OPTIMIZE, UPGRADE OR INVEST IN A NOVEL DRYER? – A BRICK FACTORY CASE STUDY

Miloš R. Vasić, Milica V. Vasić

¹Institute for testing of materials IMS, Bulevar vojvode Mišića 43, 11000 Belgrade, Serbia

Corresponding author: Miloš R. Vasić, milos.vasic@institutims.rs

Abstract: Drying has an enormous impact on the quality of final masonry clay elements. The accumulated knowledge about modeling the drying process, as well as the registered progress in computing the coupling between the heat and mass transfer during the last decade has reached the applicative industrial level. The available novel commercial drying solutions have dropped the drying cycle to 5 hours for hollow clay products and up to 9 hours for clay blocks of large size and weight. The ability to speed up the drying process also strongly depends on the properties of the raw materials. The decision on optimization of the existing dryer and its upgrade or investment in a novel drying facility must be experimentally validated. Results of the one-month monitoring and analysis of the production process in one Serbian brick factory including the material and energy balances are given in this paper. Based on the collected data, raw material limitations and costs of the novel dryer the existing tunnel dryer upgrade and the minimization of the "false" ambient air into the dryer are proposed.

Key words: heavy clay dryers, mass and energy balances, masonry clay units, industrial monitoring

1. INTRODUCTION

The industrial production of clay bricks and blocks is related to high energy demands. That is the reason why the novel and optimal scientific and engineering solutions, related to the drying and firing process, are very promptly implemented in practice. Simultaneous and coupled heat, mass and momentum transfer during masonry drying has been analyzed by various research groups all around the world. The complete and modern drying theory reported (1977) and updated in (1998) by Whitaker has introduced a revolutionary volume averaging concept. The presented equation set has included the volume-averaged macroscopic equation for conservation of mass, energy and momentum for the solid, liquid and gas phase. The available solutions of the previously mentioned equations sets differ only in the way in which the heat and mass transport in the air are accounted for in the calculation procedure. In other words, the more complex solutions require more rigorous boundary conditions to be satisfied. Perre (2015) has shown that three levels of computing can be applied. The full equation set has three independent equations with three corresponding variables (temperature, moisture content and internal pressure). When the full set is used, the spatial and temporal change of heat and mass transfer in air flow and porous material is completely covered. This kind of modeling is called conjugated. When total gaseous pressure is equal to the external pressure, a new set of equations with two variables (temperature and moisture content) is obtained. This model is not suitable for the description of highly temperature-intensive drying regimes in which internal vaporization is registered. Nevertheless, in this kind of modeling the case-specific spatial variation of the convective transport coefficients over the porous surface is used. Besides its temporal variation on the moisture content at the surface is also included. That is the reason why this kind of modeling is considered to be semi-conjugate. Finally, if the product temperature is instantly the same as the air flow temperature only one equation with one corresponding variable is defined (moisture content). The real boundary condition for vapor flux in convective drying is somewhat different. In other words, the third level of modeling is non-conjugate. In this kind of modeling, the convective transport coefficients are determined analytically or empirically in correlation with the air speed. By adopting the previously described classification procedure, it is possible to qualitatively sort any scientific studies related to drying based on the applied coupling level. For example, the typical representative of the full coupling conjugate approach is the mixture theory (Bowen R.M 1980, Kowalski 2000), volume averaging techniques at microscopic scale (Whitaker 1998, Vu T.H 2006) or pore network studies (Laurinodo J.B et al. 1998, Yiotis G.A et al. 2006). Simple diffusion models (Efremov 2002, Silva P.W 2013) are classified as non-conjugate while receding front

