

ENERGETIC AND ENVIRONMENTAL ANALYSIS OF THE DRYING OF MINERAL WITH THE USE OF RESIDUAL GASES

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Abstract— In the present research, the energetic and environmental analysis of the lateritic ore drying process in a horizontal rotary kiln it carried out. It aims to assess the feasibility of the use of gases products of the ore reduction process in vertical furnaces. In addition, it is analyzed the energetic and environmental impact of the use of these gases as energy sources. In order to meet the objectives outlined, measurements were taken at the facility, obtaining the main operating parameters. It was also applied the balance and energy methods to verify that the use of the waste gases brings to the process the 18 % of the energy required and reduces in a 26 % the fuel consumption.

Keywords— rotary drying, energy efficiency, lateritic minerals, waste gases.

I. INTRODUCTION

Drying is the process by which the extraction of all or part of the contained moisture of a substance is carried out, obtaining a product different from the initial one, either as final product or as intermediate in a manufacturing process. It is undoubtedly one of the oldest processes and elaborations made by man to which are subjected a number products during the processing stages.

Drying in rotary horizontal kilns is one of the most used methods in industries: In this process occurs simultaneously the transfer of color and mass (Fernandes *et al.*, 2009; Montero 2005) in which high temperatures are required to evaporate the water contained in the product to be dried (Vermeulen *et al.*, 2012). These facilities are known to be large energy consumers and Inefficient. In this respect, Strumillo *et al.* (1995) states that 12% of the world energy consumption at industrial level is destined to the drying processes. On the other hand Retirado *et al.* (2007) and Vinardell (2011) determined, based on analysis of annual economic reports in nickel and cobalt producing companies, that about 20% of the energy consumed in the respective metallurgical industry is used in the drying process. Other important characteristics in these facilities are the environmental impact, which, when using large amounts of fuel (such as coal, fuel-oil or gas), generate large volumes of gases composed of carbon dioxide, carbon monoxide and sulfur dioxide are discharged into the environment (Haque and Somerville, 2013).

In the present investigation is performed the energetic

and environmental analysis of the lateritic mineral drying process carried out in a horizontal rotary kiln. It aims to relate the efficiency parameters (thermal efficiency, fuel consumption and dryer productivity) to the environmental impact associated with the discharges of pollutant gases into the atmosphere.

The company where the object of study is located, is based on the ammonium carbonate technology for the production of nickel plus cobalt. This technology is distinguished by the use of equipment such as multiple hearth furnaces, thickeners and distillation columns (Góngora *et al.* 2012).

In this scheme, the mineral is obtained from several processes, which begin with the extraction of the lateritic minerals in the open pit mines which are incorporated into the technological flow through the mineral preparation plant where the object of study is found (Retirado 2012). From this process, the ore circulates through different basic production unit (reduction furnace plant, leaching and washing, nickel sulphide plus cobalt precipitation and recovery) until reaching the calcining and sintering plant, where the process culminates with the production of sintered nickel oxide; nickel powder oxide; and nickel sulphide plus cobalt, see Fig. 1.

Within this process the ore is selectively reduced in vertical hearth furnaces. These furnaces are formed internally by 17 hearths that have the shape of spherical vaults through which the mineral passes from the hearths zero to 17 (Montero *et al.* 2015).

The mixture of minerals once inside the furnace is subjected to the reduction process, which is achieved by establishing a temperature profile and a determined concentration of reducing gases (CO and H₂). For this,

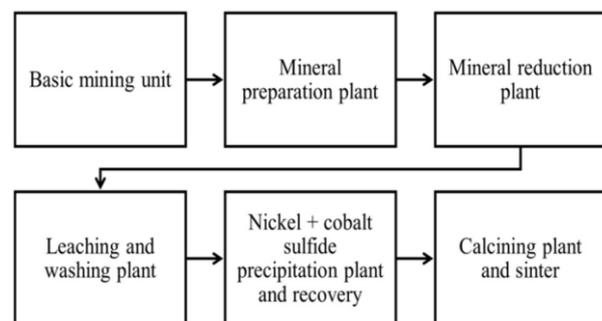


Figure 1. Schematic of the technological process of ammonium carbonate leaching.

