EXERGY ANALYSIS OF A CERAMIC TILE FIRING KILN

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1. INTRODUCTION

The firing stage is the ceramic tile manufacturing stage that consumes most thermal energy. To determine energy efficiency in this stage, a complete energy analysis is usually carried out of the kiln, in which all the energy flows in the process are identified and quantified. An energy analysis is based on the first principle of thermodynamics, i.e. on the law of conservation of energy, which treats all energy alike, without taking into account its quality or degradation during its transformation. Exergy is a parameter that measures energy quality and it is defined as the maximum useful work when a system is brought from its original state to one of thermodynamic equilibrium with the environment, without any other action than its own and that of the environment. This final state of equilibrium is called a dead state. In the dead state, the system reaches the temperature and pressure of its environment, and it has no kinetic energy or potential, nor does it interact with this environment. An exergy analysis uses the first and second principle of thermodynamics for the design and analysis of thermal systems. This method is appropriate for evaluating efficiency in the use of energy resources as it allows the location, type, and real magnitude of its waste and loss to be determined. Exergy analysis allows identification and quantification of the irreversibilities of the process or sources of exergy destruction, which point the way to ameliorating system operation, to thus improve the energy efficiency of the process.

2. OBJECTIVE

An exergy analysis was conducted of a single-deck roller kiln during porcelain tile firing, in which the energy and exergy of each stream, and the corresponding mass, energy, and entropy balances were calculated. By applying this analysis method, the results obtained enabled courses of action aimed at improving kiln efficiency to be undertaken.

3. METHODOLOGY

In exergy analysis, just as in energy analysis, all the streams involved in the process in a defined environment are identified and quantified.

In order to be able to perform exergy calculations, it is necessary to define an environment that is taken as a reference, i.e. which has a known temperature, pressure, and chemical composition, as exergy will always depend on the states of the system and of the environment (Dincer and Rosen, 2007; Gaggioli and Petit, 1977).

To perform the mass, energy and exergy balances in the kiln, this was thermodynamically considered to be a control volume (open system) and in the experimental measurements, the following assumptions were made:

a) The kiln operated in a steady regime.

b) The changes in kinetic energy and power in the input and output flows were deemed negligible. In addition, electric power was not taken into account because, compared with thermal energy consumption, this was insignificant.

c) Air, natural gas, and combustion gases behave as ideal gases.

d) No work was done inside the kiln, or when this was done (movement of material by means of rollers or kiln cars), its magnitude was so small that it could be considered negligible.

The exergy balance of a thermal system is given by:

$$\sum_i \dot{E}_{in,i} - \sum_j \dot{E}_{out,j} + \dot{E}_Q = \dot{E}_D \quad (1)$$

where $\dot{E}_{in,i}$ is the exergy of the incoming flows, $\dot{E}_{out,j}$ the exergy of the outgoing flows, and $\dot{E}_Q$ the exergy associated with the heat flows. $\dot{E}_D$ is the exergy destruction in the process.

4. CONCLUSIONS

The study shows that efficiency in firing porcelain tile in a single-deck roller kiln was mainly affected by exergy destruction in natural gas combustion, in heat transfer, and in combustion gases and cooling.

The experimental measurements showed that these factors accounted for more than 72% of the total exergy input into the kiln. That is, 72% of the exergy was destroyed or lost during the firing process.

To increase kiln efficiency, some operating parameters need to be controlled, such as excess combustion air, or some actions need to be implemented, such as preheating of the combustion air or the installation of recovery systems.

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