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# Industry Energy Optimization: A Case Study in a Biodiesel Production Site

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This paper presents a case study of heat exchanger network (HEN) retrofit with the objective to reduce the utilities consumption in a biodiesel production process. Pinch analysis studies allow determining the minimum duty utilities as well the maximum of heat recovery. The existence of heat exchangers for heat recovery already running in the process causes a serious restriction for the implementation of grassroot HEN design based on pinch studies. Maintaining the existing HEN, a set of alternatives with additional heat exchangers was created and analysed using some industrial advice and selection criteria. The final proposed solution allows to increase the actual 18 % of recovery heat of the all heating needs of the process to 23 %, with an estimated annual saving in hot utility of 35 k€/y.

## 1. Introduction

Fuel prices have been rising considerably in the past few years around the world with special impact on the industry. Many industrial companies, with their economic survival dependent of fuel markets, are looking into energy efficiency within their processes as new opportunity to increase competitiveness.
Pinch analysis, already known since the final of 70's, have been successively used as process design tool in several production processes (Linnhoff, 1993). This methodology allows the calculation of minimum cold and hot utilities consumption in a process using the operational data of available cold and hot streams. When studies based on pinch analysis are made on already running industrial processes it results in a new HEN design for maximum energy efficiency, however several restrictions may arise due to the already established process configuration (Smith, 2005).
Currently, when energy efficiency studies are conducted in industry processes, some degree of energy integration is already found. If the existing heat exchangers used for energy integration are not in harmony with the HEN established by pinch methodology, a full revamp of the grid will be necessary.
However a full reformulation of the existing HEN may face several restrictions of different types. This restrictions may include several issues such as layout, operational, controllability and economic.
This work presents a case study of an energy optimization conducted in a biodiesel production industry located in Portugal. The goal was to achieve a heat exchanger network retrofit in order to reduce the external utilities consumption in the process.
A detailed analysis of the process was performed in order to obtain a representative mass and energy balance of the most important streams of the process. The initial approach to the energy integration study was to include all the process streams with heating/cooling needs. Pinch targeting studies start to determine the maximum allowed heat integration, as well the minimum hot and cold utilities

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consumption. Based on the pinch studies outcome and taking into account the current existing heat exchangers for heat recovery a new HEN was depicted and proposed to the company.

## 2. Case study description

This biodiesel production process uses vegetable oils as raw material, where after a process of neutralization, transesterification, washing and drying, biodiesel fuel is obtained. As a by-product of the process, aqueous glycerine is also produced. A short process diagram is described in Figure 1.

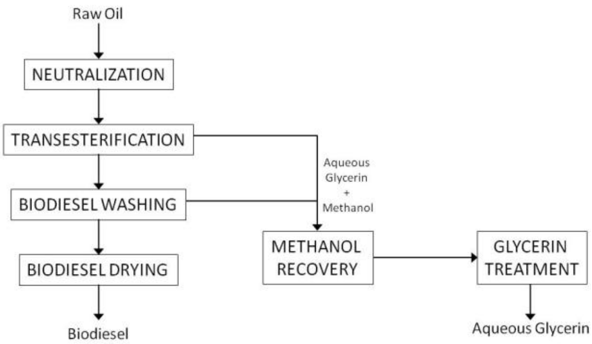



*Figure 1: Process description*

The industrial unit in analysis operates at relatively low temperatures (26 ºC to about 104 ºC) and uses water at a typical temperature of 20 ºC as cold utility and saturated steam at 2.5 bar (134 ºC) as hot utility. Any reduction of hot utility will be reflected in an economical benefit as consequence of lower natural gas consumption in the existing steam boiler. Due to the current cooling water system characteristics, there is no direct economic benefit deriving from cold utility consumption reduction. However, this will eliminate the frequent overload situations which are compensated by increasing the fresh cold water injection in the system, with inherent costs. The following references to economic benefits will account exclusively the benefits derived from the hot utility reduction.
The first step in our study was to detail all production stages and determine the mass balance of the process. This is essential to determine which streams are eligible to be used in a pinch methodology analysis, but also to characterize the thermal properties (e.g. heat capacities) of those streams.
As a first approach, eligible streams for energy integration were defined as all streams with heating or cooling needs, independently of the temperature levels. The process analysis allow to identify a total of 15 eligible streams (8 cold and 7 hot streams) to be used as heat/cold sources in a pinch methodology study.
The overall process requires an amount of hot power source that will be referred as 100 % (due to confidentiality issues, not all energy values will be presented) in Figure 2.

