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PINCH TECHNOLOGY IN THEORY AND ITS APPLICATION TO A BIOMASS INTEGRATED GASIFICATION AND HUMID AIR TURBINE PROCESS (IGHAT)

Bernardo Lafuente Garcia

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Pinch Technology in theory and its application to a Biomass Integrated Gasification and Humid Air Turbine process (IGHAT).

Referat (sammandrag)

The Pinch Technology has become a powerful tool for the optimisation of the design of heat exchangers networks during the last 20 years. In this work, the different aspects of the methodology have been studied both in a theoretical way and in a practical approach.

The first part of the work is a systematic analysis of the Pinch Technology: what it is, how it works, what are its advantages and disadvantages. There is also a brief discussion about the Pinch method and other methods which handle energy recovery problems.

Once the philosophy of the Pinch Technology has been theoretically studied, the second part of the work is its application to two different processes. The first process analysed is a relatively simple but realistically practical problem based on a two distillation columns system. The knowledge got during the calculations of this process is used in the second and more complex one. This second process is an integrated biomass gasification and humid air turbine (IGHAT) which has been already optimised by a heat balance program. The application of the Pinch Technology to this process shows the huge potential for improvements that this technology can provide in order to save energy.

All the calculations are handled by the Pinch Technology software program "SuperTarget". This program is evaluated along the work. In spite of some shortcomings that have been noticed, the usefulness of the program can be claimed.

Referat skriven av
Bernardo Lafuente Garcia

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1. The SuperTarget program

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1. INTRODUCTION.

1.1 Background.

Since the energy crisis of the early 1970s, much attention had to be focused on better process design. Whether an industrial plant makes some outputs from different inputs, most of the energy goes either to heat or to cool the various processing fluids involved. There are process streams which need to be heated and others cooled. Hence, engineers have tried to save energy through heat exchange between both hot and cold streams.

The problem is that to identify all opportunities for heat exchange is not easy at all, especially in such a complex industrial plant that performs many different operations and exits so many different hot and cold streams. For many years engineers have tried to achieve heat exchange within individual production units, and they have had to rely as much on experience and intuition as on skill in designing process to take full advantages of heat exchange opportunities. But even when every heat exchange unit operates efficiently, the overall can be inefficient if those units are linked together inappropriately [4].

The way to approach such networks was either by "rule of thumb" or a systematic mathematical examination of all possible configurations to try to achieve the best one. The research then focused on two main endeavours: the development of mathematically efficient search techniques to scan quickly as many designs as possible; the development of these "heuristics" or rules of thumb. These were used to prefer or reject families of solutions on the basis of common sense [8]. Both approaches led to good answers but neither claimed to generate the optimum solution because neither could identify the "ideal" amount of heat recovery as a target to be achieved [1]. Moreover, in the past, design engineers had no way of knowing whether even a well-designed plant could operate at greater efficiency.

In the early 1980s, and pioneered by professor B. Linnhoff [8-16,24,25], Pinch Technology [1-6,8-17,22,24-26] emerged as a tool for the design of heat exchangers networks. During all that time, Pinch Technology, or process integration, has demonstrated that good process integration pays off through simplicity of plant design and good use of energy and capital. This method allows the engineer to identify both the optimum heat recovery and the arrangement of heat exchangers which will achieve this recovery.

In the beginning, Pinch Technology was a specialised tool, used only in certain circumstances. Today, it is a general tool. Pinch Technology has evolved from a specialised tool for heat recovery into a broad-based methodology for reducing capital costs, emissions and energy consumption, spanning process design and total site planning [10].

1.2 Pinch Technology in perspective.

1.2.1 The meaning of Pinch Technology.

There are just few aspects of an industrial process which are fixed and unchangeable. The manner and order in which raw materials are prepared and combined, the types of reactors and separators used, the ways in which materials are heated, cooled, transported, etc., often can vary. Many alternative process configurations, operating conditions, equipment choices, and energy sources are feasible. But what is the best design?, and how can we find it?

Pinch Technology is a body of insights and techniques for finding the best way to assemble the building blocks of industrial processes. It takes its name from its identification of a key system temperature constraint, or "pinch", which thermodynamically limits heat recovery and thermal energy efficiency.

Pinch Technology optimises total systems. It exploits beneficial interactions among unit operations, and identifies where changes to process configuration, operating conditions and equipment selection will be truly beneficial for the specific system as a whole.

Pinch Technology goes back to fundamental process data, avoiding any assumptions or preconceptions about what the design should look like. From basic thermodynamic principles, the capital and operating costs of the process are determined prior to design. Ideas for process changes that fundamentally reduce these costs are generated. After modifying the process data to reflect these beneficial changes, the optimum balance between capital and operating costs is determined.

With Pinch Technology, industrial process managers, designers and operators no longer need to rely on empirical and iterative approaches. Though industry will remain complex, Pinch Technology provides a systematic means of identifying, analysing, and optimising the available options. The impressive results already realised in reduced operating costs and increased returns on investment speak for themselves [6].

1.2.2 Pinch Technology and exergy analysis.

Pinch Technology was derived from exergy analysis principles. Indeed, it represents and expression of those principles in a powerful but simple stand-alone design tool for heat exchanger networks. The technique makes exergy analysis applicable for synthesis, with the added advantage of accounting for equipment choice, network interactions and economic trade-offs. Pinch Technology is a special case of second law analysis, in fact is second law analysis made practical.

In the design of energy systems, first law losses describe energy flows across the system boundaries; second law losses describe lost potential. The latter form of loss is generally accepted as a more useful concept for the engineer seeking clues for design improvement. Exergy losses in an optimal design developed by Pinch Technology are rigorously inevitable [9].

1.2.3 Other benefits from Pinch Technology.

Pinch Technology has become a powerful tool to help engineers device cost-effective ways to accomplish multiple process improvement objectives. For instance, Pinch Technology can now be used to identify opportunities for process debottlenecking, and reducing waste, capital and operating costs.

In reduction environmental impact of process plants, there are three ways in which Pinch Technology has been successfully applied: reduction of the gas emissions, waste minimisation and evaluation of waste treatment options [17].

The scope and costs of pinch analysis vary widely, depending on the complexity of the process plant and its objectives. Pinch Technology can be applied to any plant that uses energy for heating and cooling, no matter what specific processes are involved.

Perhaps, one of the most impressive advantage of Pinch Technology is its flexibility. Experience has shown that correct integration in basic design not only lowers capital costs and saves energy but also makes plants more flexible in responding to ever-changing demands in the market place.

Using Pinch Technology, design engineers would have been able to look at the entire plant as a single, integrated whole [4].

1.2.4 Process integration software.

The role of software in the discussion of the Pinch Technology is specially important. Many people still think of process integration software packages (for instance, software generating composite curves, grand composite curve, total site profiles and grid diagrams) as simple one-off tools that might as well be sourced from universities or be written in-house. In reality, process integration is an integral part of process design, alongside simulation, and process integration software should be integrated into the process-design software environment with the same consideration given to user interfaces, file handling, data transfers, and so on, as is customary for simulation packages, databases, and the like.

Pinch Technology software helps the engineer to identify promising options, to establish outline feasibility and costs, and to recognise key problems and characteristics for each process.

Commercial Pinch Technology software is available from Linnhoff March, Aspen Technology, Britain's National Engineering Laboratory, Simulation Sciences, and others [10].

1.3 Discussion of the Pinch Technology.

It is hard for everybody to agree with the advantages that practitioners of Pinch Technology have claimed about it. Searching in the literature we can find different methods for how we should attack the problem of achieving the maximum energy recovery in the network.

For instance D.A. Sama [18-21] criticises the Pinch Technology approach and defends the use of Second Law Analysis. Sama found four deficiencies associated with Pinch Technology:

1. Pinch Technology emphasises the heat exchange network design, whereas the real problem is usually in the process design.

2. It is claimed that Pinch Technology will find the global optimum, when in fact global optimums generally are non-existent.

3. Pinch Technology offers no satisfactory explanation as to why poorly designed heat exchange networks are poorly designed.

4. The efficacy of the Pinch Technology method is often exaggerated by starting with flawed heat exchange networks designs.

The method proposed by Sama is based on 13 commonsense second law guidelines which are enough to easily identify second law design dictates and second law errors. He concludes that, however there is no doubt that the Pinch Technology approach to the design of heat exchange networks is both clever and useful, the Pinch Technology is usually inferior to that obtained through Second Law Analysis or, at best, the Pinch Technology solution is identical to the Second Law Analysis solution.

Many things could have been said about the above mentioned conclusion. The Pinch Technology has been used successfully for the last 15-20 years. Could we really achieve better solutions using just these 13 commonsense second law guidelines?. It is early to answer to that question, but further studies and new developments will show whether it is right or not.

At least, Second Law Analysis provides an understanding of the process which is almost absent in the Pinch Technology, maybe that is the most important conclusion.

The matter is not to decide which method is the best one and just use this one forgetting the others. We can get useful conclusions from every method which can help us in each step of the process design.

For instance, one good approach to achieve the optimum heat exchange network would be the use of the 13 commonsense second law guidelines, a heat balance program and a Pinch Technology program completing each other. In the first step of the design the 13 commonsense second law guidelines would be used to easily identify design dictates and second law errors. In the second part of the process design we should work with a heat balance program to obtain the data necessary to go to the next step; the Pinch Technology program. In this third step, where SuperTarget program can be used, the point is to optimise the heat exchange recovery that already has been identified in the first step and calculated in the second step, as a whole network. If some changes have been done during this step we should go back to the previous steps, to first step to analyse if any second law error exists and to the second step to recalculate the heat balance. Working in this way all three methods will complete each other, taking maximum advantage from each of them to find the optimum solution.

The need for the engineer is to know and understand as many different methods and techniques as possible, know when and where each one of them can be useful to the work and know how to apply it correctly. This gives the engineer the necessary flexibility to solve different heat exchange networks in the best way, saving time and resources, what will lead to achieve a competitive advantage. The engineer who just thinks about one method, and uses this only method, keeping closed to the other ones, could never compete with the one who has his or her mind opened and prepared to understand and work with all the different methods.

2. THE PINCH TECHNOLOGY. METHODOLOGY.

Conceptually, Pinch Technology is based on identifying energy targets for a process and recognising the pinch. The pinch is a temperature level in the process which is a bottleneck on energy recovery. Before design, the procedure predicts the best energy performance that a given process can possibly achieve. Next, a design which satisfies this energy target is synthesised. Finally, the network is evolved to optimise energy against capital towards minimum total cost. In summary, Pinch Technology is based on, first, synthesis for energy efficiency and, second, optimisation for capital cost [11].

2.1 Composite streams.

Almost in all industrial plants, there are many hot and cold flows involved in the process where ones must be heated and others cooled. The first step in Pinch Technology is to combine the temperature characteristics for all the streams that need to be heated (called cold streams) into a single cold composite stream, and all those that need to be cooled (called hot streams) into a hot composite stream.

In order to understand how this combination is made, we can look at the next example with four streams [1]:

Stream Number	Type	Thermal capacity rate C (KW/K)	Initial Temperature (°C)	Final Temperature (°C)	Rate of enthalpy increase (CxΔT) (KW)
1	hot	2	200	60	-280
2	hot	4	170	70	-400
3	cold	3	40	175	+405
4	cold	4,5	100	150	+225

For instance, for the hot composite curve, it is derived as shown in figure 1. The two hot streams both exit in the temperature range 170°C to 70°C, so the thermal capacity of the composite stream is therefore the sum of the two individuals stream values.

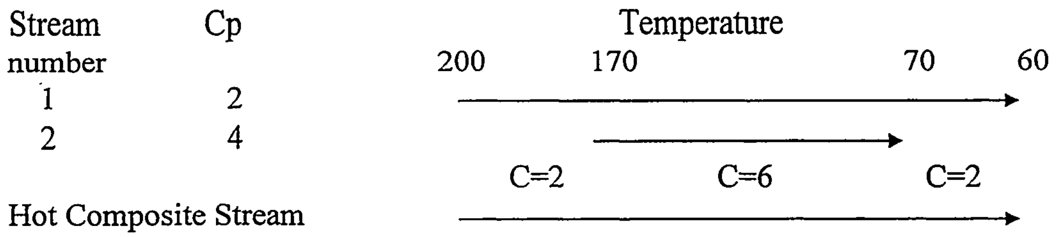


Figure 1.

We can do the same for the cold streams deriving one cold composite stream. Now we can plot both curves in a temperature - enthalpy diagram (note that the thermal capacity is the gradient of the curve). These curves are shown in figure 2.

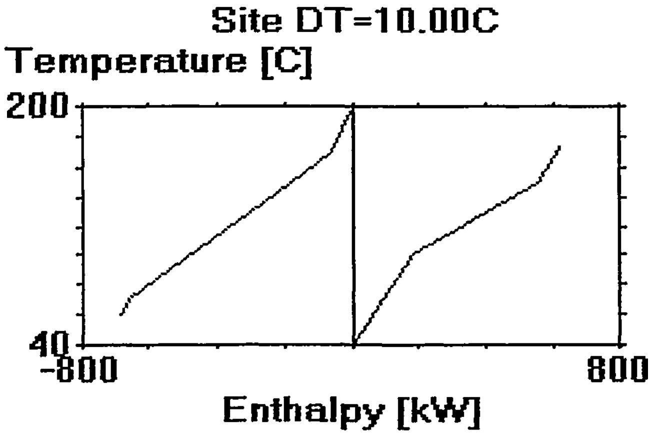


Figure 2.

2.2 The pinch point.

When we plot both curves (hot composite and cold composite) in the same temperature - enthalpy diagram (figure 3), the point where they are closest is called the process pinch. So that, the pinch point is the minimum temperature difference between the cold and the hot composite streams. In that case the pinch point is at 105°C.

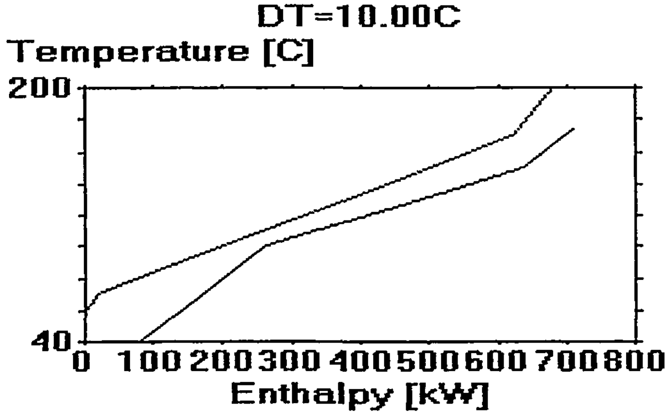


Figure 3.

2.3 Target external heating and cooling load.

In figure 2 the curves have identified the region in which the hot streams exchange heat with the cold streams. Beyond the area of overlap the curves identifies the needs for external cooling (below the pinch) and the needs for external heating (above the pinch). For that example, the hot utility target is 30 KW and the cold utility target is 80 KW.

2.4 The three basic rules of Pinch Technology.

There are three rules that must be observed in the design of the optimum heat recovery scheme:

a) No external cooling above the pinch, and
b) No external heating below the pinch.

The process pinch separates the overall process system into a heat sink (above the pinch) and a heat source (below the pinch). To achieve optimal efficiency, the final process design must ensure that no cold utilities are used above the pinch and no hot utilities are used below.

c) No heat transfer across the pinch.

It is not possible to achieve the minimum external heating and cooling targets unless there is no heat transfer across the pinch.

2.5 Design of energy recovery systems.

In order to design the optimum energy recovery system using the Pinch Technology, it must be followed the next steps:

- Construct a design chart:

In figure 4 it can be seen the design chart, where the hot streams are represented as horizontal lines from left to right between their respective temperatures and the cold streams are drawn from right to left, and both of them are broken in the middle, representing the pinch.

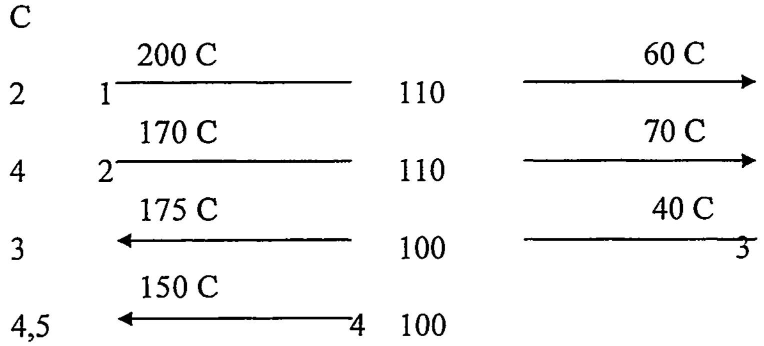


Figure 4.

- Design process.

Now we have the problem divided at the pinch. The design process consists of linking the hot streams to the cold streams by heat exchangers. Each part (above and below the pinch) has to be designed separately starting at the pinch and moving away.

