INTEGRATION OF ORGANIC RANKINE CYCLES FOR THE SIMULTANEOUS RECOVERY OF WASTE HEAT AT TWO TEMPERATURE LEVELS IN A CEMENT INDUSTRY

ALONSO OJANGUREN, Laura(1); BRUNO, Joan Carles(2); CORONAS, Alberto(2)
(1)TECNALIA Research & Innovation, Azpeitia (Spain)
(2)Universitat Rovira i Virgili, Group of Applied Thermal Engineering-CREVER, Tarragona (Spain)
Email: juancarlos.bruno@urv.cat, laura.alonso@tecnalia.com, alberto.coronas@urv.cat

INTRODUCTION AND OBJECTIVES

Cement manufacturing is an energy intensive process, in which a large part of the consumed energy is emitted as waste heat. In the process two waste heat sources mainly exist: the preheater exhaust and the clinker cooler exhaust gases, which have different temperature levels. Figure 1 shows a diagram of the preheater, kiln and clinker cooler of a cement manufacturing plant. In this work, Organic Rankine Cycle is proposed and analysed for heat reacovery of both waste heat sources. Efficiency of ORC depends mainly on the thermodynamic properties of the working fluid and its operating conditions. Therefore, selection of the working fluid plays a key role in ORC systems, and is determined by the waste heat level. For this particular application, where waste heat at two different temperature levels is available, the use of two integrated Organic Rankine Cycles is analyzed, by using suitable fluids for each heat source. Analysis of the single cycle for different fluids has been performed as well. Comparisons of different fluids and configurations have been made.

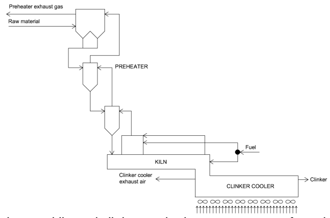

Fig 1. Preheater, kiln and clinker cooler in a cement manufacturing plant.

METHODOLOGY

First of all, a cycle with a single fluid has been analyzed, which recovers heat from both waste heat sources. Table 1 shows the mass flowrates and temperatures of the waste heat sources considered. Fluids chosen for this first analysis have been water, toluene, n-pentane, n-heptane, hexamethyldisiloxane (MM), octamethylcyclotetrasiloxane (D4), R134a and R245fa. The analysis has been performed for the cycle with and without regenerator. Figure 2 shows the configurations of the simple cycles. In the cycle with regenerator, two possible configurations exist, depending on the fluid temperature at the turbine outlet.

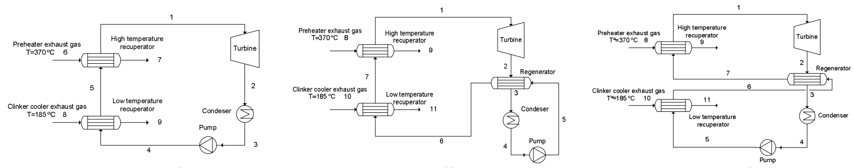
a) b) c)

Fig 2. ORC for heat recovery in a cement industry. a) Without regenerator b) With regenerator. Conf. 1 c) With regenerator. Conf. 2

	Mass flowrate (kg/s)	Temperature (ºC)
Preheater exhaust gas	80	370
Clinker cooler exhaust air	86	185

Table 1. Preheater exhaust gas and clinker cooler exhaust air mass flowrates and temperatures.

Next, the integration of two cycles has been analysed, by using different fluids for the high temperature heat source and the low temperature heat source. Figure 3 shows the three different configurations considered.