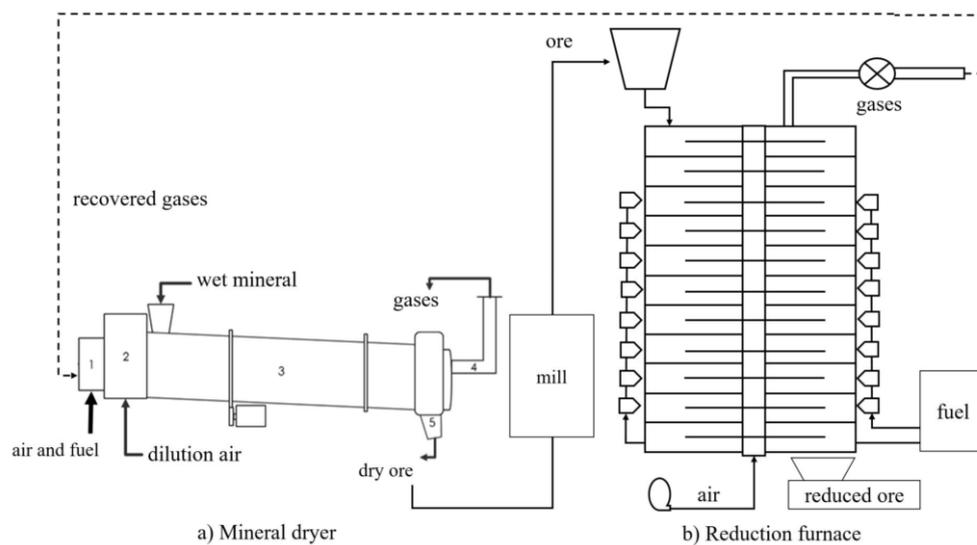


Figure 2. Schematic of regenerative gas reduction kilns.

the furnace has 10 combustion chambers with burners of high pressure for the incomplete combustion of the fuel, which also allows the temperature profile to enrich the atmosphere with reducing gases (Fig. 2b).

Initially, in the design of these processes, the gases were expelled into the atmosphere after passing them through electro-filters to reduce the emissions of the dust and polluting gases generated during the respective process. Currently, the gases produced during the reduction process are sent to the combustion chamber of the dryers, taking advantage of the high temperatures (250 to 300 °C) that these gases have in the drying process. It is evident that this recovered energy source is beneficial for drying since it reduces the fuel consumption and the amount of polluting gases in the atmosphere.

By recirculating the gases from the reduction furnaces to the combustion chamber of the dryers, the volatile compounds in the gas mixtures (H_2 , CH_4 and CO) continue to react and release heat. On the other hand, by using this gas volume, which was previously expelled to the atmosphere, they stop producing approximately that same gas volume from the fuel combustion in the mineral dryers burners.

A. Description of the installation

The dryer studied is composed of a combustion chamber (1), which is supplied with fuel, combustion air and waste gases from the ore reduction furnaces. The gases generated as a result of combustion are sent to the passage chamber (2) where they are mixed with more excess air to increase the volume of gases for ore drying.

The combustion gases inside the chamber reach temperatures of approximately 1500°C and when they get into contact with the air and the gases that come from the reduction ovens, they are cooled to 800°C. At this temperature the gases enter the drum, so that the contact with the hot gases and the mineral allows the latter to reduce its moisture content to a value close to 3%.

The rotating drum (3) is 5.4 m in diameter and 40 m

in length with an inclination angle of 15 degrees with respect to the horizontal plane to facilitate the mixing and transport of the material (Uboho *et al.*, 2013) from the entrance to the exit of the drum (Fig. 2a).

In the inner part of the cylinder, a series of welded fins are arranged to favor the material elevation and rotation while the cylinder rotates supported on the rollers, allowing a better contact between the solid and the hot gas mixture.

The gases leaving the dryer are sucked by a fan located at the exit of the dryers driving the gases towards the electro-filters that each dryer individually has. These gases carry about 36 % of the dust that enters along with the mineral or that forms during the drying process, which generally has a granulometry of 0.074 mm.

The main variables recorded during the drying process and the operation range in which the object of study works are shown in Table 1.

Table 1. Main variables that are recorded in the drying process and operating range.

