EXPERIMENTAL STUDY OF THERMAL REGENERATION OF FOUNDRY SAND IN A FLUIDIZED BED INCINERATOR

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Abstract. Successive cost increases in industrial solid waste disposal has caused the increasing necessity of foundry sand regeneration. Such fact had induced to new process development for sand regeneration in foundry industries, in order to reuse it. Among the sand regeneration processes there is the thermal treatment in fluidized beds that requires further investigations concerning process control and optimization. Sand regeneration for chemically bonded sand consists basically on the remotion of the organic compound used as a binder at core making process. The present work shows an experimental analysis of the thermal regeneration process of foundry sand in a fluidized bed combustor throught the determination of solid properties before and after the incineration process and comparing with the new sand properties. The experimental system consists of a fluidized bed combustor where the temperature is mantained at 750°C by burning liquefied petroleum gas. Tests were done at steady state condition, with chemically bonded sand containing about 5% of organic compounds. Results showed that the reclaimed sand presented the necessary properties for its reutilization.

Keywords: fluidized bed incineration, thermal regeneration, foundry sand, reclaimed sand, core sand

1. Introduction

Foundry industries are developing new processes for treatment and recycling core sand due to the increasingly disposal costs in industrial waste landfills. There is an increasing concern in this industrial sector that minimizing the amount of waste produced and reducing its hazardous degree with new methods of foundry sand regeneration are of great interest for the industry and for the environment. According to the Brazilian Association of Foundry (ABIFA) – Environment Commission (1999), the amount of sand disposed by foundry industry are around 1 million ton/year.

The classification of foundry sand, as an industrial waste, generates conflicts between the foundry industries and inspection and regulation organizations. According to McCombe (1996) there are interests from the foundry industry to classify the sand as an inert material, resulting in lower costs of handling and disposal. However, there are two possible sources of contamination, which would classify foundry sand hazardous waste. Resins from bonding system that can contain organic or inorganic compounds, such as phenol and sodium silicate and the presence of heavy metals produced during pouring stage.

Financial questions can be the principal reason for implementing a treatment system of foundry sand produced in excess by the industry. In the São Paulo State the cost for disposal of hazardous waste is up to R$180.00/t (Mariotto, 2000).

Technical, economical and environmental questions shall be considered when deciding for a treatment process of the excesses of foundry sand. For example, type of sand, characteristics of the bonding, environmental regulations and types of casting parts produced (Lewandowski *et al.*, 1996).

Hayes (1993) presented a study which summarizes the type of treatment more adequate to the type of resin, organic or inorganic, and Diehl (1998) presented a guide which helps to choose the better treatment system taking account the type of bonded material in sand; the type and complexity of the equipment for treatment and the level of purity of the sand to be treated.

Fluidized bed is a developed and successful technology for incineration of hazardous wastes; however, in the scientific literature there are few studies related with treatment and recycling of foundry sand. Nowadays there are commercially operational equipment which demonstrates that such systems are efficient. However, according to Lewandowski *et al.* (1996) while laboratory tests resulted successful, in most cases, when scaled-up for an industrial scale, they can present some deficiencies not mentioned before.

This study intends to evaluate the thermal incineration of foundry sand in fluidized bed equipment using liquefied petroleum gas (LPG) as combustible. The choice for a fluidized bed incinerator is related to the presence of organic bending wastes, which can only be retreated from the sand surface by thermal process (Ellinghaus *et al.*, 1998).

Cobett (2002) listed important physical and chemical properties of foundry sand, which shall be controlled or monitored in order to guarantee commercial and technical acceptance. The properties are: grain shape; size distribution; thinness index; permeability; density; thermal expansion coefficient; chemical composition; loss on ignition; pH and fusion point.

In this paper, experimental results for foundry sand are presented (grain size, size distribution, density, shape factor, moisture content) and tensile strength tests for disposed sand from thermal process in a fluidized bed incinerator. Organic resin-bonded sand was provided by a foundry industry located around Campinas in the state of São Paulo. We compared physical and chemical properties of core sand, new sand and reclaimed sand, in order to obtain more information about the fluidized bed incineration process.

2. Experimental System

The experimental system is shown in Fig. 1, which consists basically of a bin containing chemically bonded-sand particles (1); screw feeder (2); fluidized bed combustor (3); cyclone (4); conic valve (5); fluidized bed heat exchanger (6); and data acquisition system (7).

