CHEMICAL ENGINEERING TRANSACTIONS

VOL. 61, 2017

A publication of AIDIC

The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Petar S Varbanov, Rongxin Su, Hon Loong Lam, Xia Liu, Jiří J Klemeš

ISBN 978-88-95608-51-8; **ISSN** 2283-9216

DOI: 10.3303/CET1761189

Energy and CO_2 Savings in Fired Clay Brick Production by Using Olive Oil Residues

José A. de la Casa[a,b], Eulogio Castro[a*]

[a] Department. of Chemical, Environmental and Materials Engineering, University of Jaén, 23071 Jaén, Spain
[b] Cerámica Malpesa, S.A. Autovía A-4, km 303, 23710 Bailén, Jaén, Spain
ecastro@ujaen.es

Energy and environmental costs have a great importance in all production plants, and this is particularly the case of fired clay brick production. The use of residues from the olive oil production process to partially substitute ingredients in the clay body is studied in this work. This option was technically demonstrated at laboratory scale. The new bricks meet all requirements based on mechanical properties. As part of the scaling up studies, the simulation of the whole brick production plant is performed using Aspen Plus. The base scenario corresponding to conventional operation was compared with other options, in which residues from olive oil production such as olive pomace or olive oil mill wastewater were included. Results show that the use of these wastes can represent an important saving in gas consumption of up to 2.9 – 18 % in the plant operation. Furthermore, a reduction of up to 13 % in the actual emission rate of CO_2 can be reached, from 0.171 to 0.149 t CO_2/t product. At the same time, this option can alleviate environmental problems derived from olive oil wastes handling and disposal.

1. Introduction

In the drying operation for making fired clay bricks, the elimination of the water that was previously added to the clay, heat is required. To evaporate the water, the molded mixture of clay and water is introduced in a dryer and then in a pre-kiln. Next, by burning a fuel in the main process operation, the firing, the ceramic bodies are fired in a tunnel kiln resulting in the final products. Consequently, energy costs represent a very important part of the process. Together with energy cost, environmental aspects play also a key role in the fired clay brick industry. On the one side, the fired process produces a large amount of CO_2 that is emitted to the atmosphere; and on the other side the ceramic bodies have been used as the recipients of a wide range of residues and wastes, from a wide range of other industries, that can be eliminated by burning. Some authors discuss a list of reviews on waste incorporation into clay ceramics (Monteiro and Vieira, 2014). Other authors present different studies of incorporation of particular industrial wastes. For example, automotive industry waste sludge, glass waste and wood ash were assayed at laboratory scale by Wiemes et al. (2017). Physical-mechanical properties of bricks are reported to be improved when including glass wastes compared to conventional fired clay bricks (Phonphuak et al., 2016). The industry of fired clay brick can benefit from a reduction in energy requirements, thanks to the contribution of organic matter contained in the wastes. The kind of residues that can be used for this purpose are those derived from olive tree cultivation, e.g., biomass obtained from tree pruning, and those produced during the olive oil production process. Olive oil constitutes one of the main productions in Mediterranean countries whose profitability is compromised by the generation and management of their wastes. The characterization of the bricks produced by partial substitution of mixing water with olive oil wastewater was reported (de la Casa et al., 2009) resulting in bricks with comparable technological properties to the conventional products. The use of up to 12 % of olive pomace to substitute the clay produced bricks with lower density and higher thermal insulation effectiveness (de la Casa et al., 2012), while the addition of biomass ash, resulted in bricks comparable to conventional products (de la Casa and Castro, 2014). Before scaling up to a commercial plant, simulation studies are very useful to compare different scenarios of the eventual industrial operation. Such studies, based on the laboratory results, may be an excellent tool to identify both technical and economic issues in the industrial plant operation, being also useful

