

# Optimizing Heat Recovery: Advanced Design of Integrated Heat Exchanger Networks with ORCs and Heat Pumps

Zinet Mekidiche<sup>a</sup>, Juan A. Labarta<sup>a,b</sup>, José A. Caballero<sup>a,b\*</sup>

<sup>a</sup> Institute of Chemical Process Engineering, University of Alicante, Carretera de S. Vicente s.n. 03690, Alicante, Spain.

<sup>b</sup> Chemical Engineering Department, University of Alicante, Carretera de S. Vicente s.n. 03690, Alicante, Spain.

\* Corresponding author: [caballer@ua.es](mailto:caballer@ua.es)

## ABSTRACT

A comprehensive model has been developed to design heat exchanger networks integrated with organic Rankine cycles (ORCs) and heat pumps, aiming to optimize energy efficiency. The model focuses on two key objectives: first, using heat pumps to reduce dependency on external services by enhancing heat recovery within the system; second, utilizing ORCs to recover residual heat or generate additional energy. To achieve optimal performance, the model requires careful selection of fluids for both ORCs and heat pumps, and the determination of optimal operating temperatures for maximum efficiency. The heat exchanger network is designed to be flexible, with non-fixed inlet and outlet temperatures, while simultaneously optimizing the number and operating conditions of ORCs and heat pumps. This approach reduces costs related to external services, electricity, and equipment such as compressors and turbines. Ultimately, the model facilitates the design of a heat exchanger network that efficiently utilizes residual heat and integrates other energy streams, thus improving both operational efficiency and sustainability. It demonstrates the potential for incorporating ORCs into systems that manage various energy streams, extending beyond just residual heat.

**Keywords:** Electrification Strategies, Green Heat Integration, Low-Carbon Technology, Eco-Friendly Heat Recovery.

## INTRODUCTION

In recent years, the optimization of heat recovery networks has become a key focus in efforts to improve energy efficiency and reduce environmental impact in industrial systems. The integration of Organic Rankine Cycles (ORCs) and heat pumps into these networks offers a promising solution by recovering waste heat and converting it into usable energy, thereby reducing the reliance on external energy sources. However, the successful implementation of this approach depends on the careful selection of system components, including fluids for the ORCs and heat pumps, as well as the determination of optimal operating conditions. In this study, we explore several case studies that illustrate the potential of these technologies in different industrial settings, highlighting their impact on cost reduction, energy efficiency, and sustainability.

## CASE OF STUDY

### 1. Integration of Heat Recovery and Heat Pumps

A base case study was analyzed to illustrate the effectiveness of the proposed methodology. The process system included a hot stream (H1) and a cold stream (C1) with defined inlet and outlet temperatures (Table 1). This system has been previously studied by Holiastos & Manousiouthakis [1] to consider the introduction of heat pumps and heat engines. We assume that there are contracts with a utility plant that provided vapor in different conditions and prices as shown in Table 2. Prices are calculated using the approach proposed by Turton et al. [2] using gas natural prices from Eurostat [3].

**Table 1.** Process Streams Data

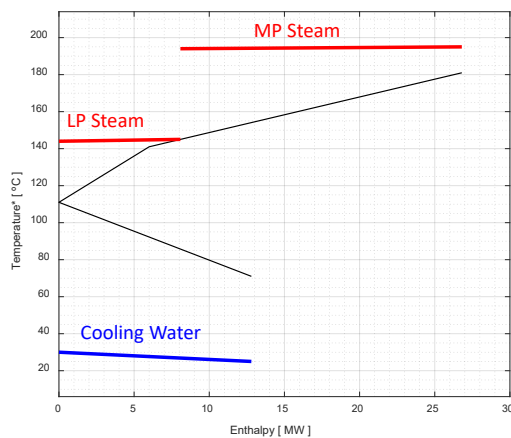
Name	T <sub>in</sub> [°C]	T <sub>out</sub> [°C]	F <sub>cp</sub> [MW/°C]
H1	106	176	0.52
C1	146	76	0.32

