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Executive Summary of the Thesis

Thermodynamic analysis and optimal working fluid selection of a reversible Heat Pump-Organic Rankine Cycle coupled to a renewable energy based thermo-chemical energy storage

Laurea Magistrale in Energy Engineering - Ingegneria Energetica

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1. Introduction

The exploitation of renewable energy sources is growing a lot due to the cost reduction of green technologies and due to the aim to reduce CO_2 production and fossil fuels consumption. But renewables sources are characterized by problems such as the control of the power output and the predictability. These aspects can lead to a lack of power produced when the request is high, and, on the contrary, there could be an excess of power injected in the grid when it is not needed. So, in order to deal with these problems, it is necessary to rely on energy storage systems, which can interact with the grid, absorbing or supplying electric energy when needed.

From a global pollution point of view, the IEA have concluded that an effective installed energy storage capacity will reduce global warming by 2°C, provided the installed capacity increases by 450 GW in 2050 as opposed to 140 GW in 2014 [3].

There are different types of energy storage, based on the different operating principle: the storage could be mechanical, electrochemical, chemical or thermal. The thermal energy storage is the most promising and still under-exploited in the world. In particular, it can be sensible heat storage (SHS), latent heat storage (LHS) or thermochemical heat storage (TCS) [2] [4].

The system studied in this thesis is based on a thermochemical energy storage system, coupled to a charging cycle (heat pump) and a discharging cycle (organic Rankine cycle). The purpose of the system is to feed the charging cycle with a low temperature heat source (renewable or waste), then use the heat released by this cycle to make the reaction take place and finally, when necessary, make the reverse reaction occur, in order to feed the discharge cycle, which produces eletricity and heats the district heating water.

2. Bibliography review

In literature are present lot of different storage system prototypes and studies. The operating principles can be very different from each other. The author studied the technical aspects of the systems most similar to the one analyzed in this thesis.

In particular, the fluids used, the type (and temperature) of the low temperature heat source, the efficiencies assumed for the turbomachines and the round-trip-efficiency values obtained are are the main parameters of interest.

3. Model description

Here is presented the functioning of the analyzed system. The charging and discharging cycles are depicted.

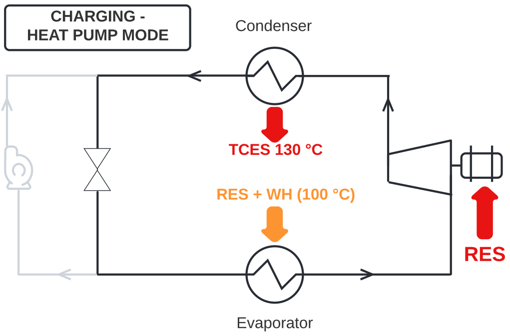

Figure 1: Plant configuration, Heat Pump mode

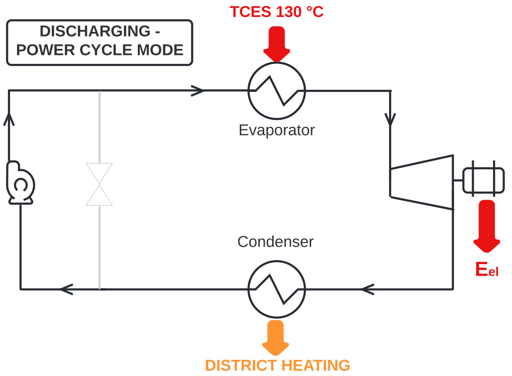

Figure 2: Plant configuration, Power Cycle mode

The low temperature heat source introduces energy into the cycle, causing evaporation of the working fluid. Then, the fluid is compressed and finally condensed. the working fluid. The condensation heat released is used into the chemical reactor to make the endothermic reaction take place. When it is necessary to carry out the inverse reaction, the products of the reaction carried out previously, are made to react, releasing heat. This heat is introduced into the discharge cycle (Power Cycle), and serves to evaporate the working fluid. The fluid is then expanded in a turbine, generating electricity, and then condensed.

When the low temperature heat source is available throughout the winter, this is called thermal integration. If there is thermal integration, the heat source, in addition to evaporating the working fluid in the charging cycle, is used to contribute to the heating of the district heating water.