models (Luikov A.V 1975, Hashimoto A. et al. 2003) are categorized as semi-conjugate. The problems which are generated during industrial drying are related to the raw material or the dryer. The ones associated with the raw material are widely reported in the literature (Tatarin et.al 2013). The other one such as the breakthrough of the “false” air, uneven temperature and relative humidity distribution throughout the chamber or a tunnel, inefficient dryer control system, condensation problems in the stuck tunnel, recirculation problems etc., are rarely reported in the literature, since the solutions are usually the subject of intellectual property of the dryer manufacturers. The upgrade of the controlling system in a typical chamber dryer using the semi-conjugated approach was reported (Shoukhoumand et al. 2011). Another interesting solution which results in much better control of the outgoing drying air inside the chamber was reported in (1997) by Dolanc. The applied system has successfully controlled the inlet chamber dumper position. The condensation problem in the stack tunnel was analyzed by Mancuhan (2009). The use of a simulation model, based on the semi-conjugated Kitcher receding model, for optimization of industrial masonry clay dryers was reported in (1997) by Velthius. The main goal of our paper was to decide is it reasonable to upgrade the counter-current classical tunnel dryer, to adapt it to reach the Keller "Para-flow" multiway level, or to invest in a completely novel Cosmes&Sacmi cross-counter tunnel dryer.

2. TUNNEL DRYER - BASIC INFORMATION

The energy for drying is obtained from the kiln. The tunnel dryer is usually divided along its length into three sections: the preheating, the constant and the falling rate zone. The purpose of the preheating zone is dual. The first one is to raise the temperature of the green ware to the wet bulb air or adiabatic temperature of 40-45°C. The second is to decrease the evaporation from the product surface into the moisture air. That is the reason why the air used in this zone is almost moist-saturated. At the end of this zone, the air relative humidity is around 80%. During the constant rate zone, evaporation from the green ware surface is enabled. The moisture of the drying air is continually decreasing up to 65 - 70%. The temperature of the green ware is kept constant at the adiabatic saturation value. At the end of the second zone, the drying front has receded from the surface of the green ware towards its interior while the green ware moisture content has reached the critical one. The main purpose of the falling zone is to rapidly dry the green ware up to its predefined final moisture content of 3 – 6%. Within this zone, the drying air humidity is decreased up to 15 or 20% while simultaneously the air temperature is raised to 70°C. When the direction of the hot air stream and green ware is used for tunnel dryer classification, three main categories are distinguished: counter-current, parallel and crosscurrent. The classical tunnel dryer presented in Fig. 1 is using the counter-current flow of the hot air and green ware. This flow pattern is the most effective in a situation where the slow drying rate is kept in the earlier drying phase and its sequential increase is favored during the later drying period. Large capacities and long drying time from 20-40 h are the characteristics of these dryers.

Fig. 1 – Schematic view of the counter-current tunnel dryer

The Anjou dryer was the first rapid dryer that uses the counter-current principle. It has two superimposed drying channels one above another and a swing suspended chains system for moving the green ware. The recirculation of the moist air was more efficient in this design. This dryer was applicable to only several kinds of raw materials. Sirroco is the Anjou dryer successor with the proven design, air flow recirculation and without fans inside the dryer. The drying cycles vary from 2 to 4 h with a production capacity of 100 tons per hour. This dryer is suitable for hollow brick and small dimensions hollow blocks drying. The Zepyer dryer also uses the counter-current flow throughout the dryer. It does not have a door. The green ware is placed on the specially

designed drying tanks which are then pulled down into the dryer. This kind of loading, which is patented, has efficiently prevented the ambient air breakthrough into the dryer and consequently the energy losses and disturbances of the drying air parameters inside the dryer were eliminated. The motors and most of the fans are dislocated outside the dryer. This dryer is universal with an adjustable drying cycle from 5 to 9 hours. Energy consumption in this dryer is less than 900 kcal/kg H₂O (Cleia website). It is well known that the counter-current flow exchangers are more efficient than the parallel or crosscurrent ones. Nevertheless, when for example the goal is to rapidly increase the green ware temperature, up to the wet bulb temperature while the control of the drying air relative humidity is rigorously kept above 85%, the application of parallel or cross counter flow design is a more suitable solution. The heat efficiency of the cross-counter flow is somewhere between the countercurrent and the parallel flow. Since the counter-current solution provides the most efficient heat transfer within the tunnel dryer in the later drying phase the completely parallel or cross-current dryers are not usually seen. The introduction of the parallel or cross-current flow in the preheating and constant zone can be seen as the start of modular dryer design. This concept has allowed much better and independent control of the drying air parameters on the level of each module. One such example is the two zones "para-flow" Keller rapid dryer, which schematic view is given in Fig. 2.

