amounts since the beginning of the project and wait some time until

they get a return of investment. On this issue, we can say,

"The economic performance of the mills were great. One example will be more than enough: At Gran Canaria, a crop which cost was 2 million maravedis, produced, one year after another, sugar with a value of 2 more million, from those seven hundred thousand were used for the capital expenditures and one million three hundred thousand were benefits for the owner, that way he recovered the investment fast. We saw how the rents allowed the capital expenditures in two or three years most [...]"

It is not surprising that with these stringent requirements just a few could build an operational mill, after the first step described where the mills belong to the messengers it came an owner secession taking advantage of the cane boom of this profitable industry, because of that big religious institutions and big investors started to participate.

The productivity growth was so big that costs got much cheaper, the crown took a dim view of an industry who got stronger and also an industry that if they kept those production levels the only option were to start exporting their products, that's why they created some rules to take control of this situation, the crown thought about all its territories that's why a rule was set regarding all the sugar must be produced on the Netherlands Antilles which doesn't have any more products to spread its incomes, but New Spain got mining as the main industry that's why all new laws were focused to make minerals the main exportation products.

⁷ Ledero Quesada Miguel A. INTRODUCCION Y CULTIVO DE LA CAÑA DE AZUCAR EN CANARIAS at www.mgar.net/azucar.htm.

As a first order, it was set the prohibition to recruit indigenous labors to work in the mills; it could recruit them for the crops, but only as paid work that's why the owners were forced to recruit black slaves to work on the mills, due to this issue the required investment increased, the second prohibition was to limit the growth of the sugar cane crops. With this order they limited the expansion of the sugar cane crops then, as a result the contraction of the sugar industry, at the end, it was ordered a prohibition for the exportations, let's remember that the crown wanted that the main exportation zone was the Netherlands Antilles. To uphold this order, the crown appointed sugar sellers, they visited the mills to supervise that they follow the rules.

These reforms made got an immediate consequence, it limited productive market to the self-consume, that means the sugar produced at New Spain were consumed at New Spain.⁸

During the viceroyalty there were some technological modifications with the main purpose of raising the production and they got this purpose exceeded, at the beginning crops at islands like Cuba or Puerto Rico engaged in a competition with European crops and with the Atlantic islands, but when the cane got popular at New Spain the prices of the product fell due to variety of causes, the two main reasons were, on the first hand increasing the crops areas they got a better recovery rate, the milling process who was the most important step of whole process was performed the whole year, on the other hand the labor price were cheaper,

⁸ Von Wobeser Gisela, LA POLITICA ECONOMICA DE LA CORONA ESPAÑOLA FRENTE A LA INDUSTRIA AZUCARERA EN LA NUEVA ESPAÑA (1599-1630) En Política Española e Industria azucarera, Estudios de Historia Novohispana, 9, Mexico 1987, p. 51-64

based on slaves brought from Caribe, slaves that were descendants of the slaves from Africa, this lowered the price of the sugar and then the sugar were a product affordable to everyone.

The American sugar got a profound impact on the world, most of the exportation sugar came from America with this European crops were left behind mainly because it is not able to follow the low market set by Americans, so the number of crops and factories in Europe felt, getting really low on some areas and disappeared in some other.

The new technologies, the modification to the crops, infrastructure needed but mainly black slaves that arrived in bigger groups each time because of the laws established by the crown, they started to transform regional customs and also morphology of the region, even the people started to intermarriage every time more often with black slaves.

Sugar production generates different by-products, among them brown sugar which was less refined, honeys and juices to produce rum and spirits, at Mexico the sugar began to be used at the kitchen, as a result it arises one sugar culture, that entrenched into the people, from that sweet bread, traditional candies, some meals, and just as one example the sugar skulls at Mexican holidays.⁹

When American viceroyalties started their independencies the sugar supply started to being affected so they started to look for surrogates for the cane, the most important was the sugar beet, at half of the XVIII century a German scientist Andreas Margraff proved that

sweet crystals obtained from the beet juice were equal to the sugar cane crystals, on that moment that finding wasn't important because of the supply of the American sugar was guaranteed, at the beginning of XIX century when the Napoleonic wars and independence wars blocked the supplies at 1811 sugar beet were introduced to Napoleon, immediately asked to plant 32000 hectares and built some sugar factories and started to use sugar beet instead of sugar cane, this situation its preserved nowadays since 90% of the sugar used in Europe its sugar breed.

4. Sugar production process

The use of water for the production process began in the crops, this required a big amount of water bigger than in any other kind of crop, this situation was widely known and also every step of the process, this was the key requirement for the sugar canes and production.

This wasn't the only difference between cane and other kind of crops, for instance, once the cane grows the leaves make harder for the farmer to walk through the field furrows, that's why they placed the furrows where they can perform the maintenance needed, if a cane is let to grow without control it start to block the fields, it block the water so not all the plants get the same amount of water, that produce plants of different size and juices of different qualities, furrows were placed in a equidistant position, irrigation systems based on pre-Hispanic techniques, with that they achieved a constant irrigation for every plant, this situation marked the most important division of the work, meanwhile indigenous where in charge of crops tasks, the trained indigenous where in charge of the production of

⁹ Von Mentz Brígida, *NOTAS SOBRE EL ESTUDIO DEL AZUCAR EN MEXICO FUENTES Y ALGUNOS PROBLEMAS INTERPRETATIVOS en América Latina en la Historia económica* N11 Enero-Junio 1999, CIESAS, Mexico 1999, p. 22.

the mills.¹⁰

As first use of the water on the production order is the irrigation, the Haciendas who work with sugar required a lot of water which was taken from the rivers or springs, this defined the destiny of entire regions like Morelos State, where the weather and topographic conditions allowed water and springs wealth¹¹, after that water follow several paths one to the production establishment, which I describe it later, and one more path to the fields, it must be considerate that field extensions were really big, that's why the infrastructure for conduction and storage must have a broad scope, it's important to say that most of the conduction were based on pre-Hispanic water distribution techniques¹².

The beginning of the whole process to obtain sugar was related with the crops but also with the irrigation techniques and sugar canes required more water than any other kind of crops, for instance, a cavalry wheat required from 2 to 3 water furrows, sugar cane required from 4 to 5 plus the water required for the whole production process and the for the driving force, that's why a project

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¹⁰ As I said this is also because of the restrictions of the crown set to the New Hispanic industry, meanwhile black farmers worked mostly inside the mills, indigenous used to be paid and developed great skill, these skills, as I will describe later, were required to get the best benefits.

¹¹ The name *herido* is related with a well where the water is obtained, I mean a well is created on a river, from this its determined the amount of water delivered to a specific zone, this hydraulic measurement like we saw on the last chapter allowed the control of the water.

¹² Let's remember because of the restrictions set by the crown the indigenous were forbidden inside the mills, and these were only allowed to work on the fields, it was not surprising that irrigation techniques were a merge of the Spanish techniques, inherited from the Arabs and the pre-hispanic techniques.

like this required a big investment on hydraulic infrastructure.

The irrigation process with pre-Hispanic techniques, required also irrigation channels, they built this channels static and semi-static, this construction process began with the preparation of the field, this step was made constantly in order to guarantee production the whole year, the main unit to build this was the lucky, they used a rod to separate the channels, with this they can repair or maintain the channels and also they ensure the irrigation process. Terea was a group of water furrows who defined one work unit, in other words, how many tasks need to perform each worker.

This layout process was accompanied by the water channel layout who will provide water to the crops, this layout helps to design the channels layout. First of all there were two supply channels, that way the cane crops got its name, those two channels were the *Apantle* and the *Tenapantle*, in the crop there were one more channel who received the surplus water and its name was the *Achololera*, at the center there were some channels helping the water not to stall, these channels were called *Milapantle*.

From the importance of irrigation, we find a quote taken from the instructions:

"Take good care to give your time to the irrigation and to the weeds of the cane, because this plant needs to be clean at the bottom and a lot of juice inside, if its missing irrigation at any time, it knots and it has just a few juice; if it doesn't gets weeded well and if it doesn't remove all the bagasse, it gets rotten and gets worms that climbs the plant kills it, and the cane splice doesn't grow anymore

and doesn't gets sweet"

What we are looking is that the irrigation established the quality of the cane who will be processed. There are many other kind of cares, weather, water wellness promote not only the growth of the cane but also the grass of the fields, and as we mentioned already grass and cane leaves made it difficult to walk around the crops and also made it difficult to distribute the water. Also as we read on the instructions, growth of leaves on the base of the plant joint with grass produce serious problems with the plan rotten it and getting pests.

That's why after irrigating the second most important task was the weeding, once the cane growths and the leaves block the sun the weeding stops, the only task that continues is the irrigating, something very important is to know that the irrigation must be suspended one or two months to avoid that the cane gets watered down, this technique is similar to the one used for cutting a tree, its really important to select a specific date in order to get the correct amount of water and sap, the idea is to get the lower amount of this elements in order to avoid deformations and carrying capacity, in the case of cane the water is so important in the whole process but even that it must be suspended, if the water gets suspended the juice gets concentrated and that's good for the sugar refinery process, if the cane gets high amount of water the flavor gets affected.

Irrigation process is represented by building channels, furrows, floodgates, aqueducts, dams, according to each zone, as I mentioned before there were two types, those who are static and help to transport water to the required zones and those who depends on the layout of the field.

After all the activities developed in

Figure 4. Engraved where it can be seen sugar cane cut and load into oxcarts, this process was done over and over, until the harvest gets to the end, children walked behind the carriage to recover the cane that felt down on its way. Source www.artehistoria.com

the field, next step is the harvest, also known as *Zafra*, the date was selected carefully in order to get the cane as dry as possible, we already mention to stop irrigation in order to get concentrated juice from the cane, in the same way harvesting used to be done in a fast way in order to preserve this concentration and delay as much as possible the fermentation process that started immediately, using a machete as a harvest tool the cane plant was cut from the base and also they cut the leaves, those were stacked in a specific zone on the field and they got burned, that's why during harvesting it was very common to find huge fires who light the nights.

It was really important to remove the leaves from the cane otherwise the grinding process were so complex and also the juice gets dirty. Besides the method of removing leaves with the machete in order to stack them as clean canes on the carriages, there were a second method of burning the whole cane with a controlled fire, in order to dry the cane as much as possible, with this only leaves got burned, whit this method the flavor of the cane was not disturbed that's the reason why despite

of the cuts that the works suffered when they removed the leaves, this technique was used just after the cane got cut.¹³ In many cases leaves and heads were used to feed animals that were used on the carrying tasks.

The canes cut close to the base and with leaves and heads removed stacked them and got carried to the refinery, for this purpose they used animals to pull the carts across roads on the fields, harvest has been always a hard task, once the cane got cut it's a race against time because of the fermentation process started immediately and it bitters the juice and won't be able to produce sugar, that's the reason why the cut process were constant, after cane cleansing and stocking process the carts travel over and over between crops and mills with children behind recovering the canes dropped on the travels.¹⁴

Besides all these steps, one more reason because of the irrigation was suspended before harvesting it's because this way they got strengthen the ground, workers can access anywhere, carts didn't get stuck on the roads, once the harvest started the layout on the field breaks, that means, channels and furrows disappear because of that advance of the workers that cut the canes and the carts that moves around the fields.

Once inside the production warehouse carts got unloaded in a specific area that was used as temporary storage, this area got the canes and they grouped by small amounts from there they took cane to the mills, at New Spain it was called *cañero* in the Batey Antilles¹⁵, these big cane groups

needed to be controlled in order to get the cane mashed as soon as it gets to the warehouse, let's remember that the process after harvesting must be quick, otherwise the cane gets bitter and then the final product gets a bad flavor.

Before the hammer mills who will be described later we will find a process similar to the one used to get olive oil, let's remember the origin of the word *trapiche* that was the word used to call the olive mills, the first step was to cut the cane in small pieces, this pieces were shelled with a stone mill, the driving force was operated by a water wheel or by animals and in some places by slaves, most of the time the mill was a vertical one, from those who spin on its edgewise, the stone mill got a hopper in order to contain inside the juices, which where guided through wood channels to the refinery.

The wheels that moves these mills must be vertical, being the vessel ones very useful because they required less amount of water to move, movement could be produced by a superior storage of water and a constant exit, that is because of the movement of the wheel only required falling water that makes it spin by gravity force, the infrastructure required for this task were very simple just channels and elevated water containers. On the other hand, a paddle wheel that required only the spin trough a water flow was really simple, since it doesn't need wheels for the movement, those who needs vessels that needed to spin slowly and needed some other techniques to take control of the spin speed.

The paddle wheels are also known as

¹³ Beatriz Sharrer Tamm, *op.cit.* p. 90

¹⁴ *Ibid.* p. 91

¹⁵ Word Batey in tania lenguaje refers to

the central space in a village, an open space surrounded by buildings, this analogy was taken to the central space from the factory where they received the cane.

Figure 5. On the drawing of the 16th century treatise we observe the initial process before the hammer mill implementation, at the front the cut of the sugar cane with a tool that according with the draw it would be difficult that it works on real life, on the right side on first plane the grinding using a stone mill moved by a water wheel, at the back side a beam press, in front of the beam press the cauldrons to process the juices. Source: *Libros de los ingenios y las maquinas*.

Aceñas, in this case these wheels needed to be located in a riverbed from with a constant flow which it was difficult to find, that is why most of the hydraulic mills at New Spain got vertical wheels that used gravity as driving force. As long as there were hydraulic resources the only task needed was taking water in a constant way to the upper part of the wheel. After this grinding, shelled and pulp obtaining there were needed a pressing process to obtain all the juice still available on the pulp.

The screw press was the next step where the pieces were taken grinded from the hydraulic mill and this screw press were operated making the mechanism spin, also in the lower part it was possible to recover juices dropped to take them to the refinery. These presses, like those who were used to obtain olive oil, got a big size, in the inventories analyzed by Beatriz Sharrer she found descriptions from these presses between 11 to 13

meters long¹⁶ that worked with a big beam as a counterweight that had a wood cylinder with a rope called spindle, when it spin it went up and down and this spin was the one that put pressure and pressed in order to extract as much juice as possible from the bagasse, these presses were pulled by animals called *press oxen* that walked around in one way and then one more around the press to make it go up and down.

Until this point, the process was similar to the one used to produce olive oil, first the mashed, then the press that extract the oil, talking about the sugar cane first it was the mashed to leave the pulp shelled and then it was pressed to get the juice, those juices were sent through wood pipelines to the refinery room, leaving on the first step (the one with the stone mill) the peel and on the second (the press) the bagasse all dry. The bagasse was used on early steps as animal feed and on later steps to burn on the cauldrons.

Regarding this process there are two descriptions, one related to how it was processed the oil at Valencia and the second one on the *21 libros de ingenios y las maquinas* both from XVI century:

*They get carried to an office, where there are men who receive them and cut them on pylons on pieces from the size of a finger, some other takes the pieces to being daubed; some others daub them; others take them to the press; some others press them; others take the juices to the cauldron.*¹⁷

The other one has one drawing where it

¹⁶ Beatriz Sharrer Tamm, *op.cit.* p. 98

¹⁷ González Tascón Ignacio, p. 363 and Viciara Rafael Martin De, *CRONICA DE LA INCLITA Y CORONADA CIUDAD DE VALENCIA Y SU REYNO*, University of Valencia, Spain 1980, p. 26

Figure 6. Beam press was used with the spindle that spin driven by workers or animals as seen on the draw, in this case the base was interrupted to allow the animals to move, this image belongs to the olive oil production process, the press moved down due to the weight of the beams in order to press the canes, juice comes out from one side and its gather to take it to the refinery process. Its important to say that in this case the counterweight it's a wood object that is embedded into the floor and its supported by the sealing with a height of 3 meters, beam presses could be 15 meters long and 3 meters tall. Image <http://www.sabor-artesano.com/prensa-viga-quintal.htm>

can be seen all the machines together with the process to obtain sugar, but as we saw before the machine who cut the sugar that is suggested by the author it was impossible that worked that way, the description of the canes was:

After gathered they cut in small pieces and, after, they mashed in a big stone roller that, at least, its nine spans tall and one span large, and must be from a strong stone, and that is how it mash as when mas the olive oils [...] and after mashed its put inside a spartan grass basket and it get pressed as the olive oils get pressed¹⁸.

These descriptions like some other engravings talks about sugar production process used during the XVI century at Europe and in the Islands from Caribe. The disadvantages from this two-way process were that it was slow and also the translation, that means it takes more time to mash and to get the juice, like I said the fermentation was almost immediately, the flavor of the sugar gets affected by the time it takes the process, the second problem was the loses during the translations, the juice it must be taken from the stone mill to take it to the press, also for the grinding on the press its needed one more step for the process that is the cut of the cane in small pieces, this makes the process time longer.

The first innovation on this traditional process it was the two-mace horizontal mill, but this was controversial about the origin, some authors refer Asia some other Sicilia, it's not an objective of this work to talk about this, that's why we will describe the mill.

Sugar production was one of the activities that were closer to the industrial behavior that will be used later all, even though industrial revolution was still developing at Europe, being so profitable sugar production were always analyzed to improve production and reduce times, this was the origin of the mace mills, the idea to simplify this process.

Let's remember that the step that set the pace was the mashing of the cane, it was so important the mashing that all the work was design according the mashing process itself. Every cane that was cut was mashed otherwise the sugar and juice properties could be modified, I already said that everything began with the harvesting.

¹⁸ Turriano Juanelo, p. 363

The first important change to improve the process was the implementation of two horizontal cylinders mills, this simplified the process since the movement transitions was direct, using a shaft who began at the center of the vertical hydraulic wheel, and some teeth on the cylinder that produce movement on a second cylinder the cane was passed through those cylinders and the mechanism was so effective that it was possible to pass the whole cane with peel so the juice was obtained.

To be clear, one of the cylinders was located on the hydraulic wheel it was on vertical position and by gravity, this cylinder was mounted on a wood structure, got one gear in one of the sides that moves the cylinder located at the top or bottom of the main cylinder and spin triggered by the gear, the cane pass entirely between both cylinders with one operator on each side that received and returned the product so this process could be done several times until it get dry.

With this cut of the cane wasn't needed anymore, and the cane goes from the field to the harvest, there are some sources that says that even though it was implemented the double cylinder wood mill it was still using the pressing juice method, this way they grow the production, it's important to say that the press was still used and the stone mills were left behind because they needed more resources to work.

The first inconvenient of the two horizontal cylinders mill, was the cylinders calibration, since the central shaft was a direct transition, the calibration was a complex process, uncontrolled spins affect the harvesting and the biggest problem was that it broke very often, this was because of it was really difficult to spread the cylinders easily, machines needed to be

Figure 7. 3 Horizontal Maces Mill, this mill triggered by hydraulic force, it's an in-between step from traditional stone mills and 3 vertical maces mill. Image Imagen Jean Baptiste Labat Nouveau voyage aux Iles de l'amerique, Paris 1722.

calibrated constantly to avoid problems but also with the calibration sometimes the distance between cylinders got modified and then they got broken as well.

In order to increase production on this mil they put two more cylinders, one on the central cylinder and the second one under both cylinders triggered by indentation on the central cylinder, those cylinders were called *miller*.

This three horizontal grinders mill helps to mash canes faster, there were two groups of workers on each side, they pass the canes from one side to the other between the grinders, in this case there were two of them, for instance one group passed the canes through the upper side and the second group received it and returned it through the lower side, this way they ground the cane; one inconvenient just like the last method with the calibration since the bigger canes could break the millers, and if that happened all the production stopped.

Regarding the stone mills replacement for wood mills its said book of Beatriz Sharrer a quote about a Dominican plant where it was replaced the stone mill for a wood mill.

“Replacing stone for wood who benefit the plant was because of avoid the risk for the workers there and made another one of wood and one more press who benefit the plant as well”¹⁹

Before continue its good to be clear on the difference between mill and plant, for some authors this difference is mainly the driving force²⁰, the mill is an animal-powered mill mainly and the plant driving force is a water wheel in most cases, the difference was the organization and production, meanwhile a mill was handmade, handcrafted on the plants was something more like semi-industrial, machines located on the sugar cane mill are the most important part of this building, its curious because the name of the whole building to process sugar comes from the rooms where the harvesting take place.

It's also important to talk about the driving force from a mill could be triggered by water using a water wheel, because of that they need buildings to keep replacement animals, since the process couldn't stop, so they took new animals from the stables and took the tired animals to rest so they can be ready for a new journey.

The run were bigger than in the haciendas who used to have this time of buildings, also it was important to think about the needs of the animals, feed them, clean them, among many others, the problem was that every plant needed a group of animals because of during the harvesting were used to transport

canes to the buildings, for the grinding process they required more animals to use them in both activities, presses also required sometimes animals to perform the activity.

Another characteristic of operation that occurs in every animal mill is the need for a “driving force” circulation around the location of the mill. This is also repeated in the press; a rhythmic circulation is created that prevents operators from working freely. This situation is corrected with the hydraulic mills, which existed both in the case of the primitives of stone and in the case of the most modern with maces.

In the horizontal mallet mill, the movement transmission wheels and the upper gears could be driven by draft animals that turned constantly as already mentioned, these animals had to be constantly changed so that the decrease in physical performance did not interfere with the rhythm of In these cases, a movement was made for the animals, leaving a peripheral space around the maces for the operators who were constantly grinding, if the mill was an animal mill, the stop control was easier just by stopping the animals, it was enough; animals had an operator who watched them raid and stop, in the case of the hydraulic mills the mallets turned constantly and the way to stop them was more difficult which caused accidents with the operators who had to manipulate the cane between the maces and the operator, sometimes they lost a member stuck between the cylinders, which could not be stopped immediately.

Although apparently the driving mechanisms only modify the force of action we also find the need to transmit the movement in different ways, the gears to operate the mill are also modified, if the mill was

¹⁹ Beatriz Sharrer, p. 104

²⁰ Rendon Garcini Ricardo, *op.cit.*

hydraulic the wooden mechanism with the gear was located in the upper part, leaving space for activities around the milling, if the mill was an animal mill, the first modification as it was already mentioned, was a circular path that surrounded the area of the mill through which the draft animals would be circulating, situation that makes it difficult to be approaching and control the grinding, these situations that were regulated by gears or by draft animals were the first ones that were tried to modify with the implementation of the three-mallet mills, on the first hand a mechanism of wood that allowed its repair more easily and on the other

a better spatial configuration for accelerating the grinding, it is also important to mention that a preliminary step between the three-deck vertical mills and the stone mills was that the vertical mallet mill, that we have already talked about, and that represented some adjustment problems, cylinder breakage and difficulty in controlling permanent grinding.

To solve this problem, the three vertical maces mill was created, the transmission of the movement had to be done from a gear system at the top of the mill, which helps to make the cylinder mounting frame more independent and

Figure 8. Hydraulic mill with 3 horizontal maces, its main contribution is the calibration of the cylinders or grinders, which can regulate the separation between them, over time they were incorporating metal parts, for the movement areas and for the jacketing of the cylinders that made them more resistant and efficient, in the case that these mills were animal mills, in the upper part of the central axis, timbers were extended diagonally down where the draft animals were held, in the drawing it is observed after the wall the hydraulic wheel image: Tarsicio Pastrana

through the three cylinders (grinders) regulate the separation, the central cylinder continued to maintain force, since this is the one that receives the transmission of the movement, but the other two could be leveled and moved horizontally, to prevent them from rotating eccentrically affecting the mill and grinding, by modifying the distance between grinders, it is also allowed to grind thicker cane, the way in which the 3 cylinders rotated was by means of teeth placed on the surface of the cylinder, in the 3 cases of this way in movement of the first (the central) towards moving the other two at the ends.

The 3 cylinders are mounted on a wooden beam that has “steps” at the top for the axes of the 3 cylinders, these at the bottom on a wooden or stone bench end in a point (lead) and this one into one piece that is designed to receive the turn, (*chumacera*), these two pieces, the tips of the cylinders and the turn pieces were in many cases made of metal to facilitate the turn. In the upper part there were in the steps of the axles for the lateral cylinders adjustment wedges that fixed the cylinders in the distance that was required.

From very early times in New Spain there is a reference of metallic jacketed to grinders, both in the horizontal and vertical models, which facilitated grinding and allowed the grinders to last longer.

This mill allowed a fast grinding because the cane was passed from one side to another with two operators one on each side, similar to the horizontal roller mill, but with the calibration advantage that the other did not have with which grinding was achieved faster, the first took it and placed it between the maces, the second took it and passed it through the other space, this was done

until the cane stopped making juice. According to Ignacio González Tascón, the yield of the press and stone mill system in obtaining cane juice was 40 to 45% of the juice, while in the wood mill systems it reached 60% to 65%²¹.

With this 3-maces mill, repairs were simpler and the same mechanism can be adapted to two types of driving force, hydraulic and animal. With the implementation of this mill, the press and the regular mill are replaced, obtaining in a single process all the grinding, being able to regulate the separation between grinders and making this calibration easier, so the cane was “dry” in the mill, the operators passed the cane again and again until the juice stopped leaving the bagasse directly to dry for the uses already mentioned and the juices were taken to the refinery.

This vertical wooden mace mill is described by Jesuit Father Rafael Landivar:

The oak cylinders of the mill offer accesses so thin, that the back of the one almost touches the one immediately, so that by turning they can squeeze the thickness of a finger.

The cylinder that emerges from the middle of the bridge is bristling with unreadable teeth, with which, when turning, turn the others simultaneously. Although these exceed with their breakwater the timbers above, in which the machine is supported by moving the central quickly, nevertheless threatens to split the roof of the house with its elongated axis, lying high.

Although the description of Father Landivar refers to an animal mill, in the upper part of the axis it is where the mechanism changed, if it was an animal mill it had the timbers that extended to tie the beasts of fire, otherwise in the

Figure 9. In the upper left corner a scheme of the use of the wooden mill, with two operators, on the left side of the mill the unmilled cane of that pile the operator one takes the cane and passes it through one of the space between cylinders, on the other side, operator two takes it and returns it through the opposite space, this process is repeated until the cane stops making juice, then the remains of the cane are thrown on the right side, the juices run down the canal to the room of boilers in this drawing behind the back wall. In the scheme of the bottom of the sheet the 3-maces mill with its parts image: Tarsicio Pastrana.

part upper we find the gears that came from the axis of the hydraulic wheel, and that made the central cylinder rotate²².

With the above we can mention that much of the XVI century grinding was done with stone and press, then the horizontal maces mill was introduced

between the end of the XVI and XVII in its two modalities 2 and 3 maces, although the use of the press, finally for the XVIII century the mill of 3 vertical maces is used that will be used in its two hydraulic and animal versions to be replaced until the second half of the XIX century by metal mills²³.

²² Valdés Octaviano (prologue version and notes), POR LOS CAMPOS DE MEXICO (RUSTICATIO MEXICANA DE RAFAEL LANDIVAR ,UNAM Biblioteca de estudiante universitario, Mexico 1973, p.107

²³ González Tascón Ignacio, op.cit. p. 367, Its said tht 1570 as the year of introduction of the wood mills, coming from Brazil, before that all the milling was done with stone. It's also said that the authors of this were the Jesuits who took it from Brazil to all America.

The main part of any of these mechanisms is found in the elements that prevent vibrations, any vibration that causes major turns or mismatch of the machinery parts causes malfunction and lately breaks on the parts, this was remedied with the periodic adjustment of the pieces, for which within the workers of the factory there had to be a carpenter who was responsible for keeping the mills and all the wooden instruments that were used in the process of obtaining sugar in operation, the carpenter had to stay to work as a plant in the mill, he specializes only in these machinery. Some of these additional activities of the carpenters are found in the instructions to the brothers of the Jesuits.

Every day in the morning the carpenters walk in the corral if there is a broken cart or a loose or a belt bushing and they dress it up²⁴.

The metal parts that are added generate another additional architectural space a blacksmith workshop, in the Hacienda, the workshops and spaces are labeled, although this construction is visibly from the XIX century and it's out of the scope of this work, the labels can give us an architectural program that tells us about the complexity and diversity of technicians that were required to operate a space of this type, we can observe carpentry and blacksmithing, these two spaces directly related to the use of machinery. Another architect who had to exist in the mill was the *pailero*, who repaired the copper boilers.

The maintenance work of this machinery was also related to the lubrication of the parts that required it, the calibration

and leveling of rollers, the replacement of parts, the elaboration of spare parts in the different workshops.

After grinding, either with the method of stone mill and press, factories or mills, cane juice is obtained by channeling to the refining room, this transfer was done in several ways, building around the mills channels of wood to take the juices to the areas where it would be collected, or by collecting it from the mill area directly, the ideal optimization is the route of these juices directly to the boiler rooms without the need for intervention by an operator.

In this stage the main by-product is the bagasse formed by the cane shells and its dried pulp that, was already mentioned, takes the sunrays to dry it completely and be able to use it to feed the refinery furnaces also called the boiler room and feed draft animals that, although the mills were hydraulic, were used to transport cane from the field.

At the beginning of the mills, large quantities of forests were deforested to obtain the necessary firewood for the furnaces, when the resource for scarce fuel was required to supply more and more remote areas, so the use of bagasse was a relief to this. In this regard, with the use of bagasse and shells with this, there were two improvements, the waste that would otherwise have to accumulate in some place and then be disposed of in the field was eliminated and no longer dependent on other types of fuels which began to be scarce as the deforestation progressed.

The next step already in the boiler rooms, was the beginning of the juice processing, so it required a set of boilers that were decreasing in size but increasing its temperature, at the beginning of this process each boiler had its burner and In fact, this system

²⁴ Von Mentz Brígida, TRABAJO, SUJECION Y LIBERTAD EN EL CENTRO DE LA NUEVA ESPAÑA, Miguel Ángel Porrúa-CIESAS, Mexico 1999, p. 216

Figure 10. In the upper part you can see the container that receives the juices from the grinding room, this pond was also called canoe and could be made of wood covered inside with metal plates, on the left side we see the battery of cauldron, ready to start processing honey, the last two were called chillers, were to warm the honey that was obtained from the last dipper also called tacho or tacha, the dipper on the floor was used to place the foams and rubbish that were removed from the different containers of the processed, at the bottom of the right side a pool with water and the mud forms soaked inside, on the right side of the pool the tendal, used to place the mud forms with honey that had just been filled with honey and wait for the honey was not so liquid, finally at the center of the room you see a channel that served to drain the wash water. Image Tarsicio Pastrana.

was used in Mexico during almost all the viceroyalty, each boiler had a caloric source independent of the others, the juices collected and boiled, in several cauldrons, were passed from one to another by those who operated in the houses of boilers, that were usually black slaves, this circulation of juices was made with very large spoons and in the opinion of the sugar master, the refining was made from cauldron to cauldron and from burner to burner, with which the fuel expenditure was higher, since different ovens were required for different cauldrons.

Also, in this process there were some transformations, these improvements

came from Jamaica.

What was implemented in Jamaica had to do with placing the cauldrons in a battery and placing them by size to obtain greater concentration of the juice, this succession of saucers that were fed by a single oven was called the nearest Jamaican train the nearest saucepan baked was also the last, and the smallest, is where the sugar received its last refining, feeding the first oven where the last cauldron, was also heated a whole chamber that was sealed by the different cases, the chimney used in the oven as well as the elongated body of the different ovens

gave its name to this set of cauldrons²⁵.

The juices were channeled to the boilers that were located on battery, starting with the largest one that was subjected to low heat and finished in the smallest but also the one with the closest heat²⁶. In this route through the different cauldrons, the water contained in the juice evaporated and an increasingly sweet juice with less water was obtained, at the end of passing through all the containers the juice was highly concentrated within these refining processes, honeys and by-products were obtained, for example from the first containers the foams and impurities were removed, at the same time of each of the following processes they obtained honey that could not be integrated into the juice.

From the fermentation of honey and juices, rum and spirits could be obtained, both products were banned for a long time, so they were manufactured in clandestine distilleries located within the same mills, these used hydraulic facilities to complete their processes, they required water for cooling systems as well as own storage areas, the prohibitions came from the crown to control the monopoly of alcoholic beverages. This prohibition was ignored since alcoholic beverages were widely consumed by the same workers of the sugar farms, being the sugar Haciendas places that tried to optimize all aspects of the process

²⁵ The advantage that got the Jamaica train battery it was a good use of the heat, with only one oven and a sealed environment, it was sealed with the cauldrons, the *tacha* that was the last one of the cauldrons y also the one who needs more heat it was the one who got fire under itself, from the it moves around all the cauldrons until it gets to the first one near the ones it was the smoke exit.

²⁶ The Jamaican Train wasnt used very often at New Spain, it was common that every cauldron got its own oven, Crespo Horacio, op cit. p 429

did not waste any of the by-products, also obtaining part of their income from the sale of these drinks for local consumption.

Honeys were not only used to produce alcoholic beverages, they were also reprocessed depending on the degree of cleanliness, or they were fed to animals, to workers and in most cases, they were sold, for extra income.

The successive refining led to the cleaning of the sugar, the more it would be refined, the whiter it would be, so white sugar was not always produced, the darker sugars had a lower price and were products of ingenuity also depending on the processes that were completed and those that were completed. no, this also had to do with the number of refinements, that is, the honey was extracted in the first buckets, you obtained a "browner" sugar that went to markets with lower purchasing power, the sugar in the last dipper was the whitest sugar. In order to achieve this bleaching, not only the complete refining was used, bleach was also added which, after a chemical reaction in the juices, would cause whiter sugar at the end of the process.

This process inside the boiler room could last all night since once the milling started the refinement had to be completed, this boiler room was the one with the worst working conditions, the extreme heat and the vapors that constantly gave off the boilers in addition to the working hours that could last all night until the juice from the milling was exhausted was one of the apparent reasons why the crown prohibited the work of indigenous people in the processing of sugar, a situation that as we saw with previously, it had the objective of limiting the growth of the sugar industry in New Spain.

The boiler rooms were tall stone

constructions usually with attached ovens or in some cases with the interior structure of the Jamaican train, with the *chacuacos* protruding on the side of the furnaces, a ventilation system on the top to allow the vapors to escape and in many cases artificial lighting for the reasons already expressed.

They also placed two more boilers that were not placed on direct fire, one of them will receive all the foams and garbage, as well as part of the unprocessed honey of the first boilers, the other called it a chiller and in it the ready honey was placed to crystallize so that it is warmed and could be added to the forms. The last boiler on fire where it was checked that the honey was ready, received the name of *tacho* or *tacha*, from this it passed to the chiller and from this to the molds or forms.