Please cite this article as: de la Casa J.A., Castro E., 2017, Energy and co2 savings in fired clay brick production by using olive oil residues, Chemical Engineering Transactions, 61, 1147-1152 DOI:10.3303/CET1761189

for the estimation of environmental parameters. Aspen Plus is a widely used simulation software which has been applied to a great variety of processes, such as the optimization of sugar concentration in the distillation step of a bioethanol production process (Ponce et al., 2015) or even the simulation of a whole production plant (Van-Dal and Bouallou, 2013). However, in the case of fire clay brick production the use of simulation software is limited in general terms to the kiln operation, and studies covering the whole plant operation are missing. Another interesting tool for system simulation is Computer Fluid Dynamics (CFD). The use of CFD has been reported in relation to kiln studies aiming at estimating emissions of CO, CO_2 and NO_x in addition to other characteristics of the industrial operation of the kiln (Tehzeeb, 2013).
The aim of the present work was to compare the performance of a fired clay brick industrial plant under different scenarios in which waste or residues from the olive oil production process were used as ingredients or substitutes of the mixing water. While the mechanical properties of the final products are determined to be sure that the replacements are technically possible, the study is focused mainly on energy requirement reduction as well as on the CO_2 emissions associated to each scenario.

2. Material and methods

2.1 Process description

Figure 1 shows the simplified diagram of the process of making fired clay bricks. The main stages include milling of the clay, water addition, extrusion of the moisturized clay, bar cutting to form bricks, drying and finally firing the bricks in the kiln. In Figure 1, gaseous streams are represented by dashed lines, while liquid and solid streams are drawn by continuous lines.

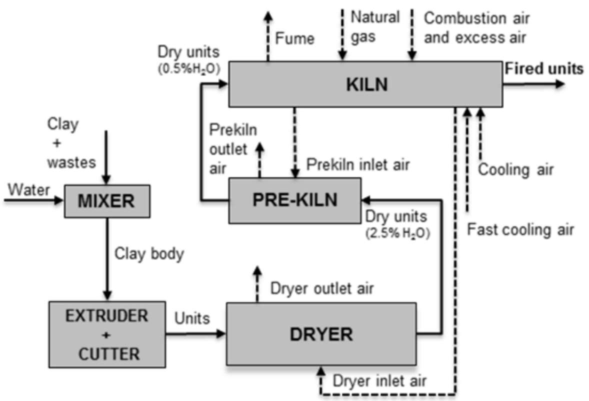

Figure 1: Simplified diagram of the process

2.2 Description of scenarios

To compare the performance of the industrial plant under the different operational conditions, the base scenario was selected as the standard operation of the plant, that is, using a mixture of clay, a red firing clay body referred to as RB that is mixed with 21 % water (de la Casa et al., 2009). The scenarios that were considered to compare with the base one differs in the amount of residues that was added to the RB clay, keeping always in the same value the water flow for mixing as in the base scenario (21 %), Table 1.

Table 1: Considered scenarios for the simulation of a brick production plant based on olive oil wastes

Scenario number	Scenario abbreviation	Description
1	RB (base scenario)	Feeding of RB ceramic body and 21 % water.
2	OOW	Feed of ceramic body RB plus olive oil washing water (OOW) and water flow for mixing the same as for RB.
3	OP3	Feed of ceramic body RB with 3 % olive oil pomace and water flow for mixing the same as for RB.
4	OP6	Feed of ceramic body RB with 6 % olive oil pomace and water flow for mixing the same as for RB.
5	WA	Feed of ceramic body RB with 10 % washed olive oil pomace ash and water flow for mixing the same as for RB.

2.3 Data collection

Data describing the basic operation (i.e., RB scenario) were obtained in November and correspond to the production of a high density fired-clay masonry unit according to EN 771-1 standard.
The RB clay mixture was characterised and supplemented with different proportions of the three wastes from the olive oil production process that are considered in the present simulation study, as described elsewhere (de la Casa and Castro, 2014).
The simulation study includes the determination of mass and energy balances. To do this, a number of parameters were recorded, including temperature, moisture content of both clay units and air streams, gas consumption and mass flow in different parts of the plants. All these data were recorded and then applied to the simulation of the base scenario. Next, the remaining scenarios were considered and simulated. No matter what the scenario was considered, constant values of the following parameters were adopted: room temperature, 10 ºC; fired unit production, 3.994 kg/s; production, 24 kiln cars/d. In RB scenario, natural gas consumption was 19,695 Nm^3/day.