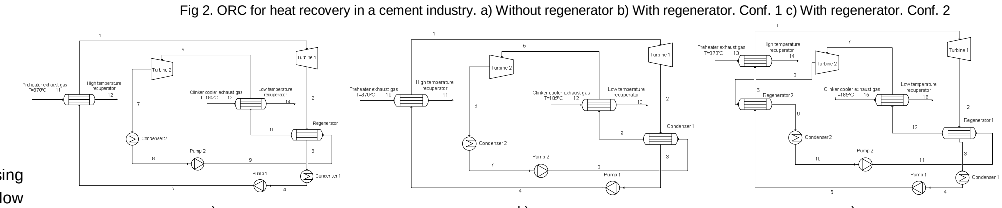
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Fig 3. Two ORC integration for heat recovery in a cement industry. a) Configuration 1 b) Configuration 2 Conf. 1 c) Configuration 3

The fluids of study have been toluene and octamethylcyclotetrasiloxane (D4) for the high temperature cycle, and n-pentane, R134a and R245fa for the low temperature cycle. Cycles have been simulated using Aspen Hysys process simulator. In all cases, cycles have been optimized in order to maximize the net output power. The thermodynamic properties of the various fluids have been calculated using the Peng-Robinson-Stryek-Vera (PRSV) equation of state.

RESULTS

SIMPLE ORC CYCLE

Toluene obtains the higher net power output. The inclusion of a regenerator increases both power output and cycle efficiency.

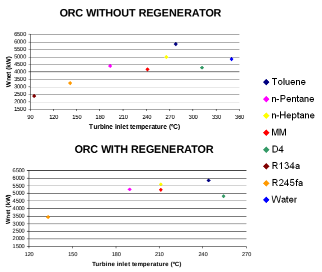

Fig 4. Net power output for different working fluids.

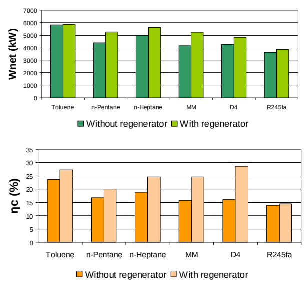

Fig 5. Net power output and cycle efficiency in cycles with and without regenerator.

INTEGRATION OF TWO ORC CYCLES

Toluene combined with n-Pentane or R245fa obtains higher output power than the single cycle, for conf. 1 and 3. On the other hand, conf. 2 obtains worse output power.

D4 combined with n-Pentane and R45fa obtains higher output power than the single cycle, for the three considered configurations.

Toluene/R134a and D4/R134a combinations obtain worse results than the single cycles. R134a could not be analysed with conf. 3, as turbine's output temperature was not high enough for heat recovery.

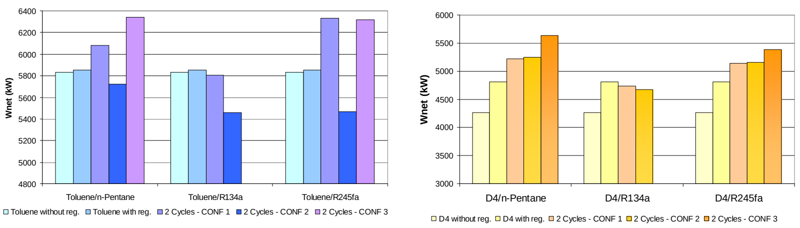

Fig 6. Comparison of net power output for single and two cycle configurations.

CONCLUSIONS

For the single cycle analysis, the best results have been obtained with toluene as working fluid. Inclusion of a regenerator increases net power output and cycle efficiency. For this application, n-pentane or siloxanes are recommended as working fluids.

For the two cycle analysis, generally the first and the third configurations analysed improve net power output, when compared with the use of a single cycle. Taking into account the results and the toxicity and flammability characteristics of the fluids, the combinations of the following fluids are recommended:

- D4/n-pentane
- D4/R245fa

The maximum power output has been obtained by using configuration 3. Extra 800kW of output power have been obtained for the D4/n-pentane combination and 500kW for the D4/R245fa combination, when compared with the single cycle configurations. It would be interesting to study the possibility of recovering the remaining heat for hot water or cold water production, by means of the absorption cooling technology; for its use in air conditioning of the cement plant or nearby buildings. Finally, it would be necessary to make an economic analysis in order to check if the improvement in output net power compensates for the higher investment and difficulty of operation with the two cycle configurations.

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Contact:
Laura Alonso
T +34 946 430 850
laura.alonso@tecnalia.com

TECNALIA
Área Anardi, 5
E-48160 AZPEITIA (Gipuzkoa) SPAIN
www.tecnalia.com

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