Process variables	Value	Unit
Wet mineral flow	100-120	t/h
Dry Mineral Flow	80-90	t/h
Fuel flow	2-2.5	t/h
Kiln gas flow	23-27	t/h
Temperature of Gases in the chamber	1200-1500	°C
Temperature of Furnace gases	250-300	°C
Temperature of Dry ore	60-80	°C
Atmosphere Temperature	22-35	°C
Temperature of the gases at the outlet	90-100	°C
Humidity at the entrance (wet base)	35-40	%
Rotation speed	6	rpm
Moisture at outlet	3-5	%
Properties of the fuel used in the process		
Lower calorific value	44204.9	kJ/kg
Chemical composition (%)		
C=85.54; S=2; H=10.9; A=0.01; N ₂ =0.7; W=0.05; O ₂ =0.8		

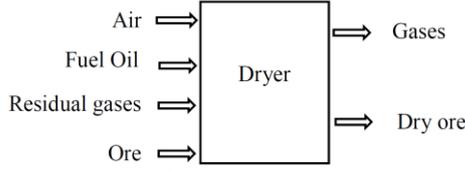


Figure 3. Main process flows.

II. METHODS

Calculations for the thermo-energetic study of the lateritic ore drying process are based on the fundamental principle of energy and matter balance. In addition, to obtain the main operating parameters of the object of study, the passive experimentation method (Montgomery 2004; Legrá and Silva 2011) was performed due to the uninterrupted production regime in which the installation is located.

A. Mineral drying model

In order to establish the equilibrium equations for ore drying, the system is examined as a black box, analyzing the input, output, and environment variables in the system. Figure 3 is the simplified representation of the system studied with the main genetic sources that enter and exit in the drying process.

Starting from the analysis of Fig. 3 and the adjustment of the second law of thermodynamics in which it is defined that thermal efficiency is equal to useful works divided by the heat supplied to the process, Eq. 1 is obtained. To set such equation it was assumed that the useful work in the installation is the heat used to dry the mineral that enters the dryer, and that the supplied heat is the sum of all the heat sources included in the process.

$$\eta_t = \frac{Q_{va}}{Q_c + Q_{fa} + Q_{mh} + Q_{gh}}. \quad (1)$$

B. Heat used to dry the mineral

To determine the heat used to dry the mineral, the following Eq. 2 is used. It takes into account the latent water vaporization heat and the flow of steam extracted from the mineral.

$$Q_{va} = \dot{m}_{mh} h_{fg} (W_{em} - W_{sm}). \quad (2)$$

The heat supplied by the fuel is the main source of energy supplied to the drying process. It is determined by the caloric power of the fuel and the fuel's physical heat (Eq. 3).

$$Q_c = Q_{fc} + Q_b^t \dot{m}_c. \quad (3)$$

The fuel's physical heat is determined by the following Eq. (4)

$$Q_{fc} = \dot{m}_c C_c T_c. \quad (4)$$

The specific heat of the liquid fuels (C_c) can be determined according to Eq. (5) (Perry 1985).

$$C_c = 1.783 + 0.0025T_c. \quad (5)$$

C. Heat from furnace waste gases

Another source of heat used in the drying process is the heat supplied through the waste gases from the reduction furnaces. This was estimated from the sum of the specific heats and the mass flow of each element that composes the gas by the temperature of the gas (Eq. 6).

$$Q_{gh} = T_{gh} \sum C p_i \dot{m}_i. \quad (6)$$

Expressions to determine the specific heats of each gas element were taken according to Perry (1985).

D. Heat contributed by coal

The heat supplied by the wet mineral is determined through Eq. (7), which depends on the productivity of the dryer and the thermo-physical properties of the mineral.

$$Q_{mh} = \dot{m}_{mh} C_{pmh} T_{mh}. \quad (7)$$

E. Heat provided by air

The physical heat supplied by the air for the combustion and for the dilution of gases resultant from the combustion is determined through Eq. (8). The air flows enter the system at room temperature, so it is the temperature value used for the calculation of the heats supplied by the air (combustion and dilution). In the same way, it should be noted that the specific heat would also be the same for both cases.

$$Q_{fa} = (\dot{m}_{ac} + \dot{m}_{ad}) C_{pac} T_a. \quad (8)$$

III. RESULTS AND DISCUSSION

To establish the energetic behavior of the object of study, based on the calculation method proposed in Section II, it was used the passive method for experimentation, taking the values of the main variables that intervene in the process directly from production without changing or modifying anything in the installation.