Fig. 2 – Schematic view of two zones "para-flow" dryer

The Company Marcheluzo's semi-rapid dryer also uses a modular design. This means that the drying temperature and humidity rigorous control is achieved at the level of every two drying wagons throughout the dryer length. The combination of parallel and counter-current flow is a characteristic of this dryer design. This kind of control is very adaptable and can follow the predefined rapid drying curve of various raw materials. The average drying cycle is about 4 hours for hollow clay products and 9 h for blocks of a large size and weight. The production capacity is ranging from 100 tons per day to 1400 tons per day.

Cosmec&Sacmi has designed a cross-current type of semi-rapid dryer divided into three zones. The modular concept is applied in each zone of the dryer. This design allows very accurate and independent control of the drying air parameters within each module. The axial fans are installed on two walls of the dryers as can be seen in Fig. 3. The overall drying time can vary from 5 to 12h.

Fig. 3. Cosmec&Sacmi cross-counter flow tunnel dryer

Even though the scientific concept of rapid drying was introduced in 1960 the industrial rapid dryers suitable for drying the large quantities of the small and large hollow clay blocks were introduced on the market in mid 90. This 35 years' gap represents a period in which scientific breakthrough from the non-conjugated type of

modeling towards conjugated was achieved. The procedure for determination of the rapid drying regime usually requires: drying of industrial-size masonry units in a special drying chamber, selecting the type of the rapid dryer and the use of specialized software based on the full conjugated modeling approach. The output of the full conjugate modeling is the ability to precisely simulate and predict the drying kinetics as well as the drying history (the change of moisture content profiles within the product). These data are then used to formulate the most suitable step-type adjustments of the drying air parameters along the length of the chosen dryer for the investigated raw material. The observed decrease of total drying time, in regard to the classical one, is very noticeable. It is a consequence of the novel modular design in which the sequential adjustments of the predefined drying air parameters are better controlled and much more correlated with the raw material nature.

3. RESULTS

External monitoring of the dryer and kiln in one Serbian brick factory was conducted in May 2017. The acquisition equipment system Ahlborn THERM 3256-6, three Ahlborn sensors of temperature and relative humidity type C 845-2, Six Omega K-type thermal probes, anemometer with turbine, United Sensors and Control Corporation Pitot-Static tubes type PCD-12-KL with k_c of 1.0, digital pressure gauge of 20 mbar, digital termohygrometer type HT-800 (up to 60°C), analog hygrometer type HT-11 (up to 120°C), digital thermometer type S-506, TMI-ORION Cerydry logger equipped with temperature humidity and shrinkage sensors and KERN balance were used during the external factory monitoring. The technological disposition of the material and energy balances within the dryer is presented in Fig. 4.