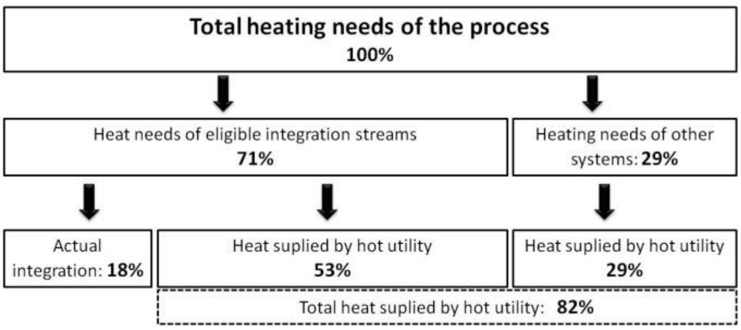



*Figure 2: Heating needs of the process*

The eight eligible cold streams are responsible for 71 % of total heating needs. The remaining 29 % correspond to hot utility consumption of other systems, as double effect evaporators, steam ejectors for low pressure purposes and for tank heating of low temperature solidification products.
The actual HEN already includes 4 heat exchangers for energy integration which are responsible for providing 18 % of the overall heating needs.
The main purpose of the energy optimization of the process is to increase the actual 18 % of energy integration, and consequently reduce the hot utility supplied to the eligible streams for energy integration. In Tables 1 and 2, a brief description of all hot and cold streams is given.

*Table 1: Cold streams description for pinch analysis. Duty in relative units (ru).*

| Stream Description | C1 Raw oil | C2 Process Water | C3 Neutral Oil | C4 Raw FAME | C5 Glycerine phase | C6 Column Feed | C7 Washed FAME | C8 Reboiler Feed |
|---|---|---|---|---|---|---|---|---|
| T in (ºC) | 29 | 26 | 45 | 36 | 35 | 48 | 50 | 104 |
| T out (ºC) | 90 | 88 | 62 | 45 | 62 | 75 | 85 | 104 |
| Duty (ru) | 2478 | 594 | 661 | 394 | 100 | 694 | 1406 | 6106 |
| Total duty (ru) | | | | 12433 | | | | |

*Table 2: Hot streams description for pinch analysis. Duty in relative units (ru).*

| Stream Description | H1 Dried FAME | H2 Neutral Oil | H3 Reactor Effluent 1 | H4 Reactor Effluent 1 | H5 Aqueous Glycerine | H6 Methanol distillate | H7 Vacuum steam |
|---|---|---|---|---|---|---|---|
| T in (ºC) | 90 | 80 | 60 | 49 | 104 | 65 | 134 |
| T out (ºC) | 35 | 45 | 52 | 36 | 66 | 65 | 27 |
| Duty (ru) | 2189 | 1378 | 383 | 617 | 817 | 5544 | 189 |
| Total duty (ru) | | | | 11117 | | | |

## 3. Pinch analysis – first approach

Using a minimum temperature approach (MTA) of 10 ºC, the maximum retrofit potential of a HEN generated by pinch analysis can be obtained from the composite curves of all hot and cold streams as shown in Figure 3a. In Figure 3b, the influence of the chosen MTA value to build the composite curves, on the calculated minimum duties from hot and cold utilities, can be observed.