**Table 2.** Utilities Streams Data

Name	T <sub>in</sub> [°C]	T <sub>out</sub> [°C]	Cost [k\$/MW·y]
LP Steam	150	149	666,43
MP Steam	200	199	700,42
HP Steam	250	249	831,42
Cooling Water	20	25	23,5

## 2. Initial Results

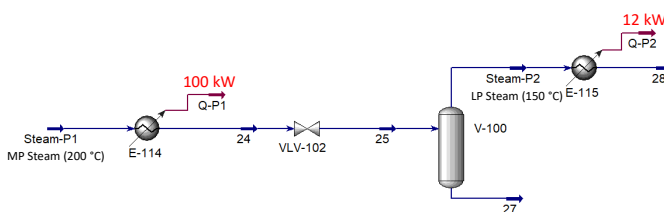
In the base case, the total utility cost was calculated at **18,797.4 k\$/y** without additional optimization. MP Steam was the primary utility with a consumption of 18.72 MW, followed by LP Steam at 8.08 MW and cooling water at 12.80 MW (Figure 1)



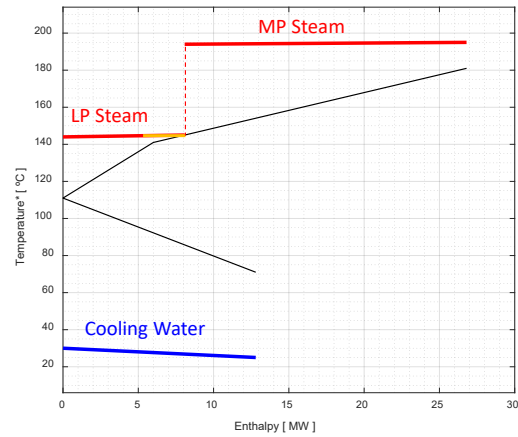
**Figure 1.** Analysis of Utilities on the Grand Composite Curve

## 3. Optimization with Re-Flashing:

The first optimization step involved re-flashing MP Steam (200 °C) into LP Steam (150 °C) (Figure 2). By recovering 2.246 MW of LP Steam, the utility cost was reduced by **1,496.8 k\$/y**, representing a **7.96%** cost reduction. (Figure 3)



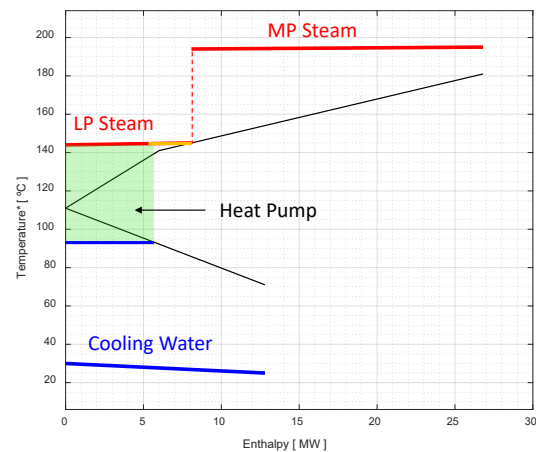
**Figure 2.** Re-flashing diagram in Aspen HYSYS.



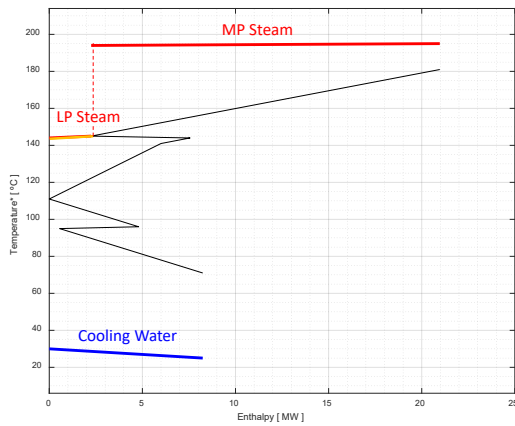
**Figure 3.** Analysis of Utilities on the Grand Composite Curve after re-flashing the MP Steam to LP Steam.