VTV – hot air fan; TV – hot air; MV – humid air; FV – „false“ ambient air; M – mass flow;
VMV₁ – humid air fan at the left side VMV₂ – humid air fan at the right side; DWW - drying ware wagon

Fig. scale 1:333

Fig.4. Technological distribution of material and energy balances within the dryer

The average outdoor drying air temperature and humidity during the monitoring period were respectively 20.16°C and 53.3%. The analyzed dryer is a classical counter-current tunnel dryer from the mid-80s. It has four drying tunnels. The first three have two drying channels. Each channel drying batch consists of 27 drying ware wagons (DWW). This is defining the maximal dryer capacity of 189 DWW per batch. The drying channel and DWW length are respectively 65 and 2.4 m long. The typical DWW has 10 rows of drying ware. The maximal DWW capacity for clay hollow blocks with vertical voids (250 x190x190 mm) is 336. The hot air from the kiln duct is used for drying. It is delivered to the central air channel which is constructed in the direction of the dryer length on its ceiling. Hot air is then directed towards dryer tunnels in which cornet air mixers, equipped with axial fans, are present. The entrance part of the tunnel dryer up to the opening for wet air extraction is characterized by the same flow of products and wet air. This position is risky in terms of “false” ambient air penetration into the dryer. This is more pronounced since in this part of the dryer the dumpers at the central hot air channel were not properly configured and the recirculation of the humid air was weak. During the monitoring period, the status of the dumper positions throughout the dryer, as well as dryer fans and cornet air mixers settings was not updated. The production was governed in accordance with the predefined factory production policies. Within the Lindle documentation for this type of dryer, the total drying time for the hollow program with small dimensions was specified to be in the range of 22 – 30 h. The records of the daily produced quantities of the green ware were also analyzed. The largest deviation of the daily records from the average one was 15%. The total drying time which corresponds to the maximal and average green ware production was 34 and 26 h respectively. At first, this was absolutely not an expected result. When the data of daily processed DWW inside the dryer were analyzed, it was found that the maximal drying time corresponds to the 104 DWW

per day. It was also determined that the average number of processed DWW was 94. From this moment, the solution to the registered differences in total drying time was known. In order to explain it in detail, only the registered drying regime data which corresponds to the day of maximal green ware production is presented. The temperature and air relative humidity were registered at 1st, 5th and 8th row, while the weight loss and product shrinkage were monitored in the 4th row. The air humidity drying probe has stopped working after 19 h at the 8th row due to the bad wiring contact. Registered drying parameters as a function of the drying time and DWW position inside the tunnel are given in Fig. 5 – Fig. 8. The Bigot's curve is presented in Fig. 9. The average inlet and outlet temperature of the drying ware were respectively 22°C and 57°C, while the corresponding values of the drying air were 27°C and 58°C. The differences in air temperature and relative humidity along the the height of the dryer have shown high uniformity. The deviations of temperature were less than 5°C while the relative humidity deviation was in the range of 5-15% except in the irregular regions. These regions are produced as the consequence of an inadequate DWW pulling rate. It can be stated that the air mixing equipment is adequate and can evenly distribute the hot air throughout the drying channels. The green ware and air temperature have reached 30°C and 36°C respectively very fast after only 1h at the 2nd DWW position. A simultaneous drop of the relative air humidity from 5 to 10 % was registered in this drying segment. During the next 7 hours, up to the 7th DWW position, the temperature was uniformly raised up to 43°C with the increase rate of 1 °C/h. The relative humidity has uniformly decreased up to 70-75%. The temperature increase rate and the drop rate of drying humidity in the dryer were much larger in the case of average raw material production than in the discussed case. The cause of this is the irregular pulling rate of the DWW during drying in the case of a larger production.