2.4 ASPEN Plus process diagram and assumptions

Aspen Plus v7.2 (Aspen Technology Inc., USA) was used to simulate the ceramic plant operation under the different scenarios. Figure 2 shows the flow diagram as depicted in Aspen Plus, where the main equipment units of the plant, including mixers, extruder, dryer, pre-kiln and kiln, are represented as different ASPEN blocks. The simulation is also based in several assumptions, as follows:

1. Steady and isothermal state at each of the process steps.
2. Ideal behaviour of gases.
3. The steps of water evaporation, pyrolysis and combustion of organic matter, combustion of natural gas, and formation of mineral phases from the mineral raw materials are instantaneous.
4. Heat streams are used to simulate the heat transfer between gas streams and solid products.
5. Heat losses at equipment units do not differ from one scenario to another.

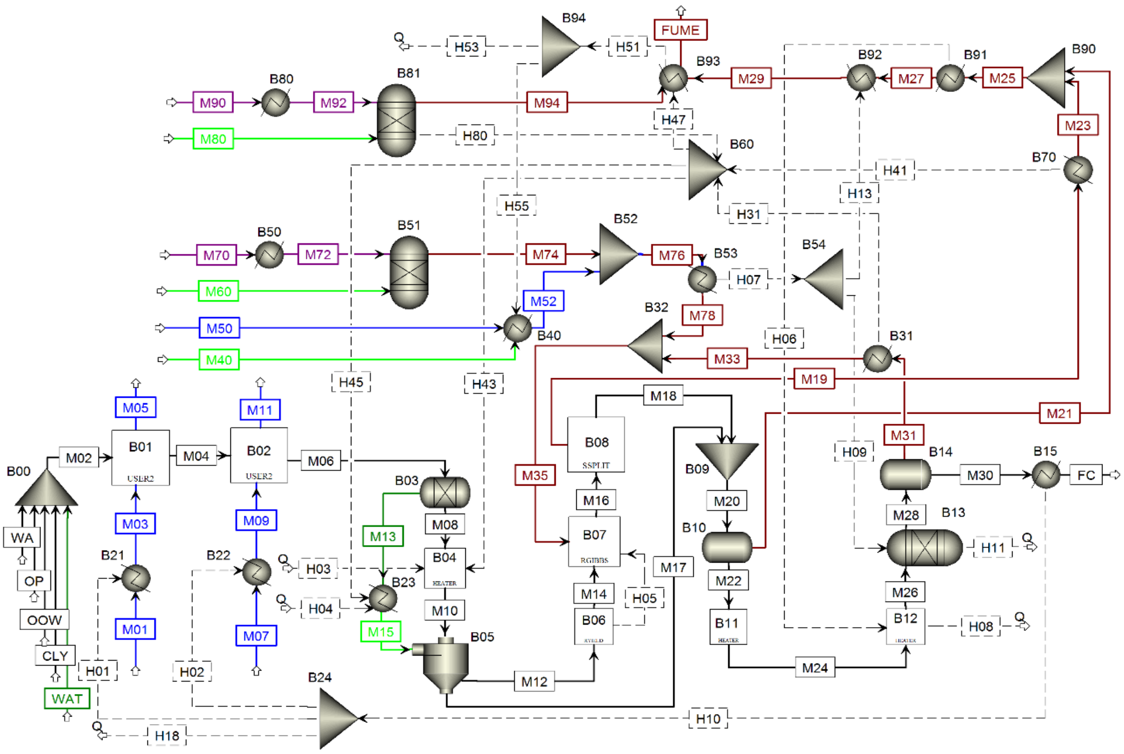

Figure 2: ASPEN Plus flow diagram of the brick production plant

In Figure 2, the main items are: <u>Streams</u>: WAT (mixing water), CLY (RB clay), OOW (olive oil washing water), OP (olive pomace), WA (washed olive pomace ash), and FC (kiln outlet fired clay). <u>Blocks</u>: B01 (dryer), B02 (pre-kiln), B06 and B07 (RYIELD and RGIBBS reactors for decomposition and combustion of biomass, respectively), B81 and B51 (RGIBBS reactors for preheating and roof burners, respectively), and B13

(RGIBBS reactor for high-temperature ceramic phase formation).
The simulation of RB base scenario consisted of using operation data for the plant to determine the flow, composition, and temperature of the streams by mass and energy balances. This simulation was validated by full match data for temperature and mass flow of streams. Then, the remaining scenarios were studied.

3. Results and discussion

3.1 Solids streams

The simulation environment requires the definition of the olive oil washing water (OOW) and olive pomace (OP) streams as non-conventional compound streams. The composition analysis for OOW was 22.03, 70.00 and 7.97 % of fixed carbon, volatile material and ash, while the corresponding values for the OP stream were 22.1, 74.2 and 3.7 %. The washed olive pomace ash (WA) stream was considered as a mixture of conventional compounds actually present and a substitutive conventional compound, albite, which does not take part in the chemical reactions. Globally, crystalline phases account for 45 % and amorphous phases are 55 %.
