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Historical analysis of accidents in the Mexican chemical industry

Análisis histórico de accidentes de la industria química mexicana

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Abstract

An analysis of accidents that occurred mainly in the chemical industry within the Mexican Republic throughout the last century was made. The country's industrial growth has boosted its economic development, increasing the occurrence of high-impact accidents inside and outside chemical plants. The main purpose of this work was to create a database that contained information related to the accidents that occurred in the Mexican chemical industry. For this extensive investigation, it was necessary to obtain information from news, reports and articles related to this topic. In the database, 267 accidents were collected from 1900 until 2019. A statistical analysis showed that *Petroleos Mexicanos*, PEMEX, is the company with the highest accidents rate, because this company was a monopoly in the Mexican petrochemical industry until 2013. The types of accidents that occurred the most were explosions and fires, 122 and 55 of these reported accidents, respectively. The most frequently reported substances were diesel and gasoline with a 20% of the total accidents, followed by hydrocarbons and their derivatives with 18.7%. Finally, the importance of creating databases like this one is commented, with the objective of implementing better safety measures and improving the regulations that govern the nation.

Keywords: chemical industry, hazardous substances, accidents, Mexico, statistics.

Resumen

El presente trabajo muestra un análisis de accidentes ocurridos en la industria química, dentro de la República Mexicana a lo largo del último siglo. El crecimiento industrial del país ha impulsado el desarrollo económico de éste, trayendo consigo un aumento en la ocurrencia de accidentes de gran impacto dentro y fuera de las plantas. El objetivo fue realizar una base de datos relacionada con los siniestros acontecidos en el país. Para ello, fue necesaria una investigación y recopilación de noticias, reportes y artículos relacionados con este tópico. En la base de datos fueron registrados 267 accidentes desde 1900 hasta el año 2019. El análisis estadístico mostró que Petróleos Mexicanos es la empresa con mayores accidentes ocurridos, debido a que fue un monopolio de la petroquímica mexicana hasta el año 2013. Los tipos de accidentes más acontecidos fueron explosiones e incendios con 122 y 55 eventos, respectivamente. Las sustancias más presentes fueron diésel y gasolina, conformando un 20% del total de accidentes, seguidos por hidrocarburos y sus derivados con un 18.7%. Finalmente, se remarca la importancia de creación de bases de accidentes como ésta, con la finalidad de implementar mejores medidas de seguridad y mejorar la normativa que rige al país.

Palabras clave: industria química, sustancias peligrosas, accidentes, base de datos, México, estadísticas.

1 Introduction

From its beginnings, the chemical industry has been characterized for the development of processes that aim for the transformation of natural resources, through the addition of energy or mass agents, creating useful products for the society. Since the human's necessities have been in constant transformation, the industry has been too. This evolution has affected how the processes are carried out. On the early years of the industry, only renewable resources were used as raw materials. But, since the XX century non-renewable resources, mainly fossil fuels, have been used for the most common synthesis processes.

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The modern industry heavily relies on fossil fuels as the base from its products. Around 6,000 products are reported to be created from petroleum, such as plastics and synthetic fabrics (Ranken Energy, 2017).

Furthermore, the industrial progress that has happened in most of the countries in the world has had consequently the increase on the number of plants and facilities dedicated to production. Therefore, there is a higher probability of the occurrence of major accidents caused by these operations. Therefore, a lot of effort has been invested on the development of processes that, are not only efficient and optimum, but are safe for human beings and the environment.

A major accident is defined as an "*unexpected and sudden event, in particular, an important emission, fire or explosion, caused by abnormal events during the industrial activity, which represents a severe danger for the workers, the population or the human environment, imminent or not, inside or outside the facilities, in which one or more dangerous substances are involved*" (ILO, 1991). The most common ones are fires, explosion and gas clouds.

On the last years, Mexico has faced a constant economic growth that has, without a doubt, been in response of the huge industrial development. However, in addition the use of high quantities of hazardous substances has increase, having as a result a significant increase on the number of major accidents occurred during the production, transport and storage of them.

Currently, in Mexico over 100 thousand chemical substances are used on the industrial sector. These are involved in several different chemical processes (e.g. Mayorga *et al*., 2020; Espinel-Rios and Ruiz-Espinoza, 2019; Lopez-Rocafuerte *et al*., 2018). Still, the country lacks an adequate legislation that helps to prevent this emergency. Because of this, different public entities, such as Civil Protection, have expressed the need to develop projects and programs aimed on the identification of these events, their causes and consequences, and preventive measures to reduce the impact of these accidents and to improve the current regulations (Sarmiento *et al*., 2003).