The experimentation was carried out in a period of 22 consecutive days, during the entire work shift of the object of study. Of the measurements obtained, only the daily averages were taken into account.

A. Thermal performance

One of the main parameters taken into account for the analysis of these facilities is the thermal performance. As shown in Fig. 4, it can be seen that it ranges from 34 to 58%. The results obtained from the thermal performance matches up with what was planned by Fito *et al.* (2002), which affirm that the thermal performance of cylindrical dryers vary between 30 and 45 %, although in several occasions the thermal performance obtained in the installation exceeds 45 %.

In this parameter, several variables have a significant influence, the fundamental ones are the humidity of the entrance and exit of the laterite ore and the fuel consumption. These variables have a direct algebraic relationship since with an increase of the first one, you must increase the fuel consumption if you want to maintain a certain output humidity value which, in turn, causes the yield to decrease.

B. Consumption index

The behavior of the drying process has a direct relationship with the fuel consumption per ton of dry laterite ore, which is expressed through the consumption index and is determined by the following Eq. (9).

$$I_c = \frac{\dot{m}_c}{\dot{m}_{ms}}. \quad (9)$$

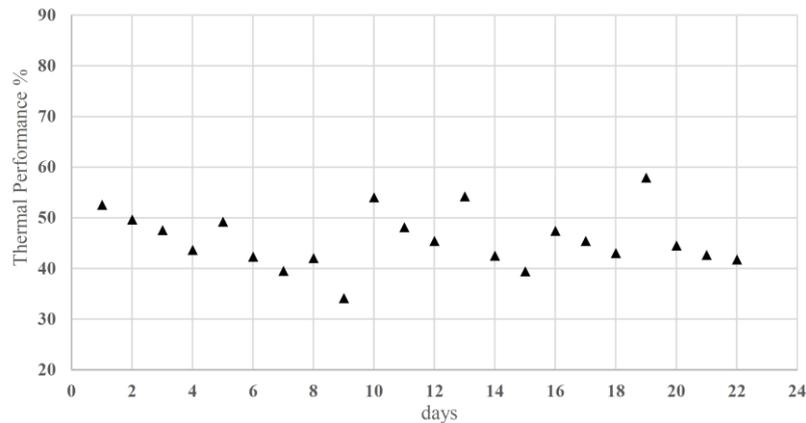


Figure 4. Thermal performance of drying process per days.

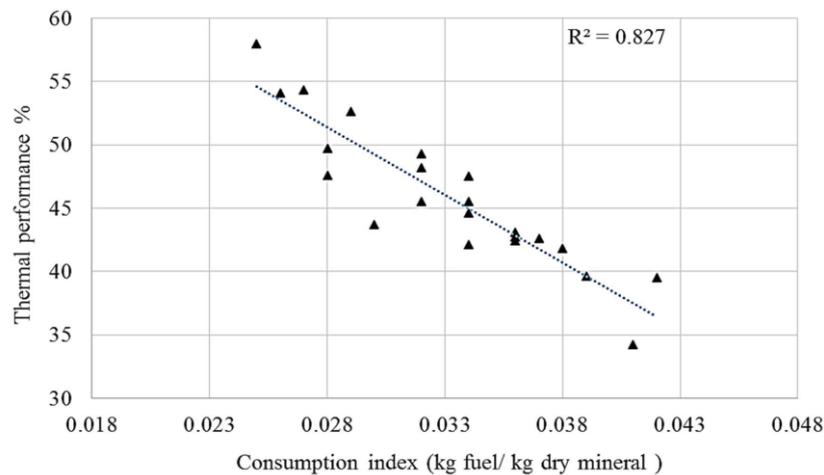


Figure 5. Ratio of thermal performance to fuel consumption index.

By means of Fig. 5, the dependence of thermal performance and the fuel consumption index for dry ore can be corroborated. It makes evident that with measures that diminish the yield, increases the index of consumption of fuel by each kg of dry mineral. In addition, it is shown a good correlation between the data presented on thermal performance and the index of fuel consumption of the dryer ($R^2 = 0.827$).