Fig. 5a. RH – t

Fig. 5.b. RH – DWW

Fig. 6a. T – t

Fig. 6b. T – DWW

Fig. 7b. L – DWW

Fig.7a - L - t

Fig.8a - WL - t

Fig.8b - WL - DWW

Fig.9. Bigot's curve

The DWW was moved faster at the beginning of the drying process. After some time, the pulling rate has dropped under the predefined optimal level. This has caused the irregularities inside the dryer which can be summarized as the decrease of the temperature raise rate and the shift of the relative humidity drop trend towards the increasing one. This zone of irregular drying air fluctuation is clearly seen between the 7th - 10th DWW position in Fig. 5b and Fig. 6b. Drying ware was in this zone for 4 h. The humidity was varied from 70 – 90 %, while the air temperature increasing rate was 0.4°C/h. Within the next 3 hours, up to the 13th DWW position, the temperature drop rate was 1.2° C/h while the relative humidity was maintained in the range of 70-80%. The registered temperature drop was a consequence of the faster DWV pulling rate. During the next 2 h, from the 13th – 16th DWW position, the DWW pulling rate was decreased. The previous air temperature maximal value was slowly reached and exceeded. The relative air humidity has finally started to uniformly decrease throughout this zone up to the level of about 60%. Within the next 5h, up to the 17th DWW position, the air temperature has reached 49°C with a rate of 0.4°C/h. The relative humidity drop rate and the achieved regulation in this period were in the range of 3 - 4 %/h and 40 and 50% respectively. Within the next 6h, up to the 22nd DWW position, the air temperature and relative humidity have reached 54°C and 25-30%. The uniform temperature increase and humidity drop rates of 0.8°C/h and 3%/h were respectively registered in this drying segment. The same uniform increase/decrease trend of drying air parameters was detected in the last 5 h, up to the final 27th DWW position.

The intensive green ware shrinkage has started after 3h at the 4th DWW position and was over 15h later between the 15th - 16th DWW positions. Intensive green ware weight loss has started after 4h at the 4th DWW position and was over 18h later at the 18th DWW position. The position of the critical point on Bigot's curve is pointing out that the raw material is very sensitive to drying since the weight loss is above 10%. This point was reached after 16h of drying at the 14th DWW position. Basic inputs which are used in the calculation of mass and energy balances are given in Table 1. Measured values of the air temperature, relative humidity and velocity at the position VTV (hot air inlet), VMV_l (exhaust air duct at the left side) and VMV_d (exhaust air duct at the right side) which is schematically presented in Fig. 4 are reported in Tables 2 and 3. Calculated energy and mass balances are given in Tables 4 – 6.

Table 1. Basic inputs

Average values	Gas consumption (m ³)	DWW/day	Mass of green ware (kg)	Mass of dried were (kg)	Number of dried hollow bricks
	1665	104	11.335	9.038	34944

Table 2. Inlet input VTV

Date	T (°C)	H (g/kg)	RH _a (%)	T _a (°C)	Duct (m)		Δp (Pa)	
					length	diameter	Min	Max
23.05.	108	0.0065	32	25	6.69	2.0	64	89
23.05.	121	0.0055	31	22	6.69	2.0	42	83

Table 3. Outlet inputs

Position	Measuring date	T (°C)	RH (%)	H	Duct (m)		Δp (Pa)	
					length	diameter	Min	Max
VMV _i	30.05	41.5	48	0.025	4.43	1.4	52	102
	30.05	42.5	46	0.0245	4.43	1.4	74	119
VMV _d	24.05	43	46	0.026	4.43	1.4	73	133
	30.05	42	45	0.024	4.43	1.4	53	118
	30.05	43	48	0.0265	4.43	1.4	53	102

Table 4. Calculated values for the input position

Date	v (m ³ /kg)	i (kJ/kg)	w (m/s)	V (m ³ /h)	M (kg/h)	E (MJ/h)	ΔE (MJ/h)
23.05	1.0898	126.1	12.91	145963.1	133940.7	16887.7	12213.2
23.05	1.1251	136.6	11.86	134057.6	119146.9	16273.9	12115.7

Table 5. Calculated values for output position

Position	Date	v (m ³ /kg)	i – (kJ/kg)	w (m/s)	V (m ³ /h)	M (kg/h)	E (MJ/h)	ΔE (MJ/h)
VMV _i	30.05	0.9261	106.0	11.94	66147.6	71427.1	7569.9	5048.5
	30.05	0.9283	105.7	13.39	74140.2	79865.7	8445.6	5626.3
VMV _d	24.05	0.9319	110.1	13.86	76746.2	82350.6	9069.6	5668.5
	30.05	0.9261	103.9	12.58	69704.4	75264.9	7822.7	5165.8
	30.05	0.9327	111.4	12.02	66597.3	71405.5	7956.1	5435.5