In 1984, Mexico had one of the most devastating events within its history, the San Juanico explosion. In many countries, this type of events created an awareness on risk management that has accomplished the legislation or creation of international organisms, promoting the prevention on the management of hazardous substances. However, in Mexico this was not the case. As a matter of fact, Albert and Jacott (2015), authors of the book México Tóxico (Toxic Mexico) assure that "*. . . in Mexico there have happen nine (over the 15%) out of the 55 most severe chemical emergencies registered between 1975 and 1993*".

One of the measures that can be used to improve the risk analysis and the prevention of major accidents is the creation of accidental databases. They are tools that have been developed in different countries by diverse organizations and research centers (Ramírez *et al*., 2019). A database consists of a set of information of many accidents; for instance, indicating causes, type of accident, human and environmental consequences, substances involved, etc.

These tools have taken a huge importance, since they detail the characteristics that guide the industries to carry out actions that help to prevent the risk and reduce the occurrence of similar accidents (Mihailido *et al*., 2012). As exemplified by Powell and colleagues (1999), an accident in the United Kingdom in 1978 could have been prevented or controlled, if they had the knowledge of a similar event that happened 2 years prior in Germany. The accidents shared many circumstances: chemical compounds, process of production, equipment, start-up stage and even the industrial company.

For similar reasons, besides of the importance focused on the industrial security and risk prevention, most of the developed countries have implemented the creation of different databases. Regarding Mexico, there is a national problem, since the information about accidents is usually incomplete, with restricted or limited access. For instance, the database for road accidents called ACARMEX is classified as "confidential" and not available for public viewing (López-Atamoro *et al*., 2010).

By contrast, the United States of America and the European Union, not only collect information about accidents occurred in their country, but internationally. Since 1996 the United States Environmental Protection Agency (EPA), under the Preparation and Prevention of Chemical Emergencies Office, has researched and reported historical cases of chemical plants inside their territory. Likewise, the Center of Chemical Process Safety, guided by the American Institute of Chemical Engineers, since 2001 oversees the emission of abstracts of the accidents (Lees, 2012).

Inside the European Union, there are three important data bases. The first one is ARIA, *Analysis, Research and Information on Accidents*, operated by the Environment Ministry in France. The second one is MARS, *Major Accident Reporting System*, created by the legislation from the Seveso Directive. The third one is FACTS, Failure and Accidents Technical Information Systems, created by TNO in the

Netherlands. And currently maintained and operated by the Unified Industrial & Harbour Fire Department in Rotterdam-Rozenburg (Powell *et al*., 1999; Pasman, 2015).

The United Kingdom has another database. It is MHIDAS, the *Major Hazard Incident Data Service*. This database contained over 11,000 incidents around the world, mainly from the United Kingdom and the United States of America. The accidents involve the transport, storage and processing of hazardous materials. The database reported accidents that have had different consequences, like human deaths, damage to the industrial facilities, private companies or the environment, among others (Nivolianitou. *et al*., 2006). MHIDAS is no longer updated from about 2008.

There are more examples of similar data bases. In Japan, through its National Institute of Science and Advanced Industrial Technology, RISCAD (Relational Information System for Chemical Accidents Database) has been developed (Wada *et al*., 2004). Another one was created through the United Nations Environmental Program (UNEP) in 1993, in collaboration with the Organization for Economic Co-operation and Development (OECD). This database includes accidents since 1990 (Mihailidou *et al*., 2012).

As previously mentioned, Mexico does not have any database of this type. For this reason, the present study has developed a survey, involving a historical analysis of major accidents within this country, from 1902 until 2019. The present database aims to be the reference point for further analysis and studies, identifying the most common events, their causes, and consequences, among other data.

It is expected that this article could be useful to whoever looks for a deeper understanding about the industrial accidents in Mexico and the agents around them. The present study also demonstrates the lack of a safety culture, involving the report and record of these events and their consequences.

1.1 Prevention

To understand the importance of this type of study, some of the accidents occurred during this century are recalled. Situations like those should not be repeated, and with their study, a better understanding of them can be achieved.

The accidents mentioned in this section involved the oil industry, which is a major sector of the chemical industry. The first one occurred in December 11th in 2005 in the United Kingdom in the Buncefield oil storage. At that time, the facility was the fifth biggest storage plant of the 108 in that moment in the UK. The Tank 912 at the Hertfordshire Oil Storage Limited was being filled. However, the level controller failed, eventually causing an overflow from the top of the tank, and the formation of a vapor cloud. After this, an ignition was followed by an explosion and a fire that lasted 5 days. Because of this event, over 40 people were injured (COMAH, 2008).

This is an example on how the industrial accidents represent a risk not only for the industrial plants or storages installations, but also for the population in general. At around 6 am from that day of the Buncefield accident, the people from the Hertfordshire County, which is 4.8 km apart from the facility "*. . . felt the violent explosion which broke numerous glasses and brought panic reactions and anxiety among the population. Right away, scary fires were rising.*" (Aparicio Florido, 2009). Besides the injured people, at least 2000 people had to be evacuated from nearby zones, and the economic losses were estimated in 963 million euros. The vapour cloud explosions could also have a propensity to create a fire storm, just as shown at the study on the vapour cloud explosions at Donnellson, Ufa and Buncefield by Bradley and colleagues (Bradley, et. al., 2013).