Immediately adjacent to the pinch, the next constraints must be obeyed for linking the streams:

Cp cold ≥ Cp hot above the pinch

Cp hot ≥ Cp cold below the pinch

and, of course:

N cold ≥ N hot above the pinch

N hot ≥ N cold below the pinch

where N hot and N cold are, respectively, the number of hot and cold streams.

Figure 5 shows the final design. The duty of each heat exchanger link is calculated by evaluating the heat transferred (C x DT). The remain needs are supplied by external heating and external cooling.

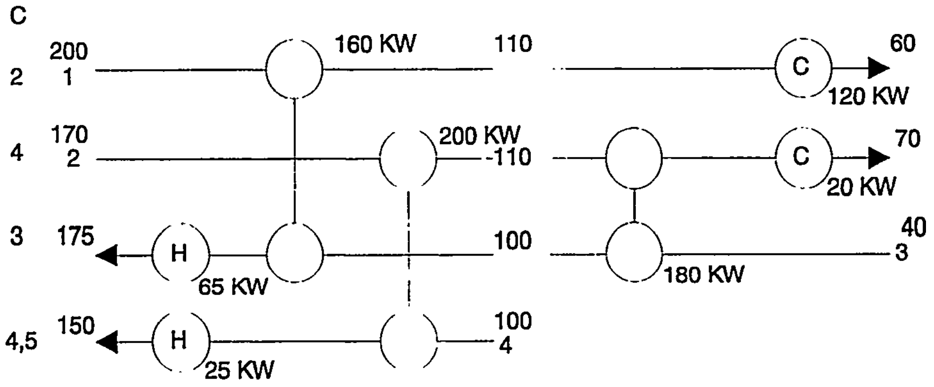


Figure 5.

- Stream splitting.

When is impossible to link streams because one of the design criteria cannot be satisfied, we have to resort to the stream splitting.

So, when we split one stream we have to choose the thermal capacity rate for each sub-stream in order to satisfy the design criteria and the requirement to have as few heat exchangers as possible to reduce capital cost. Obviously, the sum of each Cp sub-stream must equal the Cp original single stream.

Figures 6 and 7, [9], show a step by step procedure for identifying the need to split streams and generate stream splitting options at the pinch.

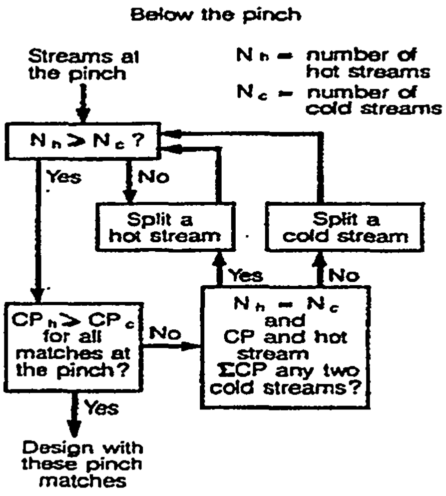


Figure 6.

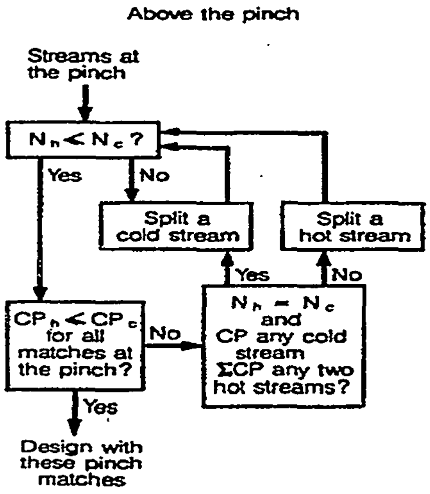


Figure 7.

2.6 Selection of the pinch temperature difference.

The total cost of the system (running costs + capital costs) is very much influenced by a good choice of the "best" temperature difference for the pinch: a small value will reduce the external duties but incur the penalty of large heat exchangers; a large value will require smaller heat exchangers but generate the need for increased external duties. It thus becomes a matter of cost, where we have to choose the optimum minimum difference of temperature (ΔTmin) that achieves the best capital-energy trade off (figure 8, [14]).

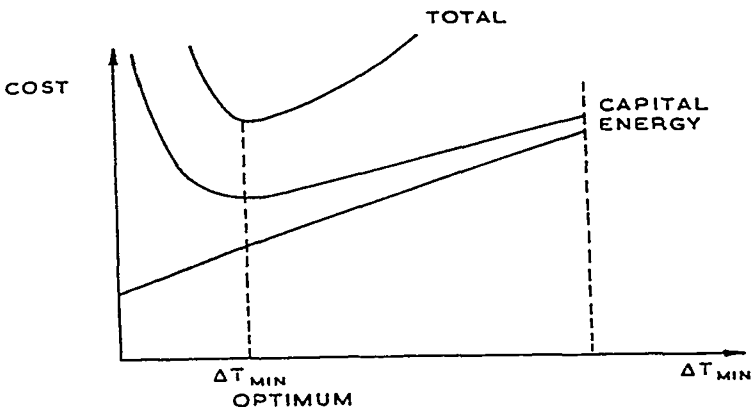


Figure 8.

2.7 Problem table algorithm (PTA).

An easier way to obtain energy targets and pinch location for a given value of ΔTmin than the method used before is the PTA which sets the energy targets algebraically.

The first step is to adjust the stream temperatures for ΔTmin. The interval boundary temperatures are set at 1/2 ΔTmin below hot stream temperature and 1/2 ΔTmin above cold stream temperature.

In the second step, after removing the temperatures duplicated, the intervals may be set-up in descending order of magnitude and determined which stream is in which interval.

The third step is to calculate the enthalpy balance for each interval, according to:
$\Delta Hi = (Ti - Ti+1) (\sum Cpcold - \sum Cphot)i$

Each interval will have either a net surplus or a net deficit of heat as dictated by enthalpy balance.

The fourth step is the cascade for positive heat flows. The idea is to transfer surplus energy from one interval to the next, which is always possible because the surplus of energy is always at higher temperature than the next interval.

The net result of this operation is that the minimum utilities requirements have been predicted and the position of the pinch has been located where the heat flow is zero (figure 9). So, the same information is obtained as from the composite curves.

```
PROBLEM TABLE

DT = 10.00 [C]

----------------------------------------------------
| Status |  Temperature  |    Duty    |
|        |            C  |    kW      |
----------------------------------------------------
|        |       195.00|        30.0|
|        |       180.00|        60.0|
|        |       165.00|        45.0|
|        |       155.00|        75.0|
|P-->    |       105.00|           0|
|        |        65.00|       120.0|
|        |        55.00|       110.0|
|        |        45.00|        80.0|
----------------------------------------------------
```

Figure 9.

2.8 The Grand Composite Curve.

Pinch Technology can help to evaluate the suitability of different types of heating and cooling systems by using the Grand Composite Curve (GCC). This curve is obtained by plotting energy surplus against adjusted temperature. The pinch appears at the position of zero surplus (figure 10).

Above the pinch the GCC shows how the demand for external heating increases and at what temperature the heating would need to be supplied. Similarly, below the pinch the curve shows how the demand of external cooling increases and at what temperature the cooling would need to be supplied.

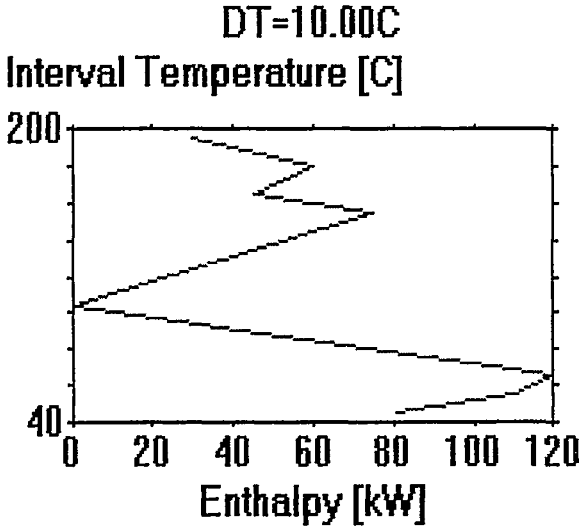


Figure 10.

2.9 Installation of heat pumps and heat engines.

Pinch Technology will guide the designer on the most effective placement of heat pumps and heat engines in heat recovery scheme:

- The correct placement of a heat pump is across the pinch, getting heat below the pinch and giving heat above the pinch.

- A heat engine can operate only on one side of the pinch, either extracting heat below the pinch or donating heat above the pinch.

2.10 Process Integration.

The technology of Process Integration has proved to be of great value to process industries in reducing energy costs. The basic ideas of generating achievable energy targets for a process gives considerable confidence in the design of new networks and redesigning of existing ones.

3. PROCESS 1. TWO DISTILLATION COLUMNS.

This process has been taken from the article referenced as [22]. All the tables and figures generated by SuperTarget and mentioned in the text are placed on the section 3.4.

3.1 Description of the process.

3.1.1 Motivation.

The process that has been chosen for this first part of the work is a relatively simple but realistically practical problem. The analysis, calculations, and conclusions obtained from this process will help to get the knowledge needed for working with more complex systems, like the process from Sydkraft, AB analysed in the second part of the work.

3.1.2 The process.

The process consists of two distillations columns in series. The current heat integration scheme uses the overheads of column 2 first to preheat the feed to column 1 and then to raise low pressure steam; the bottoms of column 2 further heat the feed to column 1. All the remaining heating and cooling loads are supplied using high pressure steam and cooling water utilities.

A minimum approach temperature (ΔTmin) of 20°C between all streams exchanging heat is assumed. Table 1 shows the process stream data with the supply and target temperature, the enthalpy change, and the mass specific heat for each cold and hot stream. Figure 11 shows the process flowsheet and figure 12 the grid representation of the actual heat exchanger network.

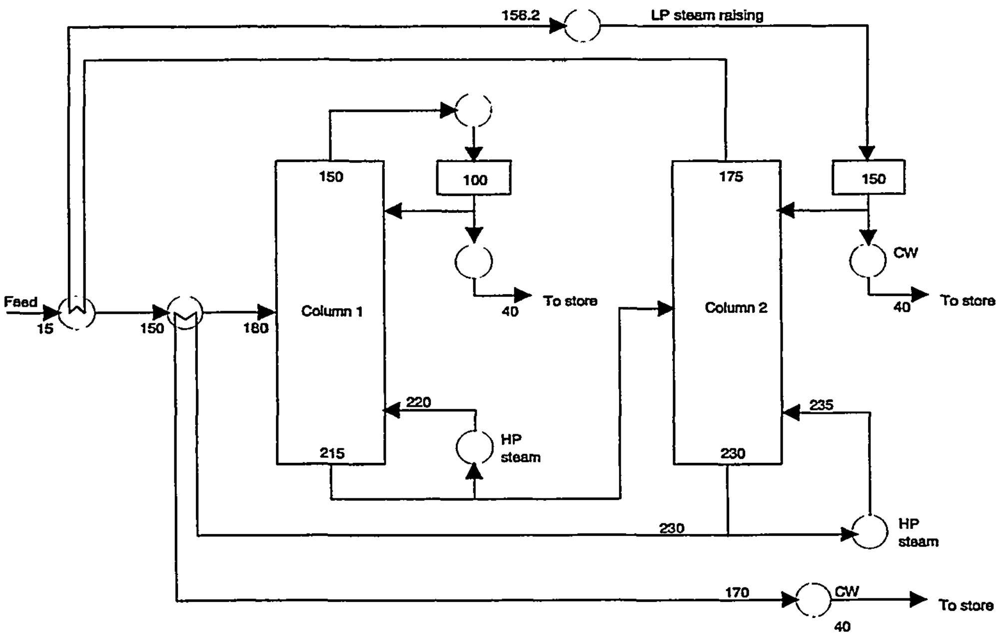


Figure 11.

3.2 The design procedure. Calculations using the program SuperTarget.

The first step will be to generate the Composite Curves and the Grand Composite Curve in order to determine the maximum energy recovery possible for the network. In doing this, the "boiler feed water for steam raising" stream will be excluded from the analysis, as the procedure used will maximise the amount of low pressure steam generated.

Figure 13 shows the Composite Curves obtained. By looking at them, the minimum targets can be determined. These minimum utility targets are then 11.4 MW for the hot utility and 10.15 MW for the cold utility.

The Grand Composite Curve is shown in figure 14. We shall use this curve to help us maximise the amount of low pressure steam raising we can perform. As the interval temperature of the actual "low pressure steam raising" temperature is 140°C, the heat available for steam raising is 8.5 MW. Allowing for the heat required to provide the heat to raise the condensate temperature from 108°C to 130°C the total energy required for steam raising is 8.86 MW. The effect on the Grand Composite Curve of this stream generation at temperatures below 140°C is shown in figure 17.

The Exergy Grand Composite Curve, which shows the work that could be extracted from the transfer of heat within the heat exchanger network, is shown in figure 15. With the new steam generation, the Exergy Grand Composite Curve becomes like shown in figure 18. In this curve, it can be appreciated that a bigger amount of heat may be used for the heat exchanger network.

The new stream data including this steam generation are shown in table 2. In figures 16 and 17, we can see the new Composite Curves and new the Grand Composite Curve. Inspection of these modified curves shows that the heat rejected to cooling water has been reduced by 8.86 MW, from 10.15 MW to 1.29 MW, this heat being used to raise low pressure steam. A comparison with the base case design reveals that the amount of low pressure steam generated has been increased from 2.16 MW to 8.5 MW.

Once the minimum utility targets have been optimised by searching for improvements looking at the Grand Composite Curve and Composite Curves, the next step is to find the heat exchanger network which achieves them. For doing this SuperTarget offers a useful interface tool.

On first inspection, the process shows that neither of the reboiler duties can be met by heat exchange with hot process streams; both require external hot utility. Hence, we should ignore the two pinch points which these two column reboiler streams create. So that, our pinch temperature is 150°C for hot streams and 130°C for cold streams.

Now, we can create the grid for the new heat exchanger network by splitting the problem into two parts: above and below the pinch, as Pinch Technology claims. Using these Pinch Technology rules, figure 19 shows the new design for the heat exchanger network, which achieves completely the targets.

In this new design, there are three coolers: one with a load of 0.3 MW for "Column 1 distillate" stream, another one with a load of 0.31 MW for "Column 2 distillate" stream, and the last one with a load of 0.68 MW for "Column 2 bottoms" stream, what sums a total of 1.29 MW cold utility. The heaters are two, for both reboilers, as already has been mentioned, with a total duty of 11.4 MW.

As a disadvantage, more heat exchangers are needed in this new design and the complexity of the flowsheet has been increased. This can be checked in figure 20, which shows the modified flowsheet of the process.

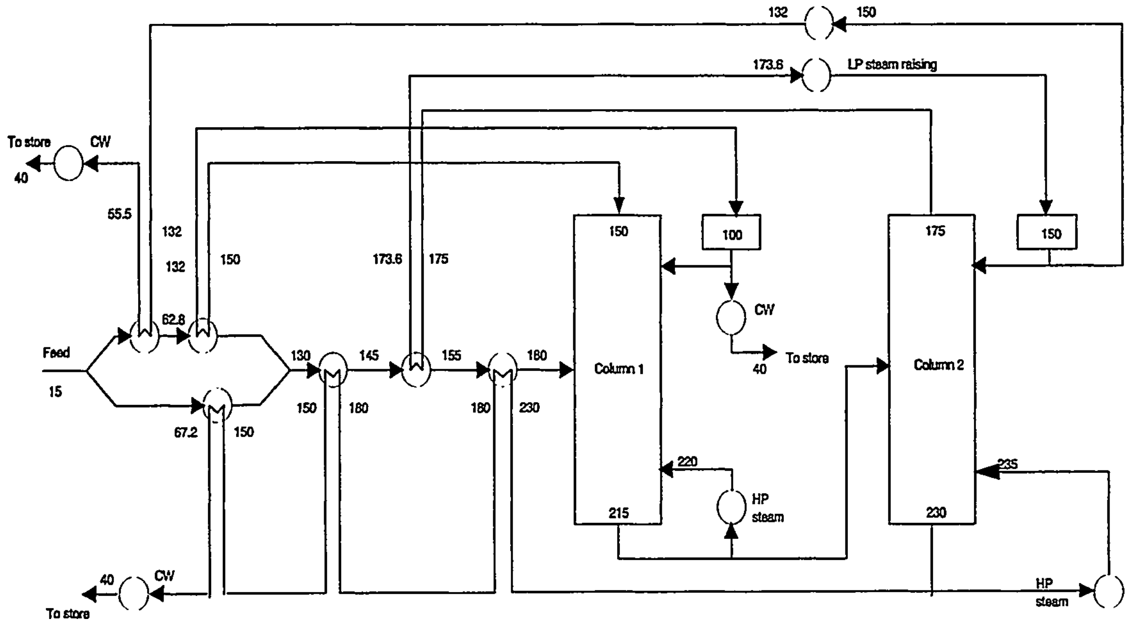


Figure 20.