The thermodynamic cycles are depicted in Ts diagram:

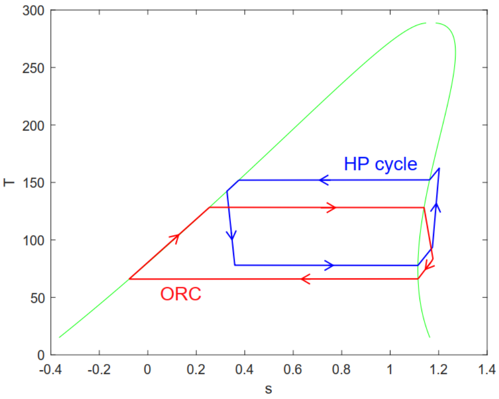

Figure 3: T-s diagram of the two cycles

After describing some basic model assumptions, such as the efficiency of the thermochemical energy storage (equal to 1), the isentropic efficiencies of the turbomachines used, the initial heat transfer coefficients for each heat exchangers, the pressure losses inside them and the temperature of the district heating system, the model is described.

The author created a set of Matlab codes in order to compute, as final result, the round-trip-efficiencies of the various fluids selected. The conceptual scheme is represented in the following figure:

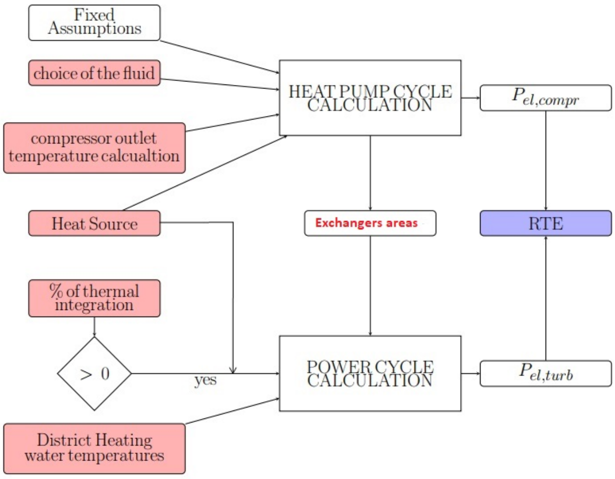

Figure 4: General conceptual scheme

Running the code for each fluid, and for each generation of district heating system, a classification of the best fluids is obtained.

The performance of the cycle is analyzed as the inlet and outlet temperatures of the compressor in the charging cycle vary. Therefore, the code calculated the minimum and maximum inlet and outlet temperatures at which compression can take place for each fluid. The code include a function that aims to avoid the unfavorable situations in which he compression end inside the saturation bell and in which he compression end outside the saturation bell but passing through it.

Furthermore, another function checks the temperature at the compressor outlet: if this temperature is lower than an imposed value (based on a pitch point with respect to the heat pump condensation temperature), it is imposed to be equal to this minimum. Knowing the outlet temperature, the inlet one is calculated. If the outlet temperature is higher than the imposed value, that value represent the minimum outlet temperature.

After calculating the minimum inlet and outlet temperatures of the compression, the code calculates the maximum temperatures at which the compression can take place.

At this point, knowing the entire operating range of the compressor (in terms of temperatures), the reference parameters and performance can be calculated.

In particular, the areas of the exchangers are calculated using the classic heat exchange formula $Q = UA\Delta T_{ML}$, in which, for each section of each heat exchanger, the overall heat transfer coefficient U is calculated through an initially assumed set of h_i and h_e. The values of these areas will then be used to calculate the discharge cycle, (which is then calculated in off design). This is because the exchangers, in this system, are the same both in the charge cycle and in the discharge cycle.

To increase the degree of precision of the results obtained, the values of h_i and h_e are calculated for each heat exchangers sections, through the appropriate heat exchange correlations for Shell&Tube heat exchangers.

4. Results and fluids classification

After the definition of a reference case, the results are investigated. First of all, the trend of the RTE with the compressor outlet temperature is discussed. It is monotonously increasing for all fluids. This means that it is convenient, in terms of efficiency, to set the maximum compressor outlet temperature. The best fluids are Benzene, DMC and R1233ZD, as it can be seen in the following figure.

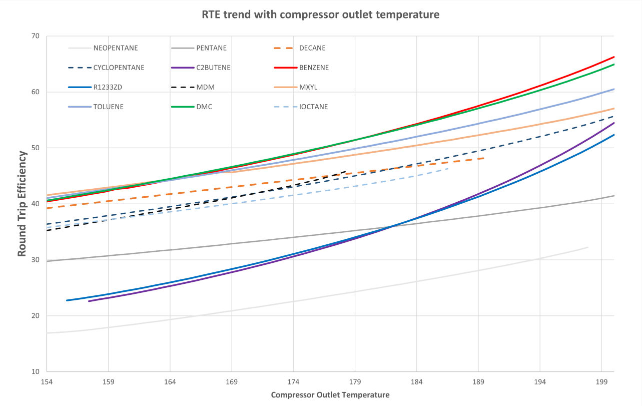

Figure 5: RTE trend as the compressor outlet temperature increases, for the reference case with no thermal integration

