EVALUATION OF WASTE HEAT RECOVERY IN THE CEMENT INDUSTRY

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ABSTRACT

The cement industry is an energy intensive sector. The production of one ton of cement requires 4 GJ of thermal energy, which is produced through the combustion of fossil fuels and 100 kWh used to drive electrical machines. A considerable portion of the heat produced is discarded into the environment without proper utilization. Currently, approximately 7% of global CO_2 emissions come from the cement industry. The gases used in the process containing waste heat are discharged through the outlets of the cyclone tower and clinker cooler at temperatures of 300 to 450°C, available for WHR energy recovery systems, such as the Organic Rankine Cycle. Will be studied the reduction of fossil fuel consumption and CO_2 emissions through the production of electrical energy using waste heat.

Keywords: waste heat recovery, organic Rankine cycle, cement industry, thermodynamic analysis, cement production

INTRODUCTION

In the cement industry, energy accounts for more than 40% of production costs [1]. According to [2], 7% of global CO_2 emissions are produced in cement factories from the use of fossil fuels and the decarbonization of raw materials during the manufacturing process. In Brazil, 600 kg of CO_2 are emitted for each ton of cement produced, below the world average of approximately 900 kg [3].

Due to the characteristics of the clinker manufacturing process, which is an intermediate cement product, a considerable portion of the thermal energy generated in the kiln through the combustion of fossil fuels is discarded into the environment. This available residual heat at low or médium temperatura can be reused to generate electricity with the implementation of a Waste Heat Recovery WHR system at the end of manufacturing process. The most studied cycle with applications for the use of gases at low temperatures is the Organic Rankine Cycle ORC.

The objective of this article is to evaluate the implementation of a WHR for the benefit of sustainability, generation of electrical energy, thus reducing the consumption of fossil fuels and consequently CO_2 emissions in places where electrical energy generation in thermoelectric plants is predominant. There will also be a reduction in the sales value of the product to the consumer. The evaluation consists of the annual value of electricity produced, the reduction in the consumption of fossil fuels and CO_2 emissions. The cost of implementing the WHR and the payback of the investment will also be studied. The characteristics of an existing industry with a cement production capacity of 1,710 tons per day, located in Madhya Pradesh, India, will be adopted.

LITERATURE REVIEW

The WHR system is related to the volume and temperature of the plant's available waste heat that define the technology and power of the WHR system. ORCs are best suited for applications in factories that have low or medium temperature and low volume residual heat [4].

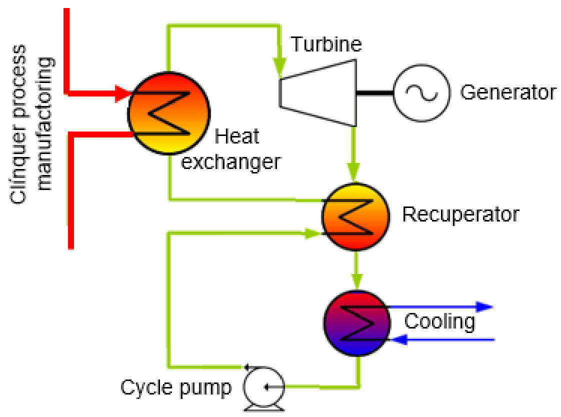

Figure 1 - Organic Rankine Cycle. **Source:** Adapted from [5].

Fig. 1 is an illustration of a WHR application with the implementation of ORC using waste heat from the clinker manufacturing process, for the purpose of generating electrical energy [5]. The construction of the ORC is similar to the steam Rankine cycle and can operate at temperatures between 80 and 300 ºC, allowing the use of residual thermal energy at medium temperature [6].

The technical and economic optimization was performed by modeling for the working fluids for ORC using the Engineering Equation Solver software. To select the most suitable fluids for organic work and exclude the unsuitable ones, the fluids R11, R124, R141b, R142b, R600, R600a, R123 and RR245fa were analyzed, considering the following criteria: critical temperature, critical pressure, saturation pressure at 35 ºC and the title. The organic fluids that proved to be the most suitable and with the highest performance from the point of view of net power, thermal and energy efficiency were R141b, R11 and R123 [7].