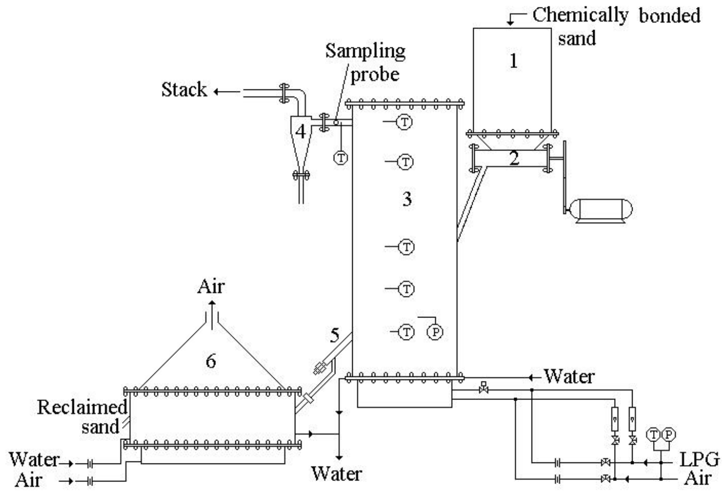


Figure 1. Flow diagram of the experimental setup

Measures were conducted at steady state regime for fixed air, LPG and solid mass flow rates ($3.44.10^{-3}$; $1.94.10^{-4}$ and $6.1.10^{-3}$kg/s, respectively). The fluidized bed temperature was maintained at 750°C. The combustor (0.900m height and 0.310m internal diameter) has a distributor plate cooled by water. The combustible was liquefied petroleum gas (LPG) introduced inside the combustor through 19 tuyere injectors. More information regarding the experimental setup can be found in Galvani (1991).

The solid material inside the fluidized bed was controlled by pressure measurements. The sand particles flow rate was controlled by the screw feeder and by the conical valve at the combustor solid outlet. Gas emissions measurements (CO e CO_2) were made in order to control the combustion process and they are not analyzed at the present work.

The foundry sand was provided by a foundry industry as waste core not used at the pouring process, with 5% of organic resin in composition. After a comminuting process, sand particles presenting Sauter mean diameter around 170µm were feed inside the bin. Measures on size distribution, pH, loss on ignition, moisture content, density and shape factor were made for the new sand, core sand and reclaimed sand. It was also made test bar from the reclaimed sand in order to verify the mechanical properties at the industrial operation conditions.

The superficial gas velocity in the experiments was 0.14m/s, the bed pressure drop was 5kPa and the solid material remaining in the combustor was 58 kg.

3. Methodology

3.1. Foundry sand characterization

In this work the regenerated sand quality was evaluated by analysis of its characteristics, before and after regeneration, and comparing with characteristics of new sand. Sand from two different points of the casting process of an industry located around Campinas were characterized and denominated as follow:

- New sand: base sand or sand from mining;
- Waste core sand: core bonded with organic resin, which had been disposed before the pouring process due to non-conformity problems.

The particles size distribution of core sand after the comminuting process was determined by sieving analysis. Procedure for the test is in agreement with Brazilian Foundry Association – Commission of Raw Material Study (ABIFA – CEMP – 081). Mean particle diameter (d_p) was calculated by Sauter method, Eq. (1) (Kunii and Levenspiel, 1991).

$$\overline{dp} = \frac{1}{\sum_i \frac{x_i}{dp_i}} \tag{1}$$

Where x_i is the mass fraction of solid particles with diameter dp_i.

Graphically, mean particle diameter distribution of foundry sand was expressed by a function of mass fraction retained in each sieve. Thinness index (M), used by Foundry Industries to evaluate size distribution, was calculated according procedure described by Mariotto (2000):

$$M = \frac{\sum (m_i * AFS_i)}{\sum m_i} \tag{2}$$

Where m_i is the amount of material retained in the 'i' sieve and AFS_i represents a randomly coefficient defined for each size distribution range by American Foundrymen's Society (Zanetti and Fiore, 2002).

An important parameter is the density of sand used to specify fluidization conditions. In this study density was evaluated through a picnometer.

Grain shape of sand particles was obtained by scanning electronic microscopy (SEM). Test results, specifically shape factor and presence of bonding material on the grain surface, provided qualitative information to characterize the studied foundry sand.