In a recent accident, this time in Tlahuelilpan, Hidalgo, Mexico, almost 120 people lost their lives in an explosion of a PEMEX pipeline. On January 18th in 2019, there was a leakage of gasoline around 5 pm. Many people saw the possibility of obtaining free fuel, and it was started being illegally collected. Around 2 hours after, the leakage was reported to the authorities, and an explosion took place. Firefighters were able to control the fire until midnight from that day. It is important to remark that fuel illegally collection directly from PEMEX pipelines is a common practice within the states of Puebla, Hidalgo, Oaxaca, among others in Mexico (Gallangos, 2019; Villegas, 2019).

A third example of a previous major accident is the one occurred in the McKee refinery in 2007 in Texas, US. Different types of accidents were involved in this major accident. There were two types of fires, a jet fire and a pool fire. After some chlorine containers were engulfed due to the fire, they released 2.5 tons of their content, eventually causing a toxic cloud. The consequences of this sequence of accidents involved 14 injured people (U.S. Chemical Safety and Hazard Investigation Board, 2008; Arderiu, 2020).

These three cases show that no region is exempt of this type of scenarios; a proper understanding of previous major accidents occurred could reduce their frequency and impact on industry, people and environment.

It is also important to identify the regulations or laws that seek to reduce the number of major accidents. "*. . . a process safety management (PSM) and risk management plan (RMP) scheme is operated. This is a system of prevention and aftercare treatment at the level of management.*" (Ahn *et al*., 2020).

There should be a list of hazardous chemicals and their designated quantities to identify if a preventive measure is needed. These lists are issued by different authorities, depending on each country. Ahn and colleagues (2020) mentioned some of the agencies or government branches that work on the prevention of these major accidents: "*In the US, chemical accident prevention is promoted by the Environmental Protection Agency (EPA) and the Occupational Safety and Health Administration (OSHA). . . the EU, the United Kingdom (UK)'s Control of Major Accident Hazard (COMAH) is being implemented by applying the 2005 SEVESO II Directive. In other words, the EU has followed the SEVESO II Directive, but recognizes autonomy by country. . . In South Korea, similar to the US system, two departments, namely the Ministry of Environment and the Ministry of Employment and Labor, implement and administer a chemical accident prevention system.*"

The industrial accidents around the world have also been the precursors of legislation. For example, in South Korea "*the 2012 Gumi hydrogen fluoride accident in South Korea resulted in the Chemicals Control Act. As a result, a process safety system was introduced.*" (Ahn *et al*., 2020).

In Mexico, the Mexican Official Norms (*NOM's*) are issued by different national government agencies, some of them involve the identification, list, and management of hazardous substances and have been issued by the Secretary of Labor and Social Security and the Secretary of Communication and Transports (SCT, 2011; STPS, 2017). The general purpose of these organizations is the same worldwide, but the designated quantities or the specific requirements could change from one region to another.

Besides the historical analysis and the databases, further interest has been associated with the use of simulations for a better understanding of accidents. They can be used to recreate past accidents and trace a more accurate description or timeline. In addition, they can also be used to identify potential hazardous conditions, and to stablish or propose new limits for the legislation.

For example, at the Texas' refinery accident (Arderiu, 2020), different simulations were run to have a better sequence of the events involved in the accident. This allows to identify the key events and to learn more from the accident. Further work is still needed, since an enormous amount of accidents does not identify the main cause and/or the specific sequence of events could be unknown.

In South Korea, different programs have been used to verify if the designated quantities for chemicals stablished by their legislation are reliable. Among the software used are the Areal Location of Hazardous Atmosphere (ALOHA) and the Korea Off-Site Risk Assessment Supporting Tool (KORA). These software evaluate five substances, among them benzene and toluene (Ahn *et al*., 2020). This kind of studies could allow the implementation of fact-based legislation to prevent industrial accidents.

There is much diversity internationally in the forms of investigations that have been employed in the furtherance of public accountability, after serious accidents. Learned Societies have played an important role in the subsequent analyses of events. Subsequent to a serious event, Governments usually assume a key role in setting up a Committee of Inquiry. In the USA, incidents have been investigated by the Chemical Safety and Hazard Investigation Board. Regulatory control is exercised by the Occupational Safety and Health Administration. In the UK, after the Buncefield explosion, the Government created a Major Incident Investigation Board of appropriate specialists that presented its findings in two volumes. The Major Incident Investigation Board consisted on an independent panel of experts that seek for a deeper understanding on the accident and ways to prevent similar scenarios. They had five main research lines. The first one concerned on the design and operation of fuel storage facilities. The second involved the preparation and emergency service response to this type of situations. The third involved the counseling to the authorities in charge of the ground planning. The fourth concerned on the study of national legislations that regulated the activities on the facility. Finally, the fifth one involved the understanding of the mechanisms that lead to the overpressures, which eventually caused the explosions (Aparicio Florido, 2009). Such panels and councils should be created after every major accident occurs, leaving aside any intervention from the parties involved on the accident to have an unbiased report.

