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Enhancement of waste heat recovery by using Cu nanoparticles in cement industries

N.A. Madlool [a,], Ali Amer A. Hadi [b]*
[a] Department of Mechanical Engineering. Faculty of Engineering
University of Kufa, Kufa-Najaf, Iraq
dr.naseer1978@gmail.com
[b]Department of Materials Engineering. Faculty of Engineering
University of Kufa, Kufa-Najaf, Iraq

Abstract—Waste heat sources in the cement plant comprise the exit gases from the pre-heater and the ejection hot air from clinker cooler. And for cogeneration power, these sources which have diverse level of temperature can be used separately or in combination. This paper aims to show the waste heat recovery significance in the clinker cooling system of cement industry. Unlike the usual process of waste heat recovery, the pipe was inserting within grate cooler to absorb a portion of the heat losses. Fluids such as water, engine oil and ethylene glycol are the fluids of conventional heat transfer and these fluids are widely used in diverse applications in the industry. It is well known that the great potential of improvement of heat transfer comes from suspended solid particles of micro size in the base fluid Cu nanoparticles at different base fluids as a working fluid were used in the recovery cycle. Engine oil indicates the best outcome of energy saving, emission reductions and cost saving among the base fluids.

Keywords—waste heat recovery; nanofluid; clinker cooler.

I. INTRODUCTION

Globally, the cement sector represents one of intensive energy consumer among the other industries. The cost of energy consumption in the cement segment signifies 20% to 40% of the total production cost. As point to preceding studies, the energy consumption is between 4 and 5 GJ/ton of cement. A considerable number of studies have been focused on the energy use and analysis in cement industry. Among them, there are very imperative and deductive papers. Madlool et al. [1] reported that the cement industry consumed about 12% and 15% of total energy in Malaysia and Iran respectively. Also Madlool et al. [2] reviewed the previous studies on energy saving, carbon dioxide emission reductions and the various technologies used to improve the energy efficiency in the cement industry. Doheim et al. [3] examined the consumption of thermal energy, losses and the potential of heat saving. Engin et al. [4] and Kabir et al. [5] implemented an analysis of energy audit for dry process. Thermodynamic analysis and cogeneration for a cement plant was presented by Khurana et al. [6]. Madlool et al. [7] emphasized the ability to recover the heat losses via convection and radiation in a grate cooler using new methods by utilizing these waste heats to heat the working fluid of a cogeneration cycle directly and indirectly. I n another article, Madlool et al. [8] determined the waste heat recovery by utilizing the waste exit gases from the pre-heater and grate cooler to generate electricity, furthermore estimation of cost saving..In Indonesia, Rasul et al. [9] assessed the thermal performance and opportunities of energy conservation. Al-Rabghi et al. [10] reviewed the waste heat recovery and its utilization in different segments of industry. Wang et al. [11] examined the waste heat recovery from the exhaust gases of pre-heater and clinker cooler using four kinds of cycles in order to cogeneration in a cement plant. Zamzamian et al. [12] investigated the coefficient of forced convective heat transfer for a double-pipe and plate heat exchangers using Al2O3-ethylene glycol and CuO-ethylene glycol nanofluids.

Most studies about waste heat recovery have only been carried out on waste gases from pre-heater and clinker cooler. It obviously needs to be studied intensively to reduce the amount of losses due to radiation and convection in the cooler. These losses can be recovered to increase the efficiency of clinker cooler.

This paper determined the energy saving which would be reflected on the reduction of energy consumption and emissions reduction. Finally, the cost saving was estimated. All the analyses and results based on the operational data for Al-Muthanna cement plant which is located in the South of Iraq.

II. WASTE HEAT RECOVERY

With the aim of reducing the consumption of energy in cement production process, the waste heats can be recovered to produce the electrical energy via cogeneration power plant. As well as no additional consumption of fuel and consequently reduce the electrical energy high cost and greenhouse emissions for cement production. In cement plant, the waste heats are classified as middle and low temperatures of waste heats and some power plants are available and well suitable for these waste heats [5]. For this analysis we will concentrate the attention to the improvement in energy recovery efficiency of the clinker cooler as it represents the theoretical opportunity for energy and cost savings.

III. ENERGY ANALYSIS

The conventional industrial process energy analysis is based on the first law of thermodynamic. Though, this analysis

represents a simple energy accounting, by means of the input energy and output energy to and from the clinker cooler are quantified.

TABLE I. ENERGY BALANCE OF CLINKER COOLER FOR AL MUTHANNA CEMENT PLANT.

Energy		
	kJ/kg clinker	*%*
Hot clinker	1377	96
Cooling air	56.47	4
Secondary air	247.64	17.2
Tertiary air	530.70	37
Cooled clinker	75.52	5.2
Hot air	255.39	17.8
Unaccounted losses	324.21	22.6

IV. UTILIZING RADIATION AND CONVECTION LOSSES

As shown in table 1 the unaccounted loss was fairly high of 324.21 kJ/kg clinker which was mostly caused because of the convection and radiation losses from the uninsulated cooler. Assuming the nanofluid as a working fluid of the recovery cycle enters the pipe which is passed through grate cooler. Table 2 presents the specific heat of Cu nanoparticles and base. This pipe will act as a heat exchanger with grate cooler to reduce these losses. And then, the working fluid will direct to heat exchanger to exchange the heat with working fluid of cogeneration cycle.