In order to have a more complete idea of the consequences of choosing a specific fluid, the author has also chosen to investigate the behavior of the heat exchange areas. The results show that the area of the high pressure heat exchanger and that of the recuperator increase as the temperature increases, and the opposite happens for the low pressure heat exchanger. The trends of the total area is depicted in the following figure:

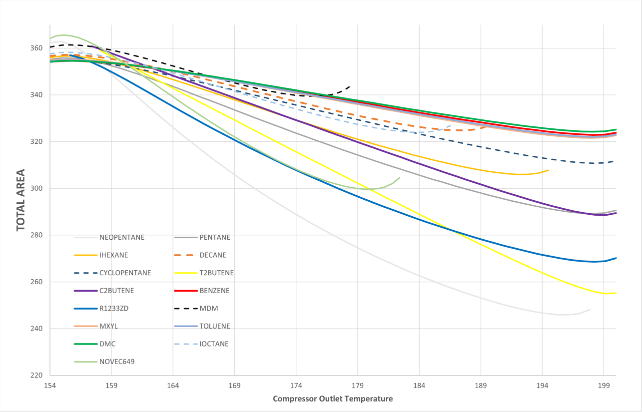

Figure 6: Total area trend with compressor outlet temperature

Finally, an analysis that simultaneously takes into account all these aspects is done. The parameter RTE/A is calculated (where A is the total area of the heat exchangers involved). Results are shown:

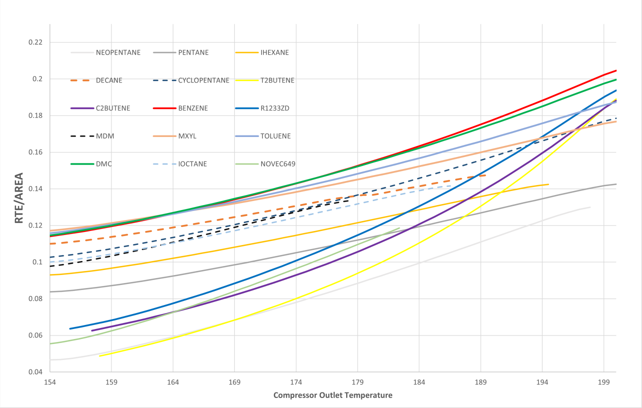

Figure 7: RTA/A trend with compressor outlet temperature

The best fluids remain the same: Benzene, R1233ZD and DMC. At this point, a sensitivity analysis is done: it is studied what happens when the temperatures of the district heating system and of the heat source that feeds the charging cycle change.
Adopting a more modern generation of district heating is beneficial for the whole system. Therefore, the lower is the supply and return temperatures, the higher will be the system RTE. The relative increase obtained by passing from the third generation to the most modern generation of district heating is shown graphically:

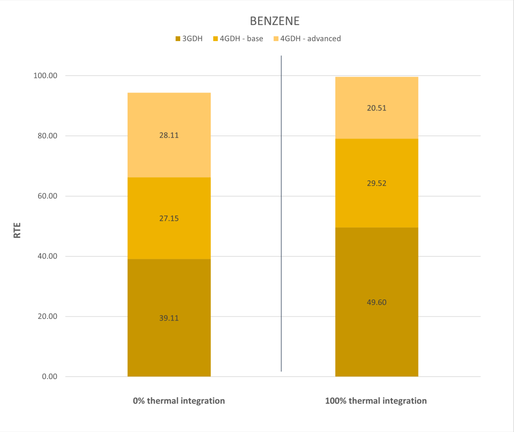

Figure 8: RTE relative increase in the three generations

The use of benzene with a modern fourth generation system, in case of 100% thermal integration of the renewable/waste heat source, permit to reach the maximum RTE in those conditions (99.62).
Finally, the last result is that by varying the low temperature heat source (thus varying the water temperature), the RTE is not particularly affected. This is a positive factor, as it makes it clear that this system can be powered by different low temperature heat sources, while maintaining good performance.

5. Conclusions

This thermochemical storage system produces excellent results when coupled with a modern district heating network. The most modern district heating networks (fourth generation) are being gradually installed all over the world, therefore the feasibility of these systems, with high performances, can be guaranteed in the years to come.
When this system is installed near an industrial plant, it can be thermally integrated throughout the year and the performance will be greater.
With regard to the best the working fluid, among the 34 fluids initially selected, Benzene is the one that guarantees the best performance in terms of RTE in any case. By changing the generation of district heating or the temperatures at which the heat source is available, it guarantees the best round-trip-efficiency, both in the case of thermal integration and in the stand-alone case. Benzene has an ODP equal to 0 and a GWP equal to 3.4, therefore it is an excellent fluid also

from an environmental point of view [1].

References

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