Particle shape factor was estimated following procedure proposed by Peçanha and Massarani (1986). This procedure considers the ratio of inscribed (d_{ins}) and circumscribed (d_{circ}) diameter of particles visualized in the micrographies, according Eq. (3), which provides errors up to 7%, as commented by the authors.

$$\phi = \frac{d_{ins}}{d_{circ}} \tag{3}$$

The content of moisture in samples of sand was evaluated by methodology from *American Society for Testing and Materials* – ASTM, procedures D 3173 to D 3175 (1988).

3.2. Loss on ignition (LOI)

Loss on ignition (LOI) was evaluated in an oven with temperature between 900 and 980ºC during 2 hours. It was used approximately 1 gram of dried material. The applied methodology was in agreement with recommendation of Brazilian Foundry Association – Commission of Raw Material Study (ABIFA – CEMP – 120). Loss on ignition test can be used as an indicator of destruction efficiency of phenolic resin, according expression proposed by Mariotto (2000). This expression compares loss on ignition test results from waste and reclaimed sand:

$$LOI = \left[\frac{(LOI_w - LOI_r)}{LOI_w} \right] * 100 \quad [\%] \tag{4}$$

Sub-indexes w and r correspond to waste and reclaimed sand, respectively.

3.3. pH

The pH tests were used to evaluate chemical behavior of sand, indicating if acid or alkaline. pH values can indicate the presence of soluble ions of H^+ and OH^-, such ions can react with components of phenolic resins causing different results. pH tests followed methodology recommended by Brazilian Foundry Association – Commission of Raw Material Study (ABIFA – CEMP – 121).

3.4. Tensile Strength

Mechanical properties of regenerated sand were evaluated by tensile strength tests in standard samples. A mixture of 4.2 kg of reclaimed sand with 0.6% of resin in sand weight had been prepared in a powder mixer. Resins were mixed with sand, separately; the first resin added to the mixture was the phenolic resin, 102 seconds after begging of mixing process, a compound of polymeric isocianate were added and mixed for more 102 seconds. The standard mixture was used to manufacturing the samples; in this stage a catalyser was added to promote reactions to cure resins. The process of adding catalyst to the mixture is defined as gas cured process.

Samples made from the standard mixture were manufactured during different intervals of time. The following tests were evaluated in each sample: shelf life; tensile strength after 24 hours; tensile strength after 24 hours in a wet chamber and; bench life. Each one of the tests had a specific objective:

- Shelf life test: it consists of samples breaking just after gas cured system. This test simulates the core extraction from the machine and its handling;
- Tensile strength after 24 hours and after 24 hours in a wet chamber tests: it consists of samples breaking which had been storied in laboratory for a period of 24 hours after gas cured system. This test simulates the core storage before use. The wet chamber represents the condition for tensile strength in an atmosphere with high quantity of moisture.
- Bench life: this test predicts the limit of time in which a standard mixture of sand can be handling, before gas cured process and without significant losses of its mechanical properties.

Testing methodology for determination of moisture, loss on ignition, pH and tensile strength were conducted in the laboratory of the Company which supplied sand to this study.

4. Results

4.1. Particle size distribution

Tables 1 and 2 show particle size distribution of new sand and reclaimed sand in the thermal process, respectively. Values of coefficients that were used to calculate the thickness index are presented. Figure 2 presents sieving data of new and reclaimed sand. Results show that there is no significant difference between the mean diameters of these materials. So, we can predict no significant changes on fluid dynamic behavior of the fluidized bed incinerator, such as minimum fluidization velocity.

Table 1. Particle size distribution for new sand

Aperture [mesh]	Aperture [mm]	dp_i [mm]	m_i [g]	x_i [%]	Coefficient AFS_i	x_i/dp_i	m_i *AFS_i
30	0.590	0.715	0.00	0.00	20	0.00	0.00
40	0.420	0.505	0.22	0.43	30	0.01	6.48
50	0.297	0.359	0.96	1.92	40	0.05	38.29
70	0.210	0.254	8.12	16.27	50	0.64	406.05
100	0.149	0.180	27.90	55.90	70	3.11	1952.77
140	0.105	0.127	10.53	21.10	100	1.62	1052.93
200	0.075	0.090	2.07	4.14	140	0.46	289.43
270	0.053	0.064	0.11	0.23	200	0.04	22.53
fundo	fundo	0.027	0.00	0.00	300	0.00	0.00
Σ	-	-	49.90	1.00	-	5.98	3768.48
Thinness index, M [%]				75.52			
Fines concentration [%]				4.37			
Granulometric concentration [%]				93.28			
Mean particles diameter [mm]				0.167			

