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Searching the Possibility of Electricity Production with Waste Heat Recovery from Iron and Steel Factory Sinter Cooler by ORC

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Requirement of energy in the life of humanity has been increasing everyday more than one day before, but in the meantime energy sources have been running out rapidly. Efficient usage of energy is sufficiently important for industrial facilities to resist the competitive conditions in the market by the reduction in cost of energy consumption and unit product cost. In this regard, waste heat recovery potential during the ore cooling process at an iron and steel facility sinter plant by using ORC system was theoretically investigated. As a result, it is determined that about 10% of 9,527 kW waste power potential would be recovered to electricity in the industrial facility by the establishment of organic Rankine cycle (ORC). Environmentally, about 5001 tones CO₂/year emission release by the combustion of coal to generate equal amount of electricity was eliminated by electricity generation by ORC. The payback period of the possible ORC system investment was foreseen about 2.4 years.

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1. Introduction

Most important input of the producers' capital is the energy. Increase in economic activity and production require the more energy consumption. Efficient usage of energy directly affects the costs in the market. Efficient consumption of the energy sustains the producers in the competitive sector. Efficient usage of energy is possible by energy efficient technologies, system enhancement and mostly the recovery of waste heat. More than 50% of generated total heat energy in industry is the low level heat and it is emitted in the range of 100 to 220 °C [1]. The organic Rankine cycle can be used to recover low grade heat (<250 °C) [2]. The ORC is the most popular one in these days to recover low temperature waste heat energy. Taking decision about waste recovery investment require the optimization of different parameters as the heat potential, cost, and sustainability. Khatita et al. (2014) studied the utilization of the ORC in an existing gas treatment plant, to recover the waste heat and convert it into electricity. The waste heat recovery using the organic Rankine cycle is a profitable process. The study shows that the payback period will not exceed 4 years. It is recommended that similar approach can be carried on other industries in order to contribute to energy saving and optimization [3]. Jung et al. (2014) investigated the technical and economic feasibility of converting waste heat from a stream of liquid kerosene. It was argued installation of a 250 kW ORC waste heat power converter on the kerosene cooling line would be technically feasible and economically viable [4]. Hammond and Norman (2014) were examined the various technologies to utilise the recovered heat. Greatest potential showed for heat use on-site and its conversion to electricity. The greatest potential for reusing this surplus heat was found to be recovery at low temperatures, utilising heat exchangers; and in conversion to electricity, mostly using organic Rankine cycle technology [5]. Zhiqi et al. (2012) analysed the performance of organic Rankine

cycle system to recover low temperature waste heat from aluminium reduction cell. For heat source temperature between 150 °C and 170 °C, R236fa gives the biggest net power and the corresponding net power ranges from 843 kW to 991 kW. They argued that the net power is easily affected by the change of temperature. When the waste heat temperature decreases 10%, the net power would deviate 30% from the nominal rating [6]. Wang et al. (2012) compared the effect of waste heat temperature and pinch point on the performance and economic characteristics of ORC system under the optimal conditions. They determined that decrease of heat source temperature, the value of payback period increases. When the heat source temperature is lower than 100 °C, the ORC technology is inappropriate [7]. Zhou et al. (2013) constructed an experimental system for heat recovery from low-temperature flue gas based on organic Rankine cycle. The maximum cycle efficiency and net output power of expander are 8.5% and 645 W was determined [8].

Iron and Steel industry is in the class of the most energy intense facilities. In this aspect an industrial facility sinter plant waste heat recovery to produce electricity by ORC was investigated.

2. Material and Method

Studied sinter plant production capacity is approximately 1,200 tons/day. Suction area of the sinter is 110 m². Cooling plant has 84 pallets and each has velocity is about 0.075 m/s. Pallets width is 3 m. Fan flow rate is 0.158 m³/s. Suction pressure is among 12 to 13 kPa. Rotary cooler has 16 bunkers. Two cooler air fans capacities are 111.112 m³/s. Each fan redundantly operates. Blown air flows from central channel to bunker front panel, the air reaches the sinter internal region and cools down the sinter. Flow rate is regulated by operator due to the temperature requirement. Facility sinter plant was illustrated in Figure 1(a, b).