METHODOLOGY

The operating manometric pressure of the Q1 stream indicated in Fig. 2, from the plant located in the city of Madhya Pradesh, India, is 35 mbar negative and the local ambient pressure indicated by [8] is 100.54 kPa. The operating temperature of the stream is 290 °C, a condition that is in the range of 80 °C to 400 °C considered suitable for use of the ORC system according to [9]. In the existing process configuration, the waste heat from the clinker cooler is cooled in the gas cooler, filtered and released to the atmosphere. The heat exchanger will be installed in parallel with the gas cooler of the clinker cooler as illustrated in Fig. 2.

The heat load of flow Q1 in Fig. 2 is 13,352.8 kJ/s, the temperature of this waste heat at the inlet of the gas cooler of the clinker cooler is 290°C and the outlet temperature is 100°C [1]. Since the implementation of the power cycle heat exchanger is installed in parallel to the existing gas cooler, the temperature variation between the inlet and outlet of the added equipment must also be from 290°C to 100°C so as not to change the variables in the clinker manufacturing process.

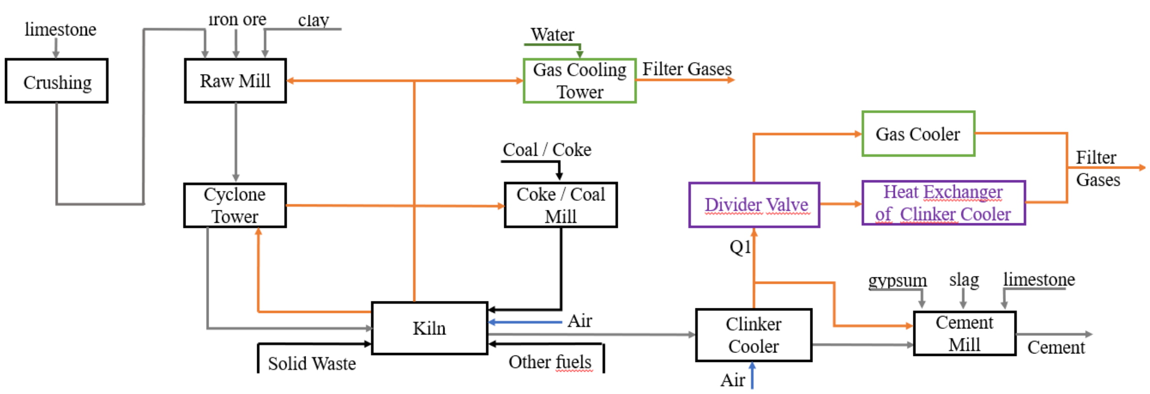

Figure 2. Arrangement of the heat exchanger and the divider valve added to the gas outlet ducts of the clinker cooler. Source: adapted from [1].

The transfer of waste heat from stream Q1 to the working fluid is controlled so that the temperature of the hot fluid at 290°C reaches 100°C at the outlet of the heat exchanger added to the original process.

The organic working fluids R141b, R11 and R123 will be used to calculate the ORC. In the proposed design of [10] the temperature at the evaporator outlet must be greater than 130°C. The temperature range for the turbine inlet is 80 to 300°C [6]. The operating pressure of the working fluid at the turbine inlet must be greater than 11 bar [11]. According to the sources, the above mentioned pressure and temperature technical data are considered adequate and show better results in similar ORC applications. The working fluid pressure adopted at the turbine inlet is 2500 kPa and at the outlet 250 kPa. The temperature of the organic working fluid at the turbine inlet was adopted at 280°C and a pressure of 20 bar.