3.3 Conclusions.

All the calculations made and the results obtained here are exactly the same as those obtained in the article refenced as [22].

The new process lay-out that has been created produces total energy savings of 8.86 MW. This numerical conclusion could lead to a more general one: the method used here, the so called Pinch Technology, generates real energy savings. The intelligent use of the curves which the method provides is the way to analyse and improve the process.

Starting by the Composite Curves, they show the minimum external heating and cooling that the process needs. The area between the hot and the cold composite curves also shows the exergy losses in the process. Therefore, we have to try to reduce this area in order to reduce exergy losses and external needs for heating and cooling.

The Grand Composite Curve, which gives the hot and cold utility requirements of the process both in enthalpy and temperature, allows us to make an appropriate utility selection.

Choosing the best utilities, based on information from the graph and process constrains, will lead to an improved process with less external needs.

The exergy curves: the Exergy Composite Curves and the Exergy Grand Composite Curve, are similar to the Composite Curves and the Grand Composite Curve, but in Carnot Factor co-ordinates. Especially important is the Exergy Grand Composite Curve because it shows the total heat that can be used for exchanging heat within the heat exchanger network, and the heat that is required or can be extracted from the process. The comparison of the two Exergy Grand Composite Curves before and after the utility generation will show how much we have improved the process.

In all this process, and in the generation of the final grid which achieves the targets, the program SuperTarget has been a very useful help tool.

We have to mention that no consideration has been made of the capital investment required to install such a network. The inclusion of economical parameters into the analysis could lead to very different conclusions. Anyway, we do not have economic data available, so the results can only be referred to the energy savings.

3.4 Figures and tables from SuperTarget.

(C) Linnhoff March Stream Data Report

Untitled: File: Chemic0.st4

No	Type	Name	TS C	TT C	dH kW	MCP kW/K	HTC kW/m^2.K	DT C	Cost law
1:1	Hot	Col 1 overheads	150,00	100,00	2150,0	43,000	None	Global	1
2:1	Hot	Col 1 distillate	100,00	40,00	300,0	5,000	None	Global	1
3:1	Hot	Col 2 overheads	175,00	150,00	9000,0	360,000	None	Global	1
4:1	Hot	Col 2 distillate	150,00	40,00	2200,0	20,000	None	Global	1
5:1	Hot	Col 2 bottoms	230,00	40,00	4750,0	25,000	None	Global	1
6:1	Cold	Col 1 feed	15,00	180,00	8250,0	50,000	None	Global	1
7:1	Cold	Col 1 reboiler	215,00	220,00	3400,0	680,000	None	Global	1
8:1	Cold	Col 2 reboiler	230,00	235,00	8000,0	1600,000	None	Global	1
9:1	Cold	BFw for steam raising	108,00	130,00	2250,0	102,273	None	Global	1

Table 1

ed:

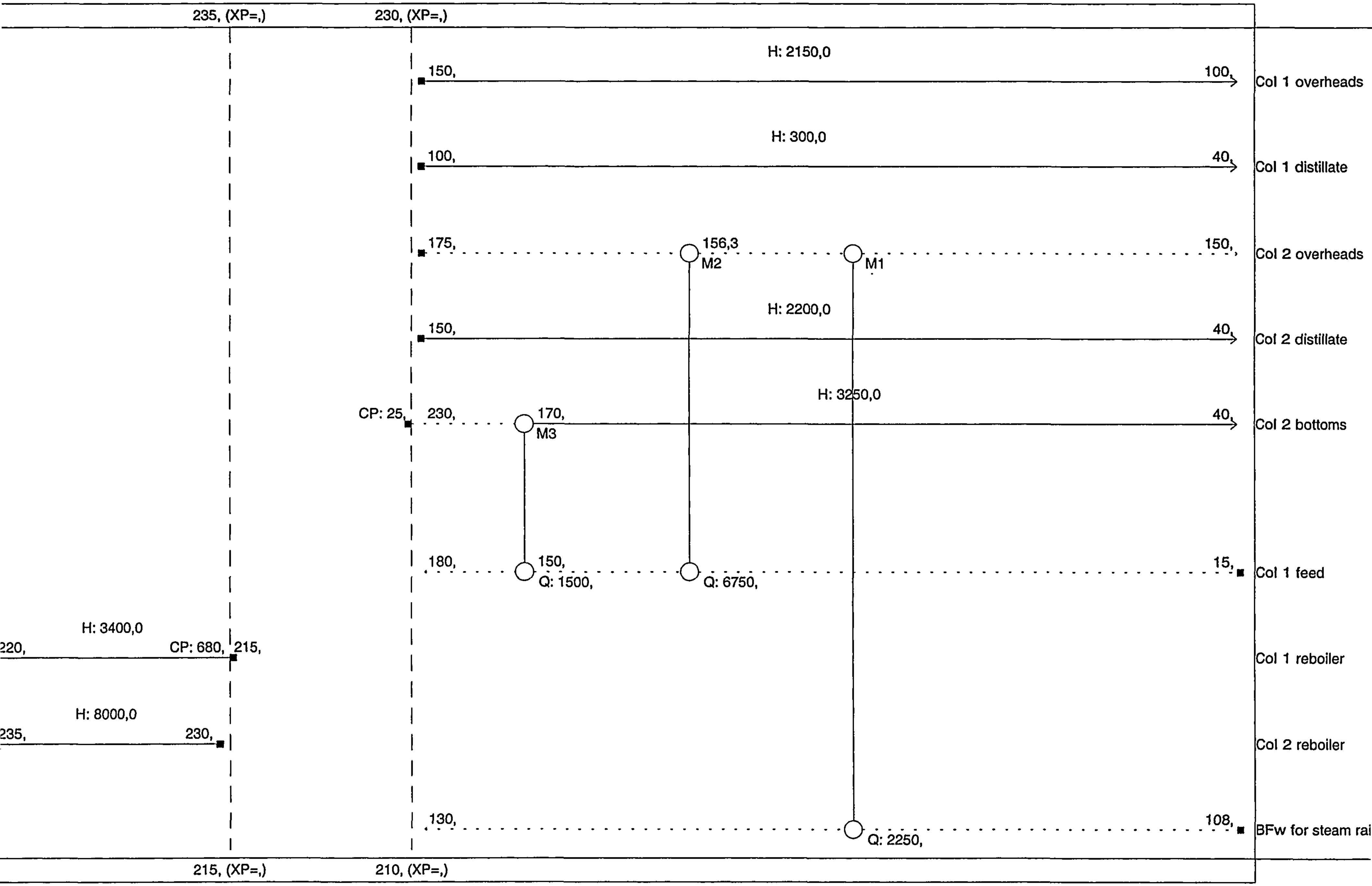

235, (XP=,)
230, (XP=,)
H: 2150,0
150,
100,
Col 1 overheads
H: 300,0
100,
40,
Col 1 distillate
175,
156,3
M2
M1
150,
Col 2 overheads
H: 2200,0
150,
40,
Col 2 distillate
H: 3250,0
CP: 25,
230,
170,
M3
40,
Col 2 bottoms
180,
150,
Q: 1500,
Q: 6750,
15,
Col 1 feed
H: 3400,0
220,
CP: 680,
215,
Col 1 reboiler
H: 8000,0
235,
230,
Col 2 reboiler
130,
Q: 2250,
108,
BFw for steam rai
215, (XP=,)
210, (XP=,)

Figure 12

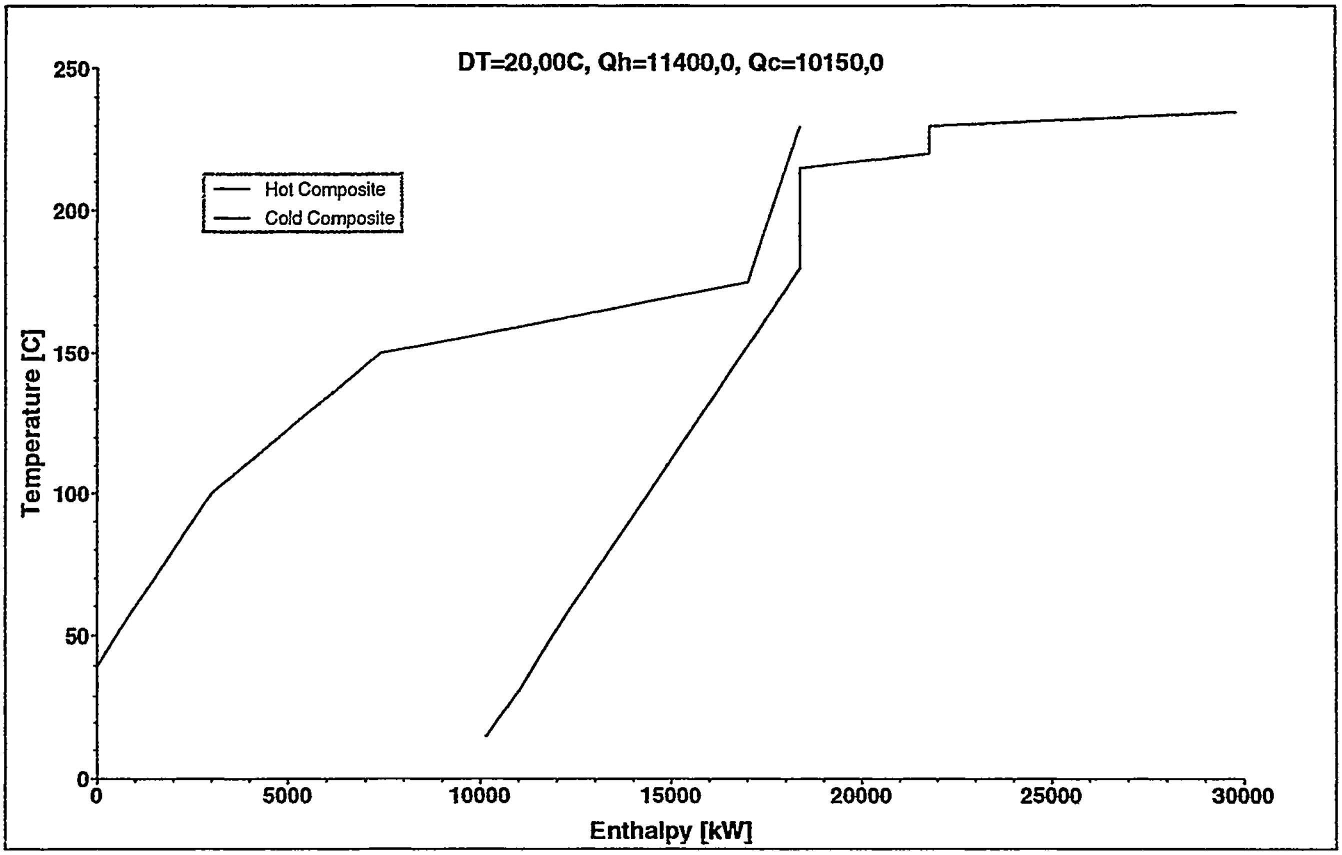

DT=20,00C, Qh=11400,0, Qc=10150,0
Hot Composite
Cold Composite
Temperature [C]
250
200
150
100
50
0
Enthalpy [kW]
0
5000
10000
15000
20000
25000
30000

Figure 13

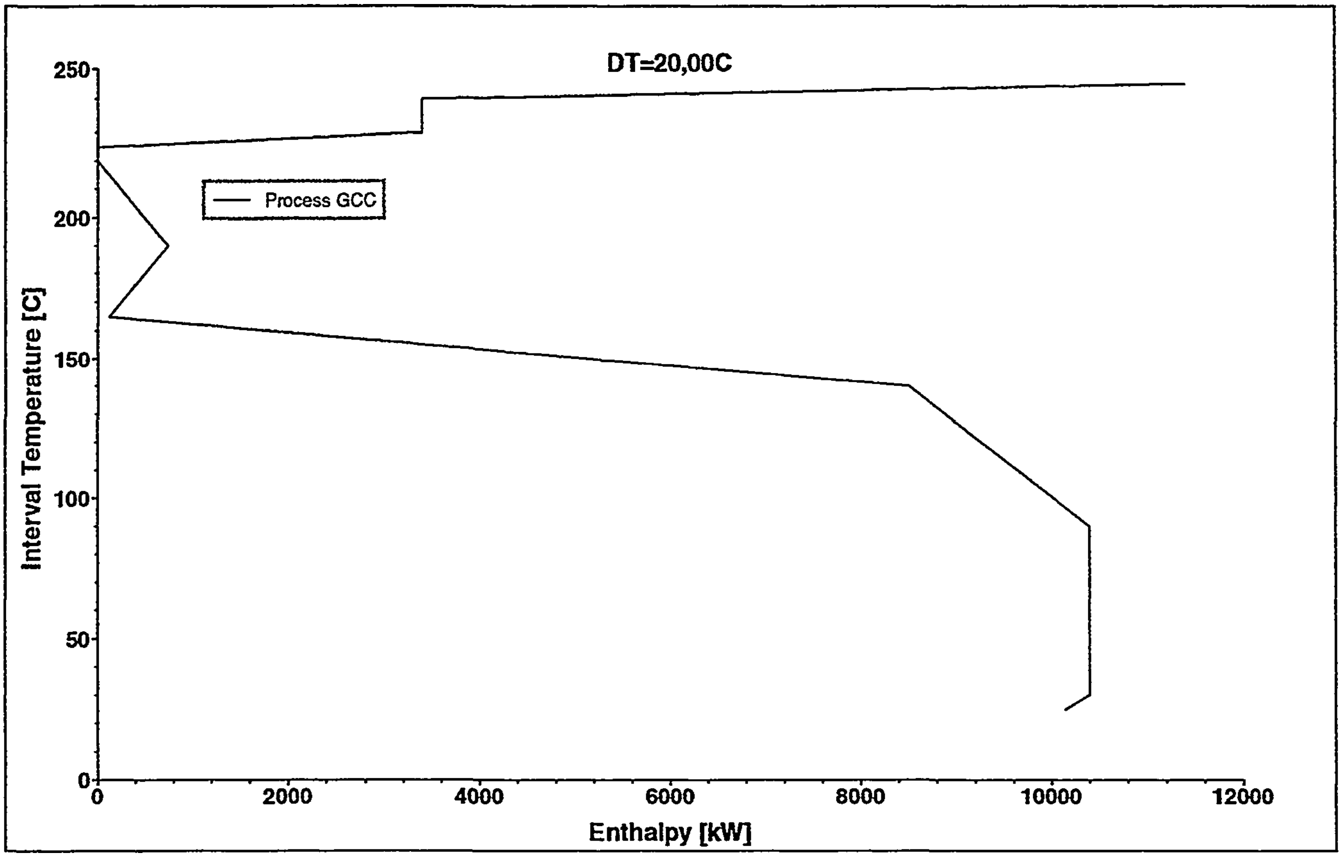
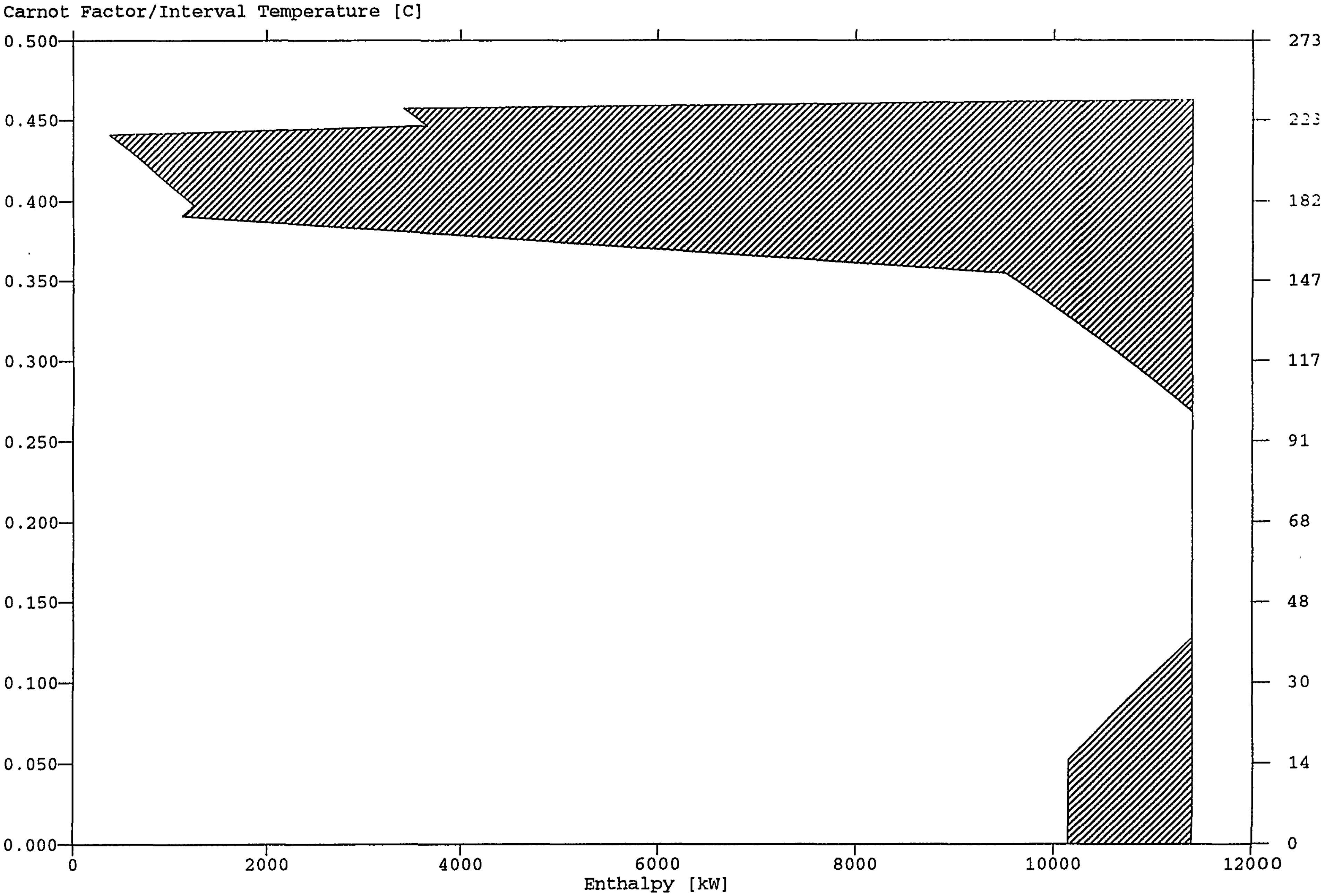

