Analysis of Energy and Exergy of an Annealing Furnace

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Keywords: Energy, Exergy, Efficiency, Furnace

Abstract. Furnace is the most common and important part in metal industries. The useful concept of energy and exergy utilization is analyzed to investigate the energy and exergy efficiency, exergy losses, energy savings and cost benefit of an annealing furnace. The exergy efficiency of the combustor is found to be 47.05 %. The energy and exergy efficiencies of the annealing chamber are found to be 17.74 % and 12.86 % respectively. The overall energy and exergy efficiencies of the furnace are found to be 16.86 % and 7.30 % respectively. The annealing chamber is the major contributor for exergy destruction about 57 % of the annealing furnace. By using a heat recovery system from flue gas, about 8.11% of fuel can be saved within the payback period of less than 2 months.

NOMENCLATURE

\begin{align*}
C_p &= \text{Specific heat capacity, J/kg} \cdot ^\circ \text{C} \\
\frac{d}{dt} &= \text{Rate of change with time} \\
\dot{E} &= \text{Rate of energy} \\
h &= \text{Specific entropy, J/kg} \\
\dot{I} &= \text{Rate of exergy destruction, kJ/s} \\
m &= \text{Mass flow rate, kg/s} \\
\dot{Q} &= \text{Rate of heat transfer, kJ/s} \\
\dot{s} &= \text{Specific entropy, kJ/kg} \\
T &= \text{Temperature, } ^\circ \text{C} \\
\Delta T &= \text{Temperature drop of the flue gas, } ^\circ \text{C} \\
\dot{X} &= \text{Exergy of the system, kJ/s} \\
\end{align*}

Greek symbols

\begin{align*}
\varepsilon &= \text{Specific exergy, kJ/kg} \\
\eta &= \text{Energy efficiency} \\
\gamma &= \text{Exergy efficiency} \\
\end{align*}

Subscripts

\begin{align*}
a &= \text{Air} \\
AC &= \text{Annealing chamber} \\
AP &= \text{Annealing product} \\
C &= \text{Combustion chamber} \\
f &= \text{Fuel} \\
F &= \text{Furnace} \\
g &= \text{Flue gas} \\
in &= \text{Inlet condition} \\
O &= \text{Outlet condition} \\
o &= \text{Reference state} \\
p &= \text{Hot product after combustion} \\
r &= \text{Recovery} \\
\end{align*}

Introduction

Energy is the most important factor for automation and modernization. Automation and modernization is increasing rapidly in the industrial sectors. The industrial sector is one of the largest consumers of energy in Malaysia. Energy demand is rising with increasing degree of industrialization and population increase [1, 2]. Approximately 12% of the world energy is used in the iron and steel industry. Energy cost is about 30% of the total cost element in integrated steel works [3, 4]. Furnace is very common equipment in the metal industries and consumes a significant amount of energy [5]. Among the various iron and steel plants, furnaces are characterized by very high specific energy consumption [4]. About 36% of total heat input is lost in the furnace [6]. By free-burning areas, 10% to 15% of the energy is transferred to the furnace wall and 5% to 10% to the furnace roof [4]. The first law of thermodynamics refers to the energy analysis which only identifies the losses of energy and effective use of resources. However, the second law of thermodynamics analysis takes the entropy portion into consideration by including irreversibilities.