The flow and composition for the five scenarios considered are shown in Table 2. It can be observed that a slight increase in the total flow was detected from the base scenario to OOW, OP3 and OP6, if a constant production rate of 1 kg/s of final fired product is considered.

Table 2: Characterisation of plant feed

Parameter	Scenario					Unit
	RB	OOW	OP3	OP6	WA	
Total flow	1.3201	1.3242	1.3334	1.3367	1.3201	kg/s
Water flow	0.2291	0.2291	0.2291	0.2291	0.2291	kg/s
Dry OOW flow	-	4.05E-3	-	-	-	kg/s
Dry pomace flow	-		1.33E-2	1.33E-2	-	kg/s

As far as the mineral composition is concerned, no differences are observed.

3.2 Gaseous streams

3.2.1 Fuel, combustion air and excess air
There are two types of burner groups associated with the kiln, the preheating burners and the roof burners, which were simulated by the B81 and B51 reactors, respectively. A stoichiometric mixture of natural gas and air is fed to these reactors.
The excess combustion air was introduced as an auxiliary stream. Once in the kiln, the excess air was mixed together with the combustion fume stream coming from the roof burners, M74.

3.2.2 Dryer streams
The dryer inlet air from the recovery zone of the kiln is charged with the evaporation of most of the mixing water of the units up to residual moisture of 2.5 %. Then, this moisture is reduced in the pre-kiln to 0.5 %. For further details are shown in Table 3.

Table 3: Characterization of inlet and outlet dryer air

Parameter	Inlet air	Outlet air	Unit
	RB	RB	
Total flow	6.154	6.355	kg/s
Temperature	10	38	˚C
Relative humidity	50	85.0	%

When the energy balance is applied to the dryer in the RB scenario, a loss of enthalpy is detected together with an 8.8 % difference between inflows and outflows. This value agrees well with the average value reported for the fired clay ceramic sector (Álvarez et al., 2012). A similar result regarding heat loss was considered for the remaining scenarios when applying also the user model.

3.3 Heat streams and energy balances

Table 4 summarizes the data concerning the main heat streams in the dryer and the kiln, as depicted in the Aspen Plus diagram of Figure 2. Zero degree Celsius was adopted as reference temperature for enthalpy calculation. The enthalpy flow of the streams entering the dryer was 971 kW.