DT=20,00C
Process GCC
Interval Temperature [C]
250
200
150
100
50
0
0
2000
4000
6000
8000
10000
12000
Enthalpy [kW]

Figure 14

(c) Linnhoff March SUPERTARGET V3.107 SN1452 16,Feb,98 14.35
Untitled: File:CHEMIC1.ST2

Exergy Process Grand Composite Curve (Shifted temperatures)
DT=20.00C



(C) Linnhoff March Stream Data Report

Untitled: File: Chemic2.st4

No	Type	Name	TS C	TT C	dH kW	MCP kW/K	HTC kW/m².K	DT C	Cost law
1:1	Hot	Col 1 overheads	150,00	100,00	2150,0	43,000	None	Global	1
2:1	Hot	Col 1 distillate	100,00	40,00	300,0	5,000	None	Global	1
3:1	Hot	Col 2 overheads	175,00	150,00	9000,0	360,000	None	Global	1
4:1	Hot	Col 2 distillate	150,00	40,00	2200,0	20,000	None	Global	1
5:1	Hot	Col 2 bottoms	230,00	40,00	4750,0	25,000	None	Global	1
6:1	Cold	Col 1 feed	15,00	180,00	8250,0	50,000	None	Global	1
7:1	Cold	Col 1 reboiler	215,00	220,00	3400,0	680,000	None	Global	1
8:1	Cold	Col 2 reboiler	230,00	235,00	8000,0	1600,000	None	Global	1
9:1	Cold	BFW for steam raising	108,00	130,00	360,0	16,364	None	Global	1
9:2	Cold		130,00	130,10	8500,0	8,50E+4	None	Global	1

Table 2

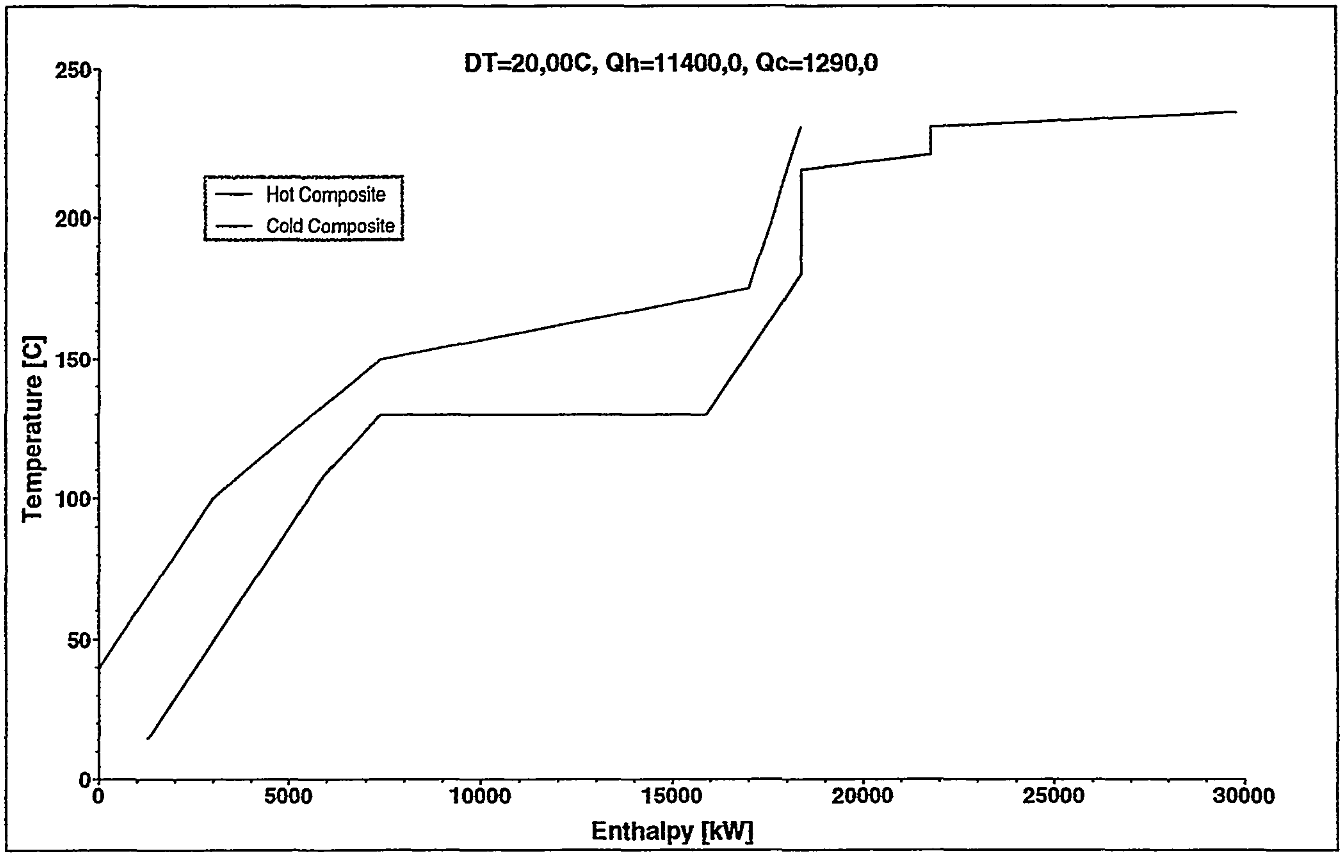

DT=20,00C, Qh=11400,0, Qc=1290,0
Hot Composite
Cold Composite
Temperature [C]
Enthalpy [kW]
0
50
100
150
200
250
0
5000
10000
15000
20000
25000
30000

Figure 16

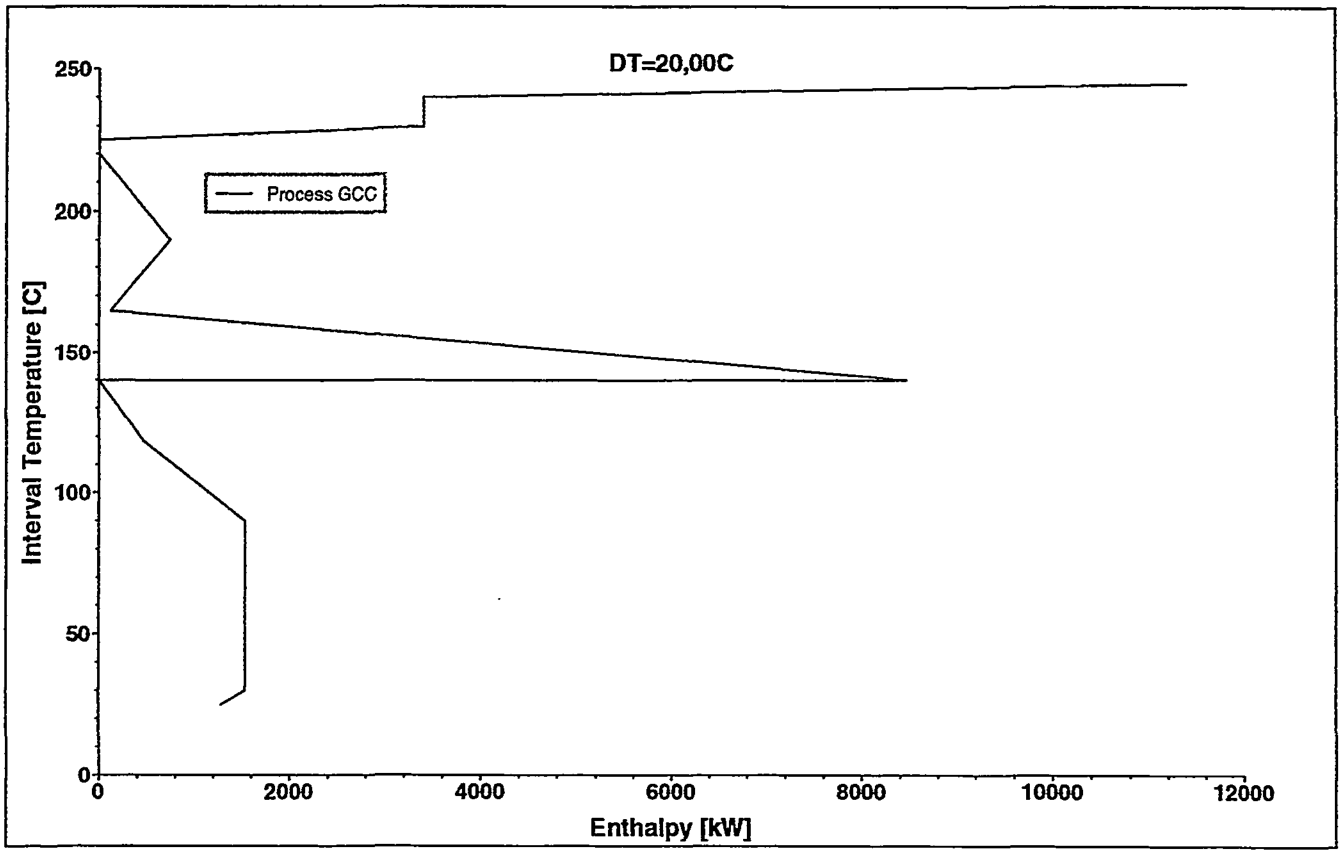

DT=20,00C
Process GCC
Interval Temperature [C]
Enthalpy [kW]
0
50
100
150
200
250
0
2000
4000
6000
8000
10000
12000

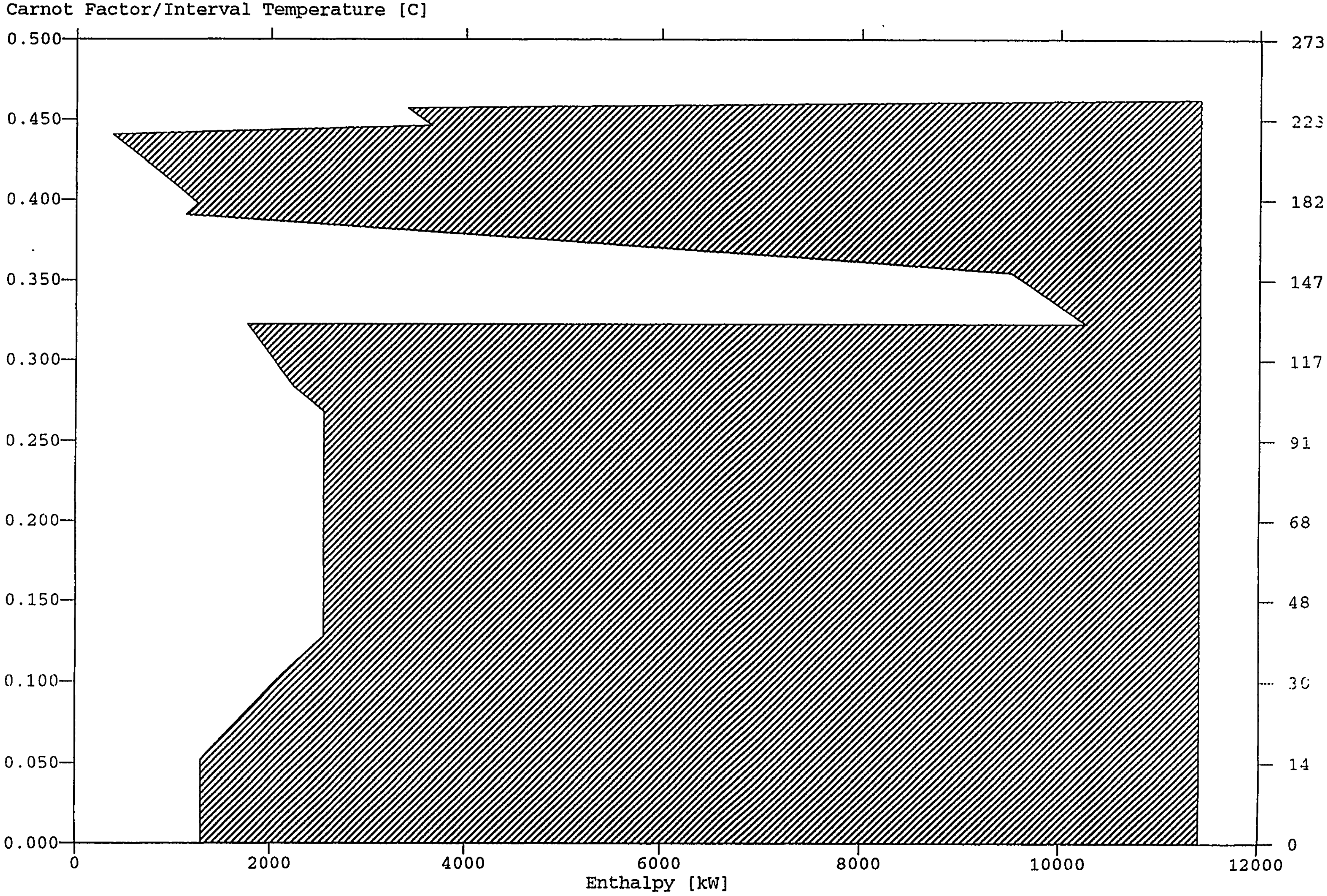
Figure 17

(c) Linnhoff March
Untitled:

SUPERTARGET V3.107 SN1452

16,Feb,98 14.36
File:CHEMIC2.ST2

Exergy Process Grand Composite Curve (Shifted temperatures)
DT=20.00C



ed:

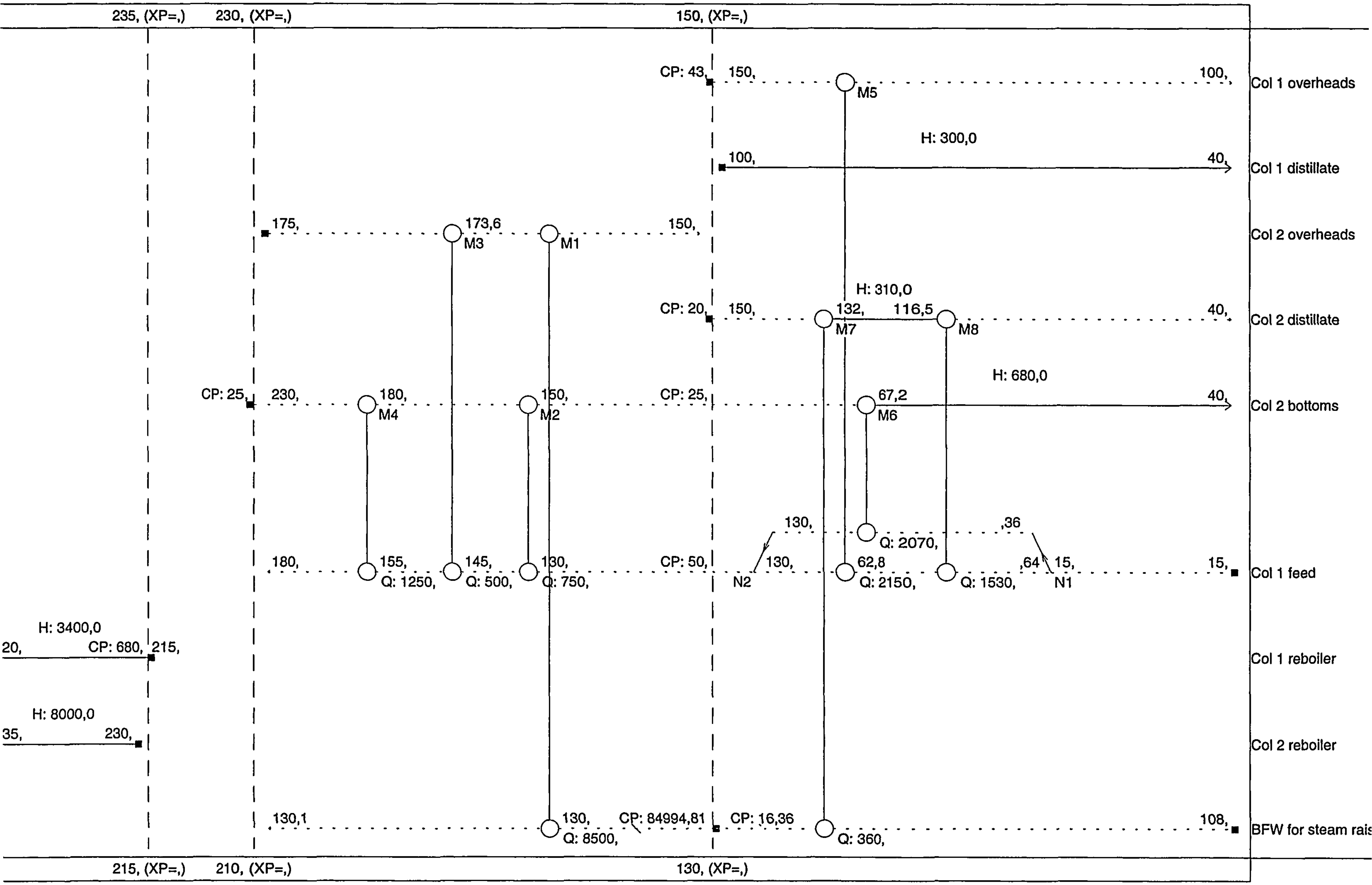

235, (XP=,)
230, (XP=,)
150, (XP=,)
CP: 43,
150,
M5
100,
Col 1 overheads
H: 300,0
100,
40,
Col 1 distillate
175,
173,6
M3
M1
150,
Col 2 overheads
H: 310,0
CP: 20,
150,
132,
116,5
M7
M8
40,
Col 2 distillate
H: 680,0
CP: 25,
230,
180,
M4
150,
M2
CP: 25,
67,2
M6
40,
Col 2 bottoms
130,
,36
Q: 2070,
180,
155,
Q: 1250,
145,
Q: 500,
130,
Q: 750,
CP: 50,
N2
130,
62,8
Q: 2150,
Q: 1530,
,64
15,
N1
15,
Col 1 feed
H: 3400,0
20,
CP: 680,
215,
Col 1 reboiler
H: 8000,0
35,
230,
Col 2 reboiler
130,1
130,
Q: 8500,
CP: 84994,81
CP: 16,36
Q: 360,
108,
BFW for steam rais
215, (XP=,)
210, (XP=,)
130, (XP=,)

Figure 19

4. PROCESS 2. BIOMASS IGHAT.

4.1 Description of the process.

4.1.1 Motivation.

The second process that is going to be studied is a more complex one. This process is an integrated biomass gasification and humid air turbine.

There are three main points that have motivated us to choose this process:

1. This is a process that has already been optimised by a heat balance program and now we want to check if a Pinch Technology program, SuperTarget, can make the process even better. By the application of the Pinch Technology to this process we could find the real advantages of the method and usefulness of the Pinch Technology program SuperTarget. Therefore, we will analyse the process in order to find the potential improvements that Pinch Technology can give to such a complex process.

2. The global process is separated in two well defined parts, the gasification process and the humid air turbine cycle (HAT). The connections between them are just limited to two flows.

3. Sydkraft, AB is interested to know what advantages could be taken from the Pinch Technology. This work will try to show the advantages and disadvantages of the Pinch method and the Pinch Technology program SuperTarget.

4.1.2 The process.

This BIOMASS IG-HAT process [23] is split in two different parts: the biomass gasification process and the humid air turbine process. In figure number 21 the global flowsheet for the IG-HAT is shown, while in figures 22 and 23 the two different parts of the process with the stream data are plotted.

1. The biomass gasification cycle.

In this first system a pressurised gasifier is integrated with a steam dryer and an evaporative gas turbine. The steam dryer is a pressurised (4 bar) tube dryer where the fuel is conveyed pneumatically in a steam atmosphere, but the energy is provided indirectly by the surfaces of heat exchangers.

The latent heat of the steam evaporated from the fuel is used for district heat production by condensing the steam in a heat exchanger.

The product gas leaving the gasifier has a temperature of 920°C at a pressure of 20 bar. Before cleaning the gas from alkali and particles, it is cooled down to a temperature of 421°C. At this temperature it is possible to clean the gas and feed it into the combustion chamber.

One of the advantages of the steam dryer is that the major part of the energy used for drying can be used for district heating by condensing the steam in a heat exchanger. The condensed water is supplied to the HAT together with the water condensed at the flue gas cooling.

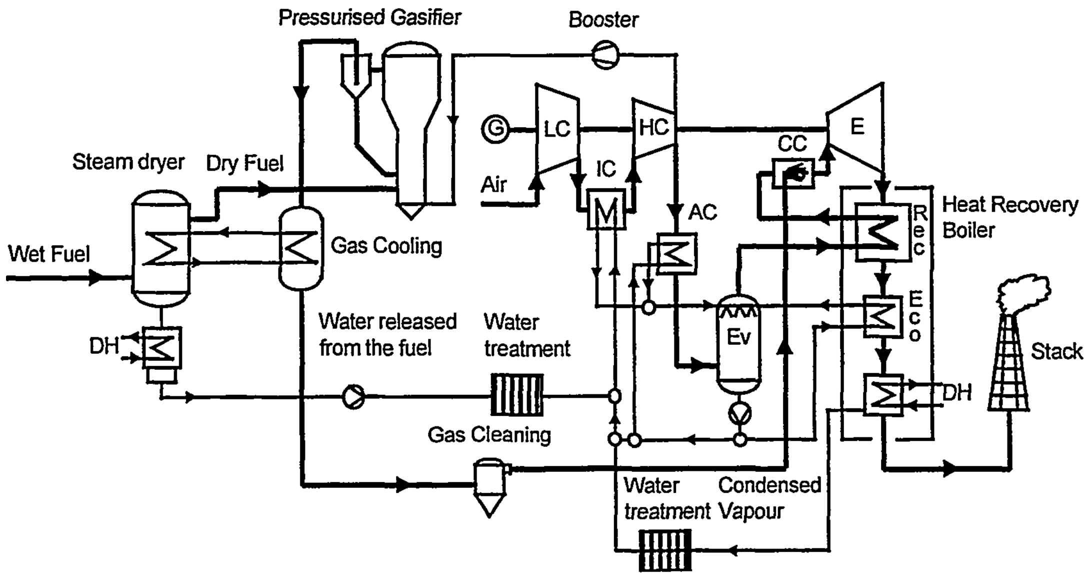


Figure 21

2. HAT cycle.

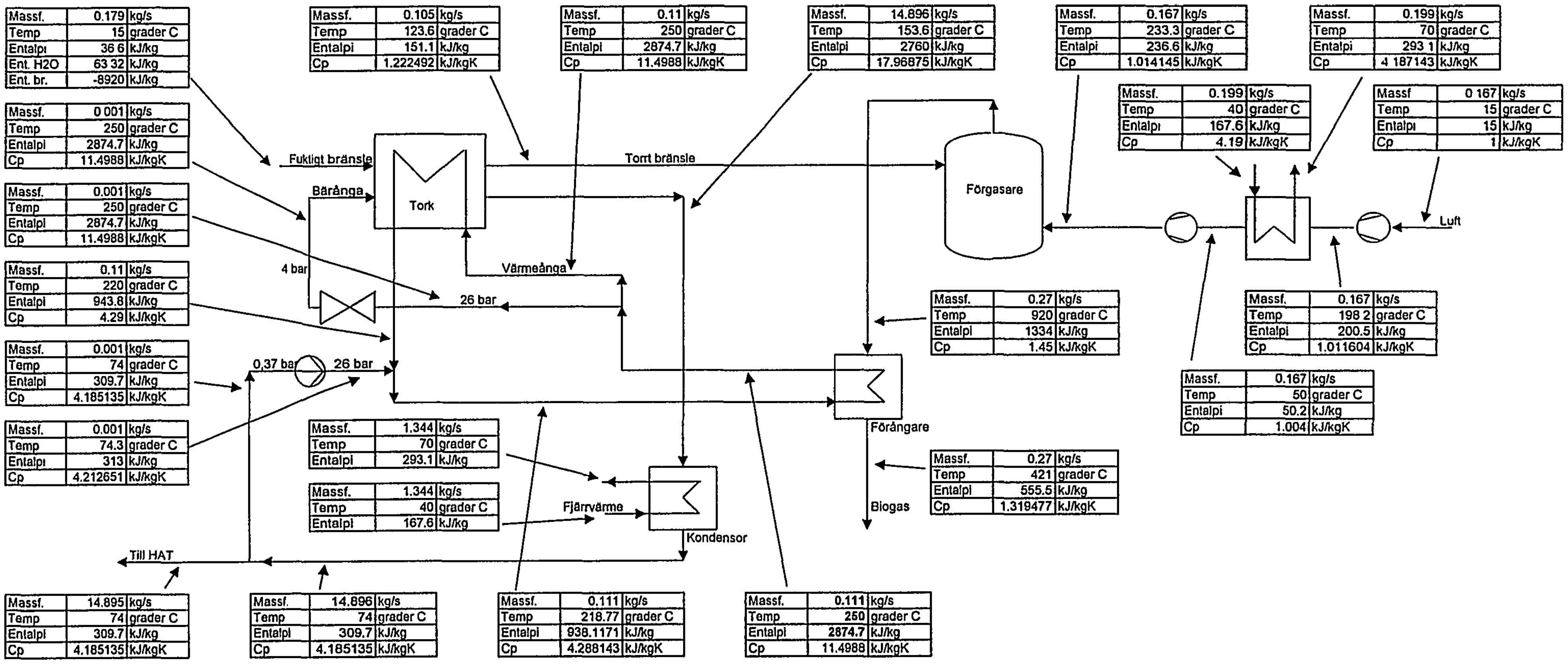
The compression of the air in the HAT is divided into one high pressure and one low pressure part with an intercooler between. After the compression, the air is cooled in an intercooler and led to the humidification tower.

In the humidification tower the air stream is brought into contact with water, resulting in a temperature decrease and an elevated humid air flow.

The water fed to the humidification tower is heated in different heat exchangers: intercooler, aftercooler and economiser. After the humidification the air stream has a rather low temperature which makes it possible to use a recuperator. So, this air stream is heated by the exhaust gases in the recuperator.

In the gas turbine the inlet temperature is 1118°C and it leaves with 568.93°C, while the pressure ratio of the gas turbine model is 13.6.

The air needed for the pressurising of the pressurised gasifier is bled-off from the compressor.



Massf.	0.179	kg/s
Temp	15	grader C
Entalpi	36 6	kJ/kg
Ent. H2O	63 32	kJ/kg
Ent. br.	-8920	kJ/kg

Massf.	0.105	kg/s
Temp	123.6	grader C
Entalpi	151.1	kJ/kg
Cp	1.222492	kJ/kgK

Massf.	0.11	kg/s
Temp	250	grader C
Entalpi	2874.7	kJ/kg
Cp	11.4988	kJ/kgK

Massf.	14.896	kg/s
Temp	153.6	grader C
Entalpi	2760	kJ/kg
Cp	17.96875	kJ/kgK

Massf.	0.167	kg/s
Temp	233.3	grader C
Entalpi	236.6	kJ/kg
Cp	1.014145	kJ/kgK

Massf.	0.199	kg/s
Temp	70	grader C
Entalpi	293 1	kJ/kg
Cp	4 187143	kJ/kgK

Massf.	0.199	kg/s
Temp	40	grader C
Entalpi	167.6	kJ/kg
Cp	4.19	kJ/kgK

Massf	0 167	kg/s
Temp	15	grader C
Entalpi	15	kJ/kg
Cp	1	kJ/kgK

Massf.	0 001	kg/s
Temp	250	grader C
Entalpi	2874.7	kJ/kg
Cp	11.4988	kJ/kgK

Massf.	0.001	kg/s
Temp	250	grader C
Entalpi	2874.7	kJ/kg
Cp	11.4988	kJ/kgK

Massf.	0.11	kg/s
Temp	220	grader C
Entalpi	943.8	kJ/kg
Cp	4.29	kJ/kgK

Massf.	0.27	kg/s
Temp	920	grader C
Entalpi	1334	kJ/kg
Cp	1.45	kJ/kgK

Massf.	0.167	kg/s
Temp	198 2	grader C
Entalpi	200.5	kJ/kg
Cp	1.011604	kJ/kgK

Massf.	0.001	kg/s
Temp	74	grader C
Entalpi	309.7	kJ/kg
Cp	4.185135	kJ/kgK

Massf.	0.167	kg/s
Temp	50	grader C
Entalpi	50.2	kJ/kg
Cp	1.004	kJ/kgK

Massf.	0.001	kg/s
Temp	74.3	grader C
Entalpi	313	kJ/kg
Cp	4.212651	kJ/kgK

Massf.	1.344	kg/s
Temp	70	grader C
Entalpi	293.1	kJ/kg

Massf.	0.27	kg/s
Temp	421	grader C
Entalpi	555.5	kJ/kg
Cp	1.319477	kJ/kgK

Massf.	1.344	kg/s
Temp	40	grader C
Entalpi	167.6	kJ/kg

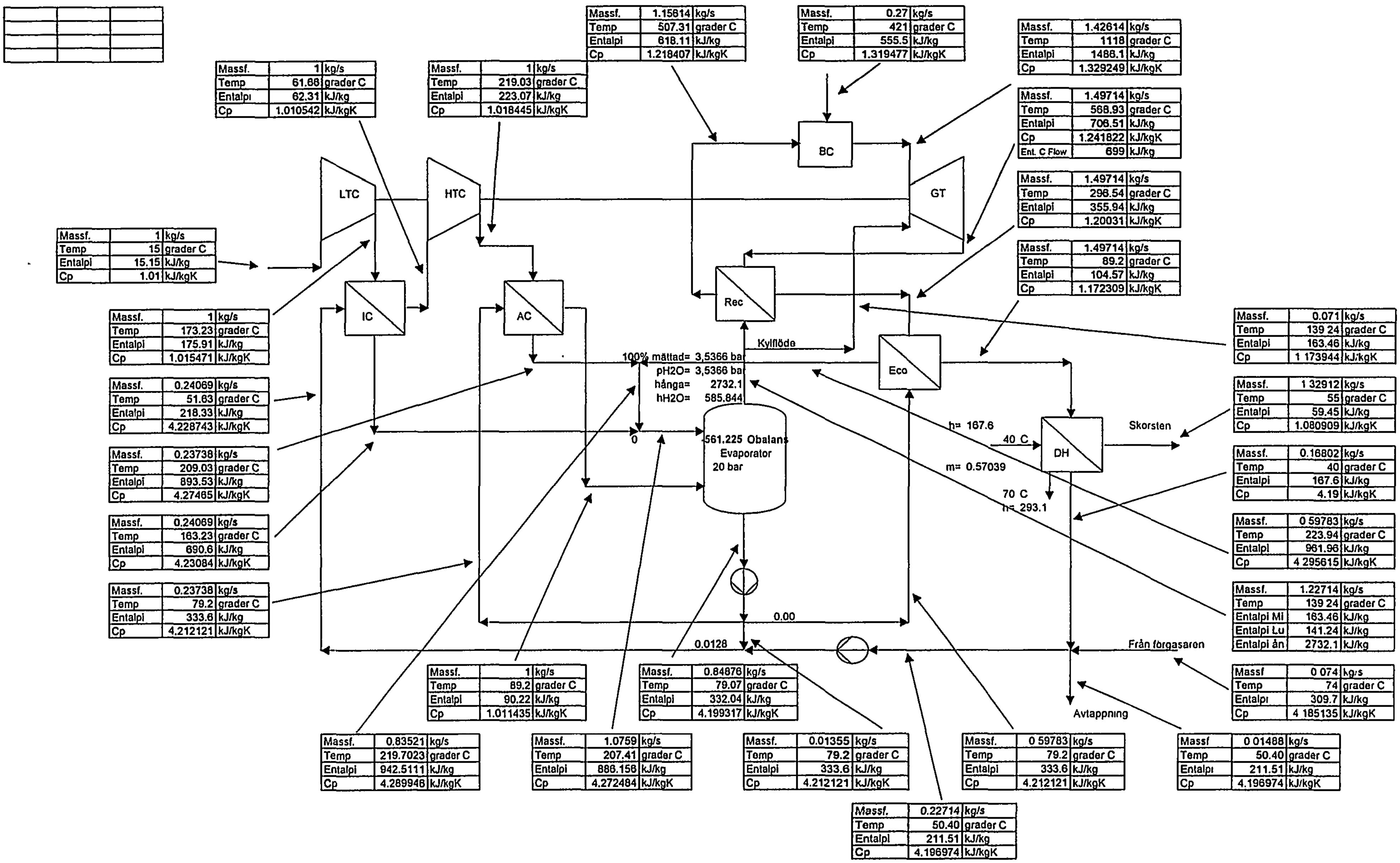
Massf.	14.895	kg/s
Temp	74	grader C
Entalpi	309.7	kJ/kg
Cp	4.185135	kJ/kgK