2 Materials and methods

With the objective of compiling and analyzing historical accidents in Mexico, and due to the absence of a database with the desired information, research was carried out through different internet websites for the qualitative study. Most of the sources come from online newspapers such as *La Jornada, Animal Político, Expansión, El País*, and *Milenio*. This was done since most of the information regarding major industrial accidents available to the public is the one reported by such media.

In addition, reports that have the condensed lists from other important databases were used, such as FACTS and MHIDAS; since they include events that took place in Mexico. Since these databases do not have a free access, secondary sources, such as reports, were used, particularly in Lees' *Loss Prevention in The Process Industries: Hazard Identification Assessment and Control* (2012) and The Major Industrial Accidents Since 1997 (Mihailidou *et al*., 2012).

After the information was gathered, it was sorted by year, establishing a range between 1900 and 2019. Likewise, the following criteria were specified for each event: type of accident, date, involved substances and both environmental and human impact. These aspects were selected, as they are important for an historical analysis, since they allow knowing the circumstances of the national industrial catastrophes. From this research, 267 accidents were collected.

Table 1. Accidents by state.

State	Number of accidents	%
Veracruz	47	17.6%
Tabasco	24	9.0%
Tamaulipas	17	6.4%
Puebla	16	6.0%
Estado de Mexico	15	5.6%
Nuevo Leon	15	5.6%
Guanajuato	14	5.2%
Sonora	14	5.2%
Hidalgo	13	4.9%
Oaxaca	10	3.7%
CDMX	10	3.7%
Coahuila	9	3.4%
Campeche	8	3.0%
Gulf of Mexico	8	3.0%
San Luis Potosi	7	2.6%
Queretaro	7	2.6%
Jalisco	6	2.2%
Chihuahua	6	2.2%
Chiapas	4	1.5%
Baja California	4	1.5%
Morelos	2	0.7%
Zacatecas	2	0.7%
Sinaloa	2	0.7%
Aguascalientes	2	0.7%
Colima	1	0.4%
Guadalajara	1	0.4%
Guerrero	1	0.4%
Tlaxcala	1	0.4%
Michoacán	1	0.4%
Total	267	100.0%

3 Results and discussion

The information collected for the development of a database, involving a historical analysis of major industrial accidents in the Mexican Republic, is presented in the following sections.

3.1 *Analysis by state of the Mexican Republic*

Figure 1 and Table 1 show the quantity of accidents by state of the Mexican Republic. Veracruz and Tabasco have been found to be the states with most occurred accidents, respectively. In these two states, almost 30% of all the collected accidents took place, Veracruz with a 17.6%; while Tabasco with a 9% of the total accidents. After them, comes Tamaulipas with 6.4%.

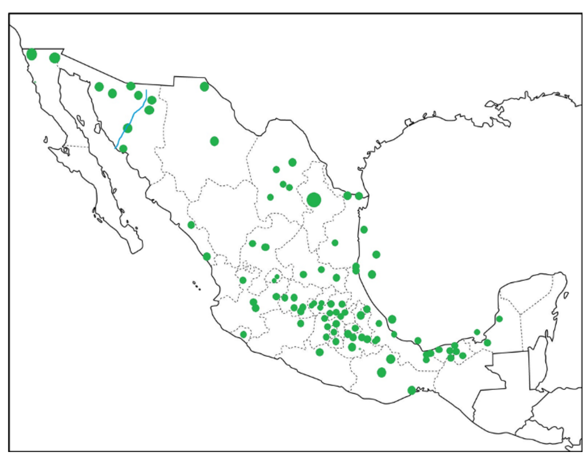

Fig. 1. Accidents' location.

This could be explained, because of the high petrochemical activity in these two states. In Veracruz, at its north and south, are located two of the most important petrochemical facilities from *Petroleos Mexicanos*, PEMEX. These two facilities, together with other five petrochemical industries located at Veracruz, produce the 80% of the petrochemical products of the country. Because of this, these states are susceptible to have this kind of major accidents. Similarly, the increase on the oil exports from Mexico affected Tabasco; since in 1977 it was responsible for the 70% of the oil national production.