Table 6. Calculated dryer balances

Position	M (kg/h)		ΔE (MJ/h)	
	Inlet	Outlet	Inlet	Outlet
Hollow block	14.924	11.900	-	419
VTV	126.544	-	12.164	-
VMV	-	151.987	-	10.761
Total	141.468	163.886	12.164	11.180
Outlet – Inlet		22.419	984	-

The "false" air breakthrough inside the dryer is quantified in Table 6 as the mass balance difference of 14,7%. When the entrance to the dryer is not secured, the ambient air will go towards the drying channel where the exhaust fans will suck it very soon. This will lead to disturbances of the ventilation within the dryer. The air humidity will start to decrease in the first zone, while in the second one the air velocity will vary also. The energy balance difference of 8,4% represents the transmission heat losses, from the dryer ceilings towards the production hall, and ventilation heat losses in the falling drying zone. If the production hall is not heated by the transmission from the drying process the equivalent cost for heating would be the use of 29,6 Sm³/h of natural gas. The specific energy consumption of this dryer is 4,021 KJ/kg H₂O which is equal to 960 kcal/kg H₂O or 0.121 Sm³/kg. This is a very good result since the deviation from the specific energy consumption of the much modern Zeyper dryer is only 10%. Even though the registered drying regime has some irregularities, due to the "false" air breakthrough and inadequate DWW pulling rate influenced by the green ware production variations, it is almost completely adequate for the applied raw material type. The drying air is evenly distributed all over the drying tunnel except at the entrance due to already stated "false" air problems. The total drying time is slightly increased in relation to the maximal manufacturer values for the hollow block program. The dryer is working close to the recommended regime typical for its design type. The investment towards the new counter-

current semi-rapid dryer is reasonable only if the investment into a new type of kiln is included too. The costs are enormous and far away from the factory budget. The adaptation of the dryer towards the Keller or Lingle "Para-flow" multiway level is possible. This means that the complete system of the hot air distribution in the preheating and constant drying zones is the main subject of the investment. This includes the adaptation of the hot air ducts along with the ceilings, installation of the recirculation ducts and new centrifugal drying fans. Besides, a part of the investment has to be directed towards the update of the existing air mixing cornets and axial fans settings within the dryer and the installation of a new one. In addition to the existing costs, related to the technical part of the investment, a loss due to the stop of the production process during the dryer technology transfer must be included in the overall cost-benefit calculation. The cost for the actual transfer of the analyzed dryer towards the "Para-flow" multiway level is estimated at several million euros and was the reason why the technology transfer investment was not approved. The costs for the upgrade of the existing dryer without updating the dryer technology level were estimated at 200.000 euros. Within this proposal, 150.000 euros are planned: for the installation of the new entrance door barriers system, adaptation of the existing dryer fans, replacement of the bad wings and dumpers in the central air duct near the entrance. The remaining investment is planned for the new regulation equipment for measuring the drying air parameters within the channel and the design of the updated system of dryer regulation. The proposed disposition of the novel measuring equipment along the dryer is presented in Fig. 10.

Fig. scale 1:333

Fig. 10. Proposed disposition of the measuring equipment

4. CONCLUSION

Results of the one-month check-up of a classical countercurrent tunnel dryer were analyzed. It was detected that the entrance part was a risk point for the penetration of the "false" ambient air into the dryer. Besides, the improper recirculation of the humid air has caused additional problems. Simultaneously, during an increased production, an irregular pulling rate of the drying wagons was noticed. These caused the optimal drying regime prolongation by up to 15%. Since the estimated costs of removing the present dryer and buying the new equipment were very high, it is recommended to make adequate changes and thus solve the existing problems in the factory. The new entrance door barriers system, adaptation of the existing fans and replacement of the parts and fans in the central air duct near the entrance are expected to improve the drying process. Besides, the new regulation equipment for measuring the drying air parameters within the channel is also proposed.