Massf.	14.896	kg/s
Temp	74	grader C
Entalpi	309.7	kJ/kg
Cp	4.185135	kJ/kgK

Massf.	0.111	kg/s
Temp	218.77	grader C
Entalpi	938.1171	kJ/kg
Cp	4.288143	kJ/kgK

Massf.	0.111	kg/s
Temp	250	grader C
Entalpi	2874.7	kJ/kg
Cp	11.4988	kJ/kgK

Figure 22



Massf.	1	kg/s
Temp	61.68	grader C
Entalpi	62.31	kJ/kg
Cp	1.010542	kJ/kgK

Massf.	1	kg/s
Temp	219.03	grader C
Entalpi	223.07	kJ/kg
Cp	1.018445	kJ/kgK

Massf.	1.15614	kg/s
Temp	507.31	grader C
Entalpi	618.11	kJ/kg
Cp	1.218407	kJ/kgK

Massf.	0.27	kg/s
Temp	421	grader C
Entalpi	555.5	kJ/kg
Cp	1.319477	kJ/kgK

Massf.	1.42614	kg/s
Temp	1118	grader C
Entalpi	1486.1	kJ/kg
Cp	1.329249	kJ/kgK

Massf.	1.49714	kg/s
Temp	568.93	grader C
Entalpi	706.51	kJ/kg
Cp	1.241822	kJ/kgK
Ent. C Flow	699	kJ/kg

Massf.	1.49714	kg/s
Temp	296.54	grader C
Entalpi	355.94	kJ/kg
Cp	1.20031	kJ/kgK

Massf.	1.49714	kg/s
Temp	89.2	grader C
Entalpi	104.57	kJ/kg
Cp	1.172309	kJ/kgK

Massf.	1	kg/s
Temp	15	grader C
Entalpi	15.15	kJ/kg
Cp	1.01	kJ/kgK

Massf.	1	kg/s
Temp	173.23	grader C
Entalpi	175.91	kJ/kg
Cp	1.015471	kJ/kgK

Massf.	0.24069	kg/s
Temp	51.63	grader C
Entalpi	218.33	kJ/kg
Cp	4.228743	kJ/kgK

Massf.	0.23738	kg/s
Temp	209.03	grader C
Entalpi	893.53	kJ/kg
Cp	4.27465	kJ/kgK

Massf.	0.24069	kg/s
Temp	163.23	grader C
Entalpi	690.6	kJ/kg
Cp	4.23084	kJ/kgK

Massf.	0.23738	kg/s
Temp	79.2	grader C
Entalpi	333.6	kJ/kg
Cp	4.212121	kJ/kgK

Massf.	0.071	kg/s
Temp	139 24	grader C
Entalpi	163.46	kJ/kg
Cp	1 173944	kJ/kgK

Massf.	1 32912	kg/s
Temp	55	grader C
Entalpi	59.45	kJ/kg
Cp	1.080909	kJ/kgK

Massf.	0.16802	kg/s
Temp	40	grader C
Entalpi	167.6	kJ/kg
Cp	4.19	kJ/kgK

Massf.	0 59783	kg/s
Temp	223.94	grader C
Entalpi	961.96	kJ/kg
Cp	4 295615	kJ/kgK

Massf.	1.22714	kg/s
Temp	139 24	grader C
Entalpi Mi	163.46	kJ/kg
Entalpi Lu	141.24	kJ/kg
Entalpi ån	2732.1	kJ/kg

Massf	0 074	kg/s
Temp	74	grader C
Entalpi	309.7	kJ/kg
Cp	4 185135	kJ/kgK

Massf.	1	kg/s
Temp	89.2	grader C
Entalpi	90.22	kJ/kg
Cp	1.011435	kJ/kgK

Massf.	0.84876	kg/s
Temp	79.07	grader C
Entalpi	332.04	kJ/kg
Cp	4.199317	kJ/kgK

Massf.	0.83521	kg/s
Temp	219.7023	grader C
Entalpi	942.5111	kJ/kg
Cp	4.289946	kJ/kgK

Massf.	1.0759	kg/s
Temp	207.41	grader C
Entalpi	886.156	kJ/kg
Cp	4.272484	kJ/kgK

Massf.	0.01355	kg/s
Temp	79.2	grader C
Entalpi	333.6	kJ/kg
Cp	4.212121	kJ/kgK

Massf.	0 59783	kg/s
Temp	79.2	grader C
Entalpi	333.6	kJ/kg
Cp	4.212121	kJ/kgK

Massf	0 01488	kg/s
Temp	50.40	grader C
Entalpi	211.51	kJ/kg
Cp	4.196974	kJ/kgK

Massf.	0.22714	kg/s
Temp	50.40	grader C
Entalpi	211.51	kJ/kg
Cp	4.196974	kJ/kgK

Figure 23

4.2 The design procedure. Calculations using SuperTarget.

The first step that must be carried out prior to make the calculations is to extract the process data and model them properly in order to be able to implement these data in SuperTarget. This step is not as easy as it could seem and many problems may arise when trying to do it.

The first problem we have found has been the model for the components which are not heat exchangers. In these components there is usually involved mass transfer in addition to the heat transfer. This problem requires to be handled with special tricks in SuperTarget.

At this point, the humidification tower has been specially complicated to model. The heat inside the humidification tower is transferred between two flows: the hot water flow, which comes in with a temperature of 207°C and goes out with a temperature of 79°C, and the cold air flow, which comes in at 89°C and goes out at 139°C. Besides, there is also a mass transfer between both flows, due to some part of the water flow which passes to the air flow (figure 24).

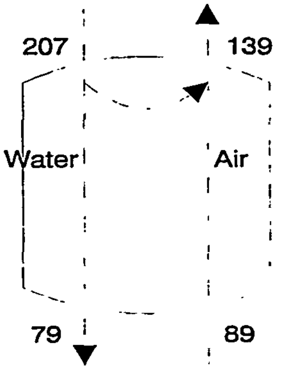


Figure 24

In order to handle these phenomena, three flows must be used in the stream data. The third stream will take into account the proportion of mass flow which is transferred from the hot stream to the cold one. Evenmore, the phase change which evaporates the water to steam has to be modelled in different steps in order to define the evaporation process more accurately.

Therefore, the global process within the humidification tower can be modelled using the next stream data:

Stream	ST	TT	ΔE (KW)	MCP
Water evaporated out	207.41	79.09	470.3	3.664
Water evaporated air	207.41	139.24	68.2	1
Steam evaporated 1	200	200.1	81.3	812.95

Steam evaporated 2	190	190.1	81.3	812.95
Steam evaporated 3	180	180.1	81.3	812.95
Steam evaporated 4	170	170.1	81.3	812.95
Steam evaporated 5	160	160.1	81.3	812.95
Steam evaporated 6	150	150.1	81.3	812.95
Air	89.2	139.24	51	1.019

Later on, some small changes will be made in the temperatures of the different steps in order to couple them better. For the same reason, the water evaporated out will be shared in different parts. The final stream data for the humidification tower model can be seen in table 4, from stream 27 to stream 35.

The second problem arises when there are phase changes inside one stream. This phenomena was not noticed at the beginning of the work. SuperTarget has not got any signal which shows that there is a phase change in the stream. Therefore, SuperTarget can not help us at this point and the engineer has to be very aware of this situations.

The first calculations were made without taking in account these phase changes, so strange results were obtained. The stream data, Composite Curves, and Grand Composite Curve generated during these first calculations are shown in table 3 and figures 25 and 26. Here, it can be noticed that the pinch point is at 45°C and located at the district heating heat exchanger. This latter result made us to think that the model of the process was not good at all because the pinch point was supposed to appear in the humidification tower.

The next step was, therefore, to write the process stream data in a way to include the phase changes. There were three streams in the process involved in phase changes:

1. The water fuel stream of the dryer (stream number 2). This is the stream which models the water that is contained in the fuel. This stream is heated up from 15°C to 153.6°C with an enthalpy change of 199.6 KW. The evaporation process occurs at 143.63°C. Therefore, in order to model this stream in SuperTarget taking in account the phase change, it should be shared in three branches:

Stream	ST	TT	ΔE (KW)
Water-fuel pre-heated	15	143.63	40.1
Water-fuel evaporated	143.63	143.7	157.9
Water-fuel super-heated	143.7	153.6	1.6428

2. The heating steam stream (stream number 3) which is also located in the dryer. This stream needs to be cooled from 250°C to 220°C, and its enthalpy change is 212.4 KW. The condensation process occurs at 226.04°C, so the model of the stream data for this stream is:

Stream	ST	TT	ΔE (KW)
Heating steam super-heated	250	226.04	8.1
Heating steam condensed	226.04	226	201.3
Heating steam sub-cooling	226	220	3.07

3. The evaporator stream (stream number 6). This stream is used to cool down the gas from the gasifier in the heat exchanger located just after it. The stream is heated up from 218.77°C to 250°C and the enthalpy change is 215 KW. The evaporation occurs, like in the previous stream, at 226.04°C:

Stream	ST	TT	ΔE (KW)
Evaporator pre-heated	218.77	226.04	3.72992
Evaporator evaporated	226.04	226.1	203.1
Evaporator super-heated	226.1	250	8.13963

A further approach was to remove the district heating from the global process, as it was considered to be external to the process itself. The first pinch point was obtained in this district heating, but after removing it and taking in account the phase changes, the pinch point changed to 139.80°C. This new pinch point is located in the humidification tower, as it was supposed to be.

The stream data table that includes all these changes is shown in table 4. There are some streams which have got a local pinch of 0°C (no difference of temperature between them) because the heat exchange occurs within the streams themselves without any material separation. These streams are located in the dryer and in the humidification tower.

Once the stream data has been extracted and modelled properly, the calculations can be started. A minimum difference of temperature of 10°C has been assumed for all streams exchanging heat. The first point will be the generation of the curves: the Composite Curves (figure 27) and the Grand Composite Curve (figure 28).

By the examination of these curves, much useful information from the process can be obtained. First, the minimum external hot and cold utilities are given in all the curves, although the way to read them is different for each curve. Thus, for a minimum approach temperature of 10°C, the minimum hot utility is 1383.5 KW and the minimum cold utility is 554.6 KW.

By analysing the curves in more detail, information about where are the exergy losses can be easily obtained. For instance, looking at the Composite Curves, the space between the cold composite curve and the hot composite curve shows the magnitude of those exergy losses. So, it can be noticed that the major amount of losses are located at the highest temperatures of the process, in the heat exchanger after the gasifier.

Now, analysing the Grand Composite curve, it can be seen where utilities could be generated. So, using this information and process constrains, we should be able to choose the best utilities in order to reduce external needs. The problem with this process is that the utility generation only can take place at very low temperatures, what makes it without sense.

For instance, one intelligent approach to reduce the exergy losses at those highest temperatures part of the process, could be the exchange of the streams between the heat exchanger located after the gasifier and the recuperator, in order to reduce the difference of temperature of the streams inside the components and, therefore, the exergy losses. Anyway, this further work of looking for improvements by the examination of the curves and the process itself will be the next step to carry out to complete this work. At section 5, it can be read some guides for it.

The next point of the design procedure is to create the Grid. By now, we have got the model for the different stream data as well as the minimum hot and cold utility that theoretically can be achieved. But we still have the restrictions of the process lay-out, which already existed. Because of this, the following step will be the generation of the grid which matches best with the present process lay-out. This grid will show us the current flowsheet for the heat exchanger network, which means we could be able to see where the heat exchange occurs and between what streams. Then, we could make the calculations for all the heat recovery system. The result of these calculations will tell us how the process with the present lay-out is close to achieve the minimum utility targets.

The Grid, represented in figure 29, has been created using the Pinch Technology method rules, so some streams have to be split and others mixed. The heat exchanger report is shown in table 5. Here, it can be checked all the virtual heat exchangers between the streams, with their duty, their temperature in and out, and their minimum difference of temperature. The split and mix report are shown in tables 6 and 7.

It must be mentioned that the vertical lines which link the hot and cold streams are not real heat exchangers, but flows of heat exchanged between these two streams or branches. The reason for that is the specific way to implement the stream data that has been done in order to model the components of the process, and the fact that the heat flow needs to be modelled in two different flows, one below the pinch and one above the pinch, even inside the same heat exchanger. Therefore, the relationship between the virtual heat exchangers, as shown in the Grid, and the real heat exchangers or components are:

- Heat exchangers M3, M4, M5, M6, and M7 all belong to the humidification tower, and they model the heat exchange inside of it.

- Heat exchangers M8, M9, M10, and M10A belong to the dryer, modelling the heat exchange in this component.

- Heat exchangers M11, M12, and M13 belong to the heat exchanger located after the gasification tower.

- Heat exchanger M14 is the condensor.

- Heat exchangers M14A and M15 are the intercooler.

- Heat exchangers M15A and M16 are the aftercooler.

- Heat exchanger M17 is the recuperator.

- Heat exchangers M18 and M19 are the economiser.

4.3 Results from the analysis.

The analysis of the Grid shows the heat practically exchanged and the external utilities that must be supplied. These latter utilities are:

HOT UTILITY	above the pinch:	1699.2 KW
	below the pinch	96.6 KW
	TOTAL HOT UTILITY:	**1795.8 KW**
COLD UTILITY	above the pinch:	315.9 KW
	below the pinch:	651 KW
	TOTAL COLD UTILITY:	**966.9 KW**

As we know that the minimum hot and cold utilities theoretically achievable are 1383.5 KW and 554.6 KW respectively, there is a penalty in the process of:

EXTRA HOT UTILITY: 1795.8 - 1383.5 = **412.3 KW**

EXTRA COLD UTILITY: 966.9 - 554.6 = **412.3 KW**

This means that there are 412.3 KW available within the process itself that can not be used by heat exchanging because of the restrictions on the process lay-out. So that, all these 412.3 KW of hot utility and 412.3 KW of cold utility have to be supplied from outside.

In other words, the heat recovery network is exchanging **81.1986 %** of the heat that could be exchanged.

4.4 Discussion and conclusions.

The result obtained from the calculation of the process by Pinch Technology shows that there is a huge potential for improvements in the heat recovery of the plant. The analysis shows that those 412.3 KW are available in the process and could be used to reduce the external utilities. This would lead then to energy savings. As in the sample process studied at section 3, this numerical conclusion could lead to the next general one: the method used here, the so called Pinch Technology, generates real energy savings, even in a process which already had been optimised by a heat balance program.

On the other side, the way to achieve those energy savings is neither easy nor cheap, evenmore for retrofit designs. Many structural changes of the process lay-out might be needed. Besides, the purchase and installation of the new heat exchangers might lead to an excessively high capital cost.

No economical parameters have been used in this work, although they are vital to determine the usefulness of the conclusions. Here, we have been working only with the "energy savings" part of the problem. But, of course, the final conclusion must be a trade-off between the energy savings and the capital cost.

A *minimum difference of temperature* of 10°C has been assumed during all the calculations of the process, which does not mean that this is the best choice. One more time, the trade-off between energy savings and capital cost should determine the optimum minimum difference of temperature.