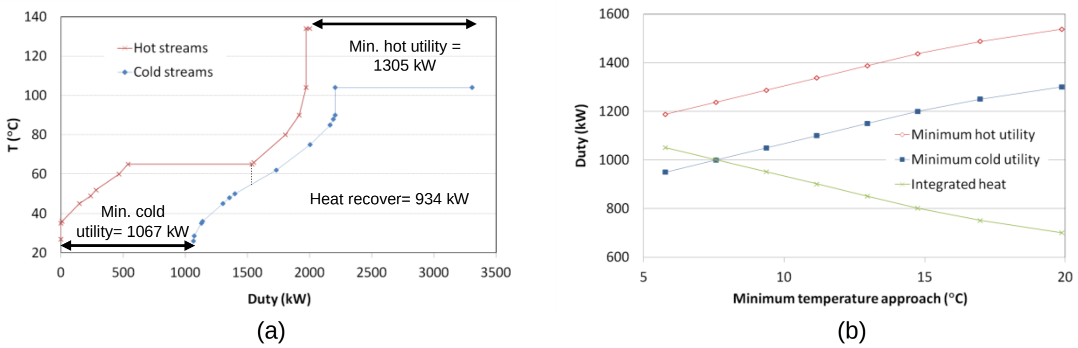
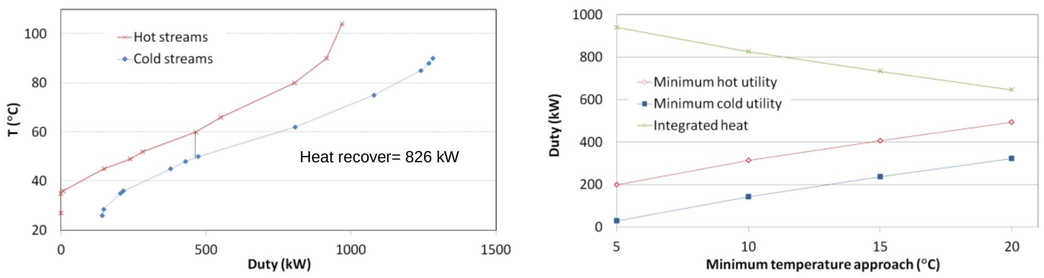



*Figure 3: (a) Composite curves for a MTA= 10 °C and, (b) Minimum cold and hot utility versus MTA.*

Using a MTA of 10 °C as reference, it was determined that the actual integrated energy that satisfies 18 % of total heating needs of the process, could be increased to a maximum of 29 %.

## 4. Pinch analysis – second approach

After a deep analysis of all streams characteristics, it was decided, due to controllability issues in certain process sections and safety reasons, to exclude the streams C8, H6 and H7 as eligible streams for integration, at this stage. This was an important modification of the initial assumptions, which will reduce the heat recovery potential.
Figure 4a shows the composite curves of the new set of streams for a MTA of 10 °C. The heat recovery potential is reduced from 29 % of the total heating needs of the process in the first pinch approach to 26 %. Figure 4b shows the influence of MTA in maximum heat recovery and minimum hot and cold utilities.




(a) (b)

*Figure 4: (a) Composite curves for a MTA= 10 °C and, (b) minimum cold and hot utility versus MTA.*

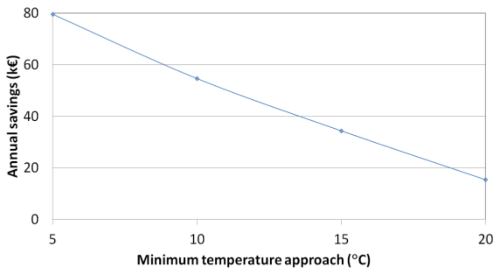



*Figure 5: Maximum estimated annual savings of a HEN retrofit for different MTA values.*

The estimated maximum economic benefit of a HEN with a MTA of 10 °C, considering exclusively the savings from heat utility reducing is about 55 k€/y. Although the capital costs are not considered here, this analysis constitutes valuable information to establish expected maximum income. Figure 5 presents a relation between the MTA and the maximum annual savings that should be expected.