Acknowledgement

This paper was financed by ministry of education science and technological development of Serbia, contract number 451-03-9/2021-14/200012. Authors M. R. Vasic and M. V. Vasic are fully employed in the Institute for testing of Materials

5. REFERENCES

1. Bowen R.M., (1980), *Incompressible porous media models by use of the theory of mixtures*, International Journal of Engineering Science, 18 (9), 1129-1148.
2. https://www.cleia.fr/images/pdf/en/zeephyr_en.pdf
3. Dolanc. G, Vladimir. J., (1997), *Improvement of the drying process control in a clay product plant*, IAF Proceeding 30(6), 1575-1580.
4. Efremov G., (2002), *Drying kinetics derived from diffusion equation with flux-type boundary conditions*, Drying Technology, 20, 55-66.
5. Yiotis.A.G., Tismpanogiannis.I.N., Stubos.A.K., Yortsos.Y.C., (2006), *Pore network study of the characteristic periods in the drying of porous materials*, Journal of Colloid and Interface Science, 297, 738-748.
6. Hashimoto S.A., Kamoeoka.T., (2003), *Simulation of convective drying of wet porous materials*, 21 (8), 1411-1431.
7. Kowalski J., (2000), *Toward a thermodynamics and mechanics of drying process*, Chemical Engineering Science, 55, 1289-1304.
8. Laurindo J.B., Prat M., (1998), *Modelling of Drying in Capillary-Porous Media: A Discrete Approach*, Drying Technology, 16 (9-10), 1769-1787.
9. Luikov, V.A., (1975), *System of differential equations of heat and mass transfer in capillary-porous bodies (review)*, International journal of Heat and Mass Transfer, 18 (1), 1-14.
10. Mancuhan E., (2009), *Analysis and optimization of drying of green brick in a tunnel dryer*, Drying Technology 27(5), 707-713.
11. Peere P., (2015), *The proper use of mass diffusion equations in drying modeling: Introducing the Drying, Intensity Number*, Drying Technology, 33, 1949-1962.
12. Silva.P.W., Cleide M.D.P.S.S, Laerson.D.S.V.S.D.F., (2013), *Drying of Clay Slabs during the Falling Rate Period: Optimization and Simulation of the Process Using Diffusion Models*, Journal of materials science research 2 (2), 1-13.
13. Shokouhmand H., Abdollahi V., Hosseini S, Vahidkahah K., (2011), *Performance optimization of a brick dryer using porous simulation approach*, Drying Technology 29 (3), 360-370.
14. Tatarin A., Vogt R., (2013), *Test methods for heavy clay ceramic raw materials: Raw material composition (primary properties) - Part 1*, Brick and Tile industry International 04/2013.
15. Tatarin A., Vogt R., (2013), *Test methods for heavy clay ceramic raw materials: ceram-technological behaviour (secondary properties) – part 2*, Brick and Tile industry International 05/2013.
16. Vu H. T., (2006), *Influence of pore size distribution on drying behaviour of porous media by a Continuous model*, Phd, Otto-von-Guericke-University Madeburg.
17. Velthuis M.F.J., Denissen M.A.J., (1997), *Simulation model for industrial dryers: reduction of drying times of ceramics & saving energy*, Drying Technology 15 (6-8), 1941-1948.
18. Whitaker, S., (1997), *Simultaneous heat, mass and momentum transfer in porous media: A theory of drying*, Advances in Heat Transfer, 13, 119-203.
19. Whitaker, S., (1998), *Coupled transport in multiphase systems: A theory of drying*, Advances in Heat Transfer, 31, 1-104.