The juice was emptied in the molds, these molds had a plug on the bottom, were conical in shape and were placed on a clay container that would have the function of collecting the non-crystallized honey, the plug was placed at the beginning to prevent warm honey from draining and being lost, since the shapes were conical and the plug was at the top of the cone they were located on the container with the narrow side down and the cap on, with the widest part from the cone up and open, in this and using a spoon the honey were placed, when the shape was full it was placed on the line that was a flat raised surface of the ground where they were lined up and waiting for cooling to take them to the purge room, until here it was the work that was developed in the boiler room.

The forms had to be saturated with water, so the sugar bread that would be formed did not stick, so near the boiler area was a tub with water where the forms were being soaked, it had a

double function, first washing of forms and then saturation of mud, of this site was taken to prepare and fill with honey. In many mills there were potteries that were dedicated to the manufacture shapes and containers that due to their nature were constantly broken.

The purge rooms were places prepared to line the shapes and containers and work with them, the mold and sugar should remain moist, in order to favor the runoff of non-crystallized honey, so the rooms purge didn't have windows, inside it was worked by removing the plugs when the sugar was already solid, placing wet mud on the top so they runoff of the water dragged from non-crystallized honey, the control of this room was very important because in it workers stock finished products²⁷.

After a time of letting them drain, that could reach 45 days, the non-crystallized honey were collected, during those days it was deposited in a container, this way the non-crystallized honeys were carried with the other honey that had already been collected in the *tachas* that were used for the aforementioned by-products, the drained breads were taken to the sunrays rooms, where they had to complete their drying process with sunlight and air currents, the only enemy of this process was the rain, so the sunshades had part of their roof structure, or with sliding roofs to prevent the rain from damaging the products.

So, in this way we obtain defined spaces that made the system more complex, the purge room needed a very large space to place the forms with their lower deposits. After obtaining the honey and hardening the sugar bread they were removed from the mold and placed in the drying areas that had to be roofed but they had to allow the circulation of

²⁷ Brígida Von Metz, *op.cit.* p.218

fresh air to allow the breads to continue drying, the drier the more whiteness, because the honey that is usually darker colors continued to drain or failing to end up not counting, the final selection caused a separation of breads that had its main impact on the price of these. From this separation they obtained different qualities of sugar.

In the same factory it was possible to determine what type of product could be obtained, depending on the process to which it followed, brown sugar was obtained from cane juices but its refining was less effective than the one of white sugar. These decisions were made within the mill, allocating some productions to obtain less refined sugar, paradoxically in the viceroyalty this was sugar for poor people, today brown sugar and other not so refined products have become more popular because they are less refined and be healthier, then they were taken to storage, there were areas where different sugar breads were stored that later they would be sold according to their quality in different markets.

Finally, it should be mentioned that water was not only used as a driving force, cleaning task was very important, a fundamental activity because any residue from a previous milling could transform the flavor of cane juice, also the fermentation process began quickly, after each milling and refinement of the juice before the new load of juices arrived, the water had to pass through the mills, studs, wood canals and also through the mud forms, if this cleaning was not done properly the residues that continued with their process of fermentation and that would be bad for the taste of the sugar, these needs had repercussions on water deposits in a large part of the architectural spaces related to refining.

Cane honey is made every Monday when there is [...] in the mill before grinding, if the mill is not washed and the canoes are washed²⁸.

5. Architecture of the sugar mill

With Numbers are marked the premises that have to do with the production process and in the order in which they participate in this process:

1. New Mill: we look at the hydraulic wheel and the mill on the left side.
2. Old Mill, larger than the previous one, we observe the place where the hydraulic wheel and the mill are located.
3. Boiler Room, as point 2 is the oldest mill, we observe that the location of this room is immediately after the mill, with some way of carrying the honey to this room, probably a line in the middle of the room.
4. *Hornallas* room to heat boiler batteries and process honey.
5. Room which probably has the pool of forms.
6. Purging, from room 4 and after finishing draining the most liquid honeys are brought to purge, that way the honey got drained.
7. Purge 8. Probably, the sun room, once the forms stop draining honey is taken to the sun room to complete drying and bleaching.
9. Aguardiente factory, note its location next to the sugar mill area to receive honey directly.
  - a. Access Aqueduct.
  - b. Vertical hydraulic wheel of the new mill.
  - c. Vertical hydraulic wheel of the old mill.
  - d. Galleries for workers.
  - e. Galleries for workers.
  - f. Workshops (carpentry, blacksmithing, form room, paila room) already commented that the arrangements of the factory were made in workshops located inside the mill, the carpentry

saw the machines and carts in addition to the wooden tools, the blacksmithing, the metal parts in machines and the tool, the form room towards the forms of mud that were constantly breaking, the paila room maintained the boilers where the juices were processed.

g. Gate of the purges, the access to the purges was controlled since in this site there were already final products that could be stolen, you can notice in the plane that the same access is used for the two purges and the sundeck.

h. Animal bathtub, taking advantage of the hydraulic wheel drain.

Figure 11. Architectural Plant of the hacienda of San Antonio Atlacomulco from a plan ordered by Lucas Alamán in 1852 for the project of an Aguardiente factory. Image: Tarsicio Pastrana

Figure 12. Architectural Plant of the Hacienda of San Antonio Atlacomulco from a plan ordered by Lucas Alamán in 1852 for the project of a factory in Aguardiente extension of the productive area image: Tarsicio Pastrana

1. New mill area, in the opposite part of the area where the mill is located, there are two boilers that receive the honey from the tank, both from this area and from the area of the old mill there must be communication with the boiler room, circulations of personal, water for washing and honey for the process.

2. Area of the old mill, the wheel determines the area where the mill is located, on the opposite side is the boiler room, there is a pipe that takes the honey to this room.

3. The boiler room shows on the left side the boilers that the honey receives, it could also be a stone tank or a wooden box covered with metal plates inside it was called a canoe, from this site it passed to the boiler battery in the upper part we can see what the grove

is possibly, where the clay forms were placed after being filled so that the last liquid honeys and could be covered and carried on purging.

4. The burner room coincides with the entire wall of the boiler room, to feed each separately the *chacuacos* are located on this room.

5. This room can have a pool where the shapes are soaked and from here perfectly saturated with water, take them to the boiler room to be filled with the honeys and then take them to purge.

c and b Hydraulic Wheels of the old and new mill, the locations of both wheels indicate that the feeding of both wheels is from the top, that means, both are gravitational devices.

II. THE MACHINE OF BATAN

1. Introduction

The *batan* is one of the most interesting hydraulic machines because of the context in which it was developed, you can't conceive a *batan* without thinking about the fabric production industry and the whole process developed from this successful production chain in Nueva Spain, the *batan* used the percussion principle, remember that the two principles of grinding are percussion and friction, in the case of *batan* percussion was the one used, although its objective was not to grind cloth garments, if it can be mentioned that some *batans* were used to grind rags and produce paper.

Let's remember that the application of the hydraulic wheel had the function of facilitating the most tedious and delayed tasks that were developed by man, in this case the most complicated part of the production of cloths had to do with the hitting process, therefore it is necessary that to apply hydraulic force to such a hard and laborious work, before the implementation of the hydraulic wheel, the hitting was done with the feet, in huge tubs where people with wooden shoes got to step on hard on the cloths, hence in many areas you call the *batanes* stompers.

The *batan* is linked to the water courses, but also to the production of fabrics, which in New Spain developed in the works, we find then as part of this productive chain, the origin of the raw material, in the case of cotton, the cotton producing areas, in the case of wool, the farms and ranches producing this material and when the morals silk were woven. These sites are the origin

of the production chain, after this site we enter the workshops that is the site where the raw material is processed to obtain the cloths, as part of the process to obtaining these cloths, the *batan* was used.

A textile region must have a center that produces raw materials, a site where the workshops are located to process that raw material and the fulling machines associated with the works as part of the production chain, together with the need for water used in several parts of the process, not only as a driving force, these requirements place textile areas close to urban centers, but mainly in water flows near these urban centers.

A deeper analysis would lead us to determine why certain cities develop as textile centers and others do not, within this work the main objective is to explain the complete process of obtaining the cloths emphasizing the parts of it that use water as a key element, the description of the hydraulic machine called *batan* will be the most important part of this section, considering its importance in conjunction with the work process in being a direct background of the current industrial areas of the country. The main workshop zones are now transformed into industrial zones.

Once again, the development of this section will follow the criteria already specified in other parts of this work, we will talk about the process to obtain materials, the history and the associated elements, but mainly about the *batanes* and the works as application elements of hydraulic technology.

2. History

The fiber cloths develop from early stages, man detects that cross-linking natural fibers is able to create key items. The first items were made from branches and palm, with which

we obtained baskets and canvas that were used in so many different ways, later these fabrics are started to produce using machines that adapt and facilitate the work of these very primitive development. To make this fabric easier they kept fixed one part of the fibers, this is how the first looms were born.

These primitive looms were vertical and the fibers of tree branches were hung to these fibers, weights were placed in their lower part, keeping the fibers tight, these vertical fibers are called warp, for the fiber that is incorporated into the opposite direction that the one who was worked through the cross-linking of the²⁹.

The cloths obtained became one of the objects of first necessity, not only for the uses that we already mentioned, later with the development of more complex and thinner fibers for the elaboration of cloths that allowed to develop dresses. The needs of more complex cloths produce the search for fibers that could provide them, from here we find rough cloths and some other fibers to create baskets, furniture and other objects of first necessity and the elaboration of thinner cloths made workers to produce different quality and characteristics cloths and fibers according to the people needs³⁰.

The dress begins as an article of first necessity, then reflects the social status of the one who uses it, it begins to create a difference between the simple dress that were used by the lower classes and that allowed them

to develop their activities and dresses which are for the higher classes that allow them to talk about the wealth and power they have, these were generally not to be functional they were simply to be displayed.

This migration of rough cloths to more refined ones, in their elaboration has to do with implementations in the looms that facilitated the elaboration of the cloths, also the threads became thinner, for example the linen that is obtained from a plant that grows in Egypt it was woven into looms to obtain lightweight cloths that were highly appreciated among the Egyptians, these fabrics generate more sophisticated looms always retaining the principles that got when they were created.

Another of the natural fibers that were used for some time to make cloths was the wool that was obtained from the hair of some animals, specially from the sheep³¹.

Wool was worked in many places including the Middle East and later in some regions of Europe. The fibers of animal origin were worked in a similar way in different regions of the world, for example in the Middle East the fiber that was woven was based on camel threads, in South America, the vicuñas and llamas, being the fibers obtained in this way raw material for the elaboration of threads that would later be woven into looms.

The procedures for obtaining the threads from vegetable or animal fibers are similar everywhere in the world with

²⁹ The same principle is used for thousand years, one part of the fiber remains fix and the other one is the one who moves to cross it, that's the same idea that modern looms use, vertical part that is the part called warp, the non-fixed part is the pattern.

³⁰ R.J. Forbes, op.cit. p. 30

³¹ Not only from the sheep were obtained the wool, from any animal with hair that could be used in looms and got the properties to become cloths, on different parts of the world we find that the process to obtain threads were different according to the animals of that region, for instance on South America they used the llama hair and on Arabic Peninsula the camel hair.

this practice, that is to say from natural fibers a similar procedure is achieved in several parts of the world to turn them into threads that can be woven into looms.

Vegetal threads were also very common, for example, the aforementioned linen and cotton that, since they were so similar to wool, were called tree wool³².

Ancient people were dedicated to produce clothes in different ways, it is curious that the principle that gives rise to the loom is discovered in various parts of the world, are of those technological solutions that are discovered in various areas without the need for contact between them; in instance, in Latin America pre-hispanic cultures had loom called waist loops to work their clothes, in the territory that is now Mexico, cotton blankets and fabrics of the same material that allowed to make dresses were highly appreciated, in addition, dyes in those regions natural gives unique characteristics to the clothes obtained, for that reason the cotton fabric was in charge of indigenous even after the conquest.

The evolution of the loom was the beginning the evolution of the clothes, the important thing was to facilitate the cross-linking of the it doesn't matter the origin of the clothes, when this part is mastered, the need to do this work quickly arise, then the surpluses are used for barter. This great need for sale and trade is the main promoter of the changes developed in the loom, on the other hand, when this need is not so pressing, the looms are kept homemade or handmade without change. The first looms were vertical and by means of counterweights they kept the warp straight, while the weft was passed in a lens way between them, this type of

loom remains for home productions for many centuries since it didn't require any improvements in the production.

Before the middle ages, the process to create clothes was done in a homemade or traditional way, the large workshops proliferate during the middle ages, during this period these small artisans began to gather in groups to work together and create weaver's guilds, trade of fibers, such as cotton and wool became very important, many cities based part of their economy on these businesses and their profits.

The cloth manufacturing process required several steps that began with sheep herds, shepherds not only obtained money from the sale of wool, but also milk and milk products, meat and leather were products that could be marketed, wool had to be carded and spun, that's the reason why these activities were also a division of labor in which many people were employed.

The threads already worked were taken to the workshops where they were woven into looms, this fabric had to be beaten to close the cloths and cause the weft to be lost to achieve cloths handier and pleasant to the touch, also with better quality, this work is the predecessor of the *batanar*.

Cloth production became a determining factor in the development of textile centers, everything that develops around this creates centers well known worldwide Flanders, England, Spain, among many others. And not only that, the sheep evolve and adapt to the regions where they are raised, so there are different qualities of wool depending on the region where the sheep came from. Spanish wool is distributed by textile centers in Europe where each region gives different characteristics to the final products.

³² R.J. Forbes, *op.cit.* p. 61

These joint workshops of the Middle Ages are mixed with the Arab techniques in Spain to later create the workshops, places where the clothes were created, these establishments were very common in the Arab areas including Spain where all the steps of the process become in productive chains of great importance where the *batanes* that were already used since the middle ages proliferate near the textile regions.

3. History in New Spain

These workshops heirs of the textile workshops of the middle ages are those that arrive to America brought by the Spanish, they installed workshops dated from XVI century, the development of these establishments in America can be considered precursor of the industries, by the organization system that is acquired, the works had to be embedded in a productive chain that depended on obtaining the raw material for the creation of the fabrics, this led to bringing the sheep, creating ranches for the raising of sheep, just like Spain people who prepared the thread, dyes, fabric etc., part of these activities were done in the workshops.

Figure 13. Drawing of a work in the Osuna codex, the pattern is shown giving directions of the right side, the work is represented as a closed space with a loom and a spinning wheel, on the lower right side the raw material bulk wool that is taken to be placed on the wheel image: Codex Osuna plate 38.

The first sheep arrived to America as supplies for the ships that transported the new settlers, they were shipped from Seville and Cádiz, or sometimes from Canary Islands, when they arrive to the Antilles some arrive alive and survived and they begin to reproduce, from there they were taken to New Spain through two different paths, in the central and northern zone by the port of Veracruz and in the southern zone by Central America³³. The grants for breeding of small animals proliferate, due to the needs of the workshops.

In a workshop the set of looms was what determined the production. The looms depended on an adequate supply of threads, and the threads could be processed in the workshop. The workshops in New Spain have been subject to multiple studies including their contribution to the structure of work and the social composition of the individuals who worked in it.

As a business that contributes to the development of the viceregal economy we can mention the following price relation: "one arroba is equivalent to 11.5 kg and one arroba of dirty wool at 2. At the beginning of the XVII century it cost around 14 reals or 1.5 pesos, this purchase, of 19,550 Kg., should have cost about 2,550 pesos" These data were extracted from a workshop established in the city of Tlaxcala in the XVI century³⁴.

Figure 14. In this image we see the interior of a workshop, with a loom operated by two people, a spinning wheel operated by a younger character and the pattern standing, interesting is also the representation of the protectorate by the holy spirit and San Miguel Archangel, Image: oil on canvas Carlos López, XVIII century Soumaya museum collection.

Later in the same text, the following comparison is made with respect to the cost of a workshop: “the cost of the equipment of a small workshop sold in 1600 was 52 pesos, and consisted of three frieze looms, two pairs of cards, six spinning lathes, a tub and a roman”³⁵. The investment of 52 pesos could be recovered quickly with the sale of the fabrics and we observed that a sale of 34 arrobas wool could cover the cost of 52 pesos.

The needs of the workshops generate auxiliary establishments that rely on the cloth industry, we already mentioned the sheep ranches and also the pigs, because the lard was used to spread the wool and was able to spin

it more easily, the domestic workshops of spinning and dyeing, which, as we have already seen, could be activities focused on the interior of the work and the *batanes*.

Up to this point, hydraulic technology has never been mentioned, although in the introduction of this topic it was mentioned that part of the process of obtaining clothes had to do with a hydraulic machine called *batan* which is the one that will be described more widely in the part where the process of obtaining the clothes is described, the *batan* simplifies the batting operation that served to close the fibers of the clothes and make it more resistant, as well as cleaning it from all the non-desired substances, it including pig fat that smeared on the threads.

Not only did *batan* depended on water to function, the process of wool and cotton required water to be completed. This take us again to the use of water not only as the engine of the machine, but also the use of water as a key part of the production process in several steps, the workshop as a pre-industrial establishment needed water, which means a pipe infrastructure and storage although not as complex as in the case of a sugar farm, but it was an infrastructure that generated certain specific spaces and needs that will be discussed later.

The diversification of the cloth production process generates the division of labor, we had already talked about the establishments that produce the raw material, such as ranches and farms, later it was necessary to spin the fibers to obtain the thread, this process may or may not be carried out within the workshop, before to this, this work was done independently, and it was common an activity of women, in the workshops it was more common for

the wool to arrive in the rough and that inside it the necessary processes were carried out, that's the reason because it was considered to be the workshop as a precursor of the industries, because we can an organization derived from a production line.

From the thread, they can continue with the dyeing of this, and since the thread is woven already, the most complex workshops had in their facilities a *batan*, this wasn't very common, so the *batan* was a separate establishment that was located in the area of the workshops and that could supply more than one, as you can see the process can be divided into several technicians and several establishments.

Another hydraulic implementation to the process was the hydraulic loom, towards the end of the viceroyalty the hydraulic wheel began to be used to move the looms, using a movement transmission to a shaft and a band, that could be removed or stopped the movement when necessary, although this was not very common because the workshop as an establishment began to enter into crisis since the XVII century due to the proliferation of workshops and homemade craftsmen who worked individually in their own homes, as was done since the beginning of the Viceroyalty with the cotton fabrics.

The work was not only the production of the workshop, it also had a particular organization that led to its decline, the work personnel were divided into free workers and slaves, in addition to this the working conditions were so extreme that Humboldt describes them as follows:

"Free Indian men and men of color are confused as rowers that justice distributes in the factories to make them work daily: all of

them are half naked, covered in tatters, skinny and disfigured. Each workshop looks more like a dark prison: the doors are double, they are constantly closed, and workers are not allowed to go home: those who are married only on Sundays can see their family. All are irretrievably punished if they commit the least offense against the order established in the manufacturing.³⁶"

By the end of the viceroyalty the establishments that survived and that were also incorporating the hydraulic improvements in more processes set the precedents for the important development that the textile industry had in the independent era but specially in the Porfirian era.

There are examples such as the Metepec factories in Puebla and the Trinidad in Tlaxcala that used the hydraulic system to transmit energy to a shaft that crossed the industrial building in which the looms were held with a band that could be removed and set again, this way the loom was driven by hydraulic force and the worker was free to focus on the clothes.

4. Cloth getting process

The origin of the cloths that were woven and had to be beaten was in the sheep ranches, in the case of cotton in the farms that produced it, let's start with the wool because it is more complex in its entire production line than cotton and also because cotton was more related to domestic weavers

³⁶ *De Buen Lozano Néstor, EL TRABAJO ANTES DE LA REVOLUCION INDUSTRIAL en instituciones del derecho del trabajo y la seguridad social Instituto de Investigaciones Jurídicas Serie G: estudios doctrinales No 188, Academia Iberoamericana de Derecho del Trabajo y de la Seguridad Social- UNAM, Mexico 1997, p. 25*

and individual looms.

The wool has different characteristics that make it very special and suitable for making cloths that later become clothes³⁷. American sheep were raised from Spanish sheep, which were mainly from the Merino breed, which is believed to arrive to Spain from North Africa and the weather characteristics develop a long and curly fur, this characteristic made them be considered the best in the world, as we have already mentioned, they arrive through the Atlantic islands and then pass through the Antilles, to be taken to America to began the production.

It is important to mention that wool production is currently very different from that of that time, to begin with, the wool that was produced by the sheep was divided into two different kinds, one was a thin and small hair that served as a thermal insulator and the other the wool that is larger in size and kept the animal dry, this situation of the double fur is repeated in other breeds, since air spaces are generated between the two types of hair that maintain a natural thermal barrier.

The wool has a natural fat called lanolin that in small amounts of moisture keeps the wool isolated and therefore dries the skin of the sheep, another important function of this longer fiber was to shelter the animal in the cold season because the sheep is not resistant to low temperatures and this hair keeps them safe, currently the animals have been crossed and improved so they do not produce so much hair and produce more and greater wool.

³⁷ The sheep fiber developed characteristics to cover from cold, inspected by a microscope wool looks with a cover like a palm. Characteristic that added to the natural waves of the material allows the air to be kept and works as thermal insulation.

We must not forget that wool is the sheep's response to its low resistance to cold, which has been reversed especially with the raising of sheep in more quality areas and with the control of the herds, in the era of the viceroyalty of sheep although they changed their pattern of growth and quality of wool, because they were found in climates as good as those in New Spain, they still have this characteristic of double hair described above, although they were changing with respect to European sheep generating a type called Creole sheep very similar to the one from the origin, the change in the fur was noticed by the sheep and had a lower production of wool per sheep and a lower quality of the yarn produced³⁸.

The shearing of the sheep to remove its protective coating is related to the region in which they live, as already mentioned the sheep is a cold-resistant animal the natural defense that they have developed over time is their wool, in cold places the shearing can only be done once a year at the beginning of the warmer season, this way the sheep has the whole year to develop once again its fur with which it will be protected in the next cold season, on the other hand, in warm areas where winters are mild, the shearing is done two or more times per year depending on the growth rate of the wool³⁹.

The sheep ranch produced different products, the most important for us is wool but they also obtained tallow for the production of candles and meat for consumption, the skin was sold to tanners, milk to make cheese, and feces as fertilizer, It is important to say that in some cases mainly in the

³⁸ Sanchez Verin Carlos Arturo Giordano, *op.cit.* p. 10

³⁹ In Mexico, shearing could be done more than once per year.

ranches administered by the Jesuits, within the same ranch the productive chains were completed, for example the sheep ranches produced candles from the tallow that was obtained from the animal, in this way the candle was sold instead of the tallow.

Normally the sheep is not slaughtered because it is constantly generating wool and the shearing becomes the starting activity for obtaining this raw material. When this operation is performed, the sheep is tied to the legs to be able to maneuver it quickly⁴⁰, the wool thus obtained is called fleece and is removed with a scissors, the animal is left with the skin exposed and the operator joins the fleeces in a areas to transport them to the workshops later, the wool guard is composed of sebaceous and sweat glands added with a large amount of lanolin whose function has already been described, the guard works as a wool support cloth and this allows it control it easier, It is for that reason that when we observe the product of the shearing it is mounted in large sections similar to the skin.

The fleece obtained have different quality and textures, it even differs in shades and colors, as a result that not all the body of the animal has the same type of fiber, in the field, the bales were transported tied to the workshop on the back of mule or using carts⁴¹, it is important to mention that the fleeces could be taken as they were to the workshops so that all the processes

were followed there, in fact it was unlikely that the sheep ranches had areas dedicated to the deep treatment of the wool. On the amount of wool that each sheep produces it was related with the breed, taking into consideration that current productions are much larger than those of the viceroyalty because current animals are crossed and manipulated to produce more⁴².

When arriving to the workshops or where the spinning will be done, they removed all the substances outside the wool that are not impregnated in it, stones, boiling earth, wood remains, etc. This process is called frosted or scarred. It was done with some combs or by hand removing strange, visible things that are not attached to the wool.

When the piles are free of the substances described they took it to wash it, at this point we have the first step of the process where the water will be used, as it has been in every process analyzed remember that the water is used in three ways, as part of the production process as in this case, as a driving force and as an input of the common needs for space and operators.

Thinking about washing in the courtyards of the workshops, they located pools that were filled with water and allowed the washing of the fleeces, which had all kinds of stains, usually organic, blood of the sheep, urine, mud, feces, earth, fat, etc., when this work was done domestically in the houses where the threads were prepared we also found the fixed sinks

⁴⁰ At this time there are two shearing methods, the Australian one who doesn't requires to tie the sheep, this one is mounted and stopped using the legs to shearing it, and the traditional method when sheep gets tied to complete the process, in both cases expert workers needs only two minutes to perform it.

⁴¹ We need to remember that the description of the process is related with the traditional methods, today these methods are different and are more sophisticated.

⁴² Inside the wool production, there are difference between the breeds, mainly related to the quality and quantity ow the wool produced. Those from Merino breed, one of the most common, produce between 10 and 18 kg. Creole breed produce only 2kg. Merine sheeps from those days didn't produce as many wools as these days, even in America sheep's produced lees wool because of the weather.

or failing tubs where the fleeces could be washed.

One of the substances that impregnates the hair of wool is lanolin adding something to what has already been said about this natural oil we can say that it is very important for the fibers to be healthy, on the contrary for the production of wool is not so beneficial, because it travels to the tip of the fiber and causes it to stain with all the aforementioned substances that combine with the oil. The washing was important to release these stains, and to obtain the real colors of the wool, this washing had to be superficial to prevent the absorption of water. The lanolin had to be completely withdrawn in order to continue the process.

The location of the workshops near the waterways was due to the need for the liquid to fill or of the pools in which the fleeces were washed, the main problem was that the water already used was returned to the same channel, which contaminated it, in the same way the works were located near the water channels because the *batanes* required this location for operation, the water that *batan* used was also returned to the contaminated source.

The water that was discarded from the work was impregnated with all the substances released by the wool of the *batan*, mainly the fat, in addition to the materials used as soap, this water contamination caused conflict because the water it made unusable for certain purposes, this raised lawsuits that had to be decided with the authorities, for example in the city of Toluca, the Carmelita convent was the last user of the water of a river that fed from its birth to several haciendas and workshops, the Carmelites allied themselves with other landowners because the workers exercised control of the water and

Figure 15. Hydraulic Batan of the XVI century, a wheel is seen that works by pushing water, that is to say, it is placed on the flow and it turns it, the two maces are on a tilting system that shares the support with that of the shaft of the wheel, finally we look at the cloth and the drawer where it crashes, image the 21 books of the mills and machines SXVI

they received very little, we must also consider the quality of the water they received as they were the last users in a long chain of works and make the real hearing ruling in favor of the religious⁴³.

Returning to the issue of washing process, remember that the purpose was to release it from stains, grease and other organic substances adhered to the fleece, the water of this wash was used several times until the concentration of these substances prevented this washing, this water was the one that returned to the rivers, after that washing, the wool began to dry in the sun in an open space.

The work required a yard where to dry the wool after this first wash, then when its already dried and sunny, wool was classified, in this process the wool was divided by quality and by the length of its fibers and also it was selected by color, length of the fiber and curly, this classification was very important for carding or combing, the short wool only needed to be combed

⁴³ Iracheta Cebecorta María del Pilar, *EL APROVISIONAMIENTO DEL AGUA EN LA TOLUCA COLONIAL EHN No 25 magazine July December*, Colegio Mexiquense, Mexico 2001, p. 81-116

to avoid knots and cakes, so that the fibers were located in one direction and arranged to pass the spinning, the carding was a similar process unlike the hairstyle required more time and patience because the wool was curled, with the card, it passed over the fleece which allowed the combing and accommodating of the fibers.

The card was a wooden brush with metal teeth that the wool passed to accommodate and form clews. The balls were the antecedent step of spinning. They were sets of wool strands arranged in only one direction and by characteristics, these strands are not yet spun.

Formerly the use of the spinning wheel and the spinning was using a distaff, the fibers have to be spun and twisted because of their length does not allow them to be woven, as the strand is removed to form thread and twist these strands threads were obtained then formed skeins.

The use of the distaff allows spinning in a more domestic way, with one hand the distaff was taken, there was a rod that at its upper end had a slit with a wool ball that was already combed or carded, with the hand that was free, fibers were taken that were twisting and lengthening to obtain the thread that was rolled, the twisted and elongated formed strands of braided thread that could then be twisted with others to increase the thickness of the threads.

With the implementation of the spinning wheel the work of twisting was done using a wheel that was spinning and at the same time this made spinning the spindle wheel that was located at the end, to then pull the threads that were placed in the spinning spindle, this way the threads were obtained⁴⁴. It is

Figure 16. Distaff or spinning wheel, in a textile workshop in the Oaxaca cross the photo was taken in 2006, the techniques are very similar to those we have seen in previous images during the viceroyalty, the child is spinning from 5 skeins of thread that can be seen on the floor, in this way it thickens the thread, this operation that is done now was done previously to create the skeins. Image Tarsicio Pastrana

important to mention that in order to be able to spin faster and more easily as already mentioned, oil was smeared off the thread that was generally lard which made it easier to handle and less dispersed, the thread obtained using this technique was a greased thread that would later be used on the loom, this point is very important because part of the felting process was to eliminate these natural fats from the fibers⁴⁵.

to Europe the spinning wheel, which is still unknown its origin, some say that it comes from India, some other from Europe, this machine allows to free the hand that use to hold the distaff, and use it to complete the process.

⁴⁵ The most common fats were added to make the process easier were the animal fats, besides that function it helped to protect the thread during the whole process.

⁴⁴ Near XIII and XIV century it was introduced

The natural dyes that were the ones that were used dyed the skeins of just done yarns, these dyes, were obtained from various substances all of natural origin such as cochineal grana for red, purple snail for purple, indigo for blue among others, after dyeing the threads were ready for weaving. At this point we have found controversy over whether the dye was made before or after weaving, at present the threads are dyed before passing to the fabric.

The fabric was made on the looms and depending on the amount of these was the production of the workshop, the weaver was the most important, since his work marked the rhythm of others, the width of the fabric was determined by the width of the loom, the workshop like we knew it disappeared already, but today we can find in several textile regions in the country, workshops where the organization is very similar to the process already described, these establishments can help up to give us an idea of how they worked on those days.

The threads of different fibers, were placed on the loom where it was adjusted and worked to obtain the pieces of fabric or cloths of different qualities according to the threads and the type of fiber they came from, the sections thus obtained were not ready even for a normal use, the fabric was open, loose and fatty as a result of the incorporation of fats and oils that, as already mentioned, were added to the fiber to facilitate spinning.

It is here where the key part of this section of the work begin, the batting was able to close the fabric and make it denser, another use of the batting had to do with the cleaning of the fabric, during the process water was added that it was used to cool the fabric and avoid its damage with the beating by

Figure 17. Interior of a textile workshop in the town La Crucecita in Oaxaca, the photograph taken in 2006 shows the environment in the workshops. image Tarsicio Pastrana

adding some substances to it, the fabric after this gets free of grease and oil.

In order to do this work before the invention of the hydraulic machine known as *batan*, a large wooden tub or pool was used where the cloths folded in water were placed, the paddlers whose name derived from the fact that they were going to be “step on” the cloth, so they put some wooden shoes to jump on the wet cloths, other variants were the beating with wooden mallets in the same tub, these activities were performed for hours and were really hard task, and was perfect for cleaning the fabric and for taking advantage of the watery environment and work percussion, also an ingredient were added as a natural detergent to the water so that the fabrics released the grease used in the spinning⁴⁶.

⁴⁶ Barragán De La Rosa Francisco José, *BATANES Y BATANADO EN CORIA DEL RIO* at <http://www.coriadelrio.es/batan.htm> on this article its mentioned the difference between the process done by hand and using the *batan*, it was performed with 3 operators working from 8 to 12 hours daily during 5 days in order to complete the process with a piece of wool from 25 to 3 meters long and 2 wide, when they started using the *batan* it took the same time for the same amount of cloths but only 1 was needed.

To replace this work, the *batan* or *pisón*, called this way in memory of the origin of this activity that had to do with the tread of the fabric. The *batan* is a very simple hydraulic machine that required a wheel that transmitted the movement directly to a shaft with cams, these cams operated a pair of wooden mallets that rose and fell alternately to hit in a container the cloths that were moistened.

The *batan* like any other machine where the rotation movement is transmitted directly without the need for gears or flashlights, required little maintenance and adjustment, the part in which more work had to be put was in that of the support for the mallets, since these were knocking all the time caused by the constant rotation of the wheel; we clearly defined three parts in the *batan*, the first, the wheel with its supports and its shaft with cams that required their respective maintenance, the second one the frame or stiff and sturdy wooden bench to load the mallets that would be constantly moving to cause the beating, the third had to do with the container where the fabric would be located to receive the blows from the mallets.

As for the wheel it did not require a strong water flow, in fact it could be driven by gravity because, more than a fast and energetic movement it required a constant force, the speed was necessary to increase the rotation and thus increase the number of percussions per minute that were worked on the container, the feeding channels could arrive from the top to rotate the wheel constantly, because the wheel transmitted its movement to a shaft⁴⁷, and that on this shaft it would be placed the bank with the

mallets, the *batan* was located close to the watercourse, unlike other water machines that could choose the best place on the river's water flow, the *batan* would always be placed besides the water flow, whether natural or artificial, the proximity of the *batan* to the water was related to the size of the shaft, it is logical that this distance was not very large because this large shaft would damage the performance of the machinery.

For this reason, canals were built to bring water to the wheel and then take it back to the river.

When the *batan* region was important and the production of cloths generated a strong demand in the use of the *batan*, a single wheel could have a battery of mallets, not only two as was common, there could be more than one pair and therefore more than a pool, workers only had to add mallets and place the corresponding cams, always alternating with respect to the other 90 degrees, this way the movement of the mallets does not occur at the same time. The amount of percussion per minute is approximately 40 according to the speed of the turn and the number of cams on the circumference of the shaft.

On the ends of this shafts the bases were placed, the first two on both sides of the wheel, a third at the end of the shaft, these bases were very important, since regardless of the stone or wood material, it was required that they support the shaft correctly and allow its movement freely, this was the key to the optimal functioning of the *batan*, the rotation of the main shaft.