The consumption of fossil fuels to generate electricity equivalent to that produced with WHR can be determined from the ratio of 3 kWh for 1 kg of coal and 9 kWh for 1 kg of natural gas. The CO_2 emissions avoided by the recovery of waste heat are found by calculating the emission rate in relation to the electricity generated by the thermal power plant. In 2021, the average Brazilian CO_2 emission rate in thermal power plants was 483 tCO_2/GWh [12]. The cost of installing WHR is given in relation to generating capacity at US$7.845 per kW [13]

1. RESULTS OBTAINED AND CONCLUSION

The results obtained are shown in Tab. 1, and correspond to the production of the ORC and SCR, the cost of implementing the WHR, the O&M cost and the net energy production.

Table 1. Results obtained

Description	WHR installed at the clinker cooler outlet
Power generated by ORC with R11 fluid – kW	1,186
Power generated by Steam Rankine cycle – kW	946
Energy produced by ORC - MWh/year	9,478
Cost of implementation – US$	8,305,000
O&M cost – US$ / year	165,003
Net energy production by ORC. Average cost reduction, related to the payback period – US$ / year	1,088,398

The electrical energy produced with the implementation of the WHR is 9,478 MWh per year. The consumption of fossil fuels for the production of the equivalent energy is 3,159 tons of coal or 1,053 tons of natural gas. The reduction in CO_2 emissions is 4,578 tons. The payback period for the implementation of WHR is 7 years and 8 months.

In the simulation of the conversion of residual thermal energy into electrical power, the ORC presented the best result using the working fluid R11. The ORC with this fluid can also operate at lower temperatures than the steam Rankine cycle.

REFERENCES

[1] Boldyryev S. 2018. "Heat Integration in a Cement Production". <http://dx.doi.org/10.5772/intechopen.75820 >

[2] Rodgers L, BBC Notícias. Aquecimento global: a gigantesca fonte de CO_2 que está em toda parte, mas talvez você não saiba . 2018. < https://abrir.link/lFelN>.

[3] Freire D. 2016. FAPESP. Especialistas discutem papel da indústria do cimento nas emissões de CO_2. <https://abrir.link/QznlF >

[4] IFC International Finance Corporation, Instituto IIP de Produtividade Industrial, Waste Heat Recovery for the Cement Sector: Market and Supplier Analysis. 2014. < https://abrir.link/UplDK>.

[5] GRENZEBACH CE. WASTE HEAT RECOVERY. 2022. <https://cnudefco.com/waste-heat-recovery/>

[6] Ahmed A, Esmaeil KK, Irfan MA AL-Mufadi FA, 2017. "Design methodology of organic Rankine cycle for waste heat recovery in cement plants". Arábia Saudita, <doi.org/10.1016/j.applthermaleng.2017.10.019>

[7] Moreira LF and Arrieta FRP 2019. Thermal and economic assessment of organic Rankine cycles for waste heat recovery in cement plants. Pontifícia Católica Universidade, Minas Gerais, Brasil.

[8] The Weather Chanel, 2024. https://weather.com/pt-

[9] Tchanche, BF, Pétrissans M, Papadakis G. Renewable and Sustainable Energy Reviews. 2014. <http://dx.doi.org/10.1016/j.rser.2014.07.139>.

[10] Moran MJ, Shapiro HN, Boettner DD, Bailey MB, 2018. PRINCIPIO DE TERMODINÂMICA PARA ENGENHARIA. The Ohio State University, 1418 p.

[11] Nemati A, Nami H, Ranjbar F, Yari M. A comparative thermodynamic analysis of ORC and Kalina cycles for waste heat recovery: A case study for CGAM cogeneration system. Faculty of Mechanical Engineering, University of Tabriz, Iran, 13 p., 2017.

[12] IEMA INVENTÁRIO DE EMISSÕES ATMOSFÉRICAS EM USINAS TERMELÉTRICAS. 2022 <https://abrir.link/xHHpg>.

[13] IFC International Finance Corporation, Waste Heat Recovery for the Cement Sector: Market and Supplier Analysis. 2014. <https://abrir.link/UplDK>.