3.2 Accidents through the time

The chemical industry is one of the principal industries in Mexico, and it had had a huge development over the years. With this progress in the industry and the sensitivity of the materials and substances handled, there it is a higher probability of causing or facing any type of major accident. Figure 2 shows the distribution of the major accidents over the decades. The number of major accidents increases as the decades go by. Still, from 1900 until 1960 there is no significant increase.

In the decade from the 60's, the number of accidents increases significantly, the number of accidents nearly doubled in this decade in comparison to the ones presented in the previous two decades. This could be related again with the national petrochemical industry activity, which has its beginnings around 1956 (Martinez, 2001). In the decade from the 90's, another huge increase is presented, there were more than three times more accidents than in the previous decade. The boom of the petrochemical industry and its exports, which began within the 80's, could influence this. The number of major accidents increased drastically in the last decade, around 51% of the total registered accidents happened in the last ten years. This could be related to the recent development faced in Mexico. Another factor that could be related with these results is that the important increase in the accidents frequency registered in the last decades, shown in Fig. 2, is also partly attributed to a better access to the information, and thus available data. Furthermore, the data collected has shown that the process industry in Mexico in the last 40 years is different from the one existing, for example, 80 years ago, this having probably an influence on the occurrence of accidents.

3.3 Analysis by material involved

The management of flammable, toxic, explosive and/or dangerous substances at the chemical industry always carries high risks. The inadequate management or carelessness make these substances being involved in major accidents within the chemical industry. Figure 3 shows the substances that were involved in the accidents. Gasoline and diesel were the two most common substances in accidents, being involved in almost 20% of the total number of collected accidents. Then, unspecified hydrocarbons and their derivatives were present in 18.7% percent of the accidents. And on a third place, come the natural gas and LP gas with 16.5%. These results indicate that the substances involved with the petrochemical industry turn the chemical industry into one that is more susceptible to a high amount of accidents.

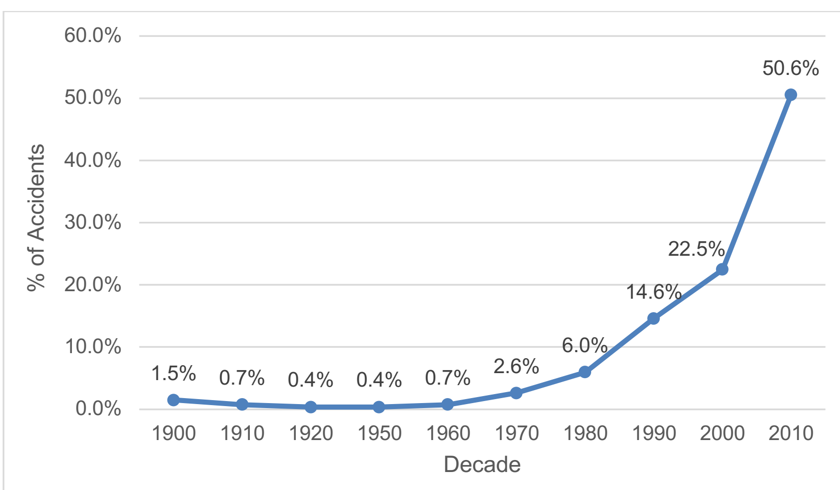

Fig. 2. Percentage of accidents by decade.

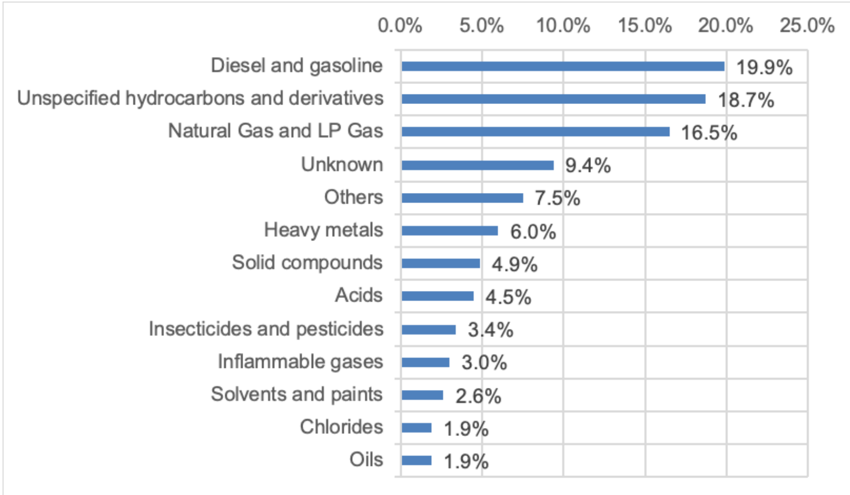

Fig. 3. Percentage of accidents by substance involved.

Table 2. Accidents by type of accident.