Figure 1(a, b). Studied sinter plant front and top view.

Estimated project was given in Figure 2.

Figure 2. Schematic illustration of the project.

Evaluation of the Project required the preparatory works at the sinter plant. In this aim, thermal measurements were done. Thermal camera was used to measure the ore

temperature, the average temperature of it was determined 350 °C and given in Figure 3.

Figure 3. Thermal view of the ore temperature.

The wasted differential temperature was determined about 150 °C. Usage of this 150 °C temperature waste heat to produce of electricity was theoretically investigated by Genetron software. Input parameters for the analysing software are determined as 150 °C evaporator air inlet temperature, 80 °C air

exit temperature and 25 °C water inlet temperature. Air flow rate is about 111.112 m³/s.

3. Results and discussion

According to the system boundary conditions and assumed data. Possible waste heat source capacity was calculated as below;

Assumed air physical properties are $\rho_a = 1.225 \text{ kg/m}^3$, $c_p = 1 \text{ kJ/kg K}$

Amount of waste heat power potential was calculated in eq. (1);

$$Q = \dot{m}.c_p.\Delta T_a = \dot{V}.\rho.c_p.\Delta T_a = 111.112 \times 1.225 \times 1 \times (150-80) \approx 9,527 \text{ kW} \quad (1)$$

It is assumed that an amount of calculated waste power potential would be recovered by ORC. In the light of this assumption, Genetron software was used to estimate and simulate the ORC cycle. Optimum organic fluid had been estimated and efficiency of the system was determined. Efficiency value was used to calculate the possible theoretical electricity production potential. The system was simulated with software for different

organic fluids are Butane, R245fa and Pentane. These fluids were chosen to study by taking into consideration of their critical temperature.

Simulation and performance evaluation resultant parameters of three different organic fluid was obtained from software user interface were given in Figure 4.

Figure 4. Software base organic fluids comparison visualization.

Analyses results estimated that the thermal efficiency of the system by using three different organic fluids are butane, R245fa and pentane is in the order as 16.61 %, 16.43 % and 16.95 %. As a result, it was shown that the most efficient ORC system was simulated by using pentane. The electricity

production from the waste heat rate would be determined by adding the generator and fitting losses on 16.95%. In this scope, assumed about 10 % of this waste heat power potential could be turned into the electrical power in eq. (2).

$$W_e = \eta.Q_w = 0.1 \times 9527 = 952.7 \text{ kW}. \quad (2)$$

The annual operation period of the system is about 6000 hours.

Annual electrical energy production = $952.7 \times 6.000 = 5,716,200$ kWh

Generated electricity selling cost is about 10.5 dollar cent/kWh.

Annual cost of saving = $5,716,200 \times 10.5 = 60,020,100$ dollar cent = 600,201 \$

1 MW electricity production capacity system investment cost = 1,442,307 \$

Payback period of the investment = $1,442,307 / 600,201 = 2.4$ years.

Environmental positive impact of the waste heat recovery on the CO₂ emission is another importance of the study. CO₂ emissions coefficient of the coal-energy chain is

currently at 875 g/kWh [9]. In this respect, annually about 5001 tonnes CO₂ emission release was eliminated by the electricity generation by ORC.

4. Conclusion

In this study, waste heat recovery potential during the ore cooling process at an iron and steel facility sinter plant by using ORC system was theoretically investigated. Software base estimations were done by Genetron Properties. Theoretical assumptions were considered and study was supported by ref. [6, 8]. Theoretical analyses results showed that 9,527 kW waste heat power could be turned into usable form. By using ORC system this usable energy was turned into about 952.7 kW electrical powers. 5001 tonnes/year CO₂ emission release to produce equal amount of electrical energy from coal was eliminated. The payback period of the possible ORC system investment was foreseen about 2.4 years.

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