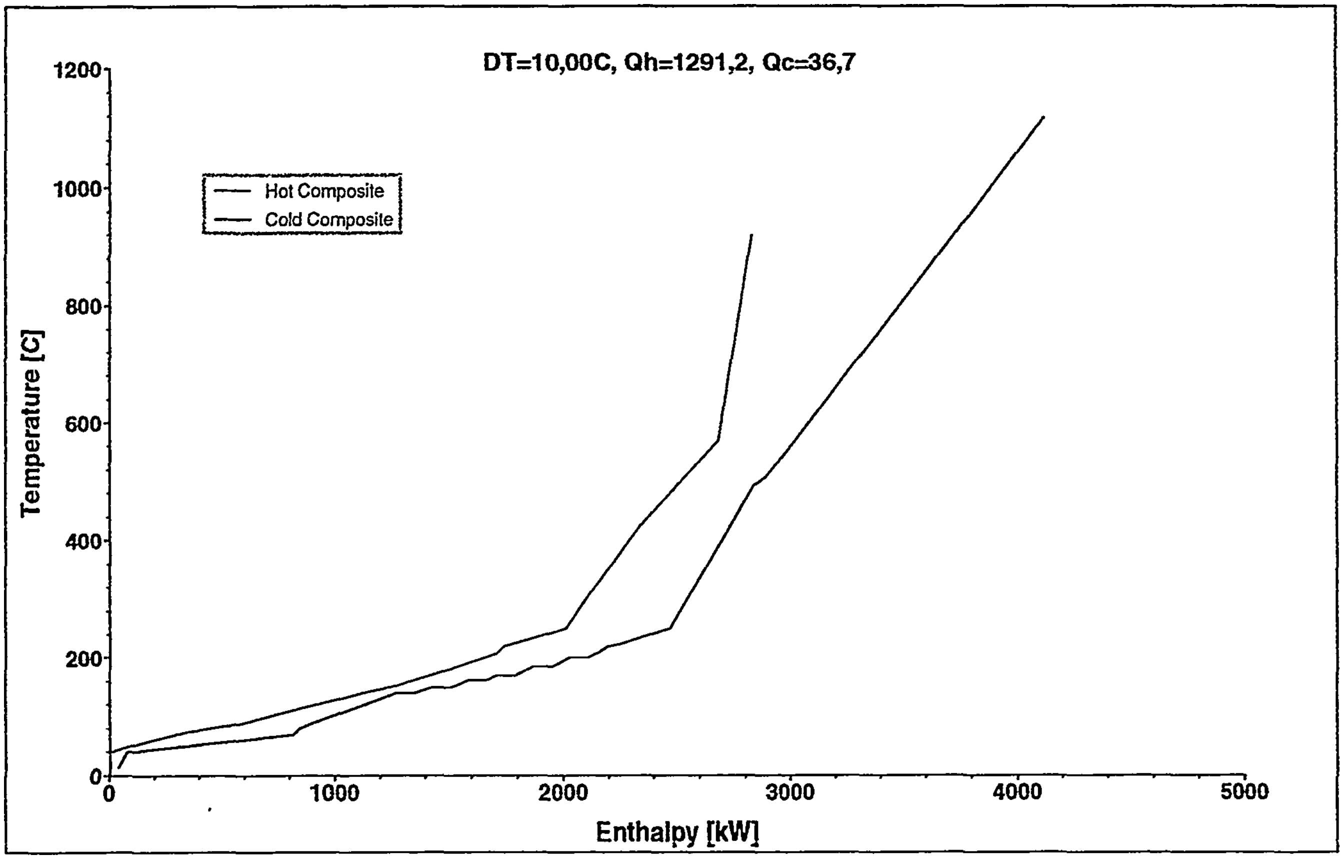
The Pinch Technology program used in this work, SuperTarget, has been quite useful for handling the calculations and the creation of the grid. But, as it has been discussed along the previous pages, many problems have appeared when implementing the process in the program. The SuperTarget program is really useful for handling huge chemical processes, where there are many heat exchangers, but it becomes more complicated with heat and power processes, where components with mass transfer are difficult to model. In addition to this, another problem with SuperTarget is that it does not notice the phase changes within the streams, and the fact that they must be modelled using some special tricks.

4.5 Figures and tables from SuperTarget.

Untitled: File: Sydk_3b.st4

No	Type	Name	TS C	TT C	dH kW	MCP kW/K	HTC kW/m^2.K	DT C	Cost law
1:1	Cold	Dry fuel	15,00	123,60	14,0	,129	None	Global	1
2:1	Cold	H2O fuel	15,00	153,60	199,6	1,440	None	0	1
3:1	Hot	Heating steam	250,00	220,00	212,4	7,080	None	Global	1
4:1	Hot	Carrier steam	250,00	153,60	1,15E-1	1,19E-3	None	0	1
5:1	Hot	Condensate	153,60	143,63	31,6	3,170	None	Global	1
5:2	Hot		143,63	74,00	181,7	2,610	None	Global	1
6:1	Cold	Evaporator	218,77	250,00	215,0	6,884	None	Global	1
7:1	Hot	Gas	920,00	421,00	210,2	,421	None	Global	1
8:1	Cold	DH Condensate	40,00	70,00	168,7	5,623	None	Global	1
9:1	Cold	DH Intercooler	40,00	70,00	25,0	,833	None	Global	1
10:1	Hot	Air IC gasif.	198,20	50,00	25,1	,169	None	Global	1
11:1	Hot	Air IC	173,23	61,66	113,6	1,018	None	Global	1
12:1	Hot	Air AC	219,03	89,20	132,8	1,023	None	Global	1
13:1	Cold	Water IC	51,63	163,23	113,7	1,019	None	Global	1
14:1	Cold	Water AC	79,20	209,03	132,9	1,024	None	Global	1
15:1	Cold	Air rec	139,24	507,31	525,6	1,428	None	Global	1
16:1	Hot	Exh. rec	568,93	296,54	524,9	1,927	None	Global	1
17:1	Cold	Water Eco	79,20	223,94	375,7	2,596	None	Global	1
18:1	Hot	Exh. Eco	296,54	89,20	376,3	1,815	None	Global	1
19:1	Cold	B.Chamb.	490,97	1118,00	1254,8	2,001	None	Global	1
20:1	Hot	DH Ex.gas	89,20	55,00	71,6	2,094	None	Global	1
21:1	Cold	DH Water	40,00	70,00	480,5	16,017	None	Global	1
22:1	Hot	DH Cond	89,20	40,00	409,0	8,313	None	Global	1
23:1	Hot	W. Ev. out	207,41	185,00	82,1	3,664	None	0	1
23:2	Hot		185,00	162,72	81,6	3,664	None	0	1
23:3	Hot		162,72	140,00	83,2	3,664	None	0	1
23:4	Hot		140,00	79,07	223,2	3,664	None	0	1
24:1	Hot	W. Ev. air	207,41	139,24	68,2	1,000	None	Global	1
25:1	Cold	Steam Ev.1	184,80	184,90	81,3	812,950	None	0	1
26:1	Cold	Steam Ev.2	200,00	200,10	81,3	812,950	None	0	1
27:1	Cold	Steam Ev.3	162,00	162,10	81,3	812,950	None	0	1
28:1	Cold	Steam Ev.4	170,00	170,10	81,3	812,950	None	0	1
29:1	Cold	Steam Ev.5	139,80	139,90	81,3	812,950	None	0	1
30:1	Cold	Steam Ev.6	150,00	150,10	81,3	812,950	None	0	1
31:1	Cold	Air Ev.	89,20	139,24	51,0	1,019	None	Global	1
32:1	Cold	Cool flow	139,24	568,93	38,0	8,84E-2	None	Global	1

Table 3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Hot Composite
Cold Composite
Temperature [C]
1200
1000
800
600
400
200
0
Enthalpy [kW]
0
1000
2000
3000
4000
5000

Figure 25

Grand Composite Curve

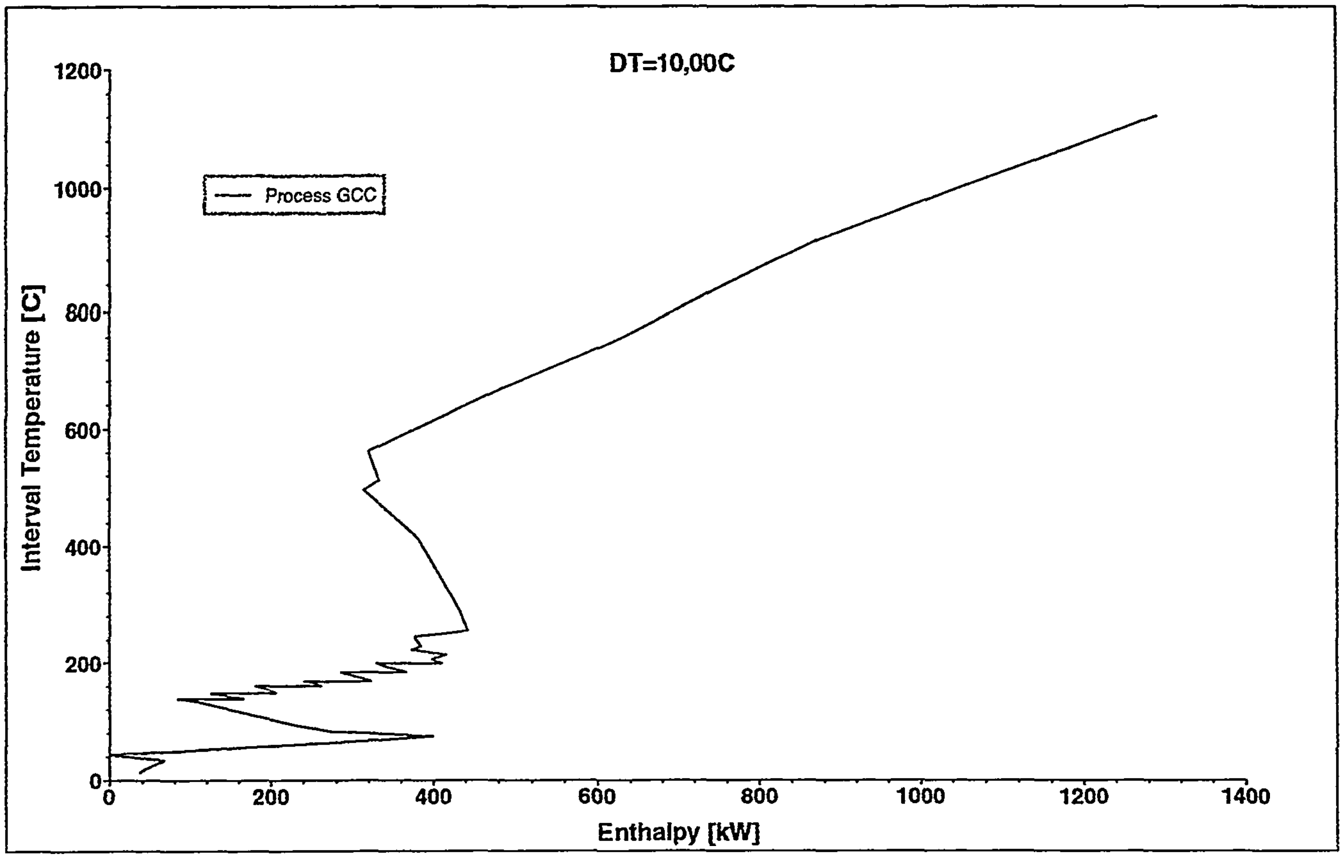
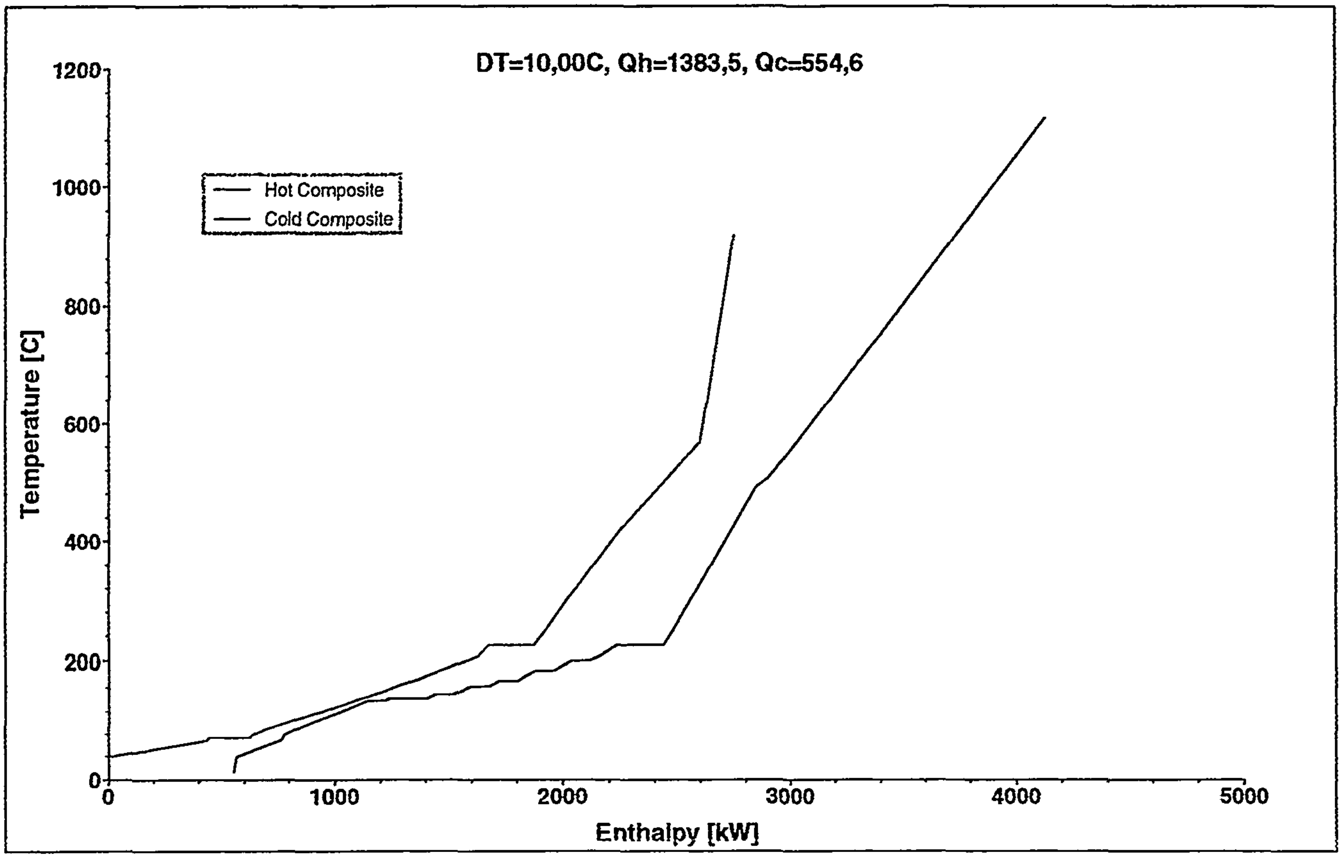


Figure 26

No	Type	Name	TS C	TT C	dH kW	MCP kW/K	HTC kW/m^2.K	DT C	Cost law
1:1	Cold	Dry fuel	15,00	123,60	14,0	,129	None	Global	1
2:1	Cold	H2O-fuel-PH	15,00	143,63	40,1	,312	None	0	1
3:1	Cold	H2O-fuel-Evap.	143,63	143,70	157,9	2255,970	None	Global	1
4:1	Cold	H2O-fuel-SH	143,70	153,60	1,64	,166	None	Global	1
5:1	Hot	Heating steam-SC	250,00	226,04	8,10	,338	None	Global	1
6:1	Hot	Heating steam-Cond	226,04	226,00	201,3	5033,345	None	Global	1
7:1	Hot	Heating steam-SubC	226,00	220,00	3,07	,512	None	Global	1
8:1	Hot	Carrier steam	250,00	153,60	1,15E-1	1,19E-3	None	0	1
9:1	Hot	Condensate	153,60	74,10	9,47	,119	None	Global	1
9:2	Hot		74,10	74,00	174,3	1743,027	None	Global	1
10:1	Cold	Evaporator-PH	218,77	226,04	3,73	,513	None	Global	1
11:1	Cold	Evaporator-Evap	226,04	226,10	203,1	3384,277	None	Global	1
12:1	Cold	Evaporator-SH	226,10	250,00	8,14	,341	None	Global	1
13:1	Hot	Gas	920,00	421,00	210,2	,421	None	Global	1
14:1	Cold	DH Intercooler	40,00	70,00	168,7	5,623	None	Global	1
15:1	Hot	Air IC	173,23	61,66	113,6	1,018	None	Global	1
16:1	Hot	Air AC	219,03	89,20	132,8	1,023	None	Global	1
17:1	Cold	Water IC	51,63	163,23	113,7	1,019	None	Global	1
18:1	Cold	Water AC	79,20	209,03	132,9	1,024	None	Global	1
19:1	Cold	Air rec	139,24	507,31	525,6	1,428	None	Global	1
20:1	Hot	Exh. rec	568,93	296,54	524,9	1,927	None	Global	1
21:1	Cold	Water Eco	79,20	223,94	375,7	2,596	None	Global	1
22:1	Hot	Exh. Eco	296,54	89,20	376,3	1,815	None	Global	1
23:1	Cold	B.Chamb.	490,97	1118,00	1254,8	2,001	None	Global	1
24:1	Hot	DH Ex.gas	89,20	55,00	35,9	1,050	None	Global	1
25:1	Hot	DH Water	89,20	68,70	6,64	,324	None	Global	1
26:1	Hot	DH Cond	68,70	40,00	412,9	14,387	None	Global	1
27:1	Hot	W. Ev. out	207,41	185,00	82,1	3,664	None	0	1
27:2	Hot		185,00	162,72	81,6	3,662	None	0	1
27:3	Hot		162,72	140,00	83,2	3,662	None	0	1
27:4	Hot		140,00	79,07	223,2	3,663	None	0	1
28:1	Hot	W. Ev. air	207,41	139,24	68,2	1,000	None	Global	1
29:1	Cold	Steam Ev.1	184,80	184,90	81,3	813,075	None	0	1
30:1	Cold	Steam Ev.2	200,00	200,10	81,3	812,950	None	0	1
31:1	Cold	Steam Ev.3	162,00	162,10	81,3	812,950	None	0	1
32:1	Cold	Steam Ev.4	170,00	170,10	81,3	812,950	None	0	1
33:1	Cold	Steam Ev.5	139,80	139,90	81,3	813,075	None	0	1
34:1	Cold	Steam Ev.6	150,00	150,10	81,3	812,950	None	0	1
35:1	Cold	Air Ev.	89,20	139,24	51,0	1,019	None	Global	1
36:1	Cold	Cool flow	139,24	568,93	38,0	8,84E-2	None	Global	1