In addition, you can see that the results obtained from the consumption index vary between 0.025 and 0.041 kg fuel / kg mineral. These average values are above the standard established by the company of 0.0250 t of fuel per ton of dried ore. This behavior is due to the direct relationship between the inlet and outlet moisture of the lateritic mineral and the fuel consumption because with an increase of the first one, the fuel consumption should increase if a certain value of output moisture is to be maintained. In turn, this makes the performance to have a tendency to decrease.

C. Mineral flow

Another variable that intervenes in the process and influences the process performance is the flow of wet mineral, as well as its moisture content, which have both a directly proportional influence on the specific consumption. An increase in these variables of mineral flow favors agglomeration, the formation of pellets and, consequently,

that only superficial moisture is eliminated (Torres *et al.*, 2000). For this reason, it increases the specific consumption of oil and forces to reduce the amount of mineral added to the dryer to obtain the desired final moisture.

D. Main sources of heat

During the analysis of the main sources of energy used for the drying process, it was determined that the residual gases from the reduction furnaces represent approximately 18% of the energy used to dry the mineral.

Apparently the 18% contributed by the furnace gases is little compared to the energy delivered by the fuel which represents 71% of all the energy. But, this reduces by approximately 0.58 t/h the amount of fuel used in the combustion chamber to generate the gases required for ore drying.

This difference in fuel consumption is for the kiln analyzed. If this result is generalized to the six dryers used in the factory for the production of nickel + cobalt, it can be deduced that approximately 82 t of fuel per day are not consumed.

From the environmental point of view, a considerable benefit was obtained, since around 41 t/d of CO₂; 1.6 t/d of CH₄; and 0.32 t/d of N₂O, are no longer emitted to the environment. These values were determined by finding the fuel savings of a dryer in a day and the emission factors of polluting gases in the fuel (Table 2).

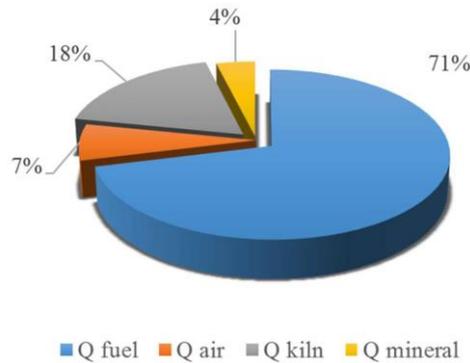


Figure 6. Main sources of energy supplied to the drying process.

Table 2. Emission factors per mass or volume unit for fossil fuel combustion.

fuel	emission factors (kg/gal)		
	CO ₂	CH ₄	N ₂
petroleum products			
fue oil	10.18	0.42	0.08

IV. CONCLUSIONS

It was determined by the thermal and mass balance that the ore dryers yield vary between 34 and 58 % due to the variability of the incoming moisture of ore and other operational factors of the process.

The new scheme in which the waste gases from the reduction process is used has many advantages, from the economic point of view, since it reduces expenses by the concept of fuel economy, reducing by 26% the fuel consumption required for ore drying.

It also reduces the effects on the environment by reducing the amount of gases emitted into the atmosphere, resulting in cleaner and more environmentally friendly productions.

NOMENCLATURE

Q_{va} :	Heat required to dry the ore; kW
Q_c :	Heat supplied by the fuel; kW
Q_{fa} :	Physical air heat; kW
Q_{mh} :	Heat supplied by moist ore; kW
Q_{gh} :	Heat from furnace waste gases; kW
Q_{fc} :	Physical heat of fuel; kW
Q_b^t :	Low calorific power; kW
h_{fg} :	Latent heat of vaporization; kJ/kg
C_c :	Specific heat of fuel; kJ / (kg·K)
C_{pmh} :	Specific heat of the wet mineral; kJ/ (kg·K)
C_{pac} :	Specific air heat; kJ/ (kg·K)
W_{em} :	Moisture of mineral input; %
W_{em} :	Mineral output moistness; %
\dot{m}_{mh} :	Wet mineral flow; kg / s
\dot{m}_c :	Fuel flow; kg / s
\dot{m}_{ms} :	Dry ore flow; kg / s
\dot{m}_{ac} :	Airflow for combustion; kg/s
\dot{m}_{ad} :	Airflow for dilution; kg/s
T_c :	Fuel temperature; K
T_{gh} :	Temperature of the waste gases from the kiln; K
T_{mh} :	Wet ore inlet temperature; K
T_a :	Air temperature; K

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