## 4. Optimization with Heat Pump:

A heat pump was introduced to enhance energy efficiency further to reduce the remaining LP Steam consumption (from 8.08 MW to 2.25 MW). The heat pump, operating between a hot stream at ~150 °C and a cold stream at ~90 °C, optimized using GAMS, required 1.259 MW of electrical work and contributed to recovering 5.83 MW of heat. This configuration reduced the total utility cost to **14,813.2 k\$/y**, reducing additional costs while maintaining process requirements, representing a **21.02%** cost reduction. (Figure 4 and 5).



**Figure 4.** Analysis of Utilities on the Grand Composite Curve after re-flashing the MP Steam to LP Steam (the green section qualitatively illustrates how to add a heat pump)



**Figure 5.** Analysis of Utilities on the Grand Composite Curve after adding the first heat pump.

For optimization in GAMS, the Pinch Location Methodology [4,5] was employed, enabling the calculation of utility costs for streams with variable temperature and/or flow rates. The heat loads associated with heat pumps or heat engines were correlated using second-order polynomials, with correlation coefficients exceeding 0.995 in all cases. The problem was solved to global optimality

This example demonstrates the proposed methodology's capability to integrate heat pumps and re-flashing processes, significantly improving heat recovery, reducing energy costs, and promoting system sustainability.

## 5. Integration of an ORC

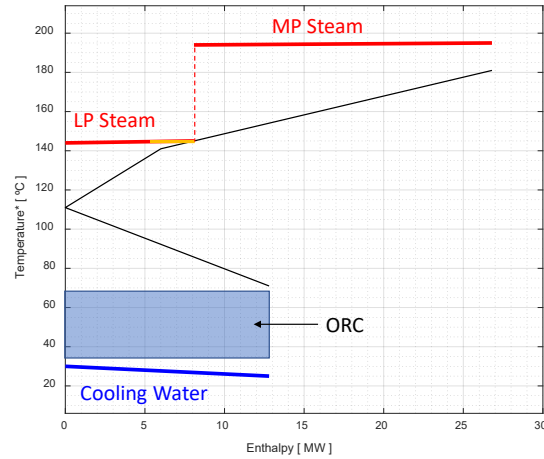
Before incorporating the second heat pump, a simulation was performed to explore the integration of an Organic Rankine Cycle (ORC) below the pinch point. Under these conditions, the simulation indicates that approximately **0.70 MW** can be recovered using benzene as the working fluid.

While this amount of energy recovery is relatively small and does not appear to offer significant economic benefits, an interesting opportunity exists to enhance the ORC's performance. By extending the heat pump's operating range to higher values, the ORC can utilize the hot water generated by the utility system. This, however, comes at the expense of requiring additional cooling water.

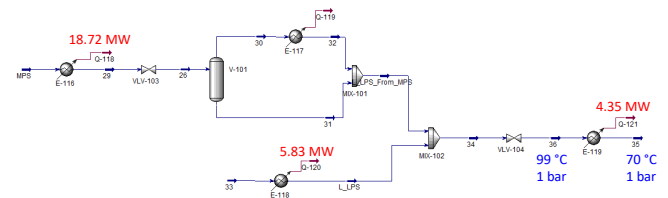
For instance, by specifying an ORC capable of expanding to around **14 MW**, we obtain the configuration of Figure 6.

This example highlights the potential for combining heat pumps and ORCs to maximize energy recovery. Such an approach optimizes the utilization of thermal resources within the system, showcasing the flexibility and benefits of integrating ORCs in conjunction with other thermal management strategies.