Table 2. Particle size distribution for reclaimed sand

Aperture [mesh]	Aperture [mm]	dp_i [mm]	m_i [g]	x_i [%]	Coefficient AFS_i	x_i/dp_i	m_i *AFS_i
30	0.590	0.715	0.00	0.00	20	0.00	0.00
40	0.420	0.505	0.10	0.21	30	0.00	6.15
50	0.297	0.359	0.52	1.05	40	0.03	41.81
70	0.210	0.254	6.13	12.32	50	0.49	615.93
100	0.149	0.180	29.04	58.38	70	3.25	4086.36
140	0.105	0.127	12.26	24.65	100	1.94	2464.52
200	0.075	0.090	1.68	3.38	140	0.38	473.65
270	0.053	0.064	0.01	0.03	200	0.00	5.23
fundo	fundo	0.027	0.00	0.00	300	0.00	0.00
Σ	-	-		100	-	6.09	7693.64
Thinness index, M [%]				76.94			
Fines concentration [%]				3.41			
Granulometric concentration [%]				95.34			
Mean particles diameter [mm]				0.164			

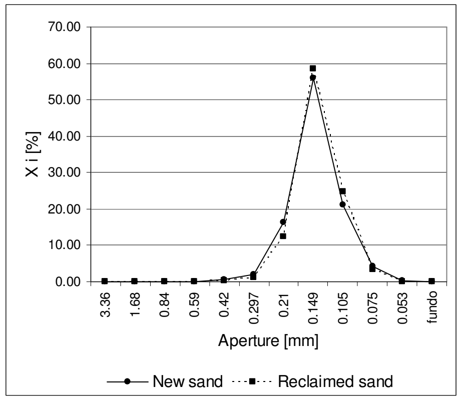
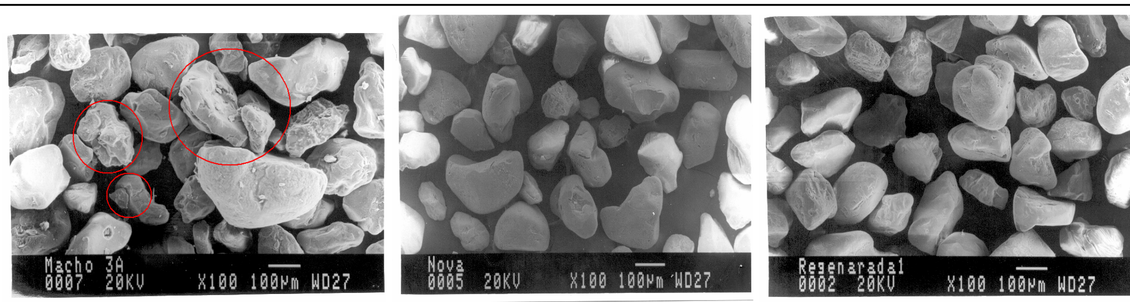


Figure 2. Particle size distribution for new and reclaimed sand

It was verified that reclaimed sand has the same classification of new sand with regard to thinness index, AFS, both in the range of 70 and 80. According to Tilch (1997) one of the problems related with reuse of waste sand is the great quantity of very fine particles, typical characteristic of mechanical recovery. Reduction in the amount of very fine particles brings economical advantages, because of the lower consumption of bonding resin due to specific surface area reduction (Mankosa et al., 1997). Another observation is that regenerated sand is slightly more homogeneous than new sand, because it presents particle concentration in a narrow range of diameters, although this difference is not significant.

4.2. Morfology

One of the objectives of this study is to give back natural characteristics to the waste sand, making possible its reutilization by the process of manufacturing new cores, in substitution of new sand. According to Leidel (1994) the objective of foundry sand regeneration is reestablishing the initial condition of grain surface. This reestablishment can be defined as the efficiency of regeneration system. SEM analysis is an useful equipment used to evaluate regeneration efficiency. Micrographies are used to evaluate superficial aspects of grain surface. Fig. 3(a) to (c) show thermal capacity of sand regeneration. It can be observed in Fig. 3(a) that phenolic resin layer and bonding among grains, after milling process of disposed cores, showing that, mechanical treatment does not guarantee complete withdraw of resin from the grain surface, indicating that mechanical recovery of foundry sand is not an efficient process.