Among the mentioned bases are the cams that are placed out of phase in both directions, that is located at a different distance from the wheel but also assembled perpendicular to each other, so that the hammering was not

⁴⁷ The measure of the wheels of the *batan* is from 2.5m to 3m, smaller wheels wont produce enough power to complete the process.

at the same time, at each turn there would be two tapping of mallets or more depending on the number of cams and mallets.

We already mentioned the hitting frequency, the distance between cams should allow the mallet to return to its place of origin, to start a new cycle so there could be no more than two cams for each hammer and for each turn, this could be modified if the circumference of the shaft was larger to allow the return of the hammer, although the *batanes* were generally very simple and their shafts were small.

While this turn was performed quickly and fluidly, the hammers would perform the work of striking quickly.

For this they needed the hammer to have a mechanism that would allow it by gravity to return to its original position, the turning cam would force the hammer to rise and when the cam stopped holding the mallet this fell hard on the container, the bench generally surrounded the shaft and the container, formed of 4 right feet and on top of a frame that contained an shaft to the center on which the mallets were literally hung the most important and most careful part was the articulation of the mallet that was made passing the wood that formed the handle of the mallet by a beam or wood with holes, this will allow it to have a circular motion that, aided by the cams, was repeated until the circulation of water

Figure 18. Drawing of a batan, the lower part in which the shaft is placed with the cams is observed, when turning, these push the mallets that when they are released fall heavily on the box in which the fabric is, it is important to mention that The Wheel will be in a lower plane than the machine, the mechanism is of direct transmission, very simple to build, the water has to flow through several parts, one of them of vital importance the box where the fabric is, already mentioned that if the batting is done dry the fabric is damaged and burned. Image Tarsicio Pastrana

was suspended, this piece could be metallic although those made of wood because of the mallet hung from the support beam worked well.

To build the mallets, heavy and dense wood was chosen, placing a beam or piece of wood on whose lower tip a generally trapezoidal mallet was placed, the top part of the mallet was placed in the system to allow its movement the assembly of each hammer could to reach the 90 kg, together with the movement of the cam, exerted a similar striking force on the cloth, this was the task of the battler taking care that the cloth was not damaged by excessive and constant hitting.

The container could contain the cloths to which water had to be added then they were wet and thus facilitate the release of fats and oils, in addition to this substances were added more ingredients according to the region in which the batting was performed for example in many sites were placed on land that helped by the regional characteristics of it in the process, in Mexico plants and soaps were used, over time and since soap was an article manufactured with more ease it was the product that was most added, the purpose of this ingredient was to remove the grease from the cloth.

The third part of the *batan* was the container, which was placed in one of its sides, perpendicular to the movement of the hammer that was constantly cared for by the batter to move the folded cloth inside, the cloths were zigzag bent the folds were on each wand, if we remember that the fabrics measured approximately 25 to 30 meters, we found that the fabric was folded approximately between 30 and 35 times, this folded was changed throughout the process of batting in addition to changing the position of

the package in the tub, this in order to make the an uniform layout, avoiding damage to the fabric, constant hitting on the fabric and lack of water could cause irreversible damage.

The water had several functions in this case, to help the natural detergent to release the oils and fats and prevent the tissue from being damaged by the constant friction of the mallets on it, as an important part of the *batan* at the height of this container should exist some channel or element that would help circulate the water, both, the waste and the new one, to prepare the mixture already described, the water had an important cooling function, if by some carelessness the fabric dried the knocking and the heat generated for this he burned or broke it, the batting had to be done wet and in part of that liquid the substances already mentioned were added.

The tub could be hollowed into a log and placed semi-embedded on the floor remember that it had to withstand the knocking of mallets that could weigh up to 90 kilos, it was also common for it to be made of wood but it was also built in so that the recessed it was resistant to knocking and the fabric was the one that had to absorb the energy generated by the blow and the reaction to the ground that supported the tub.

Talking about detergents, in Spain people talked about a soil called soap, which contains in its composition agents that help dissolve fats and in Mexico the fruit of the plant known as soap that was added to water for the same purpose of the soil already described, all these artisanal methods end up being replaced by soap⁴⁸.

Batan could be part of the workshop, but there were also independent

⁴⁸ González Tascon Ignacio, *op.cit.* p. 395

THE MACHINE OF BATAN

Figure 19. Side build of a batan, we observe the tilting system mounted on a wooden support, the wheel in the lower part that transmits its force to the cams that with its turn raise the hammer handles, when the cam leaves if the handle is held, the fabric will fall heavily, the task of the worker will be to take care of the fabric, move it periodically and keep it wet, in addition to adding substances that function as soap in the water to wash the fabric. Image Tarsicio Pastrana

establishments that were dedicated only to batting, and these establishments could supply a work area or several local artisans who worked in their homes.

In many cases the architectural space that covered a *batan* was too unstable, being small sheds or small and poor factories, so it is difficult to find the vestiges of these sites, in the case of the city of Puebla we found that the region where the bigger number of the workshops established near San Francisco river, currently this river is piped and runs through the subsoil of an avenue, the workshops remain with other uses, but the places where the works were not clearly identifiable, especially if currently the river no longer flows freely.

In this area of Puebla, the Franciscans were the first to establish an industrial

zone, taking advantage of the river's water, this subsisted for a long time under the process that we already mentioned replacing work and pre-industrial areas with industrial zones, the industries were located on the banks of this river and nowadays it is possible to find the buildings in the areas near to the convent of San Francisco.

In the case of Mexico City, the Batanes region were located at the west, taking advantage of the flows of the rivers from the hills of Santa Fe, for example, the Batanes that were in Mixcoac, in Santa Fe and in the area of Magdalena Contreras, although the largest construction areas were not in Mexico City, they were in Puebla, a town which has already been briefly discussed and in Querétaro and Celaya, at the same time regions are developed for the main cities, remember that a large trigger

of This regional development was the mining centers and the need they had to be supplied by neighboring cities. This was the case of Querétaro and Celaya that supplied the mining regions to the North, Puebla and Querétaro also had a large market in Mexico City.

After the batting the fabric could already be marketed for the production of clothes, in the workshops were made all the preliminary steps, such as the

smoothing of the fabric, the dyeing or the carding of the fabric to eliminate the fibers that were left outside the fabric, as a final point they were prepared for sale, the cloths that were sent to the tailors were produced to create dresses, regular clothes and other types of fabrics that were necessary were also produced.

5. Workshops architecture and batanes

1. Carriage Access
2. First Courtyard
3. Workshop well
4. Shop or grocery store
5. Store pantry
6. Factory entry
7. Lobby
8. Warehouse
9. Box

10. Workshop Oratory
11. Factory garage
12. Stables and Barn
13. Supply Entry
14. Cloth Winery
15. Baths
16. Inner Courtyard
17. House well
18. Access to the noble floor *continue*

Figure 20. Ground floor from a workshop of Mixcoac image Tarsicio Pastrana obtained from The workshop of Mixcoac in the XVIII century by Salvador Cárdenas Gutiérrez

- 19. Garage
- 20. Stables and haystacks
- 21. Stage
- 22. Service ladder
- 23. Kitchen
- 24. Pantry
- 25. Spiral staircase
- 26. Yarn
- 27. Chapel of the Rosary
- 28. Sacristy

- Second yard
- 29. Portal with viewpoint
- 30. Orchard
- 31. Hortelano House
- 32. Water channel from Mixcoac river
- 33. Exit and irrigation canals in the garden

Figure 21. Higer floor from workshop of Mixcoac image Tarsicio Pastrana obtained from the work of Mixcoac in the XVIII century by Salvador Cárdenas Gutiérrez

- 1. Lobby
- 2. Gallery of dyers and carders
- 3. Gallery of the warp
- 4. *Tetecadero*
- 5. Warehouse and barn
- 6. Gallery of ironers
- 7. Dye cellar
- 8. Brazil warehouse
- 9. Cloth cellar
- 10. Warehouse and loom
- 11. Terrace for wool drying
- 12. Noble Floor Access Terrace
- 13. Stand reception room

- 14. Assistance room and dining room
- 15. Sewing stay
- 16. Room of the lords
- 17. Girls' bedroom
- 18. Guest bedroom
- 19. Bathrooms
- 20. First hall
- 21. Second hall
- 22. Third hall
- 23. *Azoteguita*
- 24. Study of the Regidor
- 25. Chapel Choir

Figure 22. Hypothetical reconstruction of the Batan from San Jacinto in San Ángel image Tarsicio Pastrana based on data in the work of Mixcoac in the XVIII century by Salvador Cárdenas Gutiérrez

The house of the batan belonging to Mr. Francisco Antonio Casuso, ruler of this Noble City that was located in Los Altos of San Angel, next to the town of Atizapan (sic), is composed of hall and garage, yard, a portal or corridor, room with two bars, bedroom and fence, another five pieces with bars and stairs to the roof ... and burner and two other rooms, and another that is outside the hall, and on the roof a viewpoint, all of which is made of stone walls and mud,

beamed ceilings, bricked roofs and floors, with good doors and windows⁴⁹.

The machine was under a jacal loaded on five masonry pilasters, which was reached by crossing a bridge over the ditch where the water was taken to drive the wheel. Next to this portal were two stables, a yarn in which the cargo mules were kept and a wooden haystack, all surrounded by leafy hollows⁵⁰.

⁴⁹ Cárdenas Gutiérrez Salvador, *EL OBRAJE DE MIXCOAC EN EL SIGLO XVIII*, Panamericana University, Mexico 2002, p. 88, 89 y 90

⁵⁰ *Ibíd.* p 88,89 y 90

III. IRON AND WATER

1. Introduction

Ironworks are the places where iron is processed from its raw state, its characteristics were as in other types of establishment studied over time, to be precise, the ironworks has as main objective the work with iron, although the same method is applicable to other metals, of all types of hardware stores that existed the analysis will have to focus on those that use water as the driving force; as a peculiarity, the water mills used water for three particular purposes, the movement of the mallet, the movement of the bellows, and in the case of using the air boxes, they used water to produce an air stream that fed the furnaces; the relationship between these establishments and the water was similar to that of other pre-industrial buildings, the hard work that represented the obtaining of iron was diminished in its physical participation of the operator from the incorporation of hydraulic machines into the process.

Once again we found a primary process that incorporates the force of water to facilitate this effort, as we will see later the physical work that required an establishment of this type was really hard even with the help of water, at the same time it's really important to describe the use of water in the production of iron, from the moment that the hydraulic wheels are incorporated until they begin to replace the bellows operated by water by the so-called water tube that had the same purpose.

The hydraulic wheels are incorporated into the hardware stores in more than one process, as will be described later, and after that a device that works

from the water allowed circulation of air through the oven. In the first stage and before obtaining metals by other methods in America, the hardware stores were used for this purpose, they were part of the facilities that were within the *Haciendas de Beneficio* or Processing Haciendas and in many areas the mercury amalgamation methods could not substitute for obtaining ore by melting.

In New Spain these establishments were used for other purposes, it does not mean that there were no ironworks in the viceroyalty, they were called foundries, there iron and other metals were melted through establishments similar to those in Spain.

It is the case of the Chicomuselo smelter in Chiapas⁵¹, or the one that Andrés Manuel del Río builds and designs in Coalcoman in Michoacán⁵², we can find more frequently the smelters within the processes of obtaining ore, the furnaces used water circulation to obtain the air flow that fueled the fire⁵³, in a different section we will analyze mining and its processes related to water, in this case the analysis of the ironworks by themselves, the operation, the machine and the establishments will be analyzed, with the same methodology than the rest of this work.

The defining spaces of the genre and its analysis will be complemented by the

⁵¹ López Bravo Álvaro de la Cruz, Lee Whiting Thomas A., *LA FUNDICION COLONIAL DE CHICOMUSELO CHIAPAS en Memoria del primer congreso nacional de Arqueología Histórica*, CONACULTA INAH, Mexico 1996, p. 317-325

⁵² Yanes Rizo Emma, *PASION POR LA TIERRA ANDRES MANUEL DEL RIO en Artes de Mexico number 86 una visión de la minería*, Mexico 2007, p. 48-55

⁵³ The air flow systems that takes fresh air and moist to the furnace are documented on the first half of the XVI century, mainly in the Haciendas de Beneficio before the yard method.

process of obtaining the metal, this path allows us to analyze its components part by part in the process and then obtain from that script the spaces and machines participating in the process. It is important to emphasize that this analysis is intended to understand the origin of the smelters and how water is incorporated, in order to understand in the viceroyalty where the smelting techniques came from, always remembering that the profit farms had part of this process within its facilities.

2. The History of iron

The importance of iron, even now, lies in its characteristics and its properties that provide usefulness in many current and ancient processes, its abundance is also important is the fourth most abundant element in the earth's, representing 5% of the total, among Metals is only surpassed by aluminum that is more abundant. As an additional fact, the Earth's core consists mainly of iron and nickel, generating a magnetic field when moving.

Iron and its production marked a whole prehistoric stage to which it gives its name, as it happened with some other materials, man first dominates the fire and then applies it to various materials, thus applying it to the naturally obtained mineral he finds that he can handle and mold the rocks at his convenience.

Beats Bronze in hardness and in abundance of deposits, remember that bronze is an alloy and its components are scarcer although they are easier to work and melt, another advantage of iron over bronze is its quality of pure material, that is to say an alloy process does not have to be controlled, the reason why it is more complex to obtain iron is at the temperature it must reach to melt it around 1500 ° C which is only obtained if the fire is fueled with

constant air , this is the reason why the first iron work processes did not reach the foundry, only the plasticity necessary to work it and mold it to taste have found evidence of the use of iron, probably from meteorites, in the fourth millennium before Christ in Egypt and Mesopotamia between 2000 and 3000 B.C. appear iron objects that are distinguished from meteorite iron by the absence of nickel⁵⁴.

Hittites are considered the first people to work iron properly, around 1400 B.C., mainly producing weapons that gave them a regional advantage that lasted until the other people's began to work iron as well.

Although its main application was the manufacture of weapons and tools, jewels have also been found, for example in some Egyptian tombs the iron obtained from meteorites was the main source making it a very precious object. The iron age limits vary considerably depending on the culture and geographical area, as an example we can mention that while in Europe and Asia most civilizations knew this age, in America the pre-Hispanic cultures never knew it, although its development was very advanced both technically and socially in other areas.

The knowledge of the iron working technique is generated in the Middle East and spread throughout Europe through migrations in this case of Indo-European tribes through the Caucasus, subsequently reaching all corners of Europe by the hand of the Celtic people characterized by their excellent handling of metallurgical techniques

⁵⁴ Esteller Lores Gabriel, *APUNTES HISTORICOS SOBRE LA SIDERURGIA DESDE EL DESCUBRIMIENTO DEL HIERRO Y EL DESARROLLO DE LAS PRIMERAS FUNDICIONES HASTA LOS ALTOS HORNOS* en revista de Técnica Industrial Number 254 Sep 2004, Spain 2004, p. 24

this migration process dates from 1200 B.C. and developed until Roman times.

The process of transition between bronze and iron was slow, but in the middle of this the procedure called carburization was discovered by means of which coal is added to the iron, this was obtained in its natural state which contained many oxides and slags, within the heating process it was beaten to release the greatest amount of slag and by oxidizing the carbon, the beating had as an end, in addition to the described, obtaining more manageable ways to work them, the striking process is called wrought, the wrought iron had very carbon contents low so that it was not possible to temper properly, to incorporate the coal into the iron they heated the wrought iron with charcoal, which began to accompany the process from the first baked when doing this they submerged it in water or oil with what they achieved a layer Steel on top of the product hardness and strength in this way began to replace bronze.

The iron was forged for a long time, to confer the desired shape, some processes such as tempering were also known process by which the abrupt change in temperature can change the structure of the iron molecules to make it more resistant, the wrought iron It was used to obtain all kinds of tools, weapons and accessories for construction, including knockers, hinges, reinforcements, railings, fences, also served with other materials to make containers, chests, barrels etc.

Apparently the first to melt the iron are the Chinese in the year VI B.C. to obtain the cast iron you can work in alloys and cast it to work it by means of molds, the cast iron is born, in the iron smelting the material was obtained in its purest state and work continued through blows, the foundry managed to make the material purer and give it

characteristics with which makes the work easier.

During the XVI and XVII centuries, the Catalan *fargues* (forges) and the Basque⁵⁵ model ironworks for which in a very limited way would be installed in America during the viceroyalty were famous in Europe. The ironworks was the establishment that reduced the mineral to its purest state, from the state in which it is found in nature, in these establishments the main objective was to provide a raw material for the forges that were the places where the iron was worked to convert it into useful objects, the development of these over time developed several sections that in parts or complete were used within other processes, as we will describe in detail later the water tower furnaces were used in the New Spain in mineral smelters and in the profit farms depending on the mineral that was desired to work.

Obtaining of iron is diversified and perfected, when quantities of coal that do not exceed 2.5% are added, obtain Steel that is more resistant and that is currently the base of several industries, the ironworks as an establishment are precursors of the foundries, there that process the material for its commercialization, that's the reason why many ironworks, do the complete process from obtaining of the mineral until the manufacture of utensils.

We find names and place names that have survived to this day, blacksmith, Ferrero, Ferreira, Ferrón, Herrera etc., which speaks of activities and crafts. Also, the derivatives of the process provide us with names of places, among them the most famous is the slag, the slags being the remaining mineral residues of the process of obtaining iron.

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⁵⁵ *Ibíd.* p. 25

Figure 23. Image of a Mountain Ironworks, they were named that way because they were generally built in places where there were drafts that helped combustion. Image Tarsicio Pastrana

3. Evolution and development of the ironworks

The first ironworks that were used in Spain were the ones called mountain or air ironworks dated from XI century, to melt the iron needs 1500 degrees, temperature that was only possible to reach through fanning the fire by means of flows of air, otherwise the metal is heavily contaminated by the other substances that accompany it and is not obtained in its purest state, to provide this flow of combustion air bellows were used that were made from the skin of some animals , the size was small to allow the operator to handle it.

A different way to take advantage of the air that circulated constantly in some places was channeled it into the oven.

This system was used in a very similar way in the Inca Guayras, which were

small furnaces provided with holes that were placed in the upper part of the hills so that the air currents passed through them and facilitated the reduction, the Guayar system as it was widely used even by the Spanish in the XVI century until the arrival of methods that allowed to increase the level of production in the benefit of minerals.

This is the reason why the mountain ironworks are located on the tops of the mountains, where the air runs constantly and allows that through rudimentary devices such as reeds inserted in the oven walls the fire is fueled to get the right temperatures.

Inserting rods to blow with the mouth was a system that was used in pre-Hispanic times in Mexico, in several codices and chronicles⁵⁶ we found

⁵⁶ Dora M.K. de Grinberg, ¿QUE SABIAN DE FUNDICION LOS ANTIGUOS HABITANTES DE

that the smelting work was carried out by means of small ovens in which pockets were inserted to blow and improve combustion, it is important to mention that this pre-Hispanic system is mentioned by the similarity with the first processes of obtaining the mineral in the mountain ironworks both the Guayras⁵⁷ and the pre-Hispanic furnaces in Mexico used techniques that initially used to get iron.

The location of these ironworks not only had to do with air circulation, other factors were also required, the first of which was to be in the vicinity of a wooded area, since through the wood the coal needed for the furnace was obtained, the most common is that the furnace is built on the top of a forested hill at whose base or middle part the mineral to be worked is obtained.

With respect to the construction of the furnaces, these did not exceed 3 meters high, with a diameter of 1 meter and stone walls worked to be able to be revoked inside with a flattened clay refractory, this construction is half buried approximately 50 cm on the ground, near the base, some holes were placed to put the nozzles of the bellows or the reeds and stoke the fire by manual means or by the air circulation in a natural way.

It is logical to think that furnaces started as a house of stones and wood within which the mineral and coal were accumulated and which was set on fire and then found the residues in the background, over time the evolution

Figure 24. Image of pre-Hispanic goldsmiths melting the metals in a portable oven in which the red-hot material is seen in the interior, to which they have to blow the air with the mouth through a reed image: Florentine codex

of the process provides the furnaces that stay always with the process even today.

In some places a secondary furnace of smaller dimensions and with less requirements in which the materials were pre-calcined was placed next to the main furnace, the first step was the crushing of the metals and after this crushed the material was placed in the secondary furnace, with this exposure to heat, the metal generally got obtained and also it was based on iron oxides, then it began to lose oxygen, which would facilitate its reduction in the other furnace to which the mineral was passed once the calcination process was completed, the arrangement in the main oven was alternating layers of crushed and calcined material and coal, once the accommodation was done, the combustion that was constantly monitored.

In the reduction process, liquid slags were obtained that had to be removed with spillways placed around the oven, when the temperature was the one

MESOAMERICA? PARTE 1 en *Ingenierías*, Jan-Mar 2004, Vol. VII, No. 22, Sección de Ingeniería Mecánica, Facultad de Ingeniería, UNAM. Mexico 2004, p. 66-69

⁵⁷ **Martínez De La Torre Cruz**, *EL SUDOR DEL SOL Y LAS LAGRIMAS DE LA LUNA: LA METALURGIA DEL ORO Y DE LA PLATA EN EL ANTIGUO PERU en Espacio, Tiempo y Forma, Serie Vil, H.* del Arte, t. 12, Peru 1999, p. 11-24

needed, the iron particles are released from the oxygen and join together forming a paste that is called *Agoa*, which still needs an additional process to free it from slags and adhering dirt, this procedure is hammering, hitting it releases it from foreign substances and makes it more compact and also it is possible to shape it as bar or ingot.

The work of these ironworks required many physical resources, so the hydraulic wheel is incorporated into some of the iron production processes, firstly the hydraulic wheel is incorporated to move the bellows and the mallet, from this process the waterworks gets their name, this occurs between the XIII and XIV centuries in a massive way, although for a long time in the XV, XVI and XVII centuries both types of ironworks coexisted and were conditioned by the hydraulic resource, where this was present it was used and where it wasn't, the air ironwork was still used⁵⁸.

This substitution has several consequences one of them has to do with the location the ironworks, now they have to be built near the water source that will be their food, another consequence would have to do with the integration of different processes in the same establishment, on first place the ironwork was the furnace where the pure mineral is obtained ready to work, the second establishment called mallet or hammer was the site where these minerals already purified were worked by means of tapping to obtain commercial pieces ready to take them with the blacksmith that would turn them into items that would be commercialized later.

Figure 25. Engraving of a ironwork in which the two hydraulic devices can be observed, the hammer first driven by a vertical hydraulic wheel and with crankshafts the wafers or bellows that feed the furnace seen on the left are driven. Source engraved in the work of Jacques Strada Frankfurt 1617

Another one has to do with the increase of production, mainly because of the hydraulic wheels the bellows and the hammer were operated, both objects grew in size because previously the size was limited by the physical capacity of the operator, now that problem were solved, the bellows moved constantly and evenly, the oven became more efficient, the beating also becomes mechanical, which controls the hammering process.

Thanks to the water and the circulation of this through various ducts, it is also possible over time to replace the bellows with a tower through which water was circulated through reduced ducts, the air displaced by this air circulation was channeled towards the oven to the air towers to stoke ovens.

⁵⁸ Zabala Llanos Marta, *FERRERIAS MUSEO, PATRIMONIO Y DIFUSION DE LA SIDERURGICA TRADICIONAL VASCA* en revista internacional de estudios vascos 52, 1, 2007 287-302, Spain 2007, p. 287-302

4. Getting iron process

In order to locate an ironwork, three things were required, a water channel, nearby forests for the combustible material, whether coal or firewood, and ore deposits close to the ironwork⁵⁹, these areas were common near the river in order to store water, these are usually not so elaborate constructions and sometimes they were made with the simple stacking of stones and wood in the appropriate area of the river, the only purpose is to maintain a constant flow of food to the canals of the ironwork.

The hydraulic infrastructure begins at the dam and through channels reaches the ironworks, the channels generally take two paths, one of them to take the water to the hydraulic system and the other to the system for washing the ore and cooling system, the water path to the wheels has to reach a tank located at the top of these so its height will have to be approximately 3 to 4 meters above the floor of the work area⁶⁰, to feed the wheels by gravity, remember that the feeding of the wheels by gravity ensures its rotation and keeps it constant.

This deposit has to arrive at the top of what we will call hydraulic tunnel, confined between two thick and resistant parallel stone walls whose function is to absorb the vibrations and keep the wheels in place, one of these

walls will be coincident with the area of work of the ironworks, that's the reason why the hydraulic tunnel runs parallel to the area of work.

The first part in process of obtaining iron is related with its collection which was generally done in the open fields, loaded in containers and transported to the ironwork where it was placed in a tank or outdoors, in the same way the coal arrived which was located in tanks that were open on one side to the outside and on the other inside the work area where the oven was located, this separation had to be done with thick walls to protect the coal from the sparks of the oven and avoid the fires. We have already talked about the walls of the hydraulic tunnel and now we talk about the walls that divide the deposits of the work area, we find that the construction of a hardware store has to be thick due to mechanical and safety issues, not so much because of the load on the that the walls would be submitted.

The material was distributed first to the cleaning area, where it was washed in canals or water tanks that are inside the establishment, the water reached the hardware store through channels that, as already mentioned, came from the river, we have already mentioned the upper tank to the hydraulic tunnel, so that the hydraulic system can be divided in two, the one that is directed towards the driving force and the one that is used within the process of obtaining the iron, in the second case we find the water for cleaning the ore, the channels or reservoirs were separated because the driving force is generally at a level inaccessible to workers.

In this part of the process a constant flow of air is required inside the furnace, which was made in the mountain hardware stores using hand

⁵⁹ Ojeda San Miguel Ramón, *RECURSOS TECNICOS E INFRAESTRUCTURA EN LAS FERRERIAS DE CASTRO SAMANO* on magazine Euzkonew, Fundación Asmoz, Spain 2004, p. 4y 5

⁶⁰ Muguruza Montalbán Félix, *APUNTES ETNOGRAFICOS DEL VALLE DE LAUDIO: FERRERIAS, CALEROS, MOLINOS Y NEVERAS en 1º Concurso de "Trabajos de Investigación relacionados con Llodio-Llodio, Caja Vital Kutxa-Ayuntamiento. de Llodio y Diputación Foral de Álava. Spain 1996, p. 13*

Figure 26.

or foot bellows, with the hydraulic wheel larger bellows can be created air flow of greater volume than those of hand, to be able to drive the bellows from a rotating movement that is the one that generates the hydraulic wheel you have to make some adjustments to the machinery.

Two wheels are located in the hydraulic tunnel, one of which will serve exclusively to drive the bellows, this wheel receives water from the upper tank, to rotate it by gravity, through the shared wall passes the shaft that reaches the supports, it is say the axle of the wheel serves to load it, so that its first support is in the most extreme wall of the hydraulic tunnel and then the next support is in the shared wall and then we will find others that aim directly to the movement towards the bellows, the materials which the bellows

were made were skins and wood, with reinforcements in areas of movement and friction.

The bellows, were located on a wooden table or support that holds them in place with the outlet of the bellows towards the furnace and to the opposite end of the shaft side, from the part that faces the shaft there is a device formed by a tilting bar at the top and that in the way of a rise and fall is linked to each end of the two bellows which causes that when one is closed expelling the air the other is open filling with air and vice versa, another system is using rigid rods attached to each end of the bellows which go to a wooden structure located above them where there are two counterweights, which have the function of returning to the bellows towards its state of filling the air to start a new cycle.

Figure 27. Hydraulics factory based on bellows to blow air into the furnace, the hydraulic wheel drives the shaft with cams and these drive the bellows, which when attached to a rocker when one lowers the other rises, this way they take air and injected into the oven. Image: Tarsicio Pastrana.

The end of the shaft that coincides with the bellows table has two cams that turn when they hit the bellows causing it to expel the air inside it for filling is the system of counterweights, that we have already described, both the cams and the counterweights allow a non-simultaneous operation of the two bellows, the cams are offset at opposite ends of the circumference, so for each stroke of one of the bellows there will be another offset to the other bellows, and the counterweights will work similarly, causing a constant operation and by therefore a greater and continuous air flow.

This in a succession of cycles that allows to increase the combustion temperature, to achieve greater air flows, larger bellows are constructed, which store more air that can be expelled alternately between one and the other.

Although it is difficult to observe bellows in ironworks because of the perishableness of their constituent materials we can find similar performances in the bellows of feeding of wind organs, although most of them already work with electric pumps you can still observe the bellows their cranks for activate them and their counterweights⁶¹.

Another accessory to generate air flows is related to the Bernoulli principle and is called according to the region of water or water tower, also water furnaces, this type of furnace generates the air flow without the need to build bellows, in Mexico they have found this structure in the ironworks of Chicomuselo, but mainly in some chronicles of furnaces

⁶¹ In Tepozotlan on the chorus of the temple besides the organ there's a bellows that now it doesn't is used since it has attached an air compressor.

Figure 28. The air tube took advantage of Bernoulli's principle to generate a stream of air in the oven that is loaded with moisture since the air stream displaced by the water is charged with it and then through a duct from the chamber inside goes to the oven, for more details see the next cut. Image Tarsicio Pastrana

that were used to reduce minerals in the first half of the XVI⁶² century of mining that we will talk later.

Daniel Bernoulli, a Swiss scientist, showed that, *in a system with constant flow, energy is transformed in one*

way or another every time the cross-sectional area of the pipe is modified.

With this scientific principle a tower is designed that uses a tube (Venturi tube) through which water is circulated, in the area of the decrease in diameter two or more air inlets are located.

⁶² Ignacio González Tascon, *op.cit* p. 308

IRON AND WATER

WATER GADGET TO BREATHE AIR
INTO THE FURNACE

Figure 29. Image of the air tube, you can see the upper ducts through which the water circulates, the side ducts through which the air enters, the chamber where the water collides with the column and the air outlet ducts and of water, image Tarsicio Pastrana

This decrease in pressure causes the atmospheric pressure to be higher than the pressure that exists in the diminished diameter of the tower, which produces a circulation of air from outside to inside through the inlets already described, this air is mixed with the water that is circulating, in the lower part of the tower a chamber is made in which the water jet hits a flat surface where the air is separated from the water, although the air is loaded with moisture, the lower part of the flat surface has a siphon that prevents air from leaving that area and only water comes out from the bottom, one or more air outlets are located laterally that are channeled into the oven chamber with

moisture-laden air and with a constant flow is favorable for combustion.

The construction of this water tube was made with stone, the air inlet and outlet ducts were made with wood or mud pipe the location has to be in the common wall, with an access from the top from the tank of water and with an exit to the hydraulic tunnel since the water circulation is constant while the stove is being used, when there was a tower of this type, one of the wheels was removed, keeping only the one that moved the hammer.

Finally, we will say about the water tower that traditionally in Spain there were two producing areas of iron, Biscay and

Catalonia that got the royal monopoly of the iron; the iron that arrived at the beginning to America came from one of these two regions, more often was from Catalonia, the main difference between these two regions was the air tube, while the Catalans used to have ironworks, in Vizcaya were more common to use bellows, it is not surprising that one of the few ironwork in Mexico that have been found and explored has an air tower instead of bellows⁶³.

The use of the furnace was constant, for several hours, approximately the cycles of metal production in the furnace lasted 6 to 8 hours⁶⁴, at the end of which a new load had to be made, the amounts of fuel used were very large around of 450 quintals of coal per 100 quintals of iron obtained⁶⁵, we know that each quantity of iron obtained needed its weight multiplied five and a half times of coal or eleven if it was firewood.

At the end of the reduction process, the metal was at the bottom of the crucible in irregular shapes and in a soft state due to heating, from this site it was removed to take it to the mallet, then with the mallet the slags that could still exist were released and then it gets compacted in order to get the iron bars.

The mallet was formed by a driving wheel, the transmission shaft, the arm and the head; the wheel was in the hydraulic tunnel and in the same way that the bellows wheel its axle was

loaded in the end wall and then in the common wall, crossing the latter to enter the work room, the axle rested on its extreme inside the workroom, this axis depending on the size of the hammer head had to be more robust than the one that transmitted the movement to the bellows.

The hammer was a key item in the manufacturing process of the ironworks, as it served on the one hand, to separate the iron from the slags, since these are embedded within the mass and based on successive blows of the hammer said compaction mass of iron and the slags separated, and on the other hand made the roughing and stretched the bars; It was finally used to give these bars their last form⁶⁶.

The wooden shaft is approximately 5 to 6 meters long and 60 cm. in diameter to choose the wood, a resistant tree is chosen depending on the woods of each region and they cut in the dry season to prevent the trunk from having extreme moisture, let it rest with bark for 5 to 6 months and then shape it and work it⁶⁷.

At the opposite end of the wheel were some cams, which had to be iron and embedded at the rate of 4 in each quadrant of the circumference of the shaft, the most functional way to do it was through a piece made to the measure, this piece surrounded the entire head of the axis and in each quadrant the iron cams came out

⁶³ López Bravo Álvaro de la Cruz, Lee Whiting Thomas A, *op.cit.* p.317-325

⁶⁴ Sin embargo, se alcanzaban los 1300-1400 grados de temperatura, y se necesitaban unas 5 ó 6 horas para separar el hierro de los residuos en Iraeta Usabiaga Ainara, *EL PROCESO DE PRODUCCION DEL HIERRO en Euskonews no 87*, Eusko Ikaskuntza, Spain 2000, p. 1-12

⁶⁵ One quintal was equal to 45k, then for each 4.5 tons of iron they needed 20 tons of coal.

⁶⁶ Morís Menéndez Valdés Gonzalo, *INGENIOS HIDRAULICOS HISTORICOS MOLINOS, BATANES Y FERRERIAS en Ingeniería del Agua. Vol. 2 No. 4*, Departamento de Construcción e Ingeniería de Fabricación E.T.S- Ingenieros Industriales de Gijón, Universidad de Oviedo, Spain 1995, p. 14 y 15

⁶⁷ *Ibid.* p. 14-15

getting 4 percussions per turn, there were also those of two percussions per turn.

The handle of the hammer was made with the characteristics similar to those of the shaft although of smaller size of about 3 to 4 m and 40 cm in diameter with a support to the center to make it tiltable, the support of the center was made so that the hammer could be centered to locate it in the precise area to hit cams, with two wall-shaped poles with a channel to the center in which entered a piece of iron that was located at the center of the handle of the hammer, this piece in the form of a ring with two cylinders that came out at opposite ends rested in the channels of the walls, at the ends of these channels were wedges that allowed the centered.