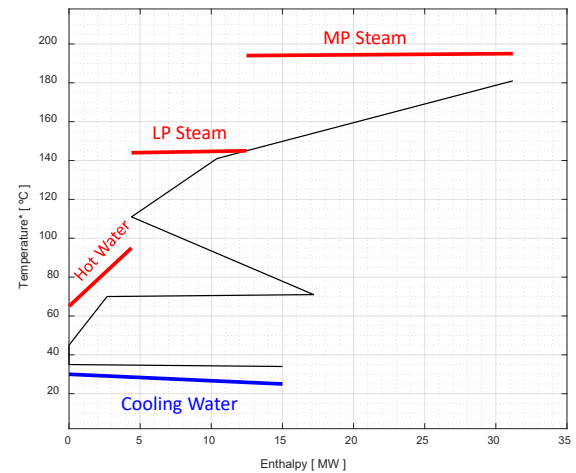
Using the available data, it is possible to calculate the amount of hot water (in MW) generated from the saturated liquid after utilizing both MP and LP steam (Figure 7)



**Figure 6.** Analysis of Utilities on the Grand Composite Curve (the blue section qualitatively illustrates how to add an ORC)



**Figure 7.** Simulation of the amount of hot water (in MW) generated from the saturated liquid in Aspen HYSYS.



**Figure 8.** Analysis of Utilities on the Grand Composite Curve after adding an ORC.

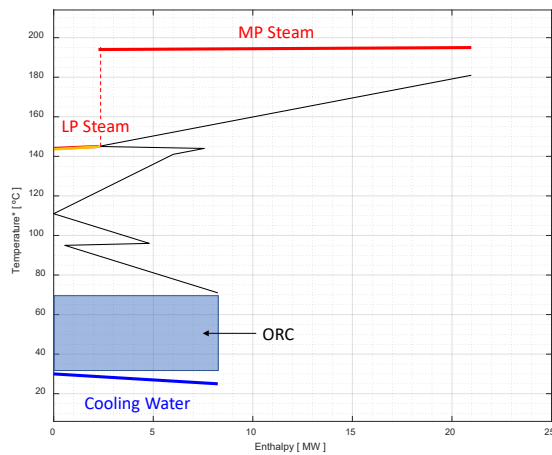
As illustrated in the schematic, the system can recover 4.35 MW of hot water at 99°C (1 bar) and reduce it to 70°C (1 bar). However, with the extended ORC design, the recovery is limited to **approximately 0.85 MW**, which

is relatively low.

This configuration reduced the total utility cost to **17,840.4 k\$/y**, reducing additional costs while maintaining process requirements, representing a **5.09%** cost reduction. (Figure 8)

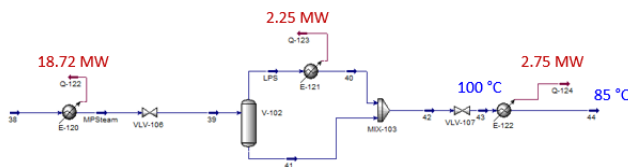
### 6. Integration of an ORC after the heat pump.

This study evaluates the feasibility of implementing an Organic Rankine Cycle (ORC) operating between temperatures of approximately 65 °C and 40 °C. (Figure 9) Tests conducted with benzene as the working fluid have demonstrated feasibility within these temperature ranges. The system focuses on recovering approximately **8 MW** from residual streams, optimizing the energy utilization of the process.



**Figure 9.** Analysis of Utilities on the Grand Composite Curve after adding the first heat pump (the blue section qualitatively illustrates how to add an ORC)

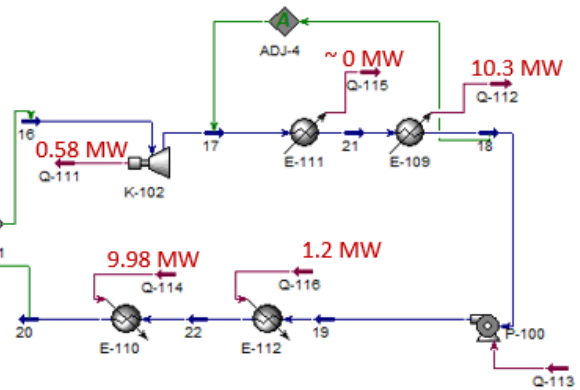
Additionally, it has been identified that by expanding liquid water from the condensation of low-pressure (LPS) and medium-pressure steam (MPS) to atmospheric conditions, up to **2.75 MW** of hot water can be generated. This recovered heat can be utilized as an additional thermal utility. (Figure 10)