## 5. Proposed HEN

Any HEN design that results from the previous pinch analysis, corresponds to a grassroot design, and would require a total modification of the current one. However a totally new HEN design could face serious limitations in this industrial site. The process used for biodiesel production is quite compact and it is spread in several floors. This represents a layout serious issue in order to find new available locations for all new heat exchangers as well all the needed piping. This last issue is heightened if the heat exchangers are fed by streams located in opposite position in the process, which would require long pipe settle.
Although it was not evaluated in detail, the predicted capital cost involved in a new HEN design would make this solution economical uninteresting. Additionally, a total modification of the HEN represents a stoppage time that the company was not willing to accept.
A new approach was then assumed, in which the existing HEN would be considered and additional opportunities of heat recovery would be searched. In this way, all existing four heat exchangers used

for energy integration would be considered despite the fact that heat exchange across the pinch temperature was occurring. The duty exchanged in the existent four heat exchangers, between some of the streams listed in Tables 1 and 2, can be observed in Table 3.

*Table 3: Actual integration heat exchangers duties. Duty in relative units (ru).*

| Heat Exchanger | HE1 | | HE2 | | HE3 | | HE4 | |
|---|---|---|---|---|---|---|---|---|
| Streams | C1 | H2 | C5 | H3 | C6 | H5 | C7 | H1 |
| T in (ºC) | 29 | 80 | 35 | 60 | 48 | 104 | 50 | 90 |
| T out (ºC) | 63 | 45 | 50 | 59 | 66 | 82 | 82 | 58 |
| Duty (ru) | 1378 | | 56 | | 472 | | 1289 | |
| Total duty (ru) | 3195 | | | | | | | |

The final HEN proposed is a result of the analysis of a set of alternative HENs in two stages. In the first stage a set of 9 HENs with a number of 2 to 4 additional heat exchangers for integration, were analysed. From this set, two HENs were found the most promising using criteria as energy utility reduction, implications of pressure loss increase in critical parts of the process, distance between new heat exchanger streams and available locations for new heat exchangers depending on the streams that are fed. In the second stage, four additional alternative HENs were considered based on the previous chosen HENs (see Table 4).

*Table 4: Alternative heat exchanger network (HEN#) with heat exchanger (HE#) status. (√–without modification, X –removed, O – Change on area).*

| | HEN1 | HEN2 | HEN3 | HEN4 | HEN5 | HEN6 | Actual HEN |
|---|---|---|---|---|---|---|---|
| HE1 | √ | √ | √ | √ | √ | √ | √ |
| HE2 | √ | √ | √ | X | x | √ | √ |
| HE3 | √ | √ | O | √ | O | O | √ |
| HE4 | √ | √ | √ | √ | √ | √ | √ |
| HE5 | C2/H1 | C4/H1 | C2/H1 | C2/H1 | C2/H1 | C4/H1 | X |
| HE6 | C4/H3 | C2/H3 | C4/H3 | C4/H3 | C4/H3 | C2H3 | X |
| HE7 | C3/H5 | C3/H5 | X | C3/H5 | X | X | X |
| Total duty (ru) | 4078 | 4150 | 3956 | 4078 | 3956 | 4028 | 3194 |

Obs.: The streams involved in HE1, HE2, HE3 and HE4 can be identified in Table 3.

Based on the already mentioned criteria, HEN1 was the chosen alternative design and will require three additional heat exchangers along with the existing four. In Table 5, the heat duty (in relative units) of the new heat exchangers for integration are presented.

*Table 5:  New integration heat exchangers duties.*

| Heat Exchanger | HE5 | | HE6 | | HE7 | |
|---|---|---|---|---|---|---|
| Streams | C2 | H1 | C4 | H3 | C3 | H5 |
| T in (ºC) | 26 | 58 | 36 | 59 | 45 | 82 |
| T out (ºC) | 48 | 52 | 44 | 52 | 54 | 66 |
| Duty (ru) | 211 | | 328 | | 344 | |
| Total duty (ru) | 883 | | | | | |

A diagram of the overall heat exchanger network can be seen on Figure 6. The proposed HEN design will enhance the actual 18 % recovered heat to 23 % (see Figure 7). The target pinch of 26 % was not reached because of cross pinch of the existing heat exchangers. Layout and economic limitations to additional heat exchangers were the reasons for not implementing the high efficient alternative. The economic benefit of the proposed HEN is estimated in 35 k€ per year.