(a) (b) (c)

Figure 3. Foundry sand particles (a) waste sand (b) new sand (c) reclaimed sand

It was observed that reclaimed sand presents a rounded surface when compared with new sand; inducing to lower consumption of resin, because of the surface area reduction (Philbin, 1995). Heat treatment and milling process do not increase porosity or cracks of grains although there are several particles impacts in these processes. Porosity and cracks could increase the resin and catalyst consumption, as observed by Magnani *et al.* (1998).

4.3. Loss on ignition, pH, moisture, density and shape factor

Results from analytical tests are presented in Tab. 3. Tests were evaluated in the Laboratories of the Foundry Industry which supplied sand for the tests. Results obtained from Eq. (3) for the particle shape factor are also presented. Tests were evaluated according to the methodology described before.

Table 3. Results of the analytical tests

	pH [-]	LOI [%]	moisture content [%]	density [kg/m³]	shape factor [-]
New sand	6.5 a 7.5	0.07	0	2717	0.589
Waste core sand	-	1.72	-	-	0.630
Reclaimed sand	6.7	0.14	0.007%	2774	0.734

PH test results are important in the evaluation of sand compatibility with applied resins. Reclaimed sand is acceptable depending of pH results, which shall be in the specified range defined by industry which will use it. There is not an ideal value for new or regenerated sand pH, nevertheless, according to Ziegler (1994), a value of 7.0 (neutral) for pH is compatible with the most agglomeration systems. Blackburn (1997) analyzed the pH of thermally regenerated sand with different temperatures and compared with the pH of new sand. Results showed an increase in pH value with operation temperature, from pH values of 4.4 (new sand) to 8.0 (regenerated sand at 800 ºC). This increment in pH value, according to the author, is essential in the moment of sand reuse.

Shape factor calculations confirm qualitative results from SEM analysis. An increase was observed on the sand sphericity due to mechanical and thermal treatments.

Comparing thermal regenerated and new sands, the first ones present values of loss on ignition equal or lower than the last ones. Analyzing the loss on ignition values we can estimate the efficiency of regeneration in a fluidized bed, according Eq. (4). The efficiency of regeneration in a fluidized bed with temperature of 750ºC was 92%.

Loss on ignition values on Tab. 3 of waste core sand show that comminution process alone can not remove the resin layer around sand grains. Comminution process can only to brake up sand lumps. For this sand a significant reduction was observed on the value of loss on ignition after incineration in fluidized bed.

High moisture content is responsible for problems in the mixture process of resins. According to Ziegler (1994) foundry industries request moisture content less than 0.1%. Moisture content after heat treatment presented moisture content of 0.007%. Peixoto and Guesser (2003) obtained a value of 0.01% of moisture content for thermally regenerated sand.

4.4. Tensile strenght tests of cores

Figure 4 presents the results of tensile strength tests. We can see that samples made from new sand and from reclaimed sand showed tensile strength values greater than the minimum specified by the process and requested by the industry. Shelf life results from reclaimed sand are greater than results for new sand. Viana (2003) found similar behavior for shelf life test in a study about thermal regeneration in a rotary oven. This result indicates that reclaimed sand allows the production of cores with good tensile strength to be handled after the manufacturing process.