Type of accident	Number of accidents	%
Explosion	122	45.7%
Spill	60	22.5%
Fire	55	20.6%
Dispersion	13	4.9%
Leakage	9	3.4%
Collision	4	1.5%
Collapse	3	1.1%
Unknown	1	0.3%
Total	267	100.0%

3.4 Accident type

Table 2 shows the type of major accident registered in Mexico. Almost half of them, 45.7% were explosions, in a second place comes the spills with 22.5%, and then the fires with 20.6%. Even though an accident could be put in more than one category, in this analysis it was only included in the category that caused the most damage. For instance, less than half of the explosions, 52 of them or 42.6%, were not reported with a fire. For the other incidents, where an explosion was the main accident and a presence of a fire was also reported, were classified into three categories, depending on the chronological conditions in which the fire presented. The first category concerns when the occurrence of the fire is not specified, the second category involves the fire occurring before the explosion, and the third one when the fire occurs after the explosion.

For the first category, 32 of the explosions, 26.2% of the total number of explosions were found. An example of this category is the explosion and fire of an alcohol plant in Mexico State in 2019. The news article reported by Jorge Becerril and Milenio Digital indicated that the firefighters worked for over an hour to control the fire, and that the explosion affected 1000 m^2 damaging three apartments (Becerril & Milenio Digital, 2018). Still it is not indicated which happens first, or if one accident was a consequence of the other.

An example for the second category is the accident in Queretaro, Mexico in 2014, inside the RecoChim plant when a fire from unknown caused a series of explosions (Rodríguez, 2014). This type of situations was found in 11 of the total number of explosions (9.1%).

For the last and third category, an example was found on the accident in the refinery from Salina Cruz, Oaxaca, Mexico in 2006. Moreno from La Jornada reported that "*...an explosion caused a fire...*" (Moreno, 2006). This type of accident represents 27 of the total reported explosions (22.1%).

With this further analysis, it is shown that fires are involved in almost the same number of accidents involving explosions. Fires are present in 125 of the total accidents, even though they are not the main cause of some of the accidents that include them.

In the preset study, a dispersion is considered when a chemical substance is released into the air, representing a risk for those who are in contact or inhale it (i.e. a toxic cloud). Both the frequency and their impact within the human casualties makes them a type of accident that should not be unnoticed. From the 13 dispersions found in the present study, 12 of them involved toxic substances, such as ammonia or sulfuric acid. In one of them, the substance involved in the accident was not reported. In addition, 8 of them (61.5%) reported more than 50 people getting injured because of the accident and 3 of them (23.1%) reported more than 5 deaths. One example of this is the phosgene released in Poza Rica, Veracruz, Mexico in 1950. The accident caused more than 300 injuries and 22 deaths (Rodríguez Tapia, 2005), due to a toxic cloud. Another example is the chlorine release by a train accident in San Luis Potosi, Mexico in 1980, resulting in 1000 injured people and 28 deaths (Cydsa, 2018).

Another accident that is worth noticed is the one occurred in Cordoba, Veracruz in Mexico in 1991 in a pesticide plant from the company Anaversa. The accident involved the release of over 38 thousand liters of different chemicals. There are no official number of deaths or injured people from this accident; however the Asociación de Afectados por Anaversa (Association of Affected by Anaversa in English) estimates that 1500 people have died from health complications related to this accident (Torres Beristain, 2016).

3.5 *Origin of the accidents*

It is important to check the process stage where a major accident is more likely to happen. Table 3 shows that 22.5% of the accidents in Mexico occurred during the production stage (process plant). Then, with a 19.1% comes the pipeline transportation. Afterwards, the storage involves 16.5% of the accidents. In a fourth place, the transport, not involving pipelines, involves 14.2% of the occurred accidents. In 12.7% of the collected accidents, the origin of the accident is not reported, or it is unknown. Other origins that represent smaller percentages have been found to be the maintenance, the obtention of raw materials, and the disposal, charge and discharge of products.

Table 3. Accidents by origin.

Origin	Number of accidents	%
Production	60	22.50%
Pipeline transportation	51	19.10%
Storage	44	16.50%
Transportation	38	14.20%
Unknown	34	12.70%
Raw material obtention	20	7.50%
Disposal	12	4.50%
Maintenance	4	1.50%
Charge and discharge	4	1.50%
Total	267	100.00%

3.6 *General causes of the accidents*

The analysis of the general causes of the accidents is shown in Figure 4. The causes of 25.1% of the accidents are unknown or not reported. The human factor was the second general cause of accidents, accounting for 23.6% of the cases, followed by external events (18.4%), mechanical failure (18%), and all remaining causes (14.9%).