Table 4: Heat streams and energy balance

Parameter	Scenario					Unit
	RB	OOW	OP3	OP6	WA	
Dryer inlet enthalpy flow	971	971	971	971	971	kW
Dryer inlet enthalpy flow loss	85.6	85.6	85.6	85.6	85.6	kW
Additional dryer heat flow	0	0	0	0	0	kW
Percentage of enthalpy flow lost in dryer	8.8	8.8	8.8	8.8	8.8	%
Heat flow HTB: Heat Transfer Balance	493	494	493	496	503	kW

Regarding the heat flows primarily from the kiln and the flue, HTB heat flow comprises heat flow not consumed in the installation, which corresponds to heat losses and unallocated heat. It is calculated as:

$$HTB = H53 + H18 - H03 - H04 \quad (1)$$

Where: H53, stack heat recovery; H18, heat loss of recovery; H03, additional heat to solids; H04, additional heat for vaporisation.
HTB heat flow is about 495 kW.

3.4 Gas consumption

Gas fuel consumption is necessary to perform ceramic reactions which produce the process of ceramic firing. The gas consumption was 2.55 mol/s for the base scenario equivalent to 2.55 mol per kg of product, considering a production rate of 1 kg/s of fired product. As a consequence of the introduction of organic matter in the remaining scenarios, the heat requirements for the firing process and hence the gas consumption were reduced. As can be observed in Table 5, the higher the organic matter in the body the lower the energy requirements in the kiln, that is, heat savings are increasing in scenarios OOW, OP3 and OP6. The reduction of gas consumption ranged between 14 and 84 % based on preheating consumption, and between 2.9 % and 18 %, based on total consumption.

Table 5: Gas consumption as a function of scenario

Parameter	Scenario					Unit
	RB	OOW	OP3	OP6	WA	
Preheating gas	0.532	0.458	0.310	0.087	0.532	mol/s
Roof gas	2.016	2.016	2.016	2.016	2.016	mol/s
Total gas	2.558	2.474	2.326	2.103	2.558	mol/s
Preheating savings versus RB	0	14	42	84	0	%
Total gas savings versus RB	0	2.9	8.7	18	0	%

It is worth noting that the clay bodies obtained under the OOW, OP3 and OP6 scenarios present higher heating values, due to the organic matter content, of 73, 255 and 520 kJ/kg clay(de la Casa et al., 2012), which represent between 2.4 – 7.3 %, 8 – 25 % and 17 – 52 % of the energy necessary for clay masonry unit manufacturing, respectively (Rentz et al., 2001).

3.5 Kiln emissions

Kiln emission, fume flow and fume composition depend on the characteristics of the ceramic body and operation of the system, and are determined by gas consumption. Table 6 shows the molar/mass flows and CO_2 molar fraction of fume in each scenario. There is a variation of both the flow and composition of the fumes when considering the different scenarios.

Table 6: Characterization of the kiln emissions

Kiln operation parameter	Scenario					Unit
	RB	OOW	OP3	OP6	WA	
Fume mass flow	3.466	3.505	3.750	4.030	3.466	kg/s
Fume molar flow	121.9	123.2	131.6	141.2	121.8	mol/s
CO_2 fume molar fraction	0.0318	0.0321	0.0314	0.0311	0.0323	-
t $CO_{2\ biomass}$/t product	0	0.007	0.022	0.044	0	-
t $CO_{2\ total}$/t product	0.171	0.174	0.182	0.193	0.173	-

Increasing the organic matter in the body results in an increased flow of fumes and a decrease in CO_2 content. As far as the emission rate of CO_2 is concerned, the values obtained for the different scenarios ranged from 0.17 and 0.19 t CO_2/t fired product, increasing with the higher organic matter of the bodies. This result is in agreement with the ICE inventory for fired clay products where a CO_2 emission rate of 0.23 t CO_2/t fired product is reported (Hammond and Craig, 2011). It is worth noting that CO_2 from the combustion of organic matter or biomass is counted as zero in terms of communication of emissions of greenhouse gases. The actual emission rate for the OP6 scenario decreases to 0.149 t CO_2/t fired product, which represents a reduction of 13 % compared to the base RB scenario.