The end of the mallet that faced the cams was reinforced by iron belts so that it received the tapping of the cams by means of this beating and the swinging effect caused a hammering movement at the opposite end of the axis the head of the hammer by means of wedges, some hammer heads weighed up to 700 kilos⁶⁸, in its resting state the head of the hammer rested on an anvil of iron located on the ground which had the height corresponding to a work table so that the Ferrero standing could work the pieces with The hammering pounding. The anvil piece was an inverted iron pyramid that was embedded in another piece of wood to give it the required height.

⁶⁸ The size of the hammer reveals the amount of energy needed to pick up, the wheels in the ironworks were most common gravity wheels, this was because getting a constant pushing force was easier "Agorregi Hammer weight is 700 kilos, that's why it's needed a big amount of water to make it work. This hammer was used with the boiling iron, ready to create any kind of tool, that later were taken to the ironworks." *Usabiaga Ainara Iraeta, op.cit. p.1-12*

The heavier the hammer, the stronger the blow, when the cam hit the handle, it rose and then when the cam left the handle got it free, it fell with the force of its weight on the anvil where the Ferrero placed the hot material to shape it, workers ability had to be high to avoid accidents in the use of the hammer.

On the other hand, if you wanted to hit even faster, it was needed to reduce the weight of the hammer head and increasing the cams on the shaft in case of having 4 cams, the beating was approximately 120 percussions per minute, which in some cases did not was enough to work the Iron before it cooled, the smallest mallets with 6 cams reached 180 strokes per minute enough to quickly work the hot metal. In this category the hammer of the ironworks of *Chicomuselo* entered since in the archaeological excavations the head with a weight of 90 kilos was found.

The operator carried the metal still hot and shaped using hammer blows, they got bars and ingots that were later cooled to take them with the blacksmith who would have an oven or forge this does not require high temperatures since the temperature is different to work the iron that to melt it, these would be the two establishments in which the iron work is divided in the Basque region.

The ironworks were divided into two, the major and the minor, in the major ones the iron was obtained from the virgin mineral and it was shaped like bars, plates or ingots, in the minor ones the iron was given a commercial form and worked in tools and items. Since smaller ironworks did not need to reduce the ore, their furnaces are less complex and require less infrastructure.

HYDRAULIC HAMMER, MALLET OR IRON MACE

Figure 30.

Finally, the description of the hydraulic system must be completed, since the tanks that were located on the work area had to have valves to block the circulation of water from inside the work area.

This was the only way to stop the machines interrupting the flow of water on the wheels, for which gates were built on the wheels that were operated by means of levers and chains from inside the work area, for this purpose the tank in some cases was built of wood on the hydraulic tunnel with the water outlets in its lower part to feed the wheels by gravity, this construction had to be done taking care that the wooden channel that in turn was the reservoir did not leak between its components.

In several regions of Spain, mainly in Oviedo, the upper channel that served as a warehouse was called *banzao*, and was supported between the two walls that contain the hydraulic tunnel, the wheels were located in the lower part of this deposit, they were made just like those of other hydraulic machines with wood treated to resist moisture and chosen among the regional species that supported more physical work, the wood had to be hard and resistant to moisture.

The wheels were built 1.5 to 2 meters in diameter and up to 25 cm thick with what we have the dimensions of the hydraulic tunnel were given by the wheels that would receive the water from the top, it is important to note that most of the ironworks will have an upper channel with a hole to let the water pass down.

5. The architecture of ironworks

The premises that have to do with the production process and the order in which they participate in this process are marked with letters:

In Chicomuselo, the southern part of the work area is occupied by the hydraulic hammer, the air tubes reduce the area that would have to be destined to the interesting boats is the double channel one for supply and another one for drainage, taking advantage of the natural slope of the terrain, another important aspect is the circulation of water between one channel and another and in that transition the location of the hydraulic wheel.

- A. Aqueduct raised to 4.5 m above the level of the work area
- B. Air tube draining on the same side of the aqueduct
- C. Air horn draining into the sink
- D. Furnace that works with the air injected through the air tubes
- E. Wash pool
- F. Lock Pretil
- G. Hydraulic hammer
- H. Gravitational Hydraulic Wheel
- I. Foundry drain channel

Figure 31. Plant of the colonial smelter of Chicomuselo reconstruction made based on the interpretation of the data in the article the Colonial Foundry of Chicomuselo, in which the vestiges found and their.

IV. WATER AND METALS

1. Introduction

Hydraulic engineering as a technological application, were used a lot on mining, it was one of the most paid and productive activities in New Spain, it was a great field to develop engineering as a tool to increase production and thus increase profits.

Mining and the benefit of minerals caused a technological development in which New Spain came from the applications and tests produced by large-scale practice to many more efficient modifications and applications of existing methods, such as the yard method that although it was not created entirely in New Spain, it was developed and perfected for its large-scale application in the profit farms of the Pachuca region by Bartolomé de Medina⁶⁹. Being this one of the first Hispanics who develop their engineering knowledge in Minas Mexicanas.

Mining for obvious reasons is one of the fields that due to the complexity of its situation in New Spain lands allows the development of engineering, three are the fundamental aspects in the development of the mineral and that encourage the development of engineers Mexicans, the low grade of minerals in New Spain, the drainage of mines and the grinding of minerals⁷⁰.

The drainage system was a key to increase the life of a mine, to rescue abandoned mines and to increase production, it was an application of hydraulic engineering basically, this factor synthesizes the activity of the en-

gineer, the mines represented different problems that were solved with different solutions, within this area we find the drain by lathes, by siphon pumps, by galleries, by boats and by mixed systems where more than one of the solutions presented were applied.

To give an example, the galleries required the excavation of a sinkhole that arrived at the mine from a lower level of land, for this reason the mine was drained, now a days, in order to perform a task like this correctly requires precision instruments that did not exist at the time or if its similar was much less precise, the investment of resources in the rescue of a mine was rewarded with the profits that could be obtained from it.

Regarding grinding we find several applications designed to improve the process of reducing the mineral. In the first place two hydraulic machines worked like mills for the grinding of minerals, those of drag that worked by means of a Rodezno, and those of rammers that work with vertical gravitational wheel, much more common than the first ones, both with the purpose of crushing To the mineral fundamental activity in the yard method for the benefit of the mineral.

To solve the problem derived from the low grade of minerals, we found the yard method perfected from the method of canoes by Bartolomé Median that allowed the benefit of silver from low-grade category deposits in which most of the Mexican mines were included.

In summary, hydraulic engineering is used in the design of drainage machines, to move crushing mills and machines to make easier the mixtures in the yard process, water is also used within other process steps, in sludge mixtures during the amalgamation, for

the washing process of the mineral and in some cases, sharing elements with the ironworks to cause temperature increase inside the furnaces when the smelting was the reduction method, in some other cases where the furnaces did not work by water, although in a smaller scale ironworks, the hydraulic wheels on the model of the ironworks could use bellows. Also, although on a smaller scale, the water allowed the excavation in the mines, especially in areas that are easily eroded.

Since mining was the most lucrative activity in New Spain, it is not uncommon to think about the extraordinary income was generated, these same revenues could be put into service of mining production, the technological applications that are divided mainly into two branches, on the first hand, invest on the normal process, that means machines to work with the mineral which would include the mills and the systems for the benefit between which the furnaces would be, and on the second hand invest on the maintenance and re-opening of mines.

As for the Mexican mining main characters who transcended their knowledge worldwide we can find Bartolomé Medina himself with the yard method and already in the decline of the viceroyalty to Andrés del Río which is remembered worldwide for the discovery of the Vanadio both men product of an activity that has been and continues to be of high benefit to Mexico.

Since mining is an activity that brings together several hydraulic applications, first of all, a general sight of mining will be discussed briefly and then the subject will be described with each of the mills.

2. Mining History

The mining activity in the world began

from the moment in which the materials had to be extracted from the subsoil, it was not the same to collect materials in the open sky that was one of the activities that were done in a primitive way to take advantage the techniques. The mine requires extractive work, although at the beginning it was dug over the surface and these excavations were superficial, this work can already be considered as mining, the metals were essentially sought in a first stage to be worked and in that primitive stage the mineral was worked directly, transferring the work techniques of wood and rock to minerals⁷¹.

The discovery that unlike a rock the mineral could be heated to melt and already in this molded state allowed the design of weapons and tools, the next great discovery was the smelting of minerals and the separation of the mineral into its purest form, with this, man ended with his dependency on the sources of the mineral in a pure state that were scarce and began to separate the minerals that were combined with others in nature, this need to obtain the mineral for the production of minerals in its pure state and subsequently its work increased the needs to collect more materials, is when man begins to dig tunnels to obtain it.

The tunnels had to be deeper and deeper with the technological complexity of digging a tunnel of these characteristics, it is when they begin to apply auxiliary elements for the exploitation of the mines.

In Spain there is the mining system of the marrows, which was used since ancient times, reaching its summit with the Romans. The marrows represent a system whose main advantage was the erosion of materials using water flows, showing us an operating system based

⁷¹ Sánchez Gómez Julián, *op.cit.* p. 442

on hydraulic engineering.

The circulation of water through different areas caused tunnels that were used to exploit the mineral, these water flows were recovered in the lower part of the system, where it was explored, to find in this rolled water the minerals, this system and its intensive exploitation at produce the transformation of the landscape in an impressive way, and this transformation is currently the main attraction of the region⁷².

Hydraulic engineering is present also in the way of handling water, circulating it through the required areas, creating hydraulic works for canalization, conduction and dams where water arrived and the materials got settled. Although the main reason for this work is to analyze the hydraulic machines and its architecture is important to talk about hydraulic engineering used in the exploitation of mines.

Different than in America, mining takes place in Europe slower, it is until the Renaissance when the demand for minerals increased, so a development of old techniques needed to be improved to increase production levels. Most of the productive mines in Europe were in the central region, closer to Eastern Europe and the area of the Netherlands and Germania, it is not surprising that the first engineers were developed in that area and then already under cover from the Spanish empire they will travel through the different mining areas.

In Spain in 1555, the Guadalcanal mine was discovered, under orders of Felipe II, specialists from all the empire of Italy, America and Flanders are transferred

to it, with which in the same place they learn and perfect techniques learned and implemented throughout the world, it is about establishing the yard method imported from New Spain, bilge pumps with the latest operating advances are placed, the ovens are already improved derived from the operating experience mainly in the new world.

It is Guadalcanal the place where the techniques of the whole world of mining in the SXVI century converge and are perfected, when the mine declines in production the specialists who had the opportunity to increase knowledge begin to travel to other parts including New Spain, It was the Spanish mining laboratory in the XVI century.

3. Mining in New Spain

From the pre-Hispanic era, in what is now Mexico, there some researches that speak of mines exploited by the natives, more interesting and that have yielded more information are the archaeological explorations that have been done in regions where mines existed before of the arrival of the Spaniards, as is the case of Balsas river and the Querétaro mountain area, which has allowed, through the discovery of multiple objects, to reconstruct how the mines were exploited, as auxiliary tools in the extraction they had hammers of stone with wooden handles, obsidian knives, bone tips, clay ladles and wooden wedges among many others.

The tunnels were lit with firebrands of ocote and pitch, the tools for the gathering were trays of mud, baskets and ropes for the elevation of the same ones, for the crushing and separation of minerals there were mills, stone mortars were attached to the walls of the mine or mobile were built, this operation could already be performed outside the mine, in addition to mul-

⁷² Camarero Concepción Bullón, Campos Jesús (Directores), *op.cit.* p. 302 Sometimes when there was gold in the fields they use the same process than in Bierzo, Leon and in some other places described by Plinio the old in his Natural Hisotry.

tiple objects associated with miners, clay pots, small gods of mud figures, among others⁷³.

Techniques, were very similar to those that with slight variations have been used and are still used in the world with the mallets the rock was beaten until a fragment was detached, with the bone tips and obsidian blades, one could work in cracks and fissures.

The buckets were used to collect objects from the ground or that came off the work area, finally Leon Portilla mentions another very interesting one, the stone was heated and then allowed to cool down, this process could be helped by wetting the stone which under the abrupt change of temperature it thundered or cracked, in these wooden wedges were introduced and then wet to cause fragmentation⁷⁴, in the places where the weather allowed it, it was drilled and water was drilled into the hole or the crack that caused the fragmentation to freeze at night.

The extraction of these minerals was made by smelting, here it is worth mentioning a method used in South America called *guairas* from quechua *huayra* which means wind air and consisted of portable ovens of sufficient size to be easily moved that were located in the upper part of the hills so that the wind circulating through them favored combustion increased the temperature and obtained the separation of the minerals, similar in its principle of operation to the wind ironworks of which it has been spoken in other chapters of this work.

When the Spanish arrived they took advantage of this knowledge of location

and exploitation of mines by the indigenous people to locate deposits of the minerals that they were interested in, the discovery of mines in New Spain shaped the territory and much of its population, the progress towards the north was largely made on the roads that linked the mining centers with the capital of the Viceroyalty, the gold and silver mines collaborated in several aspects, first of all the economy of the viceroyalty was founded, then settlements were created that had to be communicated with the capital and then with the port of Veracruz, it is in this way that they are created commercial networks that have to be strengthened by the circulation of products and people, the mining centers helps the colonization process and without that incentive would not have been so fast since having people interested in move towards the mining centers helped a lot, within this movement of people we found also a strong immigration of mainly flamenco and Germanic specialists⁷⁵ that arrived to make the mines operational in New Spain, this circulation of technology was promoted by the discovery of the mines.

With the discovery in the second half of the XVI century of the Zacatecan mines, the inland road had to link the center of the viceroyalty with the newly discovered mines in a safety way, we can divide the foundation of cities along the viceroyalty into 4 types, the first was the re-foundation of cities using the main urban centers of pre-Hispanic cultures, taking advantage of the system of existing towns and cities that were not only physical but were also subordinated to manors that turned in paid tribute to the capital of the Mexicas.

The second was under the need to found

⁷³ León Portilla Miguel, *MINERIA EN MEXICO ANTIGUO en Artes de Mexico n. 86 una visión de la minería*, Mexico 2007, p. 8-17

⁷⁴ *Ibíd.* p. 8-17

⁷⁵ Sánchez Gómez Julián, *op.cit.* p. 450

cities of Spaniards separated from indigenous cities, these cases are found in the cities in example Puebla and Morelia created in the region of influence of two cities with a strongly indigenous tradition, Tlaxcala and Patzcuaro respectively, this system was widely used throughout the Mesoamerican region.

The third is the mixed mission-presidium system with which many of the mission and presidium foundations advanced towards the northern regions gave rise to cities that were consolidating later, until these 3 we found cities carefully drawn under the precepts of urban planning very common those days and that can be seen in more detail in the letters of Felipe II, with provision of service infrastructure works planned separation of neighborhoods etc.

In all regions of the viceroyalty there was another type of foundation derived from mining discoveries, these were generally in inaccessible areas and in many cases far from the settlement lines that have been mentioned in the other 3 cases, these discoveries and all that entails its operation determined entire regions and accelerates the progress towards certain zones by configuring entire zones.

A mining region was developed close to the mines, this way the creation of cities broke the urbanistically established schemes, the streets were adapted to the orography because the mines and their communications between them were the guiding axes of this urban development, the first houses were those of the workers of the mines which were accommodated next to the paths and where the rugged orography determined it, under these circumstances the mining population centers were created.

An additional element to be discussed

later were the extraction farms that were the establishments responsible for obtaining the ore in its most useful state, these farms had to be located near the mine, usually and initially they were located near the mines, the towns around the mines and the haciendas were developed, according with the guidelines, the roads between the towns and the mine, as well as the path from the mine to the extraction farms would continue to be the guiding axes, this gives the image that we now know of the main mining centers, in examples we find Taxco in Guerrero and the City of Zacatecas in the state of the same name.

Other cities and towns grew located in better areas, developed industry and agricultural activities that would serve to provide the necessary consumption inputs in any city and that due to the characteristics of the land that we mentioned could not be near the mines, from this process, the regional configurations are obtained, with mining cities, supplying cities and roads among them, being prosperous areas we find farms of various types, mining towns, cities providing roads and intermediate villages, this is the main scenario of the development of the hydraulic engineering applied in mining, that relied on the aforementioned factors and that was encouraged by the resources applied by the mine owners to increase profits.

José de la Borda in Zacatecas makes a rescue that wondered everyone and that earned him the title of "the best miner in the world"⁷⁶; within the descriptions of the actions that we can find is the construction of a profit mine called the Willow, the purchase of another farm to have grain to feed its workers, the purchase of other profit farms to increase

⁷⁶ **Brading David A**, *LA PLATA ZACATECAS EN EL SIGLO XVIII en Artes de México* n 86 *una visión de la minería*, Mexico 2007, p 20-31

the production capacity and construction of machines to drain the mines.

It should be remembered that José de la Borda arrived to Zacatecas to rescue mines that had already been exploited and that were flooded, the old mines were usually very deep and were constantly flooded. The important thing about this data is that it allows us to imagine the infrastructure that a mining region required to operate, from this infrastructure we understand so many things of these cities and regions, of applied engineering in each case we will talk later in this section.

On a broad sight, mining in New Spain was developed, I emphasize that this activity, being the first export generator, could invest many resources in its productive improvements. Within these, we find a large part of hydraulic engineering, and especially the design of machines that allowed to facilitate the processes mentioned below, also we will describe the extraction and extraction procedures.

4. Extraction Methods

In the first place, the path that the ore traveled from its extraction to its processing place was along the roads and on the back of a mule, the extraction was done by known means and then the supplies that were taken to the profit farms were loaded. This is how Viceroy Mendoza, Marqués de Montesclaros describes the work of silver and scourge in Potosí at the beginning of the XVII century:

"These mines have their scales or roads from the surface to the depth, and over there the Indians climb the stones on shoulders, of the metal that other companions have taken off at the tip of a barrette, in cotamas, which are sacks of skins as a bash; and

when they arrive at the top, they put the load that they take out at once in different piles: each one of them is called mita, and the place where they are settled, court. Of these fields the metal is taken to the inmates, loaded on rams from the earth".

Although the description we are referring is located in the Viceroyalty of Peru, the process was very similar in Mexico, the excavations were first enhanced in the open sky, in a first stage, which was gradually transformed into a vertical tunnel system with horizontal galleries, to perform the ascent and descent of the material a system of notch stairs that were located in the shot was used, at each distance wooden platforms were placed for the rest of the miners who climbed the stairs with the mineral.

These breaks could be limited to only one wood crossed, in the wall of the vertical gallery were also located excavations in the wall, the *tenatero* climbed with a sack of ore at his back that weighed up to 120 kilos, the stairs were not lined up, they alternated with the breaks on either side of the step, in this way if anyone fell, it would not reach the bottom of the gallery without dying.

Once the *tenatero* came up with the sack, he deposited the load in the corresponding areas, in the upper part he made a prior crushing of the rocks and the ore, the high grade one went straight to the smelting furnace, the low grade was to processing, this activity called *pepena* was carried out in the yards of the mines in this activity it was common to find female employees, who were limited to perform the selection of minerals.

The transportation of the ores to the farms was done in mule tanks, that's

why the mine owners who consequently had processing farms near the miasmas invested significant amounts of money in keeping the roads in good condition, which were an extension of the productive process that was carried out inside.

5. Refining Methods

a. Melting Method

It is the first method used in New Spain, this has been used since the middle ages and as we have seen before it is a very old method that started by smelting of metals, this was the first method used by man, at the time of contact and during the first half of the XVI century, this was the main method to be used.

In the first place the ore containing the silver was melted, this was done in furnaces designed for this purpose, the silver ore was placed in the oven together with lead, this mineral achieved a fusion with the silver which was achieved at the lowest temperature possible, at the end of this first batch there were pieces of an alloy between silver and lead.

To remove lead ore from silver, they were placed in smaller furnaces that had to have a constant air flow, this was achieved in two ways, using bellows or using air tubes, both described in the section of the ironworks, and also both considered hydraulic devices before describing them in more detail, it must be clarified that the function of blowing air into the oven allows the lead to oxidize in this way is separated from the silver in the form of porous slags, the silver forms some balls that are separated and can be melted to give them the desired shape.

Brought the stone of the mines to the works or houses of smelting,

they wash it, they break it with hammers, they grind it with a wheel like oil mill, they melt it in the big furnace, a large lead flatten comes out; it, broken into pieces, melts it or refines it in small ovens, where, when the slag or grease is spilled, the silver falls to the bottom; already when it has little scum, at the end, that melted mass is suddenly cleaned without having any of the stains that it had before, being red and smooth, which is the sign that it is ready, and with this they take out the roof of Silver, more or less large, depending on the quality of the metals. From the fat or greta that the silver throws, it melts again and they take out lead⁷⁷

The description of Friar Ajofrín about the mines of Sumatlán in New Spain is accompanied by a very interesting drawing that shows us a profit farm that used the method of smelting to process the mineral, another interesting fact is that within all the furnaces represented graphically there are the two types of furnaces that require water for their operation, the bellows furnaces which are moved by hydraulic wheels and the furnaces for the processing of water that, through the circulation of water, also circulate the air, both are described with more detail in the section corresponding to the hardware stores.

In order for the smelting method to be used to obtain the silver, the ore had to be high quality otherwise the mixing with the lead was not achieved since the content of minerals other than silver was greater than silver itself, on the other hand, the infrastructure necessary to process the mineral was minimal based on hydraulic infrastructure and the construction of the furnaces,

⁷⁷ González Tascon Ignacio, *op.cit* p. 308

Figure 32. In this drawing several types of furnaces are observed, the most important thing is the specification of furnaces with water, those of wafers are not specified if they are also hydraulic, Legend: I. Small ovens to refine, the one called Galeme, with bellows. II. Furnaces with processing of water instead of Bellows. III. Baking oven. IV: Castilian oven. V. Browse where the water comes from. Image Drawing by Francisco Ajofrin on the furnaces of the Sumatlan mines in the XVI century in Spanish Engineering Overseas

in comparison with other methods that required large infrastructure works, the ore could begin to be processed with very minimal investments.

The main disadvantage was the large amount of fuels that were needed for the furnaces to work, generally wood or coal were not an abundant resource at the mining sites, if this resource was near the profit farms that used the method of smelting quickly deforested the area since the furnaces were not the only place where wood was used, the transfer of the wood had to be made from remote regions which made the product more expensive. Finally, it can be mentioned that the obtaining of the mineral was inefficient because a large part of the silver was lost in the by-products, in fact by implanting other methods such as the yard, the old slags processed, obtaining silver that had already been discarded.

b. Court method

The court method was based on the amalgamation of metals with others to be able to separate and have it pure, it must be remembered that the quality of metals in America was not very good⁷⁸ the low grade of the mineral caused the development of different methods other than those that had been applied in Europe before applying mass amalgamation.

There was an early time in which the benefit of the minerals was realized by means of smelting, by 1550 in the mines of Pachuca Bartolomé de Medina (1497-1585), Sevillian, approached in that region and started with a large-scale amalgamation, although the method already existed is attributed to New Spain and particularly to this character the development and its large-scale application, from New Spain passes to Peru and Spain.

The new method allowed to extract a greater proportion of silver from the ore, which caused the exploitation of old abandoned mines and new veins that were previously considered bad. The yard method for the process of minerals allowed obtaining silver from low grade materials, it is not surprising that the method was developed mainly in America since many of the mines provided materials with low silver content, another local characteristic that allowed this method is the low fuel consumption compared to processing ores in furnaces, which caused intensive deforestation of forested areas around mining centers, in other cases the sites where mines were discovered they lacked this resource which caused that the firewood and the coal were an

⁷⁸ The amount of silver obtained per cubic meter of material was low, this was called law, medium and low quality metals could not be processed by the smelting method, since the pure material obtained by that method was not enough to recover the investment made.

expensive and difficult to obtain input, the patio method considerably diminished the use of furnace fuels which, being the main character in the process, became secondary.

The process took advantage of the ability of mercury to merge with silver in this way and after crushing the minerals so that this amalgamation was easier, the silver separated and was obtained pure regardless of the quality of the deposit at the end of the process. Mercury could be recovered and reused. From its evolution of a small system that was initially called the canoe method, was an innovation for the yard method, innovations like those were incorporated by Mexican miners to increase the amount of ore processed⁷⁹.

The success of this method explain why it was used for more than 300 years, it was still used in the mid of XIX century until other methods such as cyanurization replaced it, another main characteristic in the choice of methods to use had to do with the amount of resources that could be used in the implementation of infrastructure to apply one or another method, it is clear that the amalgamation method required a large investment that was limited to large profit farms, owned by miners with broad economic resources, the smelting method continued to be used depending on the law of the deposit and on profit farms of lower production.

Before describing each of the parts of this process for obtaining silver in which the hydraulic mills had an important role, we must talk about the raw material for obtaining silver by merging amalgamation.

When the method already described

⁷⁹ Mainly the modification lies in the elimination of the boxes (canoes) to make the mixtures on the tiled surface of a yard, with this the volume of the mixture is increased.

Figure 33. Drawing where all the steps of the patio method are observed, in the upper part the arrival of the mineral on the back of the mule, the selection and then on the right side the milling with a mill of warehouses, to the left of the mill sifted and washing of the material, further down the drawers in the patio where the milled ore is mixed with the scouring operation called review which was done with the feet on the left side of the ducks are the ovens where the pineapples obtained in the benefit were melted, some other spaces are Housing and chapel offices, in addition to a single-head mill in the upper left corner. Image: mining mills in the town of Potosí XVIII century Bartolomé de Arzans Orsua y Vela in Spanish Engineering overseas

broadly known, the scourge was the most important input, therefore, mercury became the most precious mineral as an input for obtaining silver, in two places it was extracted, in Spain in the mines of Almadén, in America In Huancavelica; the mercury used in New Spain came from Huancavelica, it was used for the mines of Potosí now known as Bolivia, this allowed the crown to maintain the monopoly of the sale of mercury towards America, that produced a new boom to mining in Almaden whose activity and exploitation at the beginning of the XVI century was very low.

Mercury was obtained from cinnabar

mines and required dangerous and complicated processes for its processing, the toxicity of the metal and its liquid state at room temperature should be remembered, which led to difficulties in processing it, packing it and transporting it, the route from Almadén to the new Spain was covered with special and complex vessels that aimed at maneuverability during the long journey and to avoid leaks of the precious component; as a first step leather bags were made that were placed inside each other until adding three within each of these leather bags were two arrobas of metal, (23KG), these leather bags were placed in barrels or wooden boxes that contained a quintal (46KG) or quintal and a half so that each barrel or box would have inside 2 or three leather bags, this with the purpose of making it manageable, the quintal or quintal and a half was the weight that a single man could support⁸⁰.

The transport was done in carts or mule tanks in the areas that corresponded to land, from Almadén to Seville, later by boat to Veracruz, where carts or *recuas* were used, more common the second one, to take it to the capital and from there to distribute it. The costs of land transport tell us about the costs, which were higher in its transportation by land than in its maritime trip, the cost by land was 5 pesos from Veracruz to Mexico and from Mexico to Zacatecas from 3 to 4 pesos, while that by sea it was two to three pesos per quintal⁸¹.

The first step of the yard method was the grinding, it was a priority to be able to correctly make the amalgam that the mineral was made flour, Joseph de

Acosta in 1590 describes the following about the first step of the method: *The metal is ground very well first with the decks of wits ... and then well ground the metal locks it with a few sieves of wire cloth*⁸². Another chronicle is that of Viceroy Mendoza, Marqués de Montesclaros, about the work of silver and scourge in Potosí at the beginning of the XVII century: *Ingenios are wooden machines whose wheels, carried out of the water, lift mallets large, which by their order fall back on the metal and grind to dust; this powder or flours are put in square holes called drawers*⁸³.

If the smelting method required water to drive machines that helped with the bellows and water tubes, the amalgamation method required hydraulic infrastructure, not only to drive the grinding machines we are talking about, but also as part of the process for washing and mixing as noted below, so the introduction of the new method had an impact on the incorporation of mills and how to operate them.

By the end of the XVI century in New Spain there were 406 mills which 167 were hydraulic and the rest animal-force mills, the construction of one or the other depended on the abundance or shortage of the hydraulic resource, for example at the same time in Zacatecas there were only 65 all animal ore mills, while in Pachuca there were 59 hydraulic mills⁸⁴.

⁸⁰ Herrera Canales Inés, *AZOGUE Y PLATA UNA UNION FRUCTIFERA en Artes de México n 86 una visión de la minería*, Mexico 2007, p. 60

⁸¹ *Ibid.* pág. 60

⁸² Von Mentz Brígida, *TRABAJO, SUJECION Y LIBERTAD EN EL CENTRO DE LA NUEVA ESPAÑA*, Miguel Ángel Porrúa-CIESAS, Mexico 1999, p. 194 y 196

⁸³ Boccara Guillaume, *COLONIZACION, RESISTENCIA Y MESTIZAJE EN LAS AMERICAS (SIGLOS XVI-XX) tomo 148 de la serie Travaux de l'Institut Francais d'Etudes Andines*, Abya Yala Publicaciones, Ecuador 2002, p.143 y 144

⁸⁴ González Tascon Ignacio, *op.cit.* p. 309

There were two types of hydraulic mills for the milling of the ore, the *almadanetas* and the sucker or drag, the first of them used the method of percussion the second by friction in case of the water was hard to get like was the case of some mining centers like Zacatecas, animal mills were used, but the operation of the warehouses was more complex in the case of animal mills, the force was applied in drag mills. Another type of hydraulic mechanism that we will talk about later on is a pin-wheel-like windlass that is used in the washing and separation of sludge, as we will see these could also be powered by hydraulic wheels, let's start with the milling mills.

c. Animal Mill

In the case of animal mills that were used in places where water did not exist, they had to be based on a different driving force than water, their construction and design was determined by these factors. A shaft was placed on a tiled patio on which a pole was rotating freely on whose other end there was a stone that turned on its edge, the extension of the pole was used to locate the driving force, a draft animal, the paved patio served as fixed grinding wheel and the mobile crushed in its path the mineral that the slab prevented that this mill was lost in the ground could also be built a parapet to confine the ground material, the evolution of the same used a double parapet, the first of the which had the sieve so that only the mineral with the appropriate granulometry passed to the collection area although this adaptation was already late there are photographs of this type of improvement.

Within the chronicles of Father Ajofrín we find the very brief description of one of these mills relating it to the oil-making mills which, although they were hy-

Figure 34. Animal mill, in a farm of processing in Guanajuato, these mill were used when the hydraulic resource was not so abundant as to move the mills of *almadenetas*, it was more common in Zacatecas, where water was scarce and its use was preferred in the amalgamation and mineral washing process image: www.raulybarra.com

draulic, were generally dragged. The stone from the mines was brought to the works or foundries, they washed it, broke it with hammers, grind it with a wheel like an oil mill⁸⁵.

d. Pulling mills or *xuchil* hydraulic

In this type of drag mills, we found those that worked with a *rodezno* similar to other hydraulic machines although larger⁸⁶, the use of *rodezno* and its corresponding mechanism is one of the simplest hydraulic machines, since the movement is transmitted directly without gears, at each turn of the *rodezno* is one turn of the shaft, build *rodezno* mills that were also of drag, originated constructions and architectural spaces very similar to those of the hydraulic flour mills, the *rodezno* has to be located in the lower part of the place where the movement is transmitted, which necessarily fosters a space on two levels, the lower part that we call The humid part has a vault in which the *rodezno* is located and in which the wheel is

⁸⁵ *Ibíd.* p. 309

⁸⁶ The ore mill mills reached 4 rods 3.3 m while the flour mill mills did not exceed 1.5m, Data in Spanish engineering overseas.

rotated by means of a water fall, over the vault which is crossed by the axis this work area in which the wheels will be located of different kinds.

In the work area a vertical axis protrudes from the floor which is the one that rotates with each movement of the rodezno located at the bottom, in this axis they can be located by means of an axis that emerges from it a stone that rolls on its edge, like blood mills, you can locate two chained stones that roll with each turn crawling on the fixed wheel and in this drag crushing the mineral, two conical stones whose contact surface is greater than that of a single horizontal wheel, with the tip of the cone fixed to the axis of the rodezno with which they rotate on its edge, or two cylindrical stones that also rotate concentric to the axis in movement by means of a wooden axis towards the axis in movement. The described stones work as mobile stones and a stone bench or the simple floor of the paved work area works as a fixed wheel, to avoid the dispersion of the mineral flour throughout the work area, a parapet is built that borders the area ground and from which once the movement has stopped the crushed ore can be collected.

e. Sledgehammers Mills

They used a vertical hydraulic wheel, which was subject to large-scale stresses, so they were generally wheels that operated by gravity, which guaranteed as long as the constant flow of the hydraulic flow was not interrupted, this vertical wheel could extend its axis in one direction. (one-head mill, or both (two-head mill)), for the purposes of this description we will use the extension of the axis on both sides; this axis had concentric cams but located in different positions of the circumference, until this point you have the wheel to the center and the prolonged axle towards

Figure 35. The drag mills use the stone wheels, with friction grinding they crush the ore, to drive them hydraulic wheels are used, in those of the image you can see in both cases rodeznos, on the left side a superior rodezno with a grinding wheel of rotating stone placed on the edge, on the right two stones tied to the shaft that is driven by a lower rodezno that rotates them, in this way through the drag of these rocks the material is crushed, image Martínez Campan Collection, XVIII century

both ends with the cams on its surface, at both ends of the axle a pair of pillars are needed to prevent the efforts of the piece of wood from twisting it and rotating eccentrically, in this way the axle is supported by 3 points, both ends and the center of the wheel, since the axle rotates without torsional stress, an efficient work of the machine is guaranteed, for this purpose and considering that the wood will be in contact with the water, the woods are subjected to treatments to saturate them with moisture, these axes are also reinforced with metal straps

A structure is built on both sides of the wheel in which by means of four supports and wooden guides all the mallets can be mounted, in some sources this structure is called the castle, a fixed structure is required at the top that allow the vertical and other movement in the lower part to avoid movements outside the line of action, this support must have the facility to extract mallets placed in the lower part of a pole in whose upper part there was a protuber-

Figure 36. Double head mill with 12 tampers image Tarsicio Pastrana

ance that was elevated at each turn of the wheel, the lift was finished by leaving the cam to load the pole, the gravity drop of the mallet was the percussion action that ground the ore. This principle is similar to all the mills that use the percussion principle to do their job, the mallet has in its arm a piece that is operated by means of the cam on the axis that rotates constantly when this cam stops exerting its pressure on the piece of the arm this falls by gravity hitting the material.