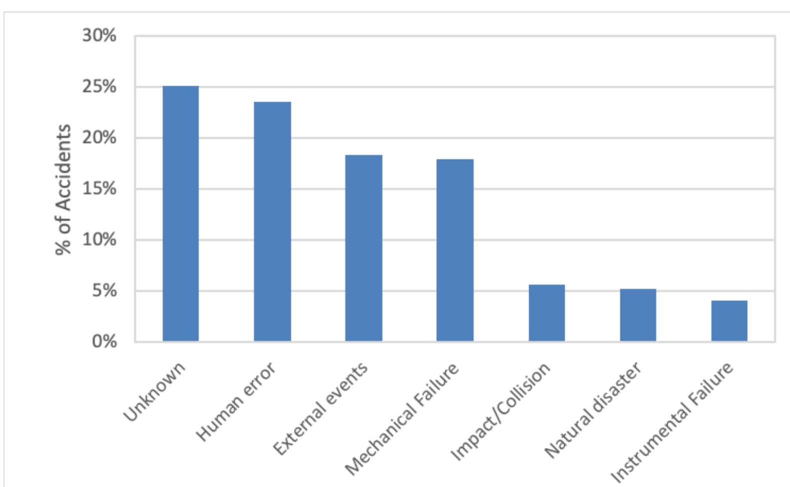

Fig. 4. Percentage of accidents by general cause.

It is important to give some examples from what it is considered as a human error in the present analysis. In the above mentioned recent major fire accident in Hidalgo, Mexico (Section 1.1), the general cause of the accident was considered as a human error, with a specific causes provoked by the illicit fuel extraction from a pipeline. This same cause has been found in several of the accidents reported in the present study. For example, in Puebla in 2011, 30 people died in a similar accident (Benitez, 2017). Another example of a cause that falls under this category involves the action of speeding while driving. For example, resulting in a pipe accident in Mexico State in 2019 (González, 2019A). Furthermore, the lack of knowledge and/or training to the operators has also been considered as human error.

3.7 *Accidents by industry type*

The type of industry involved in the major accidents has been classified as shown in Figure 5. Figure 5 indicates that the main industry involved in the major accidents is the oil industry, comprising 40.5% of the incidents, followed by the mining, with 13.5%, petrochemical industries, with 11.5%, chemical industries, with 8.6%, polymers industries, with 2.6%, and agrochemical industries, with 1.9%. These results are expected; since most of the commercial activities at the country involve oil and/or their derivatives as raw materials. When the other industries and unknown information categories are considered together, they accounted for 21.4% of the total accidents.

3.8 *Human casualties*

Human casualties from the accidents can be quantified in terms of number of deaths, number of injuries and number of evacuees. The human casualties, found through the current historical analysis, are injured and death. Of the entries studied, 81% provide the number of human casualties. The numbers of deaths and injuries have been grouped into arbitrary blocks of 0, 1-15, 16-50, 51-150, 151-250, and >250.

Most of the accidents, (211) 79.03% have reported less than 16 injured people or have not reported any information about human casualties. Three of the collected accidents (1.12%) have severe consequences, resulting in more than 500 injured people per accident. Two of these accidents occurred during the transportation of hazardous materials. One of them, with 800 injured people, involved the release of butane and an explosion, due to the crash of two trains in Chihuahua in 1972. The other one, was caused due to the failure on the breaks of a transport carrying chlorine. That accident occurred in San Luis Potosi in 1981, with 1000 casualties. The accident with the highest number of harmed people was the San Juanico Explosion in 1984. The complete results of the number of injuries by number of major accidents are shown in Figure 6.

The accident that had by far the most severe consequences was the San Juanico accident in 1984. The series of explosions from a PEMEX storage facility had as a result 540 deaths and at least 1854 injured people. According to the current historical analysis, this represents the 22.2% and 19.8% of the total deceased and injured, respectively, in more than 100 years of accidents in the Mexican Republic.

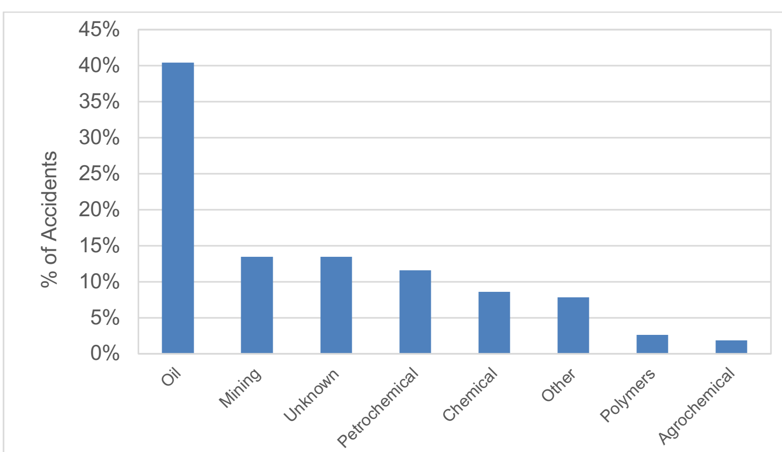

Fig. 5. Percentage of accidents by industry.