Table 4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Hot Composite
Cold Composite
Temperature [C]
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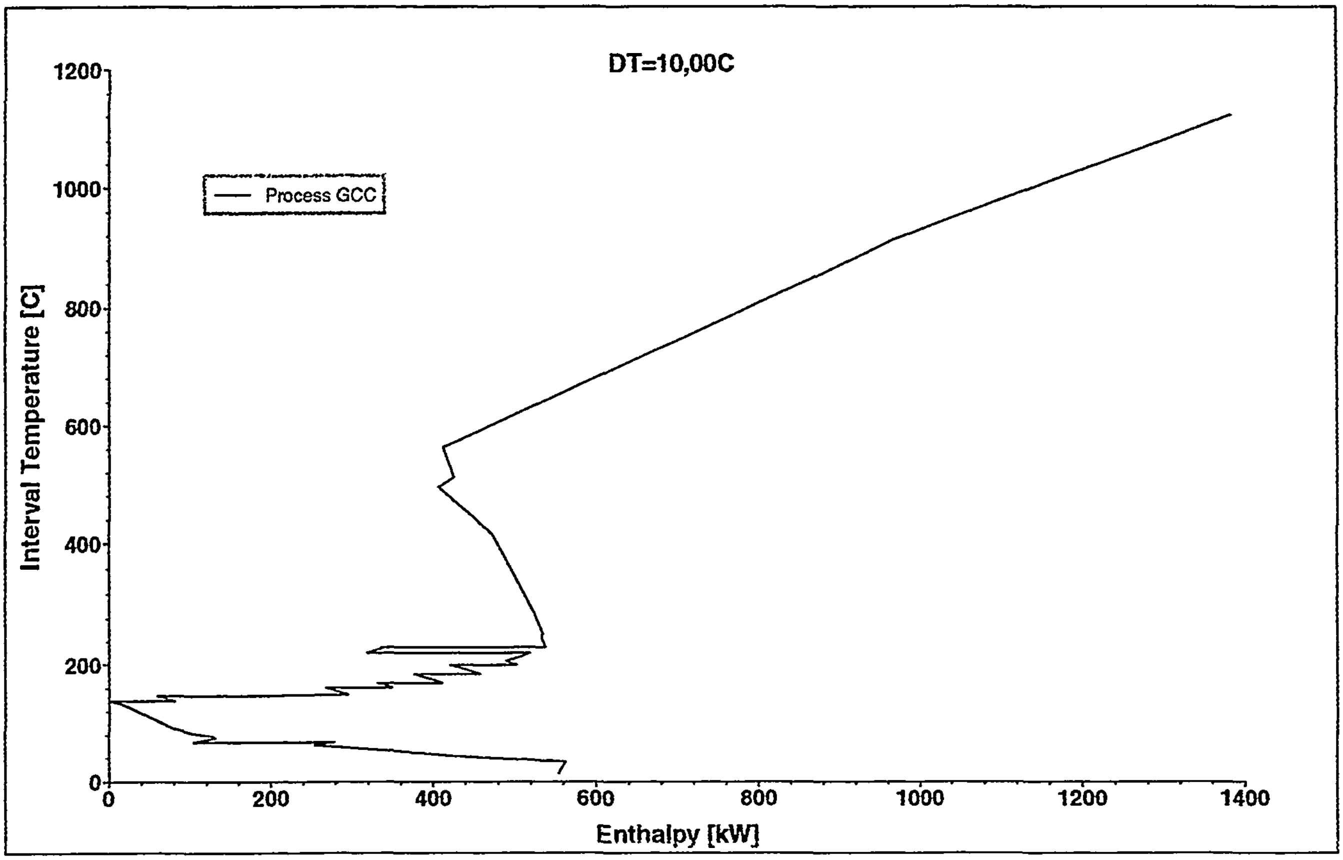
1000
800
600
400
200
0
Enthalpy [kW]
0
1000
2000
3000
4000
5000

Figure 27


DT=10,00C
Process GCC
Interval Temperature [C]
Enthalpy [kW]
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200
400
600
800
1000
1200
1400

Figure 28

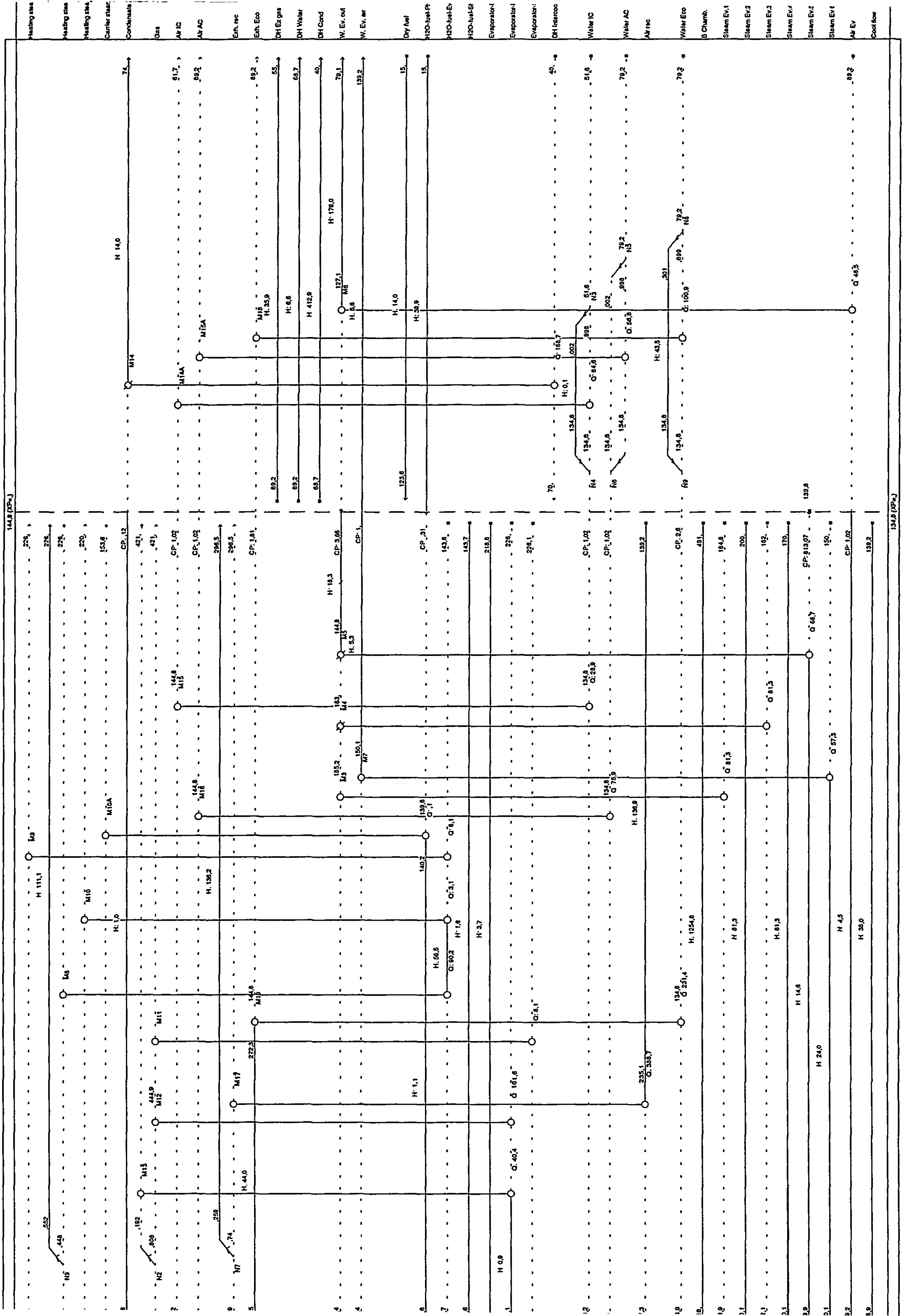
Heating stea
Heating stea
Heating stea
Carrier stear
Condensate
Gas
Air IC
Air AC
Exh. rec
Exh. Eco
DH Ex gas
DH Water
DH Cond
W. Ev. out
W. Ev. air
Dry fuel
H2O-fuel-Pt
H2O-fuel-Ev
H2O-fuel-St
Evaporator-I
Evaporator-I
Evaporator-I
DH Intercoo
Water IC
Water AC
Air rec
Water Eco
B Chamb.
Steam Ev.1
Steam Ev.2
Steam Ev.3
Steam Ev.4
Steam Ev.5
Steam Ev.6
Air Ev
Cool flow
144,8 (XP₀)
134,8 (XP₀)
M1
M2
M3
M4
M5
M6
M7
M8
M9
M10
M10A
M11
M12
M13
M14
M14A
M15
M15A
M16
M17
M18
M19
N2
N3
N4
N5
N6
N7
N8
N9

Figure 29

Untitled: File: sydk_3c.st4

No.	Name	Duty (kW)	Spec	Stm,Br	Branch	Tin (C)	Tout (C)	DtApp (C)
1	M3	81,3	T1,T3,T4	P:27,27	W. Ev. out	207,41	185,22	4,18E-1
				P:29,29	Steam Ev.1	184,80	184,90	
2	M4	81,3	T1,T3,T4	P:27,27	W. Ev. out	185,22	163,02	1,02
				P:31,31	Steam Ev.3	162,00	162,10	
3	M5	66,7	T1,T2,T3	P:27,27	W. Ev. out	163,02	144,80	5,00
				P:33,33	Steam Ev.5	139,80	139,88	
4	M6	46,5	T1,T3,T4	P:27,27	W. Ev. out	139,80	127,11	5,00
				P:35,35	Air Ev.	89,20	134,80	
5	M7	57,3	T1,T2,T3	P:28,28	W. Ev. air	207,41	150,10	1,00E-1
				P:34,34	Steam Ev.6	150,00	150,07	
6	M11	8,14	T2,T3,T4	P:13,37	P13:B13/SB1	444,93	421,00	194,90
				P:12,12	Evaporator-SH	226,10	250,00	
7	M12	161,6	T1,T2,T3	P:13,37	P13:B13/SB1	920,00	444,93	218,89
				P:11,11	Evaporator-Evap	226,04	226,09	
8	M13	40,4	T1,T2,T3	P:13,38	P13:B13/SB2	920,00	421,00	194,91
				P:11,11	Evaporator-Evap	226,09	226,10	
9	M14	168,7	T1,T3,T4	P:9,9	Condensate	144,80	74,01	5,60
				P:14,14	DH Intercooler	40,00	70,00	
10	M14A	84,6	T1,T3,T4	P:15,15	Air IC	144,80	61,70	10,00
				P:17,39	P17:B17/SB1	51,63	134,80	
11	M15	28,9	T1,T2,T3	P:15,15	Air IC	173,23	144,80	10,00
				P:17,41	P: 17/M	134,80	163,21	
12	M15A	56,8	T1,T3,T4	P:16,16	Air AC	144,80	89,24	10,00
				P:18,42	P18:B18/SB1	79,20	134,80	
13	M16	75,9	T1,T2,T3	P:16,16	Air AC	219,03	144,80	10,00
				P:18,44	P: 18/M	134,80	208,97	
14	M17	388,7	T1,T2,T4	P:20,45	P20:B20/SB1	568,93	296,54	61,42
				P:19,19	Air rec	235,12	507,31	
15	M18	100,9	T1,T3,T4	P:22,22	Exh. Eco	144,80	89,23	10,00
				P:21,47	P21:B21/SB1	79,20	134,80	
16	M19	231,4	T2,T3,T4	P:22,22	Exh. Eco	272,29	144,80	10,00
				P:21,49	P: 21/M	134,80	223,94	
17	M8	90,2	T1,T2,T4	P:6,50	P6:B6/SB1	226,04	226,00	82,34
				P:3,3	H2O-fuel-Evap.	143,66	143,70	
18	M9	8,10	T1,T2,T3	P:5,5	Heating steam-SC	250,00	226,04	82,41
				P:3,3	H2O-fuel-Evap.	143,63	143,63	
19	M10	3,07	T1,T2,T3	P:7,7	Heating steam-SubC	226,00	220,00	76,37
				P:3,3	H2O-fuel-Evap.	143,63	143,63	
20	M10A	1,15E-1	T1,T2,T3	P:8,8	Carrier steam	250,00	153,60	13,80
				P:2,2	H2O-fuel-PH	139,80	140,17	

Table 5

Stream Name	Split Name	Temperature (C)	Branch No.	Branch Name	% Flow of Inlet	% Flow of Stream
Heating steam-Cond	N9	226,04	I:6	Heating steam-Cond	N/A	100,
			O:50	P6:B6/SB1	44,8	44,8
			O:51	P6:B6/SB2	55,2	55,2
Gas	N2	920,00	I:13	Gas	N/A	100,
			O:37	P13:B13/SB1	80,76	80,76
			O:38	P13:B13/SB2	19,24	19,24
Water IC	N3	51,63	I:17	Water IC	N/A	100,
			O:39	P17:B17/SB1	99,85	99,85
			O:40	P17:B17/SB2	,15	,15
Water AC	N5	79,20	I:18	Water AC	N/A	100,
			O:42	P18:B18/SB1	99,85	99,85
			O:43	P18:B18/SB2	,15	,15
Exh. rec	N7	568,93	I:20	Exh. rec	N/A	100,
			O:45	P20:B20/SB1	74,05	74,05
			O:46	P20:B20/SB2	25,95	25,95
Water Eco	N8	79,20	I:21	Water Eco	N/A	100,
			O:47	P21:B21/SB1	69,88	69,88
			O:48	P21:B21/SB2	30,12	30,12

Table 6

Stream Name	Split Name	Temperature(C)	Branch No.	Branch Name	% Flow of Inlet	% Flow of Stream
Water IC	N4	134,80	O:41	P: 17/M	N/A	100,
		134,80	I:39	*P17:B17/SB1	99,85	99,85
		134,80	I:40	P17:B17/SB2	,15	,15
Water AC	N6	134,80	O:44	P: 18/M	N/A	100,
		134,80	I:43	*P18:B18/SB2	,15	,15
		134,80	I:42	P18:B18/SB1	99,85	99,85
Water Eco	N9	134,80	O:49	P: 21/M	N/A	100,
		134,80	I:47	*P21:B21/SB1	69,88	69,88
		134,80	I:48	P21:B21/SB2	30,12	30,12

5. FURTHER DEVELOPMENT OF THIS WORK

In this work we have analysed the current BIOMASS IGHAT process by the Pinch Technology, generating the curves: Composite Curves and Grand Composite Curves, obtaining the utility targets, and creating the Grid that matches with this present lay-out. Using that, we have reached some important conclusions about the energy efficiency of the process.

But the work should not be finished here. Further studies should be carried out in order to provide more complete conclusions about the BIOMASS IGHAT and the Pinch Technology.

Taking into account the economical parameters like the heat exchanger prices and the energy costs, could be the first step. Then, the optimum minimum difference of temperature could be determined, and used in the next calculations.

The second step would be the analysis of the different curves that Pinch Technology provides. By the detailed examination of them, new improvements for the energy recovery of the process could be found, in order to reduce the utility targets.

The next step on this work would be the creation of a new grid which could achieve the utility targets completely. Many different grids could be created at this step with different level of performance in achieving the utility targets and in making changes to the original lay-out. By an economical estimation of those grids, taking into account the capital cost for the structural changes and the energy savings, the best one would be chosen.

Working in this way, the best solution would be obtained not only in the ”energy savings” part but also in the ”capital cost” part of the global problem.

ANNEX

THE PROGRAM SUPERTARGET

SuperTarget [7] is one of the leading Pinch Technology software on the market, tried and tested robust product used on well over 1000 practical projects world-wide. SuperTarget is the state of the art software package developed by Linnhoff March to provide the process engineer / pinch technologist with the tools needed to implement Pinch Technology. It is an interactive software tool that maximises the engineer's performance and