The source of waste heat in the cement plant comprises of the exhaust gases from the suspension pre-heater (SP) and the clinker cooler discharge hot air. These waste heats can be generated the steam if directed to WHRSG. The steam generated would be used to power a steam turbine driven electric generator. This will reduce the demand of electricity because of the generated electricity will replace the purchased electricity.

TABLE II. SPECIFIC HEAT OF WORKING FLUID OF RECOVERY CYCLE.

Working fluid	Specific heat, Cp (J/kg.K)	Refrence
Water	4190	[10]
Engine oil	1910	
Ethylene glycol	2415	
Cu	385	

V. RESULTS AND DISCUSSION

A. Energy saving, emission reductions and cost saving

The energy saving with respect to the net output power which is generated by the steam turbine can be estimated according to the following equation:

$$ES = Net\ output\ power \times Working\ hours \quad (1)$$

The heat capacity of nanofluids should be minimized to get maximum heat transfer. A maximum possible temperature difference of nanofluids is needed to increase the temperature of the working fluid for the cogeneration cycle.

The value of specific heat of nanofluid is almost near to the specific heat value for the base fluid in nanofluids. Cu-engine oil has the smallest heat capacity among nanofluids, which enables maximum heat transfer and thus increases the mean temperature of heat addition in the cogeneration cycle. Thus, a high net output power is obtained which contributes considerably to energy savings as is shown in Fig 1.

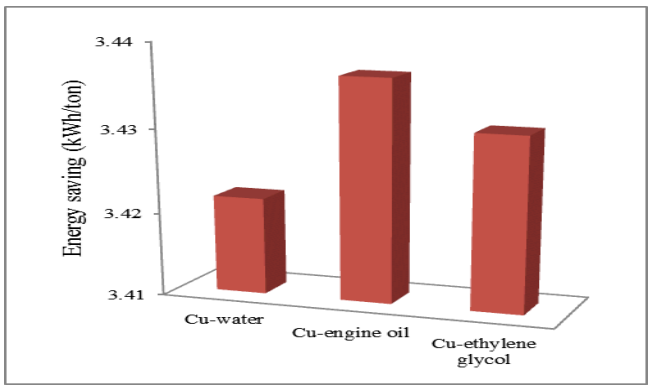

Figure 1. Energy saving at different base fluids.

The emission amount which is related to energy savings can be expected using the following equation:

$$ER = ES \times EF \quad (2)$$

As shown in Fig 2 the emission reductions calculations depend on the energy saving. Engine oil represents the best outcome among the base fluids to reduce the greenhouse gases.

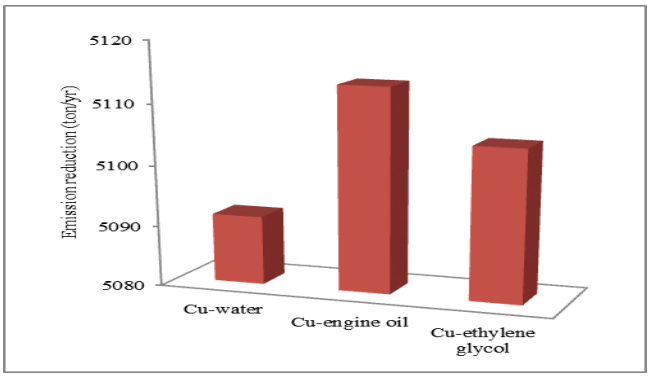

Figure 2. Emission reduction at different base fluids.

The sensible and latent heat of exhaust gases and hot air that are recovered, provide as substitutes for purchased energy in a cement production plant, thus resulting in a more competent plant.

Considering the average of electricity unit price can be taken as 0.07 USD/kWh [13]. The expected cost savings can be estimated as following:

$$CS = ES \times EC \tag{3}$$

It was noticed that use of Cu –water leads to the lowest cost saving, due to the low heat capacity allowing only low energy saving.

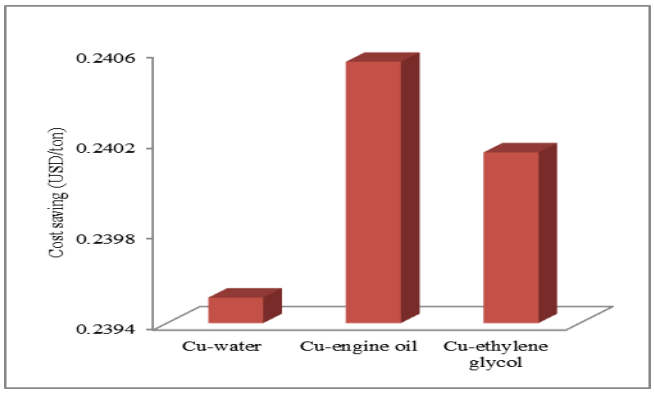

Figure 3. Cost saving at different volume fractions.

CONCLUSIONS

a) Lower specific heat points to high heat transfer between working fluids.
b) Engine oil as a base fluid with Cu nanoparticles indicates the best energy saving, emission reductions and cost saving.
c) Cu-water represents the lowest savings of energy, cost and emission reductions.

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