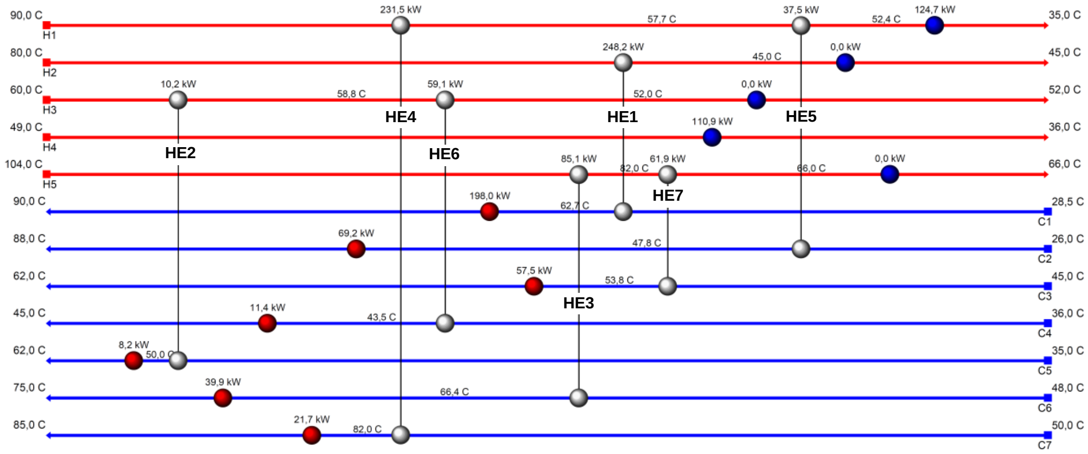



*Figure 6: Proposed HEN design*

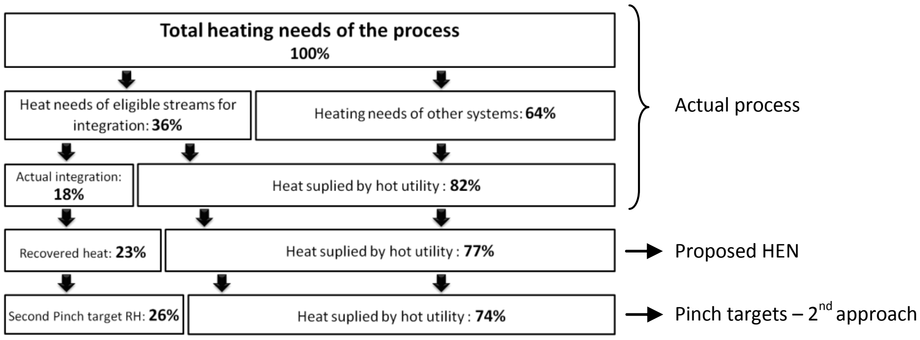



*Figure 7: Heating needs of the process considering 2$^{nd}$ approach to Pinch Analysis and proposed HEN*

## 6. Conclusions

The improvements of a thermal energy integration activity of a running production process is not a one-step task, it needs a deep interaction with the industrial partner to obtain the adequate data and the identification of the plant constraints. Minor changes in the some preliminary assumptions may require full reanalysis of the conclusions obtained in the meanwhile. In this case, pinch methodology provided an excellent tool for establishing maximum expected income from a HEN design by identifying the right modification with highest valued-added. The obtained improvement on 5 % of the recovered heat will be implemented after the adequate determination of investment cost and the payback time. A new step further to improve the heat integration and reduce the energy consumption, will be developed based on process simulation to find better operational conditions, namely in the zone of the methanol recovery.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