**Figure 10.** Simulation of the amount of hot water (in MW) generated from the saturated liquid in Aspen HYSYS.

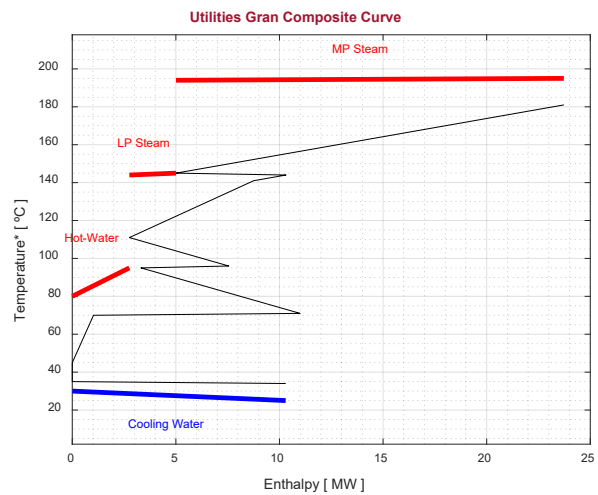
Based on these findings, the implementation of an ORC with 10.3 MW thermal power in the condenser is proposed. Although this increases cooling water consumption, it generates **0.58 MW** of electricity (Figure 11). This approach represents a technically and economically

attractive solution to maximize energy utilization in industrial processes through the integration of recovery and energy conversion technologies.



**Figure 11.** Simulation of the ORC in Aspen HYSYS.

By implementing this configuration, the total utility cost was reduced to **14,168.7 k\$/y**, representing a **24.60%** decrease in costs while ensuring compliance with process requirements and limiting additional expenditures (Figure 12)



**Figure 12.** Analysis of Utilities on the Grand Composite Curve after adding a heat pump and ORC.

## CONCLUSION

In conclusion, the integration of Organic Rankine Cycles (ORCs) and heat pumps into heat exchanger networks presents a promising approach for improving energy efficiency and reducing operational costs. The optimization of both the internal and external energy flows within a system can significantly lower the reliance on external energy services, minimizing the overall energy consumption and reducing carbon emissions. This method shows great potential for industrial applications,

especially when considering the wide range of energy streams that can be recovered, such as residual heat, and used to generate power or preheat fluids.

However, there are practical limitations in applying this approach in real-world industry, particularly when it comes to selecting the right operating conditions for ORCs and heat pumps, as well as ensuring that the integration with existing systems is efficient. The modeling complexity can also increase as the number of variables grows, making it crucial to optimize not just the design but the operation of these systems in real-time.

Heat recovery, such as from steam, has a significant impact on the energy requirements of a utility system in an industrial plant. When a heat recovery strategy is implemented, the plant's energy system is affected as the amount of energy supplied externally to meet thermal demands is reduced. Specifically, heat recovery from steam can reduce the need for additional heat provided by conventional energy sources like natural gas or coal, which decreases the demand for fossil fuels and reduces the system's carbon footprint. However, this type of recovery can also affect the amount of energy the utility system must provide to maintain thermal balance in other areas of the process. For example, if recovered heat is used to preheat feed fluids to a distillation column or heat exchanger, the plant's heating system will require less energy to generate the necessary heat, but the pumping or generation systems may need to be adjusted to handle flow or pressure variations.

Therefore, it is essential to model the impact of heat recovery on the overall energy requirements of the utility system. It should be evaluated how this recovery influences the energy consumption of pumps, generators, or cooling units, and how different energy flows within the system are balanced to optimize consumption and minimize operating costs.

## ACKNOWLEDGMENTS

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