4. Conclusions

As a result of the work performed, we can say that it is possible to reach energy savings by partially substituting clay with the wastes from the olive oil industry in the production of fired clay units.
Including biomass results in a reduction of gas consumption in the preheating zone ranging from 14 % for the OOW scenario (body with olive oil washing water) to 84 % for the OP6 scenario (body with 6 % olive pomace). These savings represent 2.9 and 18 % of the total gas consumption in each case.
The CO_2 emission rates increase as the content of biomass is increased as follows: 0.171, 0.174, 0.182, 0.193 t CO_2/t fired product for RB, OOW, OP3 and OP6 scenarios. However, the actual emission rate is lower due to the CO_2 of biomass origin, with 0.007, 0.022 and 0.044 t CO_2/t fired product.
As a final conclusion, although the introduction of wastes from the oil industry modified various operating variables and properties of the end product, the new values are within the normal range for these parameters. Also, an important fuel savings can be attained for scenarios considering washing water and olive pomace. This will be beneficial from an environmental point of view.

Acknowledgments

José A. de la Casa is grateful to the University of Jaén (Plan de Apoyo) for partial financing of this work.

References

Álvarez J., Sáez V., Jiménez J., Cintas J.M., Laguna J.A., 2012, Tools for energy optimization in the manufacture of ceramic materials, Fundación Innovarcilla, Bailén, Jaén, Spain <innovarcilla.es/servicios/servicios-avanzados/procesos-productivos>, accessed 03.04.2016.
de la Casa J.A., Castro E., 2014, Recycling of washed olive pomace ash for fired clay brick manufacturing, Construction and Building Materials, 61(0), 320–326.
de la Casa J.A., Lorite M., Jiménez J., Castro E., 2009, Valorisation of wastewater from two-phase olive oil extraction in fired clay brick production, Journal of Hazardous Materials, 169(1–3), 271–278.
de la Casa J.A., Romero I., Jiménez J., Castro E., 2012, Fired clay masonry units production incorporating two-phase olive mill waste (alperujo), Ceramics International, 38(6), 5027–5037.
Hammond G., Craig J., 2011, Inventory of Carbon & Energy (ICE) version 2.0, University of Bath, UK, <web.mit.edu/2.813/www/readings/ICEv2.pdf.old>, accessed 03.04.2016.
Monteiro S.N., Vieira C.M.F., 2014, On the production of fired clay bricks from waste materials: A critical update, Construction and Building Materials, 68(0), 599–610.
Phonphuak N., Kanyakam S., Chindaprasirt P., 2016, Utilization of waste glass to enhance physical–mechanical properties of fired clay brick, Journal of Cleaner Production, 112, 3057–3062.
Ponce G.H.S.F., Miranda J.C.C., Maciel Filho R., de Andrade R.R., Wolf Maciel M.R., 2015, Simulation, analysis and optimization of sugar concentration in an *in situ* gas stripping fermentation process for bioethanol production, Chemical Engineering Transactions, 43, 319–324.
Rentz O., Schmittinger A., Jochum R., Schultmann F., 2001, Exemplary Investigation into the State of Practical Realisation of Integrated Environmental Protection within the Ceramics Industry under Observance of the IPPC-Directive and the Development of BAT Reference Documents, French- German Institute for Environmental Research, University of Karlsruhe, Germany, 44–52.
Tehzeeb A.H., 2013, Evaluation of brick kiln performances using Computational Fluid Dynamics (CFD). PhD Thesis. RMIT University, Melbourne, Australia.
Van-Dal É.S., Bouallou C., 2013, Design and simulation of a methanol production plant from CO_2 hydrogenation, Journal of Cleaner Production, 57, 38–45.
Wiemes L., Pawlowsky U., Mymrin V., 2017, Incorporation of industrial wastes as raw materials in brick's formulation, Journal of Cleaner Production, 142, 69–77.