Each of these mallets were called heads or stockpiles, and in order to avoid the loss of the crushed material, a container was usually constructed of lime on

which the action of the head towards its work, remember that the two percussion surfaces have to be harder than the ore to be ground, although the heads of the mallets were made of hardwood the secret was the construction of these mallets in the hardest part of the wood grain, which is more resistant in a sense that on the other hand, plates and iron claws were placed in the lower part of the mallet, this being one of the most complicated parts of the process by the supply of the material that remained as a real monopoly, so that the heads and claws were made with material imported from Spain. these reinforced areas of the mallets and the place where the percussion was carried

out were reinforced for this purpose, the box where the grinding was carried out had the part that received the blow (fixed wheel) generally reinforced with a hard stone block harder than the ore to be ground, with which the crushing of the ore was done faster.

There is a mechanism to raise the mallet above the camshaft and thus prevent it from operating the mallet so that the crushed ore can be removed or reloaded. Another way to interrupt the operation of the machine to sacral the ore was the interruption of the flow of water in the wheel, this had the disadvantage of suspending the work in all the mallets of the machine. The wheel of these mills generally worked by gravity which made the flow of the water stream constant and therefore the turning force was always the same, this was guaranteed while the heads were in place that would be rising and going down crushing the ore.

In any of the three types of grinding, a powder is obtained that looms by means of sieves made with wire mesh and that marked the appropriate particle size to take it to the next step of the process, in this step is where the large yards appear, and they give name to the procedure, as it was said before in the beginning the mixtures next to the grinding were carried out in wooden crates in which the flours were placed and mixed with salt water and whip, so that to the original yard method of Medina was called the canoe method, the need to increase these levels of production is what causes yards with large surfaces to be mixed to make the mixes, in the yards large tanks were built connected with basic hydraulic infrastructure of canals to add water to the mixtures.

The deposits for the mixture could be of several types, the first ones used

were the wooden drawers, which could become large but limited the production of the sludge, secondly we found the deposits contained with lime and song walls, to keep the mixtures confined, then the temporary confinements which were maintained in what the mixture was fluid and then removed when the mixture was pasty, in any of the cases mentioned it was vital to keep the mixture in confinement to avoid loss of the scourge, another important fact considering the name of the method is that regardless of the type of containment, the procedures were performed in a large yard.

In the courtyard where the processing was realized, the flour transported from the milling areas was placed and water was added to make a mixture, then salt and flogging was added, in this regard we resorted again to the description of the process made by José de Acosta, in which are still mentioned wooden drawers:

*Hovering that the metal flour is passed to a few boxes of sea-lions, where they mortify it with salt, die every five quintals of flour five quintals of salt, and this is done so that the room bleeds the metal flour, from the mud or lama has, which mercury receive better to silver.*⁸⁷

Another description is that of the Viceroy of Montesclaros who says the following about the incorporation operation:

This powder or flour is placed in square holes called drawers, there they are flogged and other convenient mixtures so that from the lei, this is the display of silver,

⁸⁷ José de Acosta sigo XVI en **Von Mentz Brígida, TRABAJO, SUJECION Y LIBERTAD EN EL CENTRO DE LA NUEVA ESPAÑA**, Miguel Ángel Porrúa-CIESAS, Mexico 1999, p. 194 y 196

Figure 37. Image: Tarsicio Pastrana

and that stone or earth with which it was born incorporated; and to get it more briefly they help themselves with the fire and heat that they are directed by certain bottlenecks, although it is already better to use the sun⁸⁸.

It should be clarified that the embody required the addition of the whip or mercury to the mixture, a subsequent step to the casing that is the addition of the salt in an amount between 2

and 3%, before adding the mercury the flours already had water and salt⁸⁹, getting a paste that was called cake and which was the one that extended in the courtyards, when the cakes were ready to receive the scourge, it had changed its fluid consistency to a thicker one, in the courtyards it was already in wooden drawers, permanent stone or temporary deposits with simple containments the *incorpopor* was prepared.

For merger, mercury was added by the master of mercury which consisted of an amount between 6 and 8 times the amount of silver that was intended to

⁸⁸ This is how Viceroy Mendoza, Marqués de Montesclaros describes the work of silver and scourge in Potosí at the beginning of the XVII century

⁸⁹ Herrera Canales Inés, *op.cit.* p. 53-66

be obtained⁹⁰, this amount determined by the criteria and experience of the master of mercury charge highly valued within the profit farms; to do this operation, the mercury was placed in fabrics in which it was squeezed, as it passed through the fabric, it was divided into small quantities that allowed it to be added more evenly as if it were a sprinkler. Then they whip the scourge on a metal with a Dutch canvas and the scourge comes out like a dew and thus the metal is stirring so that this dew of scourge is communicated to all⁹¹.

Before continue with the review, the magistral was incorporated, which was obtained from roasting copper and iron ores to be added in quantities between 1 and 6%, their function was to improve the amalgamation process⁹², the review consisted of mixing these ingredients for up to 12 weeks, depending on the quantity, the review was done through workers who got into the mixture that sometimes reached their knees and moved in order to achieve the amalgam, they also had shovels and wooden hoes with which they moved the mixture from the banks of this, this procedure was highly toxic so it was replaced by the review with animals and in some cases by machines that achieved that neither animals nor people were in contact with mercury.

The review, as already mentioned, lasted up to 12 weeks, during which time the cakes had to be moved periodically, turning the mixture over and over again, the temperature of the mixture was of vital importance to complete the process, therefore the mercury master

Figure 38. In the image on the left you can see the procedure of the yard process, first of all the mills that in this case are of two types, one of drag that we observe in the lower left corner and several warehouses inside the houses where it is seen that the water enters and leaves, in the center we see two characters, the one on the left reviews the sludge with the feet and with a shovel the one on the right adds the mercury to the mixture, on the upper right side we find two types of oven, another situation that can be observed is the architectural arrangement of the spaces around the patio where the benefit is made, characteristics of the profit farms by yard image: Martínez Campañón Collection XVIII century

added masterly to heat it or ashes and lime to cool it. Once, in the opinion of the master of mercury, the amalgam had been completed, the sludges that were composed of various substances, including organic materials, earth, amalgamated silver, mercury, excess minerals incorporated had to be separated.

⁹⁰ González Tascon Ignacio, *op.cit.* p. 327

⁹¹ Von Mentz Brígida, *TRABAJO, SUJECION Y LIBERTAD EN EL CENTRO DE LA NUEVA ESPAÑA*, Miguel Ángel Porrúa-CIESAS, México 1999, págs. 194 y 196

⁹² González Tascon Ignacio, *op.cit.* p. 327

The next step was to wash the sludge, which was done in large wooden vats made specifically for it or using containers as lime and edge pools in which the sludge was stirred in water by means of mills that could be operated with hydraulic energy, these smaller mills had the function of keeping the mixture moving by means of this movement, the non-amalgamated mercury and the silver amalgams were separated from the sludge and useless waste in the chronicle of the viceroy of Mendoza we found the following;

and when they know they have state by the tests, they throw it in tubs like half pipes, and there they wash it inside the tub by force of arms, with a windlass that is a trace of rodezno. Often it excuses part of the work using the water to roll the windlass, and when done so they call it laundry. Washing the metal, they take out the silver and whip it in a pella, put it in an anjeo (appearance of rough canvas), they twist, they strike until it dismisses the water and some scourge; then they put it in molds and beat it again until it takes the form of pineapple

After washing, the residues that are settled by gravity in the lower part of the wash tubs have to be squeezed again with tarps and fabrics to recover the non-amalgamated mercury and use it in a new process and with the remaining material place it in clay pots with a conical cap called *desgas*, which are mud stills using heat and as a result of the mercury having a lower boiling point than that of silver, these two compounds are separated leaving the porous silver pineapples at the bottom, the pores are the holes that mercury leaves in silver.

With the porous pineapples of pure sil-

ver they are taken to the furnaces where they melt to make ingots that are taken to the real box to be tested and pay the corresponding fifth real.

clean then that is the silver and the scourge that already shines, fired all the mud and earth, take that metal and throwing a canvas, squeeze it strongly and so out all the scourge that is not incorporated in the silver [...] and being well squeezed the pella, which remains, alone, is the sixth part of the silver and the other five are of mercury.

And to split the silver from the mercury, put them on a high heat where they cover them with a glass of clay made of the molds of sugar loaves, which are like hoods and cover them with coal and give them fire with which the scourge is exhaled in smoke, bumping into the clay hood, there it curdles and distils, like the vapors of the pot in the cover, and a cannon still gives way to all the flogging that it stretches and collects, leaving the silver alone.

The complete procedure can be summarized in the following table:

Phase	Phase Development
Ground	Through the use of hydraulic mill the mine was pulverized.
Incorporate	The ground mineral ore (flour) was space (yard or incorporator) where were added, until a uniform paste accelerated by walking on it to the shovels (review). When the special mercury had incorporated the process of incorporation was extended on the conditions of the mineral washed

Washed	The cake was washed in large containers with rotating blades to separate the slat (dirt and impurities) from the <i>pella</i> (mass of whip and silver), that is, to separate the non-metallic elements of the amalgam.
Filtration	The pellet (semi-liquid product) was then introduced in canvas bags so that the greatest amount of mercury flowed through the liquid. What was left was a solid dough (pineapple).
Heating	The solid mass (pineapple) was heated under a bell (<i>chaplain</i>) and then the mercury gets vaporized and then recovered by cooling.
Foundry	The pure silver that was left melted to turn it into bars of equal size

Source

There were other methods, such as pot and cooking that the Spanish Alonso Barba improved in Peru at the beginning of the XVII century, it should be mentioned that in the Potosí area and due to the colder climate that existed in that region⁹³ a hot amalgamation system is created in copper boilers this is the pot and cooking procedure that in Mexico was not as effective as the yard method was, it is important to say that both innovations are created in America, both the Yard in Mexico as the one of pot and cooking in Peru to adapt the amalgamation method to regional conditions, both by Hispanics who came to America to work in the mines.

A different method that is a variation of the pot and cooking is the Baron Ignaz von Börn or Process of Börn Method, that was characterized by performing amalgam inside barrels with internal blades that moved using hydraulic engineering the advan-

⁹³ The height of the city of Potosí is, so the colder weather slowed the amalgamation process by the yard method

tages were, on first place, the complete amalgamation procedure could last a maximum of 4 hours, the loss of mercury was reduced and obtaining of silver was greater than in the yard method that could last as mentioned up to 3 months depending on the conditions of ambient temperature and humidity.

Within the de Börn procedure it was required to toast the material that was introduced in the barrels with a large amount of water, the master and the scourge, this procedure didn't work in Mexico because of several reasons, the first one was because the fuel that was required to roast the minerals, and that's also why the yard method had been so successful, in comparison to

the smelting one, it had reduced the amount of fuel needed, in many regions of Mexico firewood and coal was a scarce commodity.

Another reason had to do with the ore sterling, although in Mexico the sterling was low, the existing amount of the mineral was much higher than in any other region, that is, the volumes of material needed to obtain the silver were very large although the metal was so abundant this meant that the material process was large-scale, which caused the quantity that could be processed in the barrels of the Born method to be low, if it was desired to increase the processing capacity, huge barrels were required and had to be moved by large

wheels that few rivers in Mexico could move, in addition to the mining regions were in areas where watercourses are scarce or irregular, German expeditions that came to Mexico and Peru to try to implement the system towards the end of the XVIII century they were convinced that both regions had to continue with their usual methods.

In New Spain, the method par excellence was that of the yard, which was proven over 350 years, reaching the beginning of the XX century.

f. Architecture of the process farms

On the right side of the yard there was the area of laundries, with its internal water tank, to wash the pineapples obtained in the patio in the lower area of the bathtub and laundry room, the room of the floggers , the burner and the manufacture of bars , in the right end the furnaces where these pineapples melt to make them ingots in the bar manufacturing space , a ferris wheel above the tank of hoses , provides the necessary water, we insist on the carcass that gathers all the water that can contain metals and carries it to the puddle of the ores where it is reprocessed to recover what it takes from ore.

6. Mines Dewatering Machines

As already mentioned, a key feature that required more resources was the drainage of mines, the mines became deeper so there was a risk of flooding, the flooding of mines it had to do with several factors which could not be anticipated, first of all the type of terrain,

which could lead to strong leaks especially in the rainy season, secondly the

Figure 39. Plan of a farm of ideal process that serves to exemplify the architectural spaces that derive from the process of benefit by the yard method: image in Amador Manuel., *Practical and Complete Treaty of Mining Works and Benefit Haciendas*

MODELO DE HACIENDA DE BENEFICIO

Figure 40. In the upper part of the plane we see a yard where the material is received and washed, on the right side is the ferris wheel that provides water to the entire farm through a channel that is seen on the right side, not to be confused with the camber that take all the waste water to the puddle of Lamas there it can be processed again, the stables close the yard, the next line of spaces are the mills, the resayas and the tahonas , from this area the material comes out milled to pass to the patio that is divided into 8 zones for different sections in different processes, in this patio the mixture is made, placing the scourge, in the lower part of the plane are the stores, on the left side the house room, with garage, the group of offices between the warehouses and the house are the essay where the silver was tested to determine its quality, the administration, the line where the workers were paid and the main hallway.

groundwater levels of each area, which as a result of going deeper each time but it was more likely to meet that level⁹⁴.

It doesn't matter the reason, the flooding of a mine was a real tragedy, which in most cases caused the abandonment of mines that were still very productive throughout the XVI century, providing the opportunity for rescues by miners during the remaining centuries of the viceroyalty, many of these rescues were celebrated, such as the one carried out by Borda in Zacatecas that has already been mentioned, that of the Moran mine in Real del Monte with the design of a pump by engineer Andrés Manuel del Río in the XVIII century and the striped mine by Juan Díaz de Bracamonte.

The most effective technique, although the most complex to be performed, was a tunnel, which had several advantages of being successfully completed. It would prevent the mine from flooding since it was excavated with the appropriate slope so that the water flow was by gravity itself, the tunnel allowed in some cases the access of the miners to the work area without the need to climb the draft, reducing the time of transfer of the ore and saving man hours. It has so many disadvantages , the maths to make them were not always correct, since an adequate planimetry was required to begin the excavation works, which required a previous surface study to determine the possible point of water exit . The economic investment was very strong, few people could make it, time was also another element against it, generally the construction of one of these tunnels took time, in which the mine could not be exploited.

⁹⁴ **Trabulsee Elías**, *DESAGUE DE MINAS EN LA NUEVA ESPAÑA en Artes de Mexico*, n 86 una visión de la minería, México 2007,p. 34-46

The most impressive tunnel made was in San Luis Potosí in 1617, with a length of 230 meters that allowed the rescue of several mines on the hill of San Pedro⁹⁵. Although it is not the only example of tunnels practiced in New Spain, for example a failed attempt to drain in Real del Monte represents 9 years of work and an one kilometer length tunnel that failed, this same set of mines was taken by Pedro Romero from Terrosos and with an investment of one million pesos and the excavation of a tunnel this time well planned, the mine system that more than compensated for the investment applied in its rescue was drained.

One more example was in Tehuilotepic, it took 12 years to complete and reached 404 m once again the investment was quickly recovered by the profits obtained from the rescued mines.

Just a few miners could make such strong investments in the case of drainage, basically because of during the rehabilitation work there were no profits and that many times the investment could be lost with a tunnel that did not cover the objective for which had been designed, for that reason machines were used to cover this job, the simplest of them were the lathes, although its simplicity also meant a great investment in work (the man or men who had to operate spent hours doing a strenuous job) and a little productivity in the mine drain.

The winch was made up of a horizontal rotating mechanism, an axis that was supported on both sides and that was actuated by means of a crank that made it rotate, to the rotation cylinder a rope was attached that was being wound at each turn of the crank, on the other side there was a large leather bag called *zaca* that was raised from

the bottom to the place where the lathe was located, this system required more than one operator, since these were distributed in the turn of the crank and the emptying of the leather bag, also by means of this, it was possible to raise the material from the depth of the shot to the work station formed by a platform where the material or water was emptied⁹⁶.

This situation of the work stations was determined by the height and the shape of the mine, one more of the machines that were used to raise the water was the ferris wheel, which unlike the lathe could be moved by draft animals, had the great advantage that it did not require suspending work to unload the water, that means that the machine turned without stopping and drew water without stopping⁹⁷, the disadvantages lay in the wear and tear of machinery and in the exchange rate of draft animals which could not perform the work for many hours. The ferris wheel consisted of a vertical wheel that instead of pallets had a chain in which the leather shoes were tied, this chain could be variable in the design depending on the level from which the water was to be raised, the transmission mechanism from horizontal to vertical movement required a piece called a flashlight which was located in the most extreme part of the axle that moved the wheel.

The wheel was located on the shot, and the chain with the shoes hung up to the area where the water was extracted, a channel was placed at the top of the vertical wheel, the leather shoe when turning around emptied its contents in this channel and down again in the constant rotation of the wheel, the axis of

⁹⁵ *Ibid.* p. 34-46

⁹⁶ **González Tascon Ignacio.** *op.cit.* p. 306

⁹⁷ *Ibid.* p. 307

Figure 41. Working group to drain mines, using a lathe and a leather shoe, on the right side a channel of another similar system is observed, and from the left a conduit is seen towards another system, that is to say the mines were drained with stepped systems of lathes and sacks, as the procedure was slow, numerous imagery of shrinking mines in Almadén in technique and engineering in Spain was solved with work teams.

the wheel had to rely heavily on lime and edge or wood work, the extension of the wooden axis towards an end where the lantern was placed marked the area at work, in this place a horizontal gear with the horizontal face on the toothed lantern was activated by means of the extension of the shaft towards a piece of wood that is attached to the gear extended towards an end where the shooting animal was held that when walking in circles towards turning the gear.

Of ferris wheels one of the most spectacular was the one designed by Juan Díaz de Bracamonte to drain the striped mine that was flooded in 1694 because the striped stream left its course flooding the mine, before this problem the old Augustinian owners sold the mine to their lawyer.

To drain it, design a system of 8 underground ferris wheels, to locate them, galleries are designed that had to be built in the depths of the mine in these galleries, nine wooden platforms are built on wooden piles on which the machinery is located, in each one of these platforms had space for the machine, the horse, the horse's turn and the pawn that operated the work station, for the replacement of the animals ramps and access galleries were built that had the double function, first to allow the circulation of the draft animals, in this case horses which due to the working conditions inside the mine had

Figure 42. Fragment of the plan of the project to drain the striped mines in Guanajuato, with sets of ferris wheels and draft animals driving them for which an access ramp and work platforms are built, this great engineering work allowed to drain the mine, also through from the ramps and the access system of the animals it was easier to remove the ore on the back of an animal. Interior image of the 18th century striped mine in hydraulic works in colonial America

Figure 43. Design of a winch for a mine published in the gazette of Mexico in 1788 we observed the lifting system through the mechanisms operated by draft animals, which had to be constantly renewed to avoid depletion image in Technology and Engineering in Spain

to be changed periodically and to allow the ore to be using mules and tools to be carried.

In order to correct the constant maintenance of machines and gears of the Juan Díaz ferris wheels, he orders them to be built with very resistant mesquite wood, reducing the wear of the gears and, consequently, the dead times generated by the change of the worn or broken parts, with these implements Technological Rayas mine in Guanajuato was one of the most advanced of its time⁹⁸.

The next drain machine that we will describe are the winches, this machine was used in the same way to raise water than to lift material with the same principle as the ferris wheel. The name of winch is Nahuatl and it was assigned in such a successful way that the term is

used even in Europe Francisco Javier de Gamboa auditor and recognized character in the mining of New Spain said on the term the following was called the machine of the winch wheels by the axle or winder in which the ropes or ropes become entangled or detangled when going up or down. The winch is said in the Mexican language to the spindle with which the spun and from there it was transferred to that of the mines⁹⁹.

The winch was a machine powered by draft animals, using pulleys and cylinders triggered the movement of ropes that raised the containers in which the material could be lifted. The winch consisted mainly of two structures, one located on the closer side and the other at a distance of approximately 20m, it was a large table supported by two

⁹⁸ *Ibíd.* p. 340

⁹⁹ Camarero Concepción Bullón, Campos Jesús (Directores), *op.cit* p. 308

beams and which was only used to load the table and the other that was located on the side of the mine to locate cylinders for the rotation of the ropes, to the center of the table it has an horizontal axis, it was the axis of a wheel that was resting on its lower part in a box that allowed its rotation and at the top of the wheel the wheel, that was rather a cylinder, allowed a rope to be wound on it, the rotation of this large gear was made by means of draft animals, the rope was wound on it and passed by the support structure already described, to reach the second structure that was located on the mine, using pulleys, they facilitated the rotation of the mine in the case of being a winch for water extraction there was a structure that allowed to empty the channel. The rope rotated throughout the system and could as a ferris wheel have a constant movement without changing.

The main problems of the winches was the constant breakage of the ropes and their low performance to drain and lift the materials, a situation that was corrected with the construction of more winches, in some cases 28 winches were operated simultaneously which kept running in the mines of the count of ruler in the Biscayne vein in the area of Pachuca and Real del Monte or those described by Gemelli Carreri at the La Trinidad mine in Pachuca in the XVIII century had 16 winches in operation simultaneously¹⁰⁰.

At the same time, it was the first to be implemented of the pumps in Taxco mines similar to those used to shrink water on ships¹⁰¹.

These pumps were made with hollowed out logs in which a wooden pis-

Figure 44. Siphons pum in the Treaty of Agricultural Metallic these pumps worked with less height than the ferris wheels, but were very effective and faster, used in conjunction with other solutions or for small shots. Image arts of Mexico No 86.

ton was also placed, which was driven in a movement of raising and lowering by means of wooden pieces adapted to the circular movement of gears, in this vertical movement the piston was lowered and each one that rose raised the water that was introduced into the tube with a valve, in the upper part of the inlet tube there was another valve that gave a channel that carried the water to a tank, to activate the circular movement they conditioned cranks that were fixed to a structure similar to those of the ferris wheel, by means of the rotation of animals these pumps could be operated, in other cases when this was possible these pumps were operated by means of hydraulic wheels in both

¹⁰⁰ Trabulse Elías, *op.cit.* p. 34-46

¹⁰¹ Sánchez Gómez Julio, *op.cit.*, p. 451

cases the gear system it was the one that changed, since the mechanisms of elevation of the pistons were the same.

These pumps could not raise water to more than 9 meters so if it was required to raise water over greater distances, pump systems had to be built with rest stations where several of these systems were located, the water rose from one reservoir to another until it reached the mouth and was channeled into a reservoir or a river through canals.

VII. HYDRAULIC MILLS

1. Introduction

In the introduction of this chapter I talked about the outstanding importance of the mills over other factories, it is important the separation between the mills that produce food and those that produce key items, although the latter produce basic supplies, the former generate food. The importance of those who produce food over those who produce items is obvious, while flour mills proliferate regardless of the characteristics of a region, the latter are located in areas with productive and pre-industrial objectives.

Another important situation has to do with the grinding principle applied to the mill, this same aforementioned principle of friction or percussion and its various solutions are the generators of the other mills, in most cases the movements of other mills apply the percussion principle for obtaining their products, this is the reason why many mills are known as mills of something, oil mills, paper mills, rag mills, even iron mills.

Before continuing talking about flour mills, we reiterate the two fundamental physical principles applied to most mills, percussion and friction, both movements are related with the beginnings of grinding and its diverse evolutionary paths.

There were two ways of grinding: the first percussion, in which the material to be ground was located on a harder surface than him and with other elements of equal hardness that the base hit the material which was decreasing the size of its particles until the desired granulometry is obtained, the second by friction, in which it is placed on a

base in the same way harder than the material to be ground and with an element of smooth edges it is rolled on the base, this bearing rubs the material between the two hard surfaces and fractures obtaining the desired particle size.

The primitive cultures used stone or wood to achieve these purposes and the tools designed for this purpose were configured from very early times, the basic materials were the stones, when hitting one another and placing the material to be ground between it and placing a and roll the other one above both principles already described are of vital importance because they prevail in most basic devices, we will call them that because they directly apply one of these two principles.

Percussion and friction are applied to different machines to obtain different products, which are the mills of different names, although in this work each one of them is analyzed separately before mentioning them in this introduction we will talk about the name of mill, for various factories, as we mentioned for example, the *batan* was also called a rag mill, the paper mill is the paper-producing mill, the powder mills or the mineral mill, the iron mill, in all of them the name came from the factory of which they belong.

Focusing on flour mills, let's begin by talk about the origin of them, this way we will easier to understand the evolution and for that we need to the final product that these mills got, and this is the flour, that's why they were related with food, this was particularly useful for the production of bread, especially for food through grains, which included their derivatives, these were and continue to be the staple food of the different peoples of the earth. Although all the grains from different parts of the

world were and are subjected to milling processes, we will talk in particular about wheat, the evolution of the first flour mills that would derive in the hydraulic mills.

2. History of flour mills

At the beginning, wheat was consumed directly from the spike, in the collection processes of primitive cultures and in their wild state, later, as with other products that were together with man and his evolution, whether they are edible or not, the wheat passed through other processes, including milling to facilitate the intake of a grain that is hard in nature, this milling leads us to obtain flour, flour, could be wheat, barley and even legumes, mixed with water in later times these pastes of water and ground grain were still consumed as is the case of the *pulmentum*, the historical food of the Romans.

To these mixtures of flour of diverse origins and water, fire was applied to obtain a primitive bread, the first testimonies of the transformation of wheat into flour date from more than eighteen thousand years ago, the bread was then very different from the present one a cooked dough that it was not fermented similar in shape to cookies.

The most important step to obtain bread was to discover the fermentation. The Egyptians are the ones who discover how to ferment the bread around the year 2600 bC and began to elaborate it in different ways. Preparing the bread, Greek and Latin authors gave us many details. Once milled and dried, the flour was screened, mixed with a little yeast, water and salt, kneaded, shaped and cooked in the oven. There was a wide variety of bread, depending on the flour, the way it was prepared and those added to the bread.

In the early days of the Roman empire, the bread was made inside the houses (by women or by slaves), the first bakers date from the V century bC, although throughout history they practice making bread inside of the houses was still practiced. The patricians had slaves only dedicated to the elaboration of bread. The place where the bread was obtained was called *pistrinum*. This place was the professional oven. In the old *tahonas* it was the same baker who ground the grain. Hence the presence of mills next to the ovens.

Let's not separate the bread from the mills because this is the main reason of the creation and evolution of the hydraulic mill, of the need to obtain larger volumes of milled material in less time in the first instance the mills begin to grow, remember that there were two types, of percussion and friction in both cases the increase in size also represented difficulties to handle it, the larger the stones the greater the effort to move it, at this point it is where the hydraulic wheel enters, which was aimed to prevent the man from doing that work, the incorporation was really soon at the history and it is believed that the hydraulic wheels applied to the mills were from Mesopotamia,

"Stop grinding, oh women who work in the mill.

keep sleeping, although the roosters sing the arrival of dawn

Demeter ordered to water nymphs

Let them do your work.

Jumping on the wheel, they spin the axle

that makes the great crushing stones move"

HYDRAULIC MILLS

Figure 45. Roman animal mill, both fixed and mobile stones were perfectly coupled, in this way the space between them was used to friction grind the grain. Image Tarsicio Pastrana.

3. Antipater from Thessaloniki

This verse from Antipater from 84 B.C. shows that in Greece there was already knowledge of the hydraulic force to replace the work of man, specifically grinding. On his book X (first century B.C.) Vitruvius describes the operation of the vertical wheel mill called *Aceña*, which was already known in the Middle East in Persia and on the shores of the Eastern Mediterranean before the Christian Era (V century B.C.).

The called animal-force mill did not stop being used and in some cases in the cities and far from the water flows

were of more common, the Roman primitive mill consisted, essentially, in a fixed part, called a *goal*, and a moving part, the *catillus*. They could work with the force of the arms or with animal traction, using donkeys (astral mola) or horses (iumentar mola)¹⁰². This type of mills were used for a long time, especially in regions that did not contain hydraulic resources. In the city of Pompeii were found the furnaces and mills of the city, the latter of manual or ani-

¹⁰² **González Tascon Ignacio**, *LOS MOLINOS HIDRAULICOS EN EL MUNDO ANTIGUO* at *Los molinos y las aceñas diversidad tipológica y criterios de emplazamiento*, arquitectura rural en Andalucía, Spain 2004, p. 2

mal traction, in the imperial port of Ostia the discovery was similar, although there was knowledge of the hydraulic mills it was necessary that the resource be nearby.

Another impediment for the hydraulic mill to be used more consistently was the big amount of slave labor needed in constant flow and as a result of the multiple conquests reached Roman cities, while there were slaves to move the mills there was no need to the hydraulic mills, this does not mean that they did not exist, the Janicullo mills on the hill of the same name in Rome used Trajana water to move their wheels and have a high flour production.

The Romans are those who took the hydraulic mill to all the territories they conquered, this mill was a vertical wheel (water), in some places the horizontal wheel was used, which required less maintenance efforts to transmit direct force to the stones without needing gears. (whose main piece was called "flashlight")

Even from the Roman era, remains of several flour factories have been found, the change in the name of being a simple mill to be a factory has to do with the number of pairs of milling stones, in the mills of the Janicullo that I mentioned there were 6 *aceñas*, or in the factory of Barbegal near Arles in the south of France with 8 wheels of 210cm each with an estimated production of 28 tons per day¹⁰³.

With the Arab invasion in Spain the mill is enriched with new elements, they incorporate the system of bucket mills and modify the use that was widespread in the *aceñas* becoming more popular the mill with *rodezno*, the word *Aceña* comes from the Arabic Al-saniya, in

this case the wheel or mechanism that moves the axis is vertical to the water flow, in the mill it is horizontal.

The *aceña* was located in the main water channels, being its major production the mill required less hydraulic resources, placing it in streams and small courses that in most of the times required complementary works to channel the water and store it, the *aceña* needed more resources to be built, these were provided by the nobles and the rich of the region and controlled the use of mills and *aceñas*. In medieval times, the peasants were obliged to go to the mill of the Lord and pay a certain amount of grain or flour, called "*moltura*" in some places, and that later in Castilla y León will take the name of "*maquila*". The Arabs incorporate many of their knowledge into the Hispanic hydraulic tradition.

Over the years mills became the property of religious orders, military, abbeys, lay manors and councils or monasteries, which exercised the monopoly of the transport of grain and flour. From the V century to the VIII century, they extend in a general way throughout the Iberian Peninsula.¹⁰⁴

On the other hand, the construction and management of flour mills give rise to all legislation that appears both in the *Fueros*, and those were different compilations of laws and ordinances in order to regulate their operation. The construction of a sidewalk was complicated and required certain metal parts; but also, the mill could be builded by removing the metal parts and replacing them with wood, it could be built in almost any medium-sized stream or incorporating elements that allowed its operation (canals, dams, reservoir etc.)

¹⁰³ Syson Leslie, *BRITISH WATER MILLS*, BT Batsford LTD, Great Britaine 1965, p 20

¹⁰⁴ Leroux-dhys jean Francois, *LAS ABADIAS CISTERCIENSES HISTORIA Y ARQUITECTURA*, Köneman, Spain 1999, p. 46

Figure 46. Hydraulic bucket mill with only one rodezno, today there is only the small mill building in the ruined state of Cuilapan Convent in Oaxaca. Image Tarsicio Pastrana

in its construction involved groups of neighbors, who subsequently distributed the hours of use proportionally between the XI and XII centuries this property system was popularized, where the mill was owned by several people, the time was distributed to use it, there is therefore a phenomenon of pooling of construction and maintenance costs and as a consequence the times of use are also shared, this phenomenon will also be exported later to the *Aceña* property system once the stately power.

We find the treaties that talks about the importance of mills widely, commented 21 books of mills and machines in his book XI talks about the various types of mills and finally in the XVIII century the French enlightened study and describe them in the encyclopedia.

The hydraulic mills pass to America with the Spanish, prior to this in the territory that is now Mexico was ground with two instruments that persist without alteration after so long, the *molcajete* that uses the percussion principle and the *metate* used by the principle of friction, both are still used, which proves that the primitive mills are still in force.

In New Spain, mills are built following traditional techniques and customs from Spain, the way of administering them and granting concessions was similar to those already described, only the viceroy could grant permission for the construction of a mill, the mill injured was granted with a dimension specified in the document (groove, ox etc.) and the place where they had to take the water, also in New Spain the

owners of the mills were noble or people of great wealth and the clergy, only they had the necessary resources in order to keep them in operation, the mendicant orders and the religious institutes were great mill builders, just as in the Cistercian monasteries the convents in New Spain established bakeries and mills inside, example of this is the bucket mill located in the convent Dominican Cuilapan in Oaxaca a small mill that shows as a construction purpose the equipment of the convent, on the contrary, the Xuchimangas mills annexed to the Jesuit schools of Tepotzotlan, built in addition to the self-consumption to trade with the surpluses, while in Cuilapan it is of a single bucket with a pair of milling stones, in Xuchimangas there are two mills, one of 4 and one of 2 cubes that together had 6 pairs of milling stones.¹⁰⁵

The milling was still one of the most profitable businesses and the state analyzed and determined who would grant this power, the concession of a mill injured by the viceroy of Mendoza to the town of Tepotzotlán is done on a pre-Hispanic channel of this injured mill will emerge after the first mills of Xuchimangas¹⁰⁶, the authority is very involved in the concession and revision of the mills. Other cases of government intervention related to mills are described in the book by Gloria Artis Espriu talks about a dispute established by Felipe Verasmendi owner of the Hacienda Guadalupe in which a mill against Andrés de Salcedo is requested permission to establish a mill in Zinacantepec, Verasmendi claims for the proximity of the alleged mill with his argues that this will affect his production and that the permit should be

reconsidered.¹⁰⁷

Technologically, the mills had not any substantial improvement and continued this way until the end of the XVIII century, when as a result of the industrial revolution the metal parts began to replace the wooden pieces, parts such as the hydraulic wheel are made entirely of metal; at this stage the hydraulic wheel was an element incorporated into the new industries. In Mexico in the XVIII century, the mills incorporate physical and administrative elements of the industrial stage that was being lived, they become true monopolies that cover all stages of the production chain, acquire the grain, make it up, store it and distribute it; in some cases there were even bakeries in which the flour was transformed into bread, it is the case of the bakery owned by the Jesuits of the maximum school of San Pedro and San Pablo, the flour arrived from the cereal farms and mills to the warehouse of the maximum school, from there it was distributed and sold in different places, one of these was the bakery of his property.

In the XIX century around the capital of Mexico there were the following mills: Santo Domingo and Valdez in Tacubaya, del Rey in Chapultepec, Blanco and Prieto in Los Remedios, Río Hondo and Santa Monica in Azcapotzalco, Del Moral and Socorro in Chalco, the white one in Texcoco and Zavaleta in Ameca¹⁰⁸, some of these, such as Belem's, with all the metal machinery, thus obtaining better yields.

¹⁰⁷ Artis Espriu Gloria, *REGATONES Y MAQUILEROS EL MERCADO DEL TRIGO EN LA CIUDAD DE MEXICO EN EL SIGLO XVIII*, Colección Miguel Othon de Mendizábal ediciones de la casa chata, Mexico 1986, p. 19

¹⁰⁸ Cossio José L., *GUIA RETROSPECTIVA DE LA CIUDAD DE MEXICO*, Espejo de obsidiana, Mexico 1990 p115

¹⁰⁵ Pastrana salcedo Tarsicio, *op.cit.* p. 20

¹⁰⁶ *Ibid.* pag 21

Technological advances caused this type of mills to disappear, current mills are large industries that work with other types of energy such as electricity, and in which tons of grain are milled, their main architectural feature is storage silos, large cylinders of concrete that are visible in the whole, the hydraulic mills did not survive the technological transformations and a growing demand, the current large cities require flour volumes proportional to the number of inhabitants the hydraulic technology did not meet these needs, of all the transformations that have affected the evolution of the mills one of the most significant in the twentieth century is the productive need, the current mills are industrial establishments with business-type organization that produce the flour industrially distributed to different sites (bakeries, self-service stores and local stores) it was packaged with different capacities and presentations.

4. Rodezno flour mill operation

The mills had to be located in a hydraulic region, in most cases they were not isolated, they were part of complex hydraulic systems that were formed by sets of mills along a riverbank. The first element from which the mill is formed is a dam called "*azud*" that can be found in the vicinity or slightly removed from the milling facilities, which takes water from a stream or water channel and stores it forming a pond.

The channels that came out of the *azud*, were built of strong masonry, and sometimes excavated in the ground these channels distributed the water to the different systems of the complex, in this case to the mill, this channel had in its path stones with notches for the placement of floodgates that divert the water course to another secondary channel or to place grilles that retain the garbage along the path the slope of

these channels and the floodgates systems were carefully designed and studied prior to their construction to always on the same direction of the water flow and avoid stagnation in the canal.

At the entrance of the mill the master gate that closed the passage of water to the facilities was placed, in the reservoir the water accumulated, this had the function of having a liquid reserve or in the case of not having cubes generating pressure for the entrance to the needles which were placed directly next to the reservoir, if the mill was cubed, but did not have a reservoir, incisions were opened in the canal wall, these incisions with their respective gates allowed the filling of the cubes, at the end of the reservoir or the section of the canal where the cubes were located there was another gate that reintegrated the water to another channel that would take it back to the river or another area of the system.

The cube is an architectural element incorporated by the Arabs to the technology of the mills, this functioned as a water tank, usually built next to the reservoir or the main channel, its filling was controlled by means of floodgates, its construction had to conform to certain rules that, if fulfilled, guaranteed the correct behavior of water, especially in its flows.

The walls were of stone of considerable width depending on the dimensions of the cube and its storage capacity in addition to whether it was to be built underground or on the surface; In the final part of the cube the needle was placed, the base of the cube presented an inclination towards the entrance mouth of the flume which has an almost vertical path and whose exit hole was smaller than that of the entrance, this favored the water pressure which increased its strength when arriving at the gully, the

Figure 47. In the 3 types of mills analyzed, this superior set is the one that remains unchanged. Image Tarsicio Pastrana

exit of the needle had a valve that could be operated from the milling room to regulate the flow of the water that hit the *rodezno*.

The building of the mill was composed of two areas fundamentally, in the lower part the vaulted room was located to place the wheel or wheels of the mill, the needle went directly to this site, in the upper part was the grinding room where the wheels and the grain and flour management areas were located, in some cases there was a third level in which were the support areas (stables, warehouse, tool cellar, etc.) and the miller's house.

The *rodezno* was placed in the gully on a beam or a base that sank in the floor, (which used to be the natural terrain)

and that allowed to keep the wheel out of the water so that it turned freely in addition to preventing lateral movements of the *rodezno*. This beam had a mechanism that was operated from the grinding room and caused the vertical displacement of the wheel.

The *rodezno*s had a diameter that oscillated between 80 and 160 cm, their turning frequency was around 110 rpm, the speed was variable depending on the flow of the water and the pressure of the water, in its lower part the *rodezno* had a piece, called *gorrón* or *punta*, which turned on the beam, embedded in turn at the base, the base as already mentioned could be a beam or be directly to the floor. The *rodezno* was made of wood and was attached to an axis that turned as the wheel was "wound-

ed” by the water, then the water continued on its way out of the gorge and reached the exit channel that took it to another mill or back to the river again. An important contribution made by the Arabs to the design of the *Rodeznos* is the possibility of changing the spoons or blades independently in this way if it breaks one can be changed without disassembling all the *rodezno*.¹⁰⁹

The axis of the *rodezno* passed through the vault of the gully and in the middle of the fixed stone, to join the flying stone, the circular movement of the *rodezno* is transmitted to the upper wheel or flywheel by means of a wooden shaft. The shaft fits in the lower milling stone or *solera*, with a metal piece and in the upper stone with the *palahierro* that is connected to the plug, coupled to the grinder, to transmit the movement to it.

This set of stones (the fixed and the flying) were in most cases placed on a bench made of masonry to keep them raised from the floor of the grinding room¹¹⁰, they were covered with a wooden box called “dust cover” that prevented the flour from getting wet or dirty and that had only one outlet in the front, at the front of it and at a lower height the flour was placed a wooden bowl that received the already ground flour.

The diameter of the stones were between 1.30 and 1.40 meters, the eyes of the milling stones about 15 to 30 centimeters and their thickness between 20 and 30, which gives us an approximate weight of the *solera* - flounce set of about 2000kg. Of course, this weight needed an extra reinforcement

in the structure of the gully that supported it, usually the roof of the gully was made in the form of a vault to support this weight

The grain was deposited on the top of the stones in a container called hopper, which was placed on top of the dust cover or was attached to a wooden structure and was independent of the dust cover, the distance between the flying stone and the stone could be regulated. With the relief wrench that allowed the miller to regulate more precisely both the separation and the speed of the grinding wheels, the flour produced by this regulation could be fine or coarse, the first for human consumption the second for animals.

To regulate the amount of grain to be ground, a dosing system is available, at the base of the hopper and directly above the eye of the stone and the dust cover there was a channel that regulated the entry of the grain into the milling, by means of a tensioner, another attachment the “triqui-traque” that uses the movement of the axle using a cogwheel, producing a noise that is the cause of its name was placed on the axis of the system with some blades hits the channel this causes the grain to fall inside the eye; this allows the miller to get some freedom. The amount of grain has to be dosed, since if it is too much it can leave without grinding or stopping the machinery, and if it is small, excessively spend the “milling stones”.

The flour was poured through a canal to the flour container where it was collected for later packaging in sacks and transported it, this container could be made of wood, stone or in some cases cloths were laid surrounding the milling stones to collect in this way the flour around the perimeter.¹¹¹

¹⁰⁹ Reyes Meza José Miguel, *TECNOLOGIA Y ARQUITECTURA POPULAR en los molinos harineros en la provincia de Granada*

¹¹⁰ Escalera Javier y Villegas Antonio, *MOLINOS Y PANADERIAS TRADICIONALES*, Editora Nacional, Spain 1983, p. 108

¹¹¹ Navarro Domínguez José Manuel, *MOLINOS*

Figure 48. Working in a flour mill, the grain is deposited in the hopper, either manually or by gravitational means, the separation between stones is regulated as well as the speed of rotation of the rodezno, finally the flour is collected in the front part and They fill the bags. Image Tarsicio Pastrana

The entire wooden structure, from the grain inlet hopper to the flour outlet channel, was subjected to a vibratory movement, which helped the grain to enter and pour the flour into the flour. Finally, and before proceeding with its packaging, the flour was prepared by eliminating possible impurities and not properly crushed grains. The sifting was carried out manually with sieves or with a mechanical system also activated by the energy provided by the water, the sieve consisting of a roller with rotating blades, once separated flour and bran was packaged in sacks or sacks.

The streaks of the upper milling stone grooves were worn from use and had to be chiseling periodically. To move and flip the wheel, there was a device called *cabria*. On the structure on which the milling stones rested stood an angled hanger, reinforced with a bevel. At the end of the arm of the hanger hung iron clamps that were attached to the holes sculpted on the sides of the wheel. With the weight, the clamps were closed on the milling stone, that was hoisted and turned to proceed to the chime.

The chime began by lifting the flywheel with the winch flipping it and placing it on a wooden bench. With the appropriate tools similar to those of the stonecutters, stretch marks were re-

HIDRAULICOS EN LA COMARCA DE LOS ALCORES en actas de los IX encuentros de Historia y Arqueología, San Fernando Cádiz, Spain 1994.

HYDRAULIC MILLS

Figure 49. Complete system of a rodezno hydraulic mill: Tarsicio Pastrana image

paired, giving them the proper shape, depth and direction to improve cutting and grinding. This work, which had to be done regularly depending on the workload of the mill, could involve at least three hours of work to leave both stones in perfect condition.

The stones, which could be of different materials, had dimensions ranging from 90 to 140 cm of diameter and a height between 45 and 50 cm, although the wear produced by grinding and chipping reduced these dimensions, at the end of its useful life, to about 20 cm. The stones were girded, for easy handling and overhanging, with some iron straps to which two lateral holes were made to introduce the bolts that made it possible to fasten the clamps of the winch.

Apart from the fundamental work of repair and maintenance of all the parts and components of the flour mill, the person in charge also had to take care of the cleaning of the ditches of the same to facilitate the maximum use of the water flow, not always abundant in every seasons of the year.

The set described is similar in all cases of mills, the part that is modified is the location or type of hydraulic wheel and the arrangement of the elements, another type of variation is due to the nature of the water that will move the wheels, within these variations in addition to the mill of *rodezno* that we have just seen will mention those of *rodezno* and tides.

5. Regolfo Mill

Regolfo mill arises in place with rivers of great flow and much force that run by flat topographies, the rivers are not large enough to contain *aceñas* and have a high flow to waste it with the mills of *rodezno*.

According to Nicolás García Tapia, the word *regolfo* means the equivalent of standing in a stream of water trying to change it or resist¹¹² this referring to the principle of operation of the mill of *rodezno* that causes resistance to the water with which it works.

It has not been clarified with certainty the origin of the mill of *Rodezno*, it is sure that by the XVI century they were already represented in two important treaties that speak of the mills, one of them the one of the 21 books of the mills and the machines and the other about mills by Francisco Lobato¹¹³ they become very popular because they do not require additional works on the river to take the water, only a direct channeling that causes the entry of water into the stone cylinder, it was also common that in these cases of abundant currents the *rodezno*s they will locate next to the river with a derivation in the form of channel that hurt them directly. This causes water to enter the cylinder where the *rodezno* is contained and the subsequent filling of this cylinder.

The mills of *regolfo* take advantage of the principle of centrifugal force to increase the force of the turn, from the previous description what changes is the construction of the gully, in the same way the axis directly transmits the turn towards the stones because the *rodezno* is directly by under the stones, in addition to this the *rodezno* is located inside a stone cube, the *rodezno* located inside the stone cylinder works with the same principle of the air turbines, the *rodezno* is built with warped blades that oppose resistance the water.

¹¹² García Tapia N., *LOS MOLINOS EN EL MANUSCRITO DE FRANCISCO LOBATO SIGLOS XVI en Los molinos: cultura y tecnología*, Madrid, 1989, p. 168-169.

¹¹³ Córdoba De la llave Ricardo, *SOBRE EL ORIGEN Y DIFUSION DE LOS MOLINOS DE REGOLFO en III jornadas de molinología*,

Figure 50. Regolfo mill with the confined rodezno, when the cylinder is filled with water causes an effect similar to that of a turbine increasing the force of the turn, the rodezno and the stone cylinder are directly below the wheels, the transmission of the movement is directly, no storage system is needed when the current is strong and is taken directly from the river, in the same way once the water has fulfilled its function it is returned to the cause. Image Tarsicio Pastrana.

Another key feature is that the *rodezno* is almost the same diameter as the cylinder that contains it, in this way it blocks the passage of water that accumulates on the top of the *rodezno* and by gravity and design form with the wings placed in a way of the water that

goes down by gravity makes the wheel spin.

In the upper part of the cylinder there is a water inlet that causes it to accumulate on the *rodezno*, making it rotate, when the *rodezno* spins it also spins the water and this causes additional force,

once used below the cylinder there is an outlet of the water that returns to the river again.

This water storing and the eddies of water that formed give it its name as a *regolfo*.

6. Tidal mills

The operating principle of the tide mills is the same as a hydraulic mill, the difference lies in the origin of the water of the driving force, in the case of tidal mills used the force of the sea, this is why tidal mills are historical examples of sustainable architecture. Integrated into the natural environment, they take advantage of the resources it offers for the normal development of their activities.

These adaptations that start from the need to condition the space to the environment and make it work make them one of the most interesting examples of pre-industrial architecture, adaptations in which their differences with the hydraulic mills also lie and which we will analyze in parts.

This situation of the coastal environment also makes transformations in the mill's own architecture, its location in the middle of a dam and therefore surrounded by water close to the sea, transmits its first main need, a step on the water to reach to it, another characteristic is that you can take the grinding material and collect the product of it from the sea reason why you have to have spaces conditioned for that purpose, in the same way the sea miller will be different from that of river, its maintenance activities are different marked largely by the cycle of the tides from which the necessary driving force is obtained.

On the other hand, the need to locate a land on which a dam could be built

so that the tidal flows fill it refer us to specific sites of the coastlines, where complementary activities such as salt flats, fish farming and of course the use of the tide for milling configures a set of engineering works whose main interest lies in the design of the hydraulic works that make it possible, that is, the hydraulic engineer mainly transforms the coastlines that lend themselves to it and place ponds channels and pre-industrial buildings for production thereby generating areas of productive mills by the sea.

Taking advantage of the characteristics of the region, communities supported by technological improvements and their applications remain and prosper. For example, the existence of salinas and villages dedicated to these already existed in Spain for a long time at different stages of history, Phoenician Carthaginians, Romans, Christians and Muslims established settlements and colonies for the production of salt these productive units that generated colonies and villages require basic service among which the mills were.

In addition to these aspects, it should be mentioned that the hydraulic engineering related to the movement of the tides requires complementary analysis, in relation to the same tidal force and its moments of greater reach, the channels, dams, ponds and other hydraulic elements obey to the movements of the sea in addition to the rules of hydraulics that are considered for other mills.

On the other hand, it should be clarified that these mills are unlikely to have existed in Mexico, since the level between low tide and high tide is very little in both the Pacific Ocean and the Gulf of Mexico, which makes it difficult to install this type of establishment. Also, the crops associated with the need for milling were located far from the coast,

the reason why they are mentioned within this work is to specify one of the variants related to the adaptability to the environment that originate through the common hydraulic mills, its description is important to continue understanding the operation of the hydraulic machines that originate the mills and the diversity they can achieve.

Before specifying the issue of architecture and operation of tidal mills I will explain how the factors that make it possible have been done with other devices in this chapter, first of all the site or scenario par excellence of the tidal mills in the coasts, the estuaries and in second the phenomenon that allows the movement of the water and therefore its use in this type of mills: the tides.

The tides have their origin in gravity to which all the bodies of the earth are subject, in the case of water, the force of attraction of the sun and the moon causes changes in the water level which are more notorious in the sea. When the water level reaches the highest level in the day it is called high tide, on the contrary when it is at the lowest level it is called low tide, the tide cycles are constantly repeated every day, the only thing that changes is the maximum levels as we will see later, this cycle is repeated once every 12 hours so we have a low tide every 12 hours and a high tide every 12.

There are generally four tides of different levels daily: 2 high tides and 2 low tides. The difference between high tide and low tide is called tidal range. When the gravities of the sun and the moon come together, there's an effect is added by being closer to the earth, it is called living tide, than in the area where the measurement was made during the live tide we can find the maximums of the place, that means, when the gravity force of the sun and the moon are not

in their most influential stage and on the contrary they are counteracted, it is called a dead tide stage in which the difference between low tide and high tide is greater.¹¹⁴

These tides are combined with the orography of the coast to produce marshes, estuaries or estuaries that are different names for the same ecosystem, marshland is a place on the coast that during the high tide is completely flooded in the opposite stage at low tide this same place is dry, the ecosystems in these sites are rich in diversity of flora and fauna, used in ancient times with different hydraulic works for salt production and to install tidal mills.

The history of the tidal mills has a common origin with the previous one, about the mills in general we specify some differences, the objective is the use of the energy generated by the change of level in the tides. The first references of this type of establishment are found in the middle ages, on the south coast of England in the eleventh century, on the continental coast but in the same area the use of these establishments is extended, mainly in French Brittany in the Netherlands, in Holland and northern Spain, whose references date from the XII century mainly on the Cantabrian coast as we have already seen the difference in tides in this area of the North Atlantic reaches 8 to 13 meters in some places¹¹⁵ which facilitates the filling of the estuary and subsequently a better force in the water accumulated in the

¹¹⁴ All the principles indicated for the effects of the lunar gravity on the ocean can be applied to the sun, although its mass is greater (about 27 million times that of the moon) since it is about 400,000 times farther, and for this reason the effect that the moon exerts on the waters of the ocean is twice as great as that caused by the sun. The tidal forces of the sun only represent 46 percent in relation to those produced by the moon.

¹¹⁵ In the estuary of the river La Rance in France

change of the tide. This difference in the tides was observed and used for the construction of tidal mills, it is not difficult to establish the relationship between the hydraulic mill and the tide mill, the man required in the coastal areas of grinding grain, in addition to the northern Atlantic coasts aren't tropical, which facilitates the proximity of the grain crops with the coast, the design of the devices to accumulate the water that in the end would give its originality to the tidal mill over the hydraulic was obtained in these areas as we saw.

Although in the Mediterranean this difference in the tides is smaller, the differences were used to build mills that are widely documented, with graphic information (in Italy the notebooks of Mariano Jacopo Il Taccola - dated from 1438 and 1450 - and in Spain Francisco's drawings Lobato for Puerto Real in Cádiz, dated from 1545 and 1585).

Due to the differences in the weather, the absence of winds in some areas and the variable river flow in others, in addition to the production of tidal mills in many cases exceeding that of hydraulics began to fill the coastlines with this type of establishment from the coasts to the south of Spain to those of the Netherlands, also in Britain and the islands around it. In southern Spain, the establishments were managed together with the salt mines, for example, in Cádiz, where colonies had been founded by the Carthaginians for the exploitation of salt since early times, in these sites the existing infrastructure was used and conditioned tidal mills. Its decline as in the case of other mills comes with the industrial revolution and is accentuated in the XIX century where new energy methods replace the previous ones.

Although the milling in the tidal mills is no longer carried out for reasons

already analyzed, tidal power plants have been built, which under the same principle of operation of the small tidal mills spin instead of turbine turbines for electricity generation, which now on the coasts in some places that are provided for this purpose, electric power is produced, the most famous tidal power plant of these is that of the Rance in France.¹¹⁶

The site of the ideal coast to build a tidal mill is the marsh, an estuary is required for the exact site where the tide level at high tide is about 2 meters minimum at low tide, the estuary must have some protection due to the fact that the machinery was exposed to the sea side, if the mill was directly on the coast, the constant swell and the force of this would end up destroying and, in the best case, undo the machinery.

As a main element, it was necessary to find an area of the coast that was completely under water at high tide, at low tide it should be above sea level, generally outgoing and incoming from a coast with areas of rock or sand a little higher than the level of the beach were the most suitable, since these creeks off the coast and differences in level break the waves that do not reach the estuary with the same force as on the beach, a masonry wall was built on the main

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¹¹⁶ In this place the tidal range is 13.50 meters and the water enter and leaves the estuary at a rate of 18,000 cubic meters per second, producing a useful volume of more than 170 million cubic meters; In addition, its reservoir can contain 184 million cubic meters of water. The facilities consist of four main parts: the dam, the power generating plant, the navigation locks and a series of channels with regulating valves to accelerate the filling and emptying of the tank, through a dike that joins the two shores that are 750 meters away. Each of the 24 power generating machines that were installed in 1967 in the Rance, can produce 10,000 kilowatts; therefore, the maximum power output is 240,000 kilowatts and, in the year, it can reach around 670 million kilowatt-hours.

entrance that would serve as a dam this wall is the most important element of the tidal mill, every tidal mill has this wall that becomes an axis of spatial, functional and structural composition; this must have several characteristics, the first is that structurally it must contain the stored water, the second allows the transit of people and in the best case carts from the top, since it will be the communication from the mainland with the mill, since the building will be built in the middle of the estuary and the only means to reach it is the wall that will function as a bridge, due to its aquatic environment, it is also possible to reach it by boat and boat, which they become suitable auxiliaries for the transport of raw material and product obtained.

As for their shape they do not differ too much from hydraulic mills, usually tidal mills are rectangular buildings with their longest axis parallel to the axis of this wall. Due to the flow generated by the emptying of water from the dam they are generally larger buildings than normal hydraulic mills.

The mill building is made up of at least two levels, one of them coinciding with the upper level of the retaining wall and the other one a level below, where the machinery will be located, in this part it looks like normal hydraulic mills, since the support arches that define the gullies give it a characteristic view, these are located on the side facing the sea, in each of these the machinery is located.

In order to construct the building it is required that the part that will be underwater be resistant, with the characteristics similar to those of a bridge in the sense of resistance to water and materials, references have been found in which it is specified that the basement and the Arches are constructed of

marine stone denominated in Mexico Mucara, or in other cases of resistant stone, with a deep foundation whose constructive method of dry dock I considered was similar to that of bridges.

With respect to this type of mill construction on a dam that takes advantage of the unevenness of the water generated by the obtaining wall there are some models of hydraulic mills, the difference as it could already be deduced is that in the case of the tidal mill the water has a side-by-side circulation coinciding with the tidal cycle, unlike the hydraulic mill which is located in the dam's retaining wall and only allows emptying in the direction of the mill, the machinery will never be below the water level and the emptying gates only work in one direction, the tidal mill as an important part of its operation is this tilt gate that helps filling and contains the water to channel its emptying through the area of the mill as will be described later.

The most important part of the mechanism of function of a tidal mill is the gates that are located in different areas and that have a tilting mechanism that only allow the passage of water when the tide is rising which is an estuary is filled, these gates they allow the free passage of the water, at the moment when the tide begins to change direction the door locks and blocks the return of the water with which the dam is filled, the way of grinding was very simple, on the wall of containment according with each of the gullies there is a water intake with its own gates, these gates are operated from inside the mill and the water due to the unevenness begins the emptying, in this fall caused the *rodeznos* that are located in every gig. By guaranteeing a dam filled twice a day the tidal mills can be more productive than the hydraulics can have a greater number of rudders and main-

Figure 51. In the above image, the operation of the tidal mill is observed at low tide, letting the water pass through the floodgates that allow the rodeznos to operate, notice the construction of the mill next to the dam, we also see the pier in the from the back, from this site you can embark or receive products, to fill the dam the high tide is used, the filling gate only works in the direction that allows it to fill, when the tide changes it closes leaving the water in the dam, in the figure below, we observe the behavior at high tide, when the filling duct allows the water to pass and the dam becomes full, it is important to note that the mill's spring as well as the main machinery remain underwater during the Low tide. Image: Tarsicio Pastrana.

tain a constant milling speed, they did not depend on the water station or the extra storage in ponds, it was had a constant control of the amount of water that would be in storage and the production that would be achieved with that water.

When the dam is completely emptied, a cycle that begins again at high tide is completed, since when the tide rises, the doors allow the dam to be filled and subsequently emptied through the mill's gullies.

As we can assume from the previous description, the machinery of the mill remains underwater during the period of high tide, a situation that gives different characteristics to the maintenance

of this type of mills with respect to hydraulic mills, in these in addition to the tasks already known as the stone mincing is the periodic cleaning of the *rodezno*s that can bind algae in their mechanisms and hinder the movement, also the constant cleaning of the gates, due to the circulation in two directions of the water solid materials are carried that can avoid the proper functioning of the overhead doors. On the other hand, we have mentioned that these devices can be located together with others, such as salt flats, for which the movements of the tides are used in the same way, later we will talk about the operation of the channels for obtaining salt.

7. Mill architecture

Figure 52. Architectural plant of Marqueses Mill of Salvatierra, Salvatierra city, Guanajuato. Imagen Tarsicio pastrana

1. Feed channel.
2. Mill cubes, the number of cubes it is possible to determine how many pairs of wheels there were in the mill, for example in this one you can clearly see 3 cubes.
3. The production area is next to

the cubes, since from these, the *rodezno*s that are located below the work room or production area are fed with water.

4. Drain the mill, after wounding the *rodezno*s, the area in front and below the production area

receives the water that comes out of the gullies, then this water will have to be incorporated back into the canal.

5. Waterway.
6. Water channel after the drain, where the mill drain is incorporated.
7. Warehouse and administrative area.
8. Warehouse.
9. Access door to the production area.
10. Courtyard in front of the production area, serves as it was and as a sundeck, to prepare the grain before grinding it.
11. Chapel.
12. Main porch.
13. Housing area.
14. Possible service area.
15. Courtyard.

VIII.WATER AND OIL

1. Introduction

Olive oil is a product highly appreciated by man, cultivated for thousands of years and worked to extract its valuable oil from olive. It is very likely that, as Indro Montanelli says in his book *Historia de Roma*, one of the first real uses in addition to the culinary oil obtained directly from the fruit, was spread to help the healing of wounds caused by the sun, however almost Parallel since primitive times the uses were diverse, among them the most important was the nutritional one with the passage of time the cosmetic use is maintained, the curatives, the ritual are added, for the illumination among others but all of vital importance for the primitive societies, to all this are added the qualities discovered already in the XX century and that make it so useful in the care of diseases related to circulation, the highly praised Mediterranean diet owes much of its virtues to this oil.¹¹⁷

The production of olive oil required crushing and grinding the olive to separate the oil from the fruit, in addition to removing the hazelnut from the bone that was considered bad to consume, so that the basic principle of processing passed through the primitive stage of all the processes addressed were similarly milled with stone that milled paper, wheat, and other processes that include basic milling in their initial process. As a second stage the systems are specialized and it is not the same to mention a sugar mill for sugarcane production than an oil mill although both originally used the same machinery.

This leads us to analyze the process in two stages, the first most primitive and which is common in machinery to the primitive stages of the other processes and the second where the oil mill acquires its own characteristics that make it different.¹¹⁸ It is also important to mention that there were two types of driving force (this is also similar in all cases analyzed) human or animal force (blood mill) and hydraulic force although this second was much less abundant than the first is It is important to include it in our analyzes mainly for finding this type of hydraulic oil mills in the main hydraulic treaties of the time.

The specialization of the machinery and the use of hydraulic force are the two factors that determine an evolution that continues to this day, the difference is that the machinery has changed and has been technified, but the production of olive oil is one of the activities that continue in many regions without alteration over time although the machines that support their production are those that have evolved over time, essentially preserving the same parts of the process over time.

It is these machines in their viceregal hydraulic stage that will be analyzed in this subchapter, focusing mainly on the productive stage in which these were used, analyzing the main changes and the operation of these oil mills, remembering that their diffusion in New Spain was scarce.

2. History of olive oil

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¹¹⁸ The processes of obtaining different products that depended on grinding have to do with the application of the primitive stone mill, which lasted with very small variations for a long time until the specialization of machinery and processes began, is derived from the experience of hundreds of years and the intention to increase production and improve the product.

Figure 53. In A the olives were placed, the operators were in B and they placed the stone weights C on top of the olives that were being pressed and the oil was collected in D. Primitive press of the second millennium BC in Gezar Palestine. Image <http://www.hojiblancaycordoliva.com/index.htm>

The Middle East area is considered as the origin of olive oil production, approximately in the year 4000 B.C. an oily fruit was consumed from a small shrub that is found throughout the Mediterranean area called *oleastro* that can be consider as an antecedent of the olive tree although its fruit is not so profitable, once again a specific region is mentioned but it is common that in various parts it was discovered that the oil of this fruit was very nutritious.

The olive tree, as it is known, was a mixture of shrubs of this type that was sought in order to obtain the most oily and good-tasting fruit. These mixtures are achieved in the Middle East and its cultivation and exploitation begins very early in Egypt, Palestine, the Greek islands and mainly Crete where it is known from archaeological evidence that the main activity of the island was the cultivation of the olive tree, although the exact origin is unknown, there is a history of olive cultivation that is a wild bush that gives a fruit similar to olive but of different characteristics.¹¹⁹

In the great empires of antiquity, including the Minoan culture, the harvesting and commercialization of oil represented an economic and cultural development of great proportions. The importance of the oil lay not only in its nutritional values, it was used as already mentioned in medicine, cosmetics, lighting, religious rituals etc. transforming into an essential article.

It was the Phoenicians who carry the oil throughout the Mediterranean, always its long-distance transportation was carried out in mud amphorae that had characteristic shapes according to the region of production of origin, this served to determine qualities according to origins, something similar to the denominations of current origin.

The amphorae were covered by a ceramic plug and a lime paste that solidified, creating a continuous surface through which no part of the liquid could es-

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Verdu Francisco, *EL ACEITE DE OLIVA EN LA ALIMENTACION MEDITERRANEA en aceite de oliva y salud 1er congreso de cultura del olivo*, Universidad De La Rioja, Spain 2007, p. 708 y 709

¹¹⁹ Barbancho Cisneros Francisco y Mataix

cape on the long journeys. The Roman Empire gave the routes of oil and its consumption a capital importance, we must remember that consumption was not the only use of oil so the Roman metropolis became the first oil receiving center all the colonies where it was produced. In Rome, an artificial hill was created on the site where the villagers were going to discard the empty amphorae, the olive oil trade was of vital importance throughout the Roman Empire.

At the fall of the Roman Empire, this great network established for consumption and commercialization collapses, but the custom of consuming it does not, as it became a sumptuous article, its consumption was significantly limited to religious areas and social groups that could afford it, the town began to replace the oil with another type of fats, mainly animals. The exception is presented in North Africa and southern Spain, which, being dominated by the Arabs, manage to maintain and improve the system that existed during Roman times, increasing and improving some parts of the productive system.

For the Arab culture, oil also represented cleanliness and situations related with their liturgical rites in which they had to be anointed with olive oil, a situation preserved in Christianity throughout the middle ages, the kings had to be anointed, just like the newly born. The church could not do without oil and they were one of the main consumers at the time described.

With the rebirth and the improvement of the production methods derived from human concern to achieve improvements, the cultivation and production began to spread throughout the Mediterranean and the oil began to be sold again at different levels of the population.

Figure 54. Hydraulic oil mill, the wheel is vertical and transmits the movement through a series of gears to a stone that turns inside a stone container where the olives are deposited, image the 21 books of the mills and the SXVI machines

oWith the discovery of America and the constitution of viceroyalties in America, the cultivation of olive oil in America begins mainly through religious orders¹²⁰ as they required this for their ceremonies. The cultivation of olive oil is favored by the climate and by the situation of New Spain in which agriculture is developed, the wide water resources, the climate and the cultivation areas with good soil begin to favor the appearance of this and other crops.

At the beginning the cultivation of several species and their transformation into products of first necessity was en-

¹²⁰ The olive groves in Mexico City are clearly distinguishable by retaining their name now in the periphery colonies, an example of this is the Olivar de los Padres and the olive grove of the count, both in the western part of the city that coincides with In the area of mills and batanes of the city, this region had several water runoffs that descended from the mountains and made the area suitable for all types of pre-industrial establishments, including olive groves with their annexed oil production establishments. Olive, also the name of olive grove of the parents tells us about the property of these a religious order that in the beginning were the only ones that had the technical knowledge and resources to launch a crop of these characteristics. In the atrium of the convent of Tzin Tzun Tzan we find olive trees of 500 years that are attributed were planted by Vasco de Quiroga.

couraged by the crown among these products were several that in the subsequent centuries would be controlled and prohibited for example olive oil. During the XVI century, the Crown itself promoted in the colonies a process of import substitution of the main consumer goods of the Spanish communities settled in the New World. This is how the local production of wheat, wine, olive oil, and textiles began in New Spain and Peru.¹²¹

The metropolis wishes to maintain the monopoly in the cultivation for which and given the rapid development that the cultivation and production was having creates a prohibition to produce it in America, Carlos IV signed the Royal Decree of January 17, 1774, for which he commissioned will viceroys do not plant vineyards or olive trees in Mexico. A few years later motivated by the same desire to stop the olive oil industry, 1777 in which he ordered the complete destruction of all the existing olive trees in Mexico. When Humboldt visits New Spain there were only two regions with olive groves in the entire basin of Mexico, one was in Tacubaya the so-called olive grove of the parents that belonged to the secular clergy and the other in the area of Tlahuac, the crown had fulfilled its objective.

This decision was decisive, even after independence the crop did not resume falling over time, the consumption of the oil was not favored by what is replaced with other oils and fats, mainly of animal origin, currently recommended for a healthier diet, oil has to be imported as a result of the lack of custom in its conscience generated a weak domestic industry. On the contrary, the oil exporting countries among which Spain

is, developed through the traditional methods of production improvements in machinery and equipment with which the production of different oils is carried out easily and quickly, the method is preserved intact over time what has changed are the machines and accessories, the analysis of the machines that correspond to the era of the Viceroyalty in America is the one that will be described in the next part of the work.

3. Obtaining olive oil.

We already commented that the olive tree comes from a wild bush that was domesticated and crossed to obtain the varieties that are known as the olive oil fields with their rows of trees arranged so meticulously are a permanent companion of the site where it is made The oil, unlike other types of cultivation, the olive has to be processed immediately because its fermentation process begins immediately in addition to being very fast, being a fruit with a high amount of water this is combined with the agents of the environment and with the characteristics of the fruit to produce a rapid fermentation, the oil that cannot be combined with water as is known, oxidizes quickly changing the characteristics that distinguish it.

The olive is processed the same day of the cut to avoid both fermentation and oxidation all this in order to preserve the flavor and quality of the oil. It is for this reason that the initial part of the manufacturing process is the rapid collection of the fruit and after this a selection to choose from the same moment of the observation in the tree the fruits most suitable for the grinding of the day.

When the olive collects the olive it does so through a selective process, with which at first glance it considers that they are ready to move to the estab-

¹²¹ Márquez Graciela, *MONOPOLIO Y COMERCIO EN AMERICA LATINA SIGLOS XVI-XVII*, Centro de Estudios Económicos El colegio de Mexico, México 2001, p. 25

ishment where it will be ground called the oil mill, this harvest can be done by hand or with scrapers¹²². The olives are harvested without leaving the tree completely without fruits, selecting them according to their ripening process in this way some fruits are left for the next harvest, there should always be fruits to collect so the production does not depend exclusively on the harvest, the harvest of Olives in different degrees of maturation provide different types of oil, the black olive produces an oil, the other green and the other white.

The harvest process is similar to the one that was carried out thousands of years ago, for example, the table olive is harvested first than the olive for oil, this reaffirms the idea of a harvest of several months in which the fruit is selected depending on the use that will be given and the type of oil to obtain.¹²³

The cycle of the fruit begins at the end of winter, with a total flowering at the end of May, and from there about 2 and a half months to obtain the first ripe fruits, the crops are made in the summer and the oil mills are loaded of olives that in this way begin to produce oil, the cycle ends in mid-winter with the oils produced and the rest of the oil mill.¹²⁴

One of the main consequences of this harvest and in turn of the situation of rapid fermentation that the olive suffers is the location of the oil mill next to the production field, in the case of oth-

er products to be transformed as the different wool already saw with wool steps of the production process can be housed in different spaces that will not necessarily be together, in the case of mills and olives their mills will have to be next to the crop field.

On the yield of a crop field, the following data are available, the olive tree is currently planted at least every 7 meters, this in order that motorized vehicles can enter between the rows of trees and can help in the different parts of the crop and the harvest, previously the same function had the carts this distance facilitates the development of trees that are pruned to have extended fronds near the floor level, with this measure we obtain 225 trees per Hectare being able to reach 400 If the distance between them was shortened to 5 meters, each tree is obtained depending on the droughts and the amount of rain from 15 to 25 kilos of olives.¹²⁵

The yield of the olive is approximately 20%, that is to say that each kilo can produce 200ml and in an oil mill you can grind and process 100kg a day, an oil mill that produces for a field of one hectare would work 57 to 100 days a year depending of the quantity and quality of the olive, this measure is a quantifiable fact, although the fields were not of a single hectare were much more.¹²⁶

Once the oil mill is reached with the containers full of fruit, the olive as a first step should be washed and classified, when a large amount of water is required, a container or sink is required that allows the handling of the olives by a person and the systems of channels

¹²² Accessory with shape of rake allows to collect olives that are already ripe and that cannot be reached by hand.

¹²³ **Barbancho Cisneros Francisco y Mataix Verdu Francisco**, *op.cit.* p. 717

¹²⁴ **L. Ravett A. Matías**, *CARACTERIZACION DE LOS ACEITES DE OLIVA VIRGENES DE CATAMARCA ARGENTINA FISILOGIA Y FENOLOGIA DE LA INOLICION*, Instituto Nacional de Tecnología Agropecuaria, Catamarca, Argentina. Istituto di Ricerche sulla Olivicoltura, C.N.R., Perugia, Italia.

¹²⁵ Forum: Trebujena sobre el cultivo del olivo, registro de preguntas y respuestas at website Trebujenanet: http://www.trebujena.net/el_olivo

¹²⁶ *Ibíd.*

Figure 55. Production of olive oil in the XVI century, 3 hydraulic mills are observed in front one of them can be used interchangeably with a draft animal or with rodezno, in the front you can see the olive deposits, after the 3 mills the containers where the paste is placed that is carried to the presses that are located in the back, in the central part of the presses the esparto mats where the paste is pressed, to the center the containers that receive the oil and in the background the burner to process the waste of the paste and obtain other types of oil. Image the 21 books of the mills and machines

to drive the water to this container, we find the water as a direct participant, the olive is washed to eliminate the foreign substances that when milled could transform the flavor of the oil, this situation generates an architectural space where the olive waits to be washed and where before the washing is separated, the separation is done in the first instance by colors and sizes, in addition to removing any organic material that should not be crushed leaves branches earth stones, this separation aims to obtain a uniform product at the time of grind it different types of oil are obtained from different types of olives

We must remember that much of the production is destined to the manufacture of oil, but the fruit of the olive tree is used to be consumed in its fruit state, to cook dishes to dress food, this separation determined the best fruits

for obtaining the oil, by contrast some of the olives were discarded but were used for some of the uses described.

The space required is generally closed so that the olive is not in the sun, in the book *The olive*, clean and washed, should not remain more than 48 hours without grinding because it could ferment and affect the quality of the oil¹²⁷. A maximum period of 48 hours between collection and milling is mentioned, in either case transition space and cleaning space are required, on some sides it is a patio next to which you have access to the water sinks for washing.

Once the fruit is released from foreign substances, it is crushed, in the first instance the olive is taken care not to chop it before milling because any wound olive lets its oil and water escape through the wound, starting the fermentation so faster and sourcing all oil production, this care is done from the moment of collection and in all handling, separation, washing and transport to the mill.

The milling is one of the most important parts but at the same time more arduous, man began from very old times to generate machines to help him with this task, the first mills were of stone and there was no distinction in the product that would be ground in the , then in a first stage of technical specialization separate mills according to the material to be ground.

The first mills were stone or wood mortars, the olives were placed in the mortar receptacle so that by means of human force the paste was formed inside which the oil was extracted, the first most technified mill although not they weren't really differentiated by the ma-

¹²⁷ La almazara y el proceso de obtención del aceite de oliva virgen en <http://www.cerespain.com/almazara.html>

Figure 56. Press beam image Tarsicio Pastrana

terial to be ground would be the vertical wheel attached to the center of a circular space by an east axis we have already seen it in other parts of this work and it is the most primitive of all, the next step is the incorporation of the hydraulic wheel In the event that this is possible, the oil becomes an essential item that is not only manufactured in places where there is water.

If water were the main driving force, the gears would be responsible for transmitting the turn to the stone that remains horizontal and that rolled over its edge over and over the fruit until it is chopped and formed into the paste, in this paste the shell liquid and oil join with the bone hazelnut to form the aforementioned paste, raw material already transformed.¹²⁸

¹²⁸ In the treaty of the 21 books of the mills and the machines, an oil mill is illustrated that has

Some of the oldest mills referenced worked with a wood and stone press, with the olive pressing principle to extract the oil. Although over time the types of grinding are divided mainly because the breakage of a bone involved the change of the flavor of the oil, a first grinding is carried out in which a paste is obtained.

In this first grinding it is where the bones are separated to prevent the bones from getting pressed into the press, this also determines the design of the mill, since the stone must have the necessary strength to crush without breaking the bone that also It would modify the taste of the oil. Reaffirming the idea, the vertical stone blood or hydraulic mill was one of the first used to produce the oil.

the double motive force, being able to be moved by a rodezno or by a draft animal.

The difficulties that mills of these characteristics could show due to their small grinding surface¹²⁹ the needs to crush more olives with the turn and the inconveniences of adjustment of the moving parts generate changes in the mills as already mentioned in other works the technological changes are generated by greater production needs, in the case of Home-made systems will remain unchanged for a long time, the production needs derived from the commercial are those demanded by technological implementations.

Several mills are known for milling the olives, the first and most primitive one we already mentioned was the grinding stone placed vertically that could be driven by hydraulic force or animal force, then these are modified derived from the need to increase the contact surface between the mobile stone and the fixed stone, is when the mill of two conical stones is obtained, this is the one that was most used until the mechanization of the process already in later times.

This is formed by two conical stones placed on the edge and joined in the center by an axis that extends towards the top to be fitted in a gear from which the axle for the hydraulic wheel comes out¹³⁰ or to hold the collars of animals, the ease of this mill over the previous one is the control that can be had of the rotation of the axis, and the transmis-

sion of this rotation to the two stones attached to the center of the axis by ropes or metallic elements, the carving of these stones had to do with the size that would sweep, that is to say, a conical body would rotate concentrically towards a certain point, by placing two stones one at one end of the axis and the other in front it is possible to sweep with the surface of grinding an area equal to the measure of the inclined face that ends at the tip of the cone, past a small area that would remain unswept becomes a collecting channel.

This change meant greater sweeping surface and, for the time being, greater grinding area. With this type of mill we found that the production of ground material in the first mill was around 8 to 15 bushels per day.¹³¹

Another way to make the mill was with a stone platform on which the conical stones rotated in the perimeter of the platform that is circular in shape is an equally perimeter channel where the paste generated by the milling is collected. In all these cases described, the upper shaft is inserted into a piece called a flashlight on which the gear shafts that are moved by the hydraulic wheel or the cane that is fixed to the animal's collar can be derived.

From the perimeter channel through ducts the paste deposits are reached (if they exist) and from there it is taken to the screw press, the oil mills usually take the oil out of the perimeter channel through containers, although it was not difficult to find channels forged to channel and accumulate the pulp produced, known as pomace.

¹²⁹ These mills could only grind a small amount of material because the contact of a circle (mill stone) with a straight line (floor pavement) is only made at one point, which was enlarged by the bearing surface and the width of the stone, however this remains a small surface for milling needs.

¹³⁰ It is important to mention that the use of the blood mill was more common than the hydraulic one although hydraulic treaties are found where the mills for olives driven by hydraulic wheels of various types are described, including those of rodezno.

¹³¹ According to this grinding data, which does not run in that way would be in the 500 kilos of olives per day, this grinding was fragmented by the situation of grinding only what is going to be pressed in those moments, which is the next step after of the first mill.

Figure 57. Hidraulic mill of stone to olives production. Image Tarsicio Pastrana.

Due to the nature of the oil and the value of this, it was a matter of not wasting material, so the runoff surfaces had to be of a low absorbent stone and in many cases it was treated with a coating that closed the pores of these surfaces, in the same way that was done with the amphorae that would receive the final production.

The paste obtained and from which the bones were already removed is passed to the screw press, in which under a very strong pressure the sections and pieces of fruit are squeezed and water, oil and bagasse are obtained, this separation is carried out at through pressure and separation is done by physical means since the by-products are of different densities, leaving the oil floating on the surface of the paste, the water in most of it and in the background the remnants of broken fruit. Screw presses

are not only used to obtain oil, but also with slight variations we can observe them in the paper process and in the primitive sugar production procedures

Other methods of pressing widely used and that is prior to the use of the screw press are beam presses that consist of a wooden beam of large proportions some measure up to 12 or 14 meters long by 3 high, which is they find fixed a wooden bench that generates an equilibrium point in the center or loaded towards one of the ends allowing the swinging movement of the beam at the end of which is also a wooden hammer that falls on a container that contains the olives, same principle of the mills that work with mallets like the *batanes* and the paper mills, but with a counterweight and a screw so that all the weight of the press fell on the paste and its various components could be sepa-

Figure 58. Almazara, in the background the hydraulic mill, in the middle of the beam press and in the foreground the semi-buried jars to store the oil image Tarsicio Pastrana

rated with this method is pressed the paste taking advantage of the weight of the beam and the mallet.¹³²

The towers of the oil mills are common for pressing, by applying high pressures the separation of the substances is obtained, the pressed paste is separated into the components it contains.

Both the spindle press and the beam press are intended to apply the greatest possible pressure on the paste to extract all the possible oil, the components of the remaining liquid are those that interest the oil makers because

among them is the olive oil. The product obtained was diverse, the qualities of the oil had to do with the number of pressures and with the processing of the waste, the best of course is that of the first press, later there were more presses that determined the change in quality, until arrive at the processing of the waste of the paste that caused another type of oils (the one of *alpechín* and the one of *orujo*).

In fact, as already mentioned in the section that talks about sugar and taking into account that archaeologically there is evidence that the manufacture of olive oil is much earlier than that of cane, it is determined that the primitive process of obtaining sugar from the cane was derived from applying the already known process of obtaining the oil to

¹³² Cara Barrionuevo Lorenzo y López Rodríguez María Juana, *UN CAPITULO CASI OLVIDADO EN LA HISTORIA ALHAMEÑA LAS ALMAZARAS Y EL ACEITE* at the Eco de Alhama No4, Spain 1997, p. 4

the cane, just as the grain mill that is the most primitive was applied to various materials to be ground, the cane was treated with the procedure that was already known for obtaining the oil, later it was specialized according to the experience and the characteristics of the cane although we reiterate that at the origin they had the same procedure of obtaining.¹³³

Returning to the subject after pressing, the paste separated, its main components being water, oil floating on its surface and bagasse and olive remains in the background¹³⁴, this separation was done by decantation.

The most tedious process was the decantation, carried out in jars that were buried at different heights through which through grooves it was possible to go from one jar to another always the part that was higher, being the oil the floating part this was going from one to another in this process the impurities that were deposited by gravity in the bottom of the jars were released, the leaks that were made sporadically were made through cotton blankets and cloths of very closed tissue.

One of the by-products of this process of obtaining the oil was pomace oil, which was obtained from the boiling of the pressing residues, the difference between one oil and the other lies in the refining, the olive oil is virgin because it obtained cold by pressing, in

the case of the pomace the residue has to be boiled to obtain the oil that has remained in its parts.

When removing the oil from the surface, it must go through filtration processes to separate the particles that could float in the oil. The filtrates were made with very closed cotton fabrics that were placed in the mouth of the containers when the oil was emptied from one another, this separation of substances produced by the presses was carried out by sedimentation, decantation, or filtering, the rest allowed the maturation of the oil and the sedimentation of the bodies that were floating in the oil that were going to the bottom, in both cases were passed from one deposit to another.

When the product is obtained, the oil is placed in clay amphorae so that it can be transported. The colors of the oils talked about their origin and what kind of olive they came from. The green olive oil which is not ripe is still golden green, the black ripe olive oil is golden, in this way by the color they were identified.

Finally, before distribution, the clay amphorae were engraved with the symbols of the oil producing region, the clay forms, the vessels and other container elements had different shapes depending on the region from which they came, a common situation was the placement of a sealed ceramic lid with a mixture of lime that solidified and created a closed container, between the shape of the vessel and the brands, greater control was obtained and the region of origin was known, so that the different flavors were also known of the olive tree

The vessels could be accommodated by their shape, the transport and use of these vessels was so common that in Rome near the Boario forum an artificial hill was formed that did not exist from

¹³³ Taking as reference the sugar mill illustrated and explained in the treaty of the 21 books of the mills and the machines, we observe the procedures of olive oil in obtaining the sugar, the milled cane to obtain a paste and the press to extract the juice of the cane of the pasta, the subsequent processes of refining are only particular to the obtaining of sugar.

¹³⁴ These wastes were used for different uses of the main one was the feeding of cattle, in addition to the waste could be processed to obtain another type of oil.

Figure 59. Architectural plant of an olive mill image Tarsicio Pastrana taken from *Dispersa Rural Architecture Seville The olive grove of Aljarafe olive groves*

the accumulation of vessels and their remains in an area of the forums that was the popular dump of the vessels that already being empty had no other use, over time this surface was so extensive that I formed the hill, which with abandonment was covered with vegetation, this hill called the testaccio mount is a First-level documentary source of the type and origin of the olive oil consumed in Rome of the 40 million amphorae that have been located 50% of the brands come from Hispania.¹³⁵

4. Architecture of the oil mills.

1. Olive storage and reception area.
2. Olive Mill Area.
3. Beam Press Area.
4. Decantation and storage area of final product.
5. Water well and hydraulic system.
6. Stone grindstone.
7. Stone grinding for grinding.

8. Mill Drive System.
9. Hot water.
10. Counterweight tower for beam press.
11. Chapel of the press where the counterweight and the recesses are.
12. Pressing area.
13. Well to receive the oil.
14. Pressed Pomace Deposit.
15. Beam press and oil settling tanks.
16. Spindle.
17. Storage and decantation jars.

¹³⁵ Garrido González Luis, *EL ACEITE EN ESPAÑA ORO VERDE* at La aventura de la Historia paginas 68-75

IX. PAPER AND WATER

1. Introduction

The manufacture of paper was limited to its production in the Iberian Peninsula, this as other products was subject to monopoly by the crown, this is the main reason why there were no paper factories in Mexico during the viceregal period except for one case, the Culhuacan paper mill designed, built and operated by the Augustinians to complement the convent of their order in the same town, this convent was particular because it was considered a center for learning and teaching activities for which the paper mill is built, that is to say, there was no interest in establishing a paper industry in the viceroyalty, as a result of which this article was not of first necessity, at least for the population, on the contrary it was for the government and administrative aspects, so that the import of paper from the Iberian Peninsula was constant.

In the case of the hydraulic technology that is applied to the paper, the part called the paper mill is very interesting, which once again as in other cases analyzed, this factory gives its name to all the establishments dedicated to the production of paper, so when says the paper mill is talking about the entire factory and not just the main machine. Returning to the issue of the mill as a machine, it was generally moved by hydraulic force, it was aimed at crushing the fibers to produce the paste that, as we will see throughout the subject, was the initial part of the process, its operating principle was the percussion.

By the XVIII century the Dutch mill was invented¹³⁶, which was also powered by hydraulic force, although due to its temporality it is unlikely that during the viceroyalty there was a machine of these characteristics in Mexico.

Finally another important machine although this was not moved by hydraulic force was the press with which the paper was finished, so to talk about the paper mill we will have to explain the whole process to properly insert the hydraulic technology into it, similar to the production of wool and other procedures analyzed, water is not only used as a driving force but also as an important part of the process, so its inclusion within the factory represents a storage and channeling system that will have to be mentioned.

This divides the technological applications in relation to hydraulics into three main branches, water as the engine of the machines or rather water as force and energy, the second water that participates in the production process, either as a component or as a complement and the third as the drinking water for personal activities of the workers but that do not have to do with the process of obtaining the product (cleaning, consumption, cooking etc.) although this division is not very common in the viceroyalty if we can consider that these canalization and storage works not only supplied the pre-industrial establishment.

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¹³⁶ In the XVI century the Dutch machine that helped in the milling process arises, although in many mills both machines were found, in addition to the mallet batteries and the press there were Dutch machines, as already mentioned in others processes analyzed at the beginning of the paper production, the rags were milled in flour mills, either hydraulic or blood, and then specialized and technified in their own machines and mills.

2. Paper History

It is a need of man since they start using encrypted codes to record events and a livelihood to receive those codes, this strong need to record history and events has allowed us to know life before our lives, and although now the paper and in fact the electronic media show us the friendliest and most practical face of the said sustenance in the past, different techniques had to be generated to create these materials.

The first and simplest was the stone, in the stone the symbols that told the stories were carved, this was very good for previous generations because the stone is a very enduring material. The petroglyphs were carved into the stone and the stones were placed in places where they could be observed so that these records were available to everyone (at least the information that could be published). The use of the stone generated other problems that are obvious, for example, the handling of a stone 3 meters high was not an easy situation, this stone could serve to record extraordinary information and would like to perpetuate on the contrary, this support was limited for more generalized and daily use information.¹³⁷

This situation was resolved in places where there was no stone with the clay tablets, as in Mesopotamia, which had the cuneiform writing and the sustenance of this writing was the clay tablets that could be handled and transported in a simpler way what put the invention of writing at the service of more common things, inventories, population administrative records, administrative

¹³⁷ The pre-Columbian cultures recorded in stone facts that they wanted to perpetuate, the Mayan steles are dated representations of important events, the placement of these steles in public places expresses the desire of their manufacturers to achieve a massive reach.

Figure 60. Figure 55. Drawing in Chinese ceramics of a tub full of paper pulp and the papermaker putting a mold to get the paper, in the background you can see the stacks of finished product image: The designer, Industrial, Graphic and Digital Design <http://www.atikoestudio.com/designer/industrial/materials/paper/history%20del%20papel.htm>

issues were reflected in the tables that even when they improved substantially in relation to the stone was still an awkward means to be stored, preserved and transported.¹³⁸

The type of writing develops from the nature of livelihood, of this one of the best examples is cuneiform writing, since having the need to work with incisions in the mud is easier for the instrument to write to be a small branch

¹³⁸ The clay tablets were handled in different sizes and could be stored in a more practical way than the stone, on the contrary the material is more perishable, the great advantage of Mesopotamia is the extremely dry climate and that has allowed the conservation of the tablets over thousands of years.

with tip that over time causes a writing based on the use of this instrument on livelihood, since it is difficult to trace curved lines, they are eliminated or never used until they reach the known writing¹³⁹. In the same way the use of brush allows more stylized writings and graphic representations based on a desire to represent reality, examples of this Egypt, the pre-Hispanic cultures of Mexico and the stylized symbols of writing in places like China and Japan.

The need to create a thin livelihood that could be folded rolled up and light was created in different parts of the world similar solutions with different types of plants, crushing a vegetable fiber and then flattening it is the principle that to date governs paper, in Egypt was the papyrus, made from the plant of the same name that grows on the banks of the Nile was obtained from the spinal cord of the plant stem which is formed by concentric membranes rolled one on top of the other, these were separated and placed on a wooden platform, then the process was repeated in the opposite direction similar to the weft of a fabric the sheet that was obtained was agglutinated with silty water that was also obtained from the Nile, finally pressed and beaten to give it the correct thickness¹⁴⁰, it was polished with cedar oil applied with horsetail brushes.

On the other hand, the parchment is an animal skin without tanning and with-

out hair, whose process starts from the correct cleaning, the maceration in lime, pressed and smoothed water, its production gives its name to the city of Pergamum in Asia Minor where produced of excellent quality and from where they were exported to Europe, the persistence of the parchment came to the birth of the paper.¹⁴¹

In Mexico, *Amate* paper is produced from the bark and roots of certain tree species that were cut into its inner face in the form of strips, these were flattened on a flat surface, after the strips were obtained they overlapped each other placing the strips in one direction and another as the Egyptians did with the papyrus strips to give more consistency to the paper, the binder was the same sap of the tree from which the strips were impregnated.

The *amate* was allowed to dry for the final step which had to do with a polishing process carried out with smooth stones that were passed over and over the paper.¹⁴² Some of the old papers had as a principle, as already seen with papyrus and *amate*, the rolling of pulps or vegetable pulps obtained from existing plants in their environment.

This principle of laminated pulp that is essentially the origin of the paper became obsolete when the paper began to be an essential item and a mass production was needed in China the paper had been used but not as sustenance to receive writing, these papers they were decorative and to wrap, it is believed that this was the reason why in 105 B.C. in China and covering the demands of a government with several bureaucratic processes that required registration,

¹³⁹ Ramírez Alvarado María del Mar, *LA REPRODUCCION DE LA IMAGEN Y SU IMPACTO EN LA CONSTRUCCION DE NUEVAS REALIDADES: HISTORIA DEL PAPEL Y DE LA IMPRENTA EN EL CONTINENTE AMERICANO* en *Ámbitos revista andaluza de comunicación* No 13 y 14, Universidad de Sevilla, Spain 2005, p. 248 y 249

¹⁴⁰ Hidalgo Brinquis M^a del Carmen y Asenjo Martínez José Luis, *EL PAPEL 2000 AÑOS DE HISTORIA EXPOSICION ITINERANTE DE LA ASOCIACION HISPANICA DE HISTORIADORES DEL PAPEL*, Asociación Hispánica de Historiadores del Papel, Spain 1998, p 2

¹⁴¹ *Ibíd.* pág. 3

¹⁴² Ortega Rodrigo y Domínguez Minerva, *EL PAPEL AMATE en Eara* código boletín 17 *October 2006*, Encuadernadores Artesanales de la República Argentina, Argentina 2006, p. 1-2

the technique to obtain paper from vegetable fibers of different origins is created .

Under the order of the emperor, Ts'ai Mon crushes mulberry bark, bamboo fibers, hemp, old fishing nets and used clothes in a tub with water where he lets them macerate and then pass it to another and grind it, the paste thus created he puts it on a grid of bamboo, possibly letting it dry and he obtains the paper that once dried showed that he could remain united.¹⁴³

The principle tested was the one that with different variations would be used over time, the grinding of the rags combined with certain vegetable fibers created a pulp suspended in water that was subjected to laminating and drying processes that were explained widely later and that provided a more manageable role and above all easier to produce, the Chinese kept the secret for a long time, those who took the production technique to Europe

It was the Arabs who in the expansion stage of their empire had contact with regions of China from where they obtained the technique for obtaining paper, specifically in the city of Sarmakanda in 751B.C. during the Battle of Fabrics two papermakers are captured that preserving their life they reveal the secret that had been so well kept, they immediately established paper mills in Baghdad in 795 A.C. and North Africa in Egypt for 800 A.C.

The paper arrives in Europe through the Silk Road, Baghdad, Damascus, Egypt, Sudan, Fez, Ceuta, and particularly through Toledo already in Spain, by the tenth and eleventh century paper mills already appear in Toledo , Se-

Figure 61. Drawing that shows the Arab technique to obtain paper, at the top we see the hydraulic mill and the mallets to grind the paste, on the left side two men work in the preparation of the pasta, at the bottom you see a character that with a mold removes paste from a container, different utensils for paper making are observed, in the background the drying of the paper by hanging it, in this diagram you can see that the technique introduced to Europe by the Arabs is very similar to the one that arrived in Mexico in the sixteenth century. Image The role of Xátiva. Robert I. Burns. SI (translation by Rafael León) / Excm. Town Hall of Xátiva (Delegation of Culture) Sarq al-Andalus El Papel. htm

villa and Córdoba, is established in Játiva for 1155 which is the documented date of the first paper mill in this city, from there and for a long time it will become one of the most important paper centers in Europe¹⁴⁴.

¹⁴³ Fundación Chile, *LA CIVILIZACION DEL PAPEL: DEL PAPIRO A LA CELULOSA*, Fundación Chile y Ministerio de Educación de Chile, Chile 2006. P. 1-8

¹⁴⁴ Hidalgo Brinquis M^a del Carmen y Asenjo Martínez José Luis, *op.cit* p. 4

In this city there was everything necessary to produce paper, cotton and hemp fields, numerous bodies of water and springs, together with the technological scientific knowledge of the Arabs, a paper region similar or more important than those located in other cities is created. To the north of Africa, in the Arabian Peninsula and even in Spain itself, capable of displacing the Egyptian papyrus that until these times was the best-known livelihood.

The main cause of the development of the paper through the Arab territories is due to the need that the caliphates had to use it, the development of the Arab Empire goes hand in hand with an exponential cultural scientific development, the study centers and the main capitals of the Arab empire, they need paper¹⁴⁵. If we think about the needs of cultural and political centers, paper is a fundamental part of these, so the main Arab cities will have nearby regions or in the same population center full regions dedicated to the production of paper, as already seen in the case of Játiva.

Arab scientists and cults develop techniques to improve production, their excellent hydraulic and agricultural knowledge allow the establishment of improvements in production and the

establishment of specific places for this production.

Important for this work is the implementation of hydraulic mills for the production of pasta, the Arabs being the first to use it, also the bleaching of the fibers with lime, the gluing to facilitate writing, this was done by means of gum Arabic, paste or starch, increased the use of fibers of different types, such as ramie, flax and hemp, in addition to perfecting the paper shape.¹⁴⁶

In the reconquest the Catholic kingdoms conserve paper centers and use them to their advantage the Spanish government required large amounts of paper, because the process initiated in the reconquest was continued with the discovery of America, as the territories also increased the needs were up.¹⁴⁷

There were two ways of introducing paper in Europe, both routes were a characteristic of the historical moment that the continent lived. The first one was already described through the silk route and from the Arabian Peninsula through North Africa to Spain and then through the South, the other through the commercial and cultural exchange promoted by the Crusades and part of the peninsula Arabic, passing through some regions of North Africa and arriving directly in Italy, from where it is distributed through the south east of France and north through the same country to reach central and northern Europe.

For some chronicles and in other cases by the municipal archives the dates of foundation of the first paper mills in various parts of Europe are established,

¹⁴⁵ Like the Romans, the Arabs gave legitimacy to their empire through culture and science, both activities reflected in substantial improvements in ways of life, during the Middle Ages the European cultural centers were in the east and in the dominated areas by the Arabs mainly the cities of Al Andalus where Toledo was one of the main ones. A similar situation will be presented in the Spanish golden century where the second Felipe empire relies on cultural and scientific development, the role is very important in this type of regimes because it allows to record the knowledge and advances achieved on paper remember the records Alfonso does the wise and these records are part of the knowledge left by the Arabs in the areas that the Christian kingdoms were recovering.

¹⁴⁶ **Hidalgo Brinquis** M^a del Carmen y **Asenjo Martínez** José Luis, *op.cit* p. 4

¹⁴⁷ Since its conquest in 1424, all the territories of the Crown of Aragon are already supplied with this paper.

in Spain the oldest are found, then France and Italy follow, as we saw the route they followed. These mills went directly from the Middle East through the Crusaders, just a little while before the invention of the printing press the paper mills arrive in Central Europe and Northern Europe¹⁴⁸ where the invention of the printing press is going to make paper an essential article which transforms the original process, almost handmade and begins to be technified, large amounts of paper were needed to print the books and texts required.

Already in the XVI century with the discovery of America, paper needs increased, Spain maintained control and monopoly of the paper taxing it and controlling its manufacture, which was mostly in the area of Catalonia and Aragon at the time of greater production Spain exported to Mexico in the second half of the seventeenth century from Seville and Cádiz 34,983 paper balls (a ball had 24 reams and a ream 500 sheets) which gives us an approximate of 420 million sheets¹⁴⁹.

In America, paper could not be manufactured, so the establishment of paper mills in present-day Mexico took place late after independence was declared, except for the Culhuacan mill (1575), which was administered by the Augustinians to supply paper to its educational centers located in the same area, its production was local and its function was to produce paper for catechisms, psalms, dictionaries and more texts necessary for evangelization and for learning by the friars of local languages.

¹⁴⁸ Already mentioned Játiva España en 1155, Fabriano en Italia en 1276, Langedoc Francia 1350, Colonia Alemania 1390, Genept Paises bajos 1428.

¹⁴⁹ **Hidalgo Brinquis** M^a del Carmen y **Asenjo Martínez José Luis**, *op.cit* p. 8

3. Procedure to obtain the paper.

The process for obtaining paper from rags and plant fibers recovers certain aspects of obtaining paper of a more primitive type, in which the grinding of the described substances is implicit. The system described below shows the concern of mechanizing the most complicated processes that required more effort by the artisan, in this case the grinding of the fibers, it is convenient to clarify that all the procedures described in this work are those that they were used in the viceroyalty.

The water in the context of the paper mill as well as for other types of mills must have an infrastructure that allows channeling and use in the different types of widely discussed uses, in the case of washing two types of pipeline are required, the that feeds the wash tubs and the one that allows the drain when the water has already been used, in addition to this we will have the water for the maceration, the water that moves the hydraulic wheels, so that the water that arrives at an establishment of this type is generally divided into two paths, the one that reaches the interior of the workshop that provides the water for the particular processes and the one that goes to the area where the wheels are located, which will use the water as the driving force, inside the In the workshop there must be a drain which usually carries contaminated water and in the other case the water that has already moved the wheel must return to the river with the water without contamination.

This necessary hydraulic infrastructure inside a paper mill is magnified when we talk about a complete region where raw materials require their own hydraulic infrastructure, of which the mills are only a small part. Water is associated in an important way in obtaining raw

materials, particularly in the case of plantations where some of the vegetable fibers were obtained for some types of paper, paper as already seen could be obtained from different materials, In the case of specific crops to obtain plant fibers, such as flax or hemp, they require irrigation for their development.

On the other hand, the rags of cotton or other fibers already processed and the same materials of vegetable fibers have to undergo a previous wash since they arrive at the factory, most of the rags came from already used clothes and textiles that were discarded and had to be released from substances and accessories that if left in subsequent steps would damage the process.

These rags and fibers arrived at an area of the factory where they had to release substances and particles other than fiber that could affect the milling in the case of rags, buttons or accessories of clothing, stains, grease etc. The fibers were washed, so that they were free of dirt and different substances (sand, stones) The accessories and buttons that may exist on the clothes were manually removed when the fabric was left alone, the washing was carried out, with which they removed the stains and substances impregnated in the rags, in this step of the process water was used as an active part.¹⁵⁰

The next step after washing the rags is a prior crushing, the rags were cut into pieces or strips that provide greater control at the time of milling this same procedure is done in the case of plant fibers, both operations were usu-

ally done by hand, with knives or scissors on suitable wooden supports cut benches in case of knives; after the previous cut they are placed in containers to take them to the maceration.

At this point there are strips or fragments of rag or vegetable fibers that are already clean and divided into small parts to be taken to tubs where they will be placed in water for some time with this process the decomposition of the fibers begins and through of the impregnated water they wear out so that in the milling the pulp can be achieved more quickly, these raw materials in the wet state are passed to the crushed, it is here in the crushed where the paper mill enters.

The paper mill is a mechanism that uses the percussion principle to carry out its work, so that the transmission of the movement will be through a horizontal axis with cams on its surface, the vertical wheel is located at one end as in the ironworks, in a particular architectural space as a corridor with stone walls containing said space, the wheel can be gravitational or not, so that the feeding channel can go at the top or only be located at the bottom with the slope sufficient to roll the wheel when the water circulates, the wall adjacent to the paper mill is perforated so that it passes through the prolongation of the wheel axle, this axis is the most important part in regards to the transmission of the movement, so that its rotation must be guaranteed without vibrations, the supports are constructed at the origin serving for this purpose on many occasions the same wall of the workshop and at its end or final, both supports are more resistant than the rest and can be made of stone or wood.

Throughout its entire length, different cams can be located, all placed in different parts of the circumference to avoid

¹⁵⁰ In this same work we have talked about the three uses of water, as a driving force, as part of the production process and as an element of consumption and cleaning, washing is an active part of the paper production process since through this washing remove the stains that the rag has that comes from fabrics and clothing that were already used.

Figure 62. Battery of 9 mallets to grind paper rags, image Tarsicio Pastrana.

hitting all the mallets at the same time, which would cause a distribution of the force in all the mallets and a smaller hit than the one needs to.

This in the case of being a battery of mallets since the mill can work with only one. The friction zones of the main shaft generally have refrigerant methods since it is the part of the mechanism that is subject to the most work, the refrigerant can be water that is added manually or through some channel made specifically.

When the wheel rotates the axle does the same and the cams begin to drive

the hammers, which are made of wood with the wooden head embedded in the opposite end of the handle that is on the side of the axle, to be able to hit the hammers they are tilting, which is achieved with a central support that allows them to perform the movement of up and down since both ends are free, in its natural state of rest the mallet will be permanently with the head down because this is the part heavier, thanks to this constructive characteristic the mallet can hit in the mortar as follows, the cam hits the opposite end of the hammer one or more times in each turn this hit at the end of the handle causes the head or mallet to rise When the cam has

Figure 63. Battery cut of 9 mallets to grind paper rags, image Tarsicio Pastrana

stopped working, the head falls heavily by gravity, giving a blow.

The part where the mallet will hit must have the ability to contain an aqueous solution and at the same time contain the beating, so they can be constructed of wood or stone but in both cases robustly in the case of wood, the joint must be taken care of to avoid leaks of the aqueous solution between the pieces of wood, for a battery of mallets the place where the mallet falls is like a mortar in which the interior has been properly finished, in which the I wipe the fibers depending on the type of paper and add water.

The mallet starts hitting the fiber content again and again with water crushing at each stroke, this crushing initially causes a deeper washing of the material so that the water changes, as the grinding progresses the water stops be removed because the ground particles are so small that it already forms a suspension in the water, forming a paste, this paste is allowed to work with the mallet until it reaches the proper consistency to remove it, in this part the water is very important, since the ma-

terial to be ground if it is dry ground would burn by friction, the suspension is made in water through the grinding of the fibers.

The heads of the mallets can be reinforced with metal or are usually made of more resistant wood, due to their constant work the wear they can suffer is much greater. There are mills that the cam is operated on the same side as the mallet so the opposite end only serves to place an axis that allows the pivoting action of the handle and the hammer, the handle extends over the head of the hammer and this axis what stands out is in which the camshaft does its job.

Another grinding machine driven by hydraulic force is the Dutch machine, which was created in Holland towards the end of the XVIII century, this machine consists of a tub in which a wall is placed in the center that divides it into two but does not reach touch the ends of the tub, creating a zero-shaped deposit in whose center is the wall.

From the wall to one end of the tub there is a blade roller that rotates by

Figure 64. Dutch tub for grinding cloth, cut, image Tarsicio Pastrana

means of an axis that is attached to a hydraulic wheel this blade cylinder in its turn passes very close to the bottom of the tub where another set can be located of blades in the lower part, the space between the rotation of the cylinder and the blades in the bottom is small, the rotation agitates the mixture and makes the fibers pass through this space, with each step of the fibers they are more and more crushed, the rotation of the cylinder generates a circulation of the suspension that revolves around the wall to the center of the tub, passing again and again through this cylinder until the necessary consistency in the suspension is obtained.

The Dutch machine arose from the desire to combine in the same step the two initial parts of the process, the creation of the pasta through the crushing and its subsequent placement in the tub from where the molding would be done in any of the previous cases the pasta had to reach the tub, these tubs could be made of wood or stone, the transmission of the paste was done manually in the case of mallet batteries

or automatically when the Dutch roller was placed in it.

It is convenient to mention that before these machines both the Dutch and the mallet batteries the rag, hemp and linen were ground using the stone wheels of the flour mill, which caused that the ground was not uniform, and the crushing was not It was carried out in a deep way, the use of stone mills does not allow the hydration to be adequate causing the paper to be coarse and coarse, the hydration in the milling process is basic because if the water is missing friction can alter the nature of the fibers that are being ground, the change towards the described methods allows the paste to be obtained by fine crushing of the fibers and by the correct hydration the addition of water is very important in the process of obtaining the pulp from which the paper will be obtained.

To add the water to the mixture, deposits were used that could be located inside or if a water channel for motive force was carried inside the factory, it was taken directly from this site.

Figure 65. Tub of rag paste to fill molds image Tarsicio Pastrana

We must remember that the preparation of the paste required water to form it but also so that the grinding did not take place dry since this situation could generate excessive friction that would burn the raw material. After the milling and with the paste obtained, it could be placed in the pasta tub at this site, the water paste contained the fine granulate in the suspension state of the milling product. From here you had to get the paper this would have to release the water that had worked as a means of suspension. The first step is the introduction of the shapes or molds in the tub to obtain a very thin layer of the suspension.

The mold used had the standard size of the sheets of paper that will be discussed later, it was like a wooden tray with the porous bottom, the mesh would allow the passage of water but not of the suspension, which when being in a state pasty would remain on the mold, the papermaker introduces

the mold into the suspension and then moves it over the suspension to make it distributed throughout the area.

Once the correct distribution of the paste has been obtained uniformly over the mold, it is taken to a place where it is placed so that the water continues to drain, in some cases this is another attachment of the tub, on which an inclined plane is placed of wood so that the suspension continues to drain and the water that has suspended particles is not wasted. Already it was the inclined plane whose drain was over the tub or the racks that by means of pulleys could lower or raise the paperworker tried not to waste the surpluses of the pulp.

It is convenient to briefly expand the description of some of the accessories of the analyzed machines that allowed this excess runoff process, in some of them a briefly inclined wooden surface was placed on the side of the tub, leav-

Figure 66. Manual press for paper after the paste dried in the mold and this could be handled without breaking it was passed to the press, where the sheets were placed between canvases of felt to finish drying it give it texture, in case they were coarser papers it was pressed with cloth, if you wanted to satin the paper, the metal plates were used. Image Tarsicio Pastrana

ing part of it on the tub for ensure that the plane did not cover the place where the mold would be submerged, when the papermaker managed to properly distribute the paste on the mold, he placed the mold laterally, the metal mesh of the mold did not remain on the surface, inclined which would have prevented the water drained, so there was an edge where one side of the mold was placed and this helped not to stick with the plane, in another case the tub of greater proportions has a frame on which the molds are placed to drain on the tub, in this case a set of pulleys and ropes allows to regulate the height and position of this frame to help with the preliminary drying.

The mold is made of wood with two handles at the short ends with perim-

eter edge of wood that determines the size of the leaf, the base is a closed mesh to allow the passage of water but not the suspension that will ultimately be the leaf of paper. At the beginning of this way of producing paper in China the mesh was made with bamboo.

The mold is the most delicate part of this section of the process, in this you must distribute the paste to form what the sheet will be, it is important to mention that the skill of the papermaker was noticed in the way of distributing the paste so that it would remain uniform on the mold, the next step was to allow the water to drain to obtain a leaf that was manageable, if the leaf was removed very fresh it would not have enough cohesion to be managed, on the contrary a leaf that was allowed

to dry in the mold required long time in which this could not be used to produce another sheet.

When the sheet could be removed it was passed to the screw press, in order to perform this pressing, the placement of the still wet sheets between felt canvases that were placed in zigzag was used, between each turn of the felt a sheet would be located, when obtained a succession of high sheets this pile was put in the press and enough pressure was applied so that the sheet released the remains of liquid that it could have, this operation was repeated several times to get the water to be released from the sheet.

This pressing was done in one direction and in another, many times the drawing of the felt was marked on the surface of the sheet this is the reason why the sheets were located in one direction and in another to help the fading of the mark of the tissue.

Depending on the finish that would be given to the paper was the number of presses that were applied, for example a more rustic paper would have less presses, a smoother and finer paper would have greater number.

After the pressing process the leaves were taken to a terrace where wooden rods or ropes were located crossing in the short direction of the room, with a cross ventilation to facilitate the circulation of air through it but without the direct ray of the sun and without the exposure to the weather, in this place the sheets were hung for the last drying, which would cause them to lose all the remaining moisture, this part of the process was also very important, any subsequent step required the paper to be completely dry. It was only achieved in this drying room.

This room sported the ropes and the hanging sheets similar to what would now be a clothesline, unlike this, the drying of the paper would be covered, in many of the cases analyzed this terrace was located at the top of the mill of paper having the walls open for air circulation with the possibility of somehow blocking this circulation and a roof to avoid direct exposure to wind and sun, but especially to a possible rain that could cause the paper to get wet and return to a state similar to the pasta from which it came.

4. Additional procedures

Depending on the use that would be given to the paper, additional processes were required, remember that the raw material of the paper would be the vegetable fibers already described, so that the paper as it was not suitable for writing, the wool or cotton rags that could be used created a very absorbent paper that would cause the ink used to be diluted making the writing unintelligible, to avoid this the paper intended for writing had to go through two more processes, gluing and satin, the first one consisting of soak the leaves in diluted solutions of animal glue which gave it a layer that closed the pores and on which the ink was defined.

To achieve this, in one section of the mill, ovens were placed on which a metallic copper was placed with the tail diluted in boiling water, when the mixture was warm, the already dried paper was submerged again and again, taking care that the temperature did not disrupt the paper, which after the multiple pressing and release processes of excess water acquired a stronger consistency and allowed the handling and treatment in the glue solution, once the paper was glued it was taken back to the dryer so that the solution will dry on the surface.

Figure 67. Final part of the paper process on the right side the place where glue is added to the paper to close its texture with the burners and the tail in the saucepan where each papal leaf is immersed, in this way the paper did not absorb so much ink, otherwise the ink was extended and the writing was not legible, on the left side the area of laying of the sheets with crossed air circulation for the final drying image Tarsicio Pastrana

Most of the paper was intended for writing, so that almost all the paper was passed through the copper with glue to give the surface adequate consistency and it could receive the ink.

More pressing processes on surfaces other than felt gave other finishes to the paper and this apart from gluing allowed to improve the surface, the satin process consisted of placing the papers back in the press, but this time instead of felt that absorbed the water. Plates of metal or plain cardboard are placed, the sheets are placed between sheets of metal and are subjected to a more intense pressing than in the case of mois-

ture extraction, the paper is smoothed, the procedure is similar, a and another time between the sheets of metal, then the sheets of metal are removed and the sheets are crossed putting them in one direction and in another, the paper shines and closes the pore more, if a more rustic paper is required, the pressing is minor and the metal sheet is replaced by other types of surfaces, we must remember that as with the felt, the drawing of the material that is placed between sheets can be marked on the paper, so to achieve smoother peels, that will be used as metal plates have already been widely mentioned.

The sizes of the sheet had to do with the size of the mold, the sheet being the equivalent to the complete piece obtained in relation to the size of the mold, the pieces were always divided into halves of the previous one, creating the half sheet the fourth the eighth, always dividing the previous size in two.

The last part of the process had to do with the brand of the mill similar to the watermarks, for this they had another press is formed by an axis with a support point and on one of the sides a piece of wood that ended in a tip where an engraving that would be placed on the sheet was placed, each sheet was placed on a semi-hard surface and the press was lowered so that it left the mark on the sheet, being a mark on the paper did not interfere with the use that would be given and in this way a mark

was obtained to determine the origin of the paper.

This was particularly important because depending on the region was the quality of the paper obtained, varying according to the raw material the ways of manufacture, many papers became especially coveted so that the brand was decisive to confer authenticity similar to what is now the designation of origin in alcohol-based drinks.

When the paper was marked and dry, it could be marketed. To conclude and by way of summary it is convenient to mention that there were basically two hydraulic machines that are the mallet mill and the Dutch machine, also inside the machines although we can no longer increase the screw press and the press for the paper marks.

Figure 68. Loreto mill plan image Tarsicio Pastrana taken from Loreto history and evolution of a paper mill

5. The Architecture of paper mill.

From observing the plan and the premises, one can deduce the existence of the two mills mentioned in the book, the premises for the flour mill, patio and sunken, rail to deposit the washed wheat, laundry, of the paper mill, the Two-room press, the factory houses, the sundeck, the patio, we observe the hydraulic system, the two buckets, the river at the top and some common areas such as the 18 that says “run for various things.”

Figure 69. In this example of a paper mill in Palencia Spain, the hydraulic system, in black, the complete walls, in gray, the walls that functioned as containment, was observed as it was built on terraces to take advantage of the water in different mallet batteries in the case of this mill 6 batteries of 6 mallets each, the area of the mallet batteries is clearly visible. Tarsicio Pastrana image obtained in Overseas Hydraulic Engineering

X.WATER AND GUNPOWDER

1. Introduction

Finally, I will talk about one of the most controlled mills by the crown, the manufacture of gunpowder.

For obvious reasons this factory was of singular interest, gunpowder was tied with military control since the different firearms used gunpowder to work, but also for the construction and execution of engineering works, in which it was used to demolitions, both activities of a strategic nature, as for the military, even when these were not officially constituted at the beginning, there were needs for firearms that were used in defense and control, and for large projects often financed by the same government.

The operating and installation permits of the mill that was used for its manufacture were controlled by the crown, because it was this that had to know where and how much was produced, by keeping it as a tobaccoist, the crown also guaranteed to encourage or mitigate the activities that they developed around it, that is, the factories would be located only where the crown wished.

The productive characteristics of gunpowder that derives from the mixing and grinding of materials that once joined are highly dangerous, configures the architectural spaces for production but also on ways to keep both the ingredients and the final product safe and secure, within the milling and mixing we find the incorporation of hydraulic mills, which have particular characteristics since gunpowder had to be treated very carefully, hydraulic

facilities and mills are the heart of the gunpowder-producing establishment.

After production we find the storage of gunpowder, although gunpowder was only produced in some places authorized by the crown, storage and distribution also causes particular architectural spaces, we insist that the configurator of this situation is safe storage and control of the product.

It is this final section of the hydraulic machines we will find a complicated process, divided in the obtaining of different products that could be found in the same space or in other particular ones that configured in the first place the obtaining of the raw material and then the appropriate mixture of these raw materials in gunpowder, the crown knew very well that gunpowder control exceeded commercial aspects to place itself in the strategic product area for all that entails.

2. Gunpowder History

Gunpowder is a highly flammable compound whose main ingredients are found in nature, and whose main purpose was pyrotechnics, the mixture of ingredients 75% potassium nitrate, 15% carbon and approximately 10% sulfur caused the moment of combustion a violent release and gases, an increase in volume and temperature in a few minutes. Each component had a specific role. Saltpeter increases power and retards combustion, sulfur increases flammability and coal accelerates combustion.

The materials are divided in two by their type of explosion, detonators that are instantaneously transformed and that occur in the entire explosive, as a result this process cannot be controlled. The others are deflagrators, in which the process is slower and they are produced by layers, generally from

the surface of the explosive towards the interior of the same of controlled way. These seconds are those of common use in the artillery because they are more controllable

The inventors of this mixture were the Chinese around the IX century aC, we insist that it was originally invented for pyrotechnic purposes, that is to say, in rocketry and fireworks.

Apparently the Arabs are the first to use it for military purposes, and the first applications had to do with the desire to have more range in the shells that were sent to the enemy camp, the artillery existed since long ago, apparently the root came from the Latin artilleries and this, derived from arts, art that means as we saw in chapter 1 technique, these primitive machines sought to throw projectiles on the enemy that caused the greatest possible damage to both the enemy and its fortifications.

There are references in writings of the thirteenth century long before the use of gunpowder for war purposes in which artisans are called artisans responsible for building and operating mills, machines and carriages for war, carpenters and blacksmiths for their field of application were known as gunners. This data is important to separate the gunner from the gunpowder, although later the gunners would be the ones who would use the gunpowder in the handling of firearms in wars as an evolution of the activity that gave rise to them, it is these who also develop such weapons, the first bombs that are from the middle of the fourteenth century are the development of gunners, who apply the power of gunpowder to the machines that were already building and operating.

Within this evolution of the gunner and his weapons, we have the first references to the use of gunpowder in the wars

between Arabs and Christians in Spain, the Arabs who own a vast empire have contact with the gunpowder and apply it in projectiles not only to throw them, also so that at the moment they violently percussion a surface they destroyed when launched with such force become smaller projectiles, the chronicles that I mention refer to the battles carried out by the Moors of Mohamed IV of Granada against the Christian borders of Alicante and Orihuela, in the year 1331.

They chronicle the chronicles of the Plaza de Algeciras, besieged by the Castilians of Alfonso XI (1342-1344),

.. [the Arabs] threw many pellets [balls] of iron that threw them with thunder, of which the Christians felt a great fright, since any member of the man who was reached, was severed as if they cut it with a knife; and since he wanted the man to be injured, he died later, because there was no surgery that could cure him, on the one hand because [the pellets] came burning like fire, and on the other, because the powders with which they were thrown were of such a nature that whatever sore they did meant the death of man.

Although it is assured that 100 years before the Arabs already used gunpowder for military purposes, it is likely that they had contact with it in the Asian regions they dominated, it is not surprising that in the desire to cause more damage and throw more distance the projectiles will be considered to apply the powder to these ends.

The tradition of manufacturing gunpowder inherited from the Arabs to the Hispanic regions was preserved during the reconquest, as the Spanish copied the new techniques and incorporated them into their repertoires of artillery and military techniques. This situation its obvious since both sides fought for the same territory, technological ad-

vances had to be quickly incorporated to not enter disadvantages with the other side in Castilla y Aragón the invention was adopted immediately, from the mid-fourteenth century the Artillery It took a strong hold and began to develop among the Spanish kingdoms.

An advance of these characteristics quickly spreads throughout Europe, it is manufactured in England in 1334 in Germany in 1340. During the siege of Pisa in 1403 the gunpowder was not only used in artillery, it was attempted to reach the base of the fortifications to use it as a demolition of the defenses, by way of the uses that would later be given to it in civil engineering for demolitions, given its strategic nature, already by the XVI century most states had turned gunpowder into a monopoly under direct control of the respective governments. Derived from this monopoly, the states regulate its manufacture and use.

Between the XV and XVII centuries there is a wide development of technology applied to firearms, gunpowder confers additional features that are used for the development of more powerful weapons and smaller muskets for individual use that were still considered as a support to the old weapons, in fact in those years the use of firearms in the battles was vile, since the honorability marked that not the one with the best weapon would win, but the one that was stronger and more skilled.

The manufacture of gunpowder required the milling of the ingredients mentioned above, which once joined were highly explosive, the mills that were initially manual had to be made of materials that when producing percussion did not produce sparks, there are two images that show the Inside the workshops where gunpowder was produced before the arrival of hydrau-

Figure 1. Figure 65. The invention of gunpowder according to Jacopo Coppi in the image we can see the different processes of obtaining gunpowder, of particular interest for this work, the bottom mill, which is rammed but manual, in front of the wheel you can see a crosshead with the tips of the rays with counterweights, which served to facilitate the turn that in turn would move the mallets. Image The invention of gunpowder according to Jacopo Coppi 1523-1592 Palazzo Vecchio Florence

lic engineering, both are in the Uffizzi gallery in Florence, and in them you can clearly see the mills that were powered by manual wooden wheels, in the extension of the tip of the spokes they placed metal balls so that these counterweights made the rotation easier.

In two processes, hydraulic engineering begins to be used, in the mixture which was introduced into barrels that were driven by a hydraulic wheel and in the milling, which is carried out by means of rammers similar to those used for grinding mineral but less hard materials to avoid sparks and slower speed,

Figure 1. Figure 66. Image of the hydraulic mills of Villafeliche, we observe from left to right, the sieves to screen the powder, the 3 mallets and the holes where they grind and mix the ingredients, from the right side the wheel. Image: Villafeliche mill in Hydraulic Works in Colonial America

therefore being the wood mill and require less force are smaller mills.

Several gunpowder factories are established in Spain, the most famous that would be used as a model for American factories including those in New Spain were installed in Villafeliche Zaragoza, the reasons for this strategic location are best described on the page of the town hall itself.

The manufacture of gunpowder in Villafeliche began in the XVI century. The town had saltpeter mines and abundant hemp to make charcoal and fiber. In addition, it is located in a closed valley, sheltered from the wind and relatively close (170 kilometers) from the sulfur mines of the Turolense town of Libros. With these facilities, in 1764 Villafeliche had 165 powder mills, which became more than 200. The

*complex formed the Royal Powder Factories.*¹⁵¹

The importance of these factories lay in several innovations that, as already mentioned, are dispersed by Spanish possessions overseas, the first and most important was the incorporation of hydraulic engineering for milling, the second is the construction of several small isolated mills, of this way when one exploded did not fly to the whole plant, the powder mills were isolated and formed small productive units, any accident did not stop production.

Villafeliche is radically transformed and its entire economy revolves around the production of gunpowder, there were several potters in the town whose main function was the elaboration of the clay containers in which the gunpowder was

¹⁵¹ Tourism website of Zaragoza. www.turismodezaragoza.es/provincia/tradiciones.php?site=20&ncode=80

transported and stored, near Villafeliche they were the sulfur and saltpeter producing regions, because coal was produced in the area, this whole industry was declining until the last mill was closed in the second half of the XX century.

3. Gunpowder in New Spain

In New Spain there are references to the manufacture of gunpowder, perhaps the first gunpowder that was manufactured was the one that orders Cortes, for which Pedro de Alvarado has to climb the Popocatepetl to get the necessary sulfur.

*Speaking of Tasco tin, that they used to melt the first cannons, Cortes says: and for sulfur, since V: M: I have mentioned a mountain range that is in this province, which leaves a lot of smoke: and from there entering a Spanish 70 or 80 fathoms, tied upside down, has been removed so far we have sustained; from now on there will be no need to put ourselves in this work, because it is dangerous; and I always write that they provide us with Spain.*¹⁵²

The Spaniards have to make firearms, and therefore they need gunpowder that is manufactured with the materials they obtain, in the same book that I just quoted it is said that in some small volcanoes that were in Tulyehualco it is also possible to obtain sulfur.

There is an antecedent, called *tequezquite tamal*, which was prepared in a very simple way, mixing the saltpeter that was very abundant in the peripheries of the lake area with lime, the resulting mixture was placed on corn leaves

Figure 1. Figure 67. Craft manufacturing of gunpowder before hydraulic mills, the rammer mill is seen in the background with its crosshead to turn it around, on the walls you can see various accessories that help production in front of it, the screening is seen, as in the Jacopo Coppi's painting the crosshead to handle the mill has iron spheres at the tip of its rays. Image the manufacture of fresh gunpowder in the Uffizi degli gallery by Bernardo Poccetti

similar to the *tamales* hence its name comes, its main application was to detach large blocks of stone, in which a hole was made and this hole was retouched with *tequezquite tamales* when the hole was full water was used that caused a reaction that expanded the material and caused the separation of the stone fracturing in the area of the hole.

The manufacture of gunpowder must have been done by hand in small workshops until the so-called ammunition house that was most likely inside the city is established, which made it quite dangerous, although the manufacture of gunpowder on this site was due of being handmade like the one I already mentioned in the frescoes of the Uffizi gallery.

This house is established in 1555 and should have functioned until the beginning of the XVII century in which, and with help of de la real hacienda, a gunpowder factory in Chapultepec is de-

¹⁵² Villa Roiz Carlos, *POPOCATEPETL MITOS, CIENCIA Y CULTURA (UN CRATER EN EL TIEMPO)*, Plaza y Valdez Editores, México 1997 pág.153

signed and built.¹⁵³ It is interesting that it is placed in a strategic place so that any incident on the Chapultepec hill would serve as a protection between the gunpowder factory and Mexico City.

The incidents were many accidents caused damage to walkers and surrounding areas, this situation was not exclusive to Mexico City, by the end of the XVIII century, being more specific in 1764 Joseph Del Campillo was commissioned director of the real factory of Villafeliche to prepare a document that would serve as a basis for reforming the different factories in America, the mills of Chapultepec receive this document and expansions are projected based on the innovations implemented in Villafeliche, even two potters will come to work in New Spain that would be dedicated to developing the vessels to contain and handle gunpowder.¹⁵⁴

Despite the reforms carried out at the Chapultepec factory, it was decided to build a new one, in the year of 1778, entrusting the task to Miguel Constanzó, it is located in the Santa Fe area to take advantage of the currents in the same way as other mills that descended from the saw of the crosses, it is interesting that the new factory is built from the beginning with the reforms tested in Villafeliche on this Santa Fe factory there is a chronicle of Humboldt that visited her:

The Real de Polvoras factory, the only one that exists in Mexico, is close to Santa Fe, in the valley of Mexico, three leagues from the

*capital, surrounded by hills; the buildings are very beautiful; They were built in 1780 according to the plans of Constanzó, head of the body of engineers, in a narrow valley that abundantly supplies the water necessary for the movement of the hydraulic wheels and through which the aqueduct of Santa Fe passes. All parts of the machines, mainly the wheels, whose axes rest on friction pulleys, as well as the bronze epicycloids that serve to play the pylon batteries, are arranged with great intelligence ... The buildings of the old gunpowder factory, established near the fort of Chapultepec, today they only serve to refine potash nitrate.*¹⁵⁵

Humboldt allows us to analyze how was that new factory that worked with hydraulic mills and was located in a strategic site, as an additional comment it can be mentioned that when the new factory was being built the Chapultepec gunpowder mills suffered an accident, this is one of the reasons that in my opinion determined to cancel the most dangerous functions that were carried out in the old mill leaving only part of the process in its facilities.

4. Gunpowder manufacturing process.

The procedure began with the particular processes of obtaining the materials, for the saltpeter procedures had to be followed to obtain it, in the work of Bernardo Perez de Vargas De Re Metallica dated 1568 describes:

Take this greasy and salty earth and put in a wooden bucket a floor of it, and another floor or bed of two parts of quicklime powder,

¹⁵³ González Tascon Ignacio, Spain 1992, *op.cit.* p. 382

¹⁵⁴ Keller Alexander G. y Silva Manuel, *PROTOINDUSTRIA: UNA PERSPECTIVA DESDE LOS VEINTIUN LIBROS DE LOS INGENIOS Y LAS MAQUINAS TOMO 1 En Técnica e Ingeniería en España*, Real academia de ingeniería, Pressas universitarias de Zaragoza, Institución Fernando el católico Spain 2004, p. 533

¹⁵⁵ González Tascon Ignacio, Spain 1992, *op.cit.* p. 384

*and three of oak ash or oak or quexigo, or cork oak, and so on for beds swell to the mouth, so that if the glass has a deep twelve spans or measure one has to swell, and this vacuum swells of water, and after pouring the water open the bobbin below and receive Water in a glass.*¹⁵⁶

These lands were constantly sneaking into clay or wood containers, with a slow drip and the accumulation of water in the container it was possible that the water dissolved the majority of the saltpeter contained in them, the water that was constantly passed from one container to another I was concentrating on salts, to review the change of the lands an experiment was carried out that most of us carried out in the primary school, an egg was deposited in the water, if it stayed afloat it meant that the lands had salts and therefore the water continued to concentrate salts, otherwise if the egg sank the earth had to be changed.

On the lands we find another very interesting quotation in the 21 books of the mills and the machines on the earth that is placed in the wooden drawers or in the earthenware vessels, the following barren land of walls is said where there are filths of people and even of animals, as it is where the pigs are and even from the land of the garbage that they take from the houses.¹⁵⁷

The remaining procedure was the gradual concentration of the water that came out through the strainers, similar to what was done with the honey juices, placing the water on the fire and concentrating the saltpeter was made from one boiler to another, until the

Figure 1. Figure 68. Scheme of obtaining saltpeters, in the upper part the boxes for the casting of the earth, in the circle to the center the salt water is collected, then take it to the series of boilers that are seen in the lower part and finally on the bottom of the containers to crystallize the saltpeter, picture the twenty-one books of the mills and the machines

water remaining completely saturated was taken to the precipitators that were wooden or mud vats where the concentrated water began to dry and the saltpeter was deposited at the bottom and the edges, as the water lowered by natural evaporation the edge and the bottom were filled of salts

The other ingredients were sulfur, which had to be searched outside for dry and dry and immediate volcanoes away from swampy lands.¹⁵⁸ about the additional particulars that come in sulfur later mentioned it is achieved with art and care to leave them perfectly purified to use them in the gunpowder factory¹⁵⁹ this sulfur had to be purified to be in its pure state at the time of manufacturing the powder.

¹⁵⁶ Camarero Concepción Bullón, Campos Jesús (Directores), *op.cit.* p. 328 y 329

¹⁵⁷ Keller Alexander G. y Silva Manuel, *op.cit.* p. 542

¹⁵⁸ Chew Gutiérrez Karim, *ARQUITECTURA PARA LA FABRICACION, VENTA Y ALMACENAJE DE POLVORA tesis de Doctorado*, UNAM, Mexico 2005, p. 107 citas del AGN pólvora caja 16 exp. 5 fojas 42-68, México 1783

¹⁵⁹ *Ibid.* p. 107

Finally, for coal it was produced in the same way that it was produced for other purposes, a raw material that was placed in ovens was sought in the region so that it was reduced as much as possible and added to the mixture, not delved into the procedure for obtaining coal, the only thing that should be mentioned is the fact that in New Spain the willow was used to produce this coal, to conclude the issue of coal we will mention one.

The art of carbonation is very simple reduces to form pyramids in the form of truncated cones in whose upper part a vent or chimney is left to leave, water, oil and other volatile bodies in vapors, and several openings following the floor to facilitate air aspiration and must maintain combustion;

*the pile is covered with a layer of earth and it is given fire.*¹⁶⁰

The process began with the milling of the 3 ingredients, the proportions were always a matter of discussion varied over time and depending on the country, in the case of the proportion used in New Spain it can be mentioned that it was similar to that of Villafeliche, remember that these mills and their procedures were those that were used for the American models, although before the XVIII century the proportion must have been similar to those used in Spain since the apprenticeship was in Spain.

As for the proportions we find in The Art of the Militia by Diego García de Palacio

¹⁶⁰ *Ibíd.* p. 107

*Order 1: take seven parts of saltpeter, well refined. Two of sulfur and one of coal, and made according to art; and the best of common gunpowder will come out, being as they should be simple, well prepared and good.*¹⁶¹

There was adequate granulometry so that the materials were previously ground in manual blood stone mills, these materials were moistened to form a paste that was less risky to handle, later it was taken to the mashing mills that also had the function of mixing the pasta.

As for the stone mill, it was similar to what we have been seeing as a wheel of song moved by animal or human force. There could also be variations of it, with cylindrical stone that turned on a hard surface.

The other mill that completed the process was the one of mashing mill that worked in a similar way to that of mineral rammers, with various modifications, in the Villafeliche models we found mills of two or three rammers, these big mashers were of wood with slow percussions, that is to say a not very large wheel that allowed a blow of each mallet per lap, the heads of the rammers were lined with leather and the mortar where the ram hit was made of soft stone, with the shape of the container rounded this in order to minimize the risk of explosion. This ground and mixed lasted about 8 days in which the humidity of the pasta had to be controlled.

The safety innovations had to do with installing these small units of the production process in isolated sheds, in this way the explosion of some of them

would not throw large amount of materials, in the plane analyzed at the end of the section of the mills From Chapultepec, we can see two types of mills, the first one is a cube which is an older installation than the aforementioned reforms, we can also see some sheds without walls where the mills that I think are the new mills are located.

These have to be next to a ditch so that they can move the hydraulic wheels, these wheels of few vanes turned slowly and this turn was transmitted to the axis where for each ram there was a cam so that the beating was slow, this grinding has in order to standardize the grains and mix the ingredients perfectly.

The next step was the screening of the mixture, so that it was drying and separating the grains that were still greater than those required, these residues that did not pass through the sieves were taken back to the mill, the uniform and dry cast mixture It took to dry in patios on blankets to obtain a perfect drying we must remember that the granulate was already uniform.

The final process required another factory in which paraffin was added to all grains, this process was called lumbering was done inside a wooden barrel in which paraffin and dust were added, that barrel was subject to a gear that was moved by the same axis that moved the rammers, inside were placed pallets that stirred the mixture, the safety lay in the handling of dust, which was inside the barrel that was completely wooden.

Finally, gunpowder was placed inside clay pots for handling and commercialization, these pots were made in the same factory, they were intended to keep the gunpowder dry since if it got wet or damp it would not work the same.

¹⁶¹ **García De Palacio Diego**, *EL ARTE DE LA MILICA DIALOGOS MILITARES DE LA FORMACION at historia de la ciencia en México siglo XVII*, Trabulse Elias, op.cit p30

Figure 1. Figure 69. In the upper part we observe the general plan of the Royal Gunpowder Factory of New Spain and in the lower part an enlarged detail of the plane above, in the set we can observe the mill sets with their cubes, in gray you can see the previous mill, in black and white walls the extensions that will be described in detail below, the great hydraulic system is interesting and as we mentioned throughout the section the safety implementations separating the mills from the rest of the factory and these isolated from each other. Image Tarsicio Pastrana based on the project of three new mills in the real factory of Gunpowder of New Spain of Joseph González.

Legend:

1. A mill.	8. Warehouses for factory waxes.
2. Two mills.	9. Sulfur Warehouse.
3. Polishers.	10. Saltpeter warehouse.
4. Water tank.	11. Sulfur and Carbonera sow.
5. Atarjea that brings water to the mills.	12. Bakery.
6. Mills Butler Gallery.	13. Saltpeter laundry.
7. Office to dust gunpowder.	14. Office for refining.
	15. Office for calcining.
	16. Carpentry.

17. Rooms for factory dependents.
18. Kitchen.
19. Stables.
20. Chapel.
21. Pylon with its source.

The following letters cover the two planes of the previous page

- a. Mills.
- b. Burnisher.
- c. Channel system between the mills and the burnisher.
- d. Atarjea principal that takes the water above the upper wheat mill of the Count of Santiago.
- e. Windmill.
- f. Grab to feed the mills below.
- g. Saltpeter set.
- h. Pylon shed for refining burners.
- i. Patio of the houses.
- j. Grinder for old mills.
- k. Office for calcining saltpeter.
- l. Barn.

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