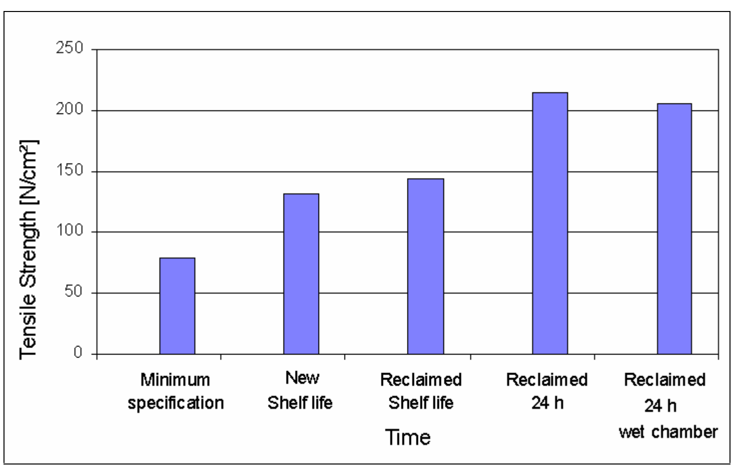


Figure 4. Tensile strength results

We can presume that greater values for core strength are related with particle size diameter distribution of regenerated sand. Particles with lower content of fines and greater concentration of particle size diameter distribution demand lower consumption of resins because of few quantities of interstices among grains. Additional tests with greater concentration of resins with different values from the present study could confirm this statement, in such a way to have cores with tensile strength values according to requested by industry, resulting in lower consumption of organic resin. Bauch (1990) obtained similar shelf life results using reclaimed sand with 10% less organic resins than standard mixture, indicating that core manufacturing with reclaimed sand can be done with lower consumption of resin.

Tensile strength results after 24 hours (in dry and wet chamber) show that samples made from reclaimed sand present greater values than shelf life results and also presents greater values than the minimum specified by industry. According to Ellinghaus *et al.* (1998) the values for tensile strength after 24 hours have a normal tendency for reduction, nevertheless, different behavior was observed as showed in Fig. 4. Results presented by Stahl (1994) are in agreement with the present study, but the author had not presented an explanation for this fact. We believe that this behavior is related to chemical reactions with resins, but further studies are necessary.

Figure 5 presents results of bench life for reclaimed sand, new sand and minimum tensile strength necessary for industrial process. It was observed that reclaimed sand presents the same behavior of new sand, with reduction of tensile strength, after mixture preparation. This reduction in tensile strength is more accentuated on the first 30 minutes after organic resin addition and mixture. This result is in agreement with literature, according Diehl (1998) and Peixoto and Guesser (2003). Results obtained are in the acceptance range, always beyond minimum limit requested by industry, indicating that thermally regenerated sand in fluidized bed is a successful process for foundry industry.

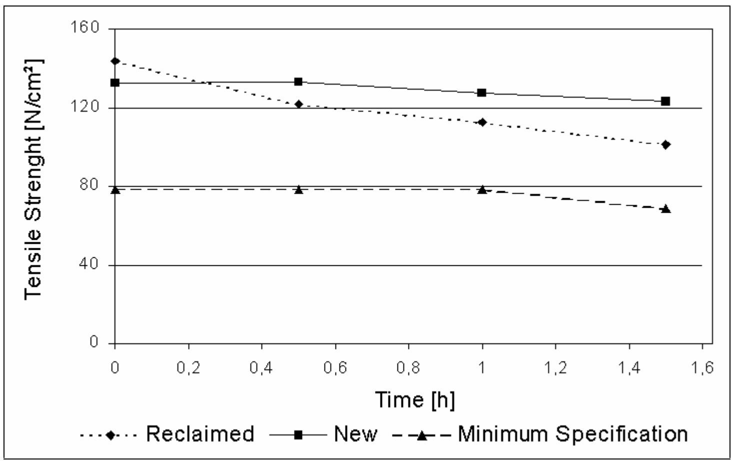


Figure 5. Bench life results

5. Conclusions

The main objective of this work was to analyze sand properties after thermal processing of waste foundry sand in a fluidized bed incinerator in order to verify their influence in the core process. Conclusions can be resumed as follow:

- There was not a significant variation between densities of new and reclaimed sand;
- Both comminution and incineration processes affect grain shape, modifying particle sphericity. Greater rounding of grain sand was observed after each one of these process;
- Physical processes, like comminution, were not enough to promote the withdraw of resin layer from sand grain;
- A significant change was not observed on the mean particle diameter after comminution and after incineration processes of reclaimed sand, when compared with new sand;
- The pH of reclaimed sand was not modified by heat treatment;
- Reclaimed sand presented better results than new sand for shelf life and tensile strength after 24 hours (for dry and wet chamber);
- Bench life results showed that reclaimed sand presented a more accentuated tensile strength reduction on the first 30 minutes after mixture preparation; however the results were good enough for industry.

The obtained results are considered initials, but they provide important parameters that can indicate thermal regeneration of core sand as an efficient method for sand reuse. Further research about the studied treatment is important in order to obtain information about volatile organic compounds (VOCs) emissions and gas-solid suspension fluid-dynamics as a function of operational factors. On top of this information, an economical analysis of the process is necessary, for evaluation of the industrial feasibility of fluidized bed incineration of core sand.

6. Acknowledgements

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