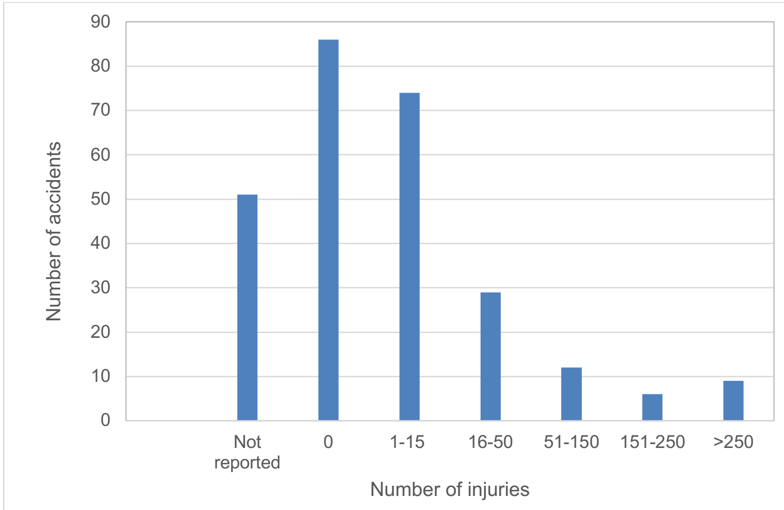

Fig. 6. Number of injuries.

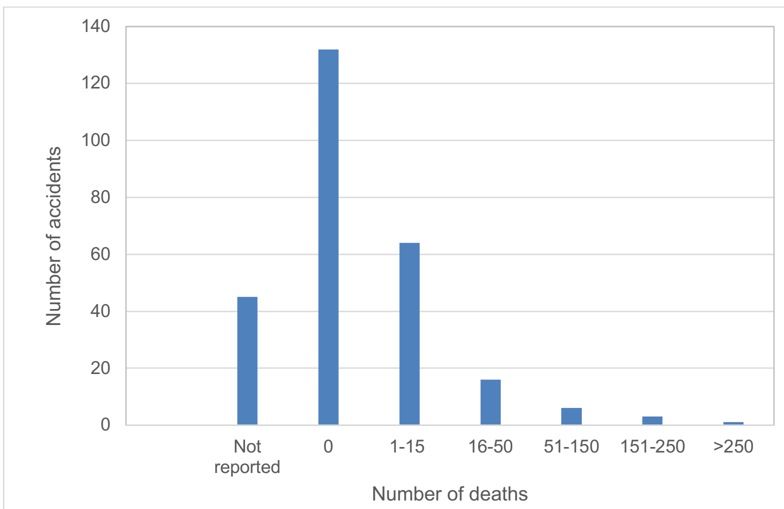

Fig. 7. Number of deaths by number of accidents.

Figure 7 shows the number of deaths by number of accidents. It has been found that at least 2435 people have lost their life due to accidents at the Mexican Chemical Industry. In almost half of the accidents (49.4%), there were no deaths; whereas the largest block of remaining accidents (24%) was 1-15 deaths. The 16.9% of the accidents do not provide the number of deaths; and ten of the accidents have reported more than 50 human deaths.

It is important to note that the number of deaths reported are the ones that occurred during the accidents or on near days within in; the ones that might have occurred months or years after the accident, as a consequence of, have not been included. Furthermore, if different sources had different number of deaths or injured the highest number has been taken for this analysis.

Conclusions

Due to the industrial growth in Mexico, the number of major accidents involving hazardous materials such as oil, vinyl's, benzenes, among others, has increased. Therefore, studies to prevent and mitigate the direct effects of the diverse major accidents occurring in industrial installations or in the transportation of hazardous materials should be developed. However, no studies have been carried out on its significance.

The current survey has the objective to develop a national database that quantifies and analyzes the cause, consequences and characteristics of major accidents, occurred at the Mexican chemical industry, during the last century. Some of the findings, obtained through the current historical analysis, are: (i) the number of accidents has significantly increased in the last decade; (ii) *Petroleos Mexicanos*, PEMEX is the company with the highest number of accidents; (iii) Veracruz is the state with the most occurred accidents in Mexico; (iv) human factor is the second general cause of major accidents in Mexico; (v) gasoline and diesel are the two most common substances in major accidents; and (vi) major accidents mainly occurred at process plants.

Finally, it should be noted that (i) looking into past events in depth, could lead to a safer future for the Mexican chemical industry with better policies and practices; (ii) promoting the simulations of major accidents, for a better understanding of the industrial accidents, and support for legislation; and (iii) the development of a new and updated Mexican legislation could be convenience to change the trend detected by this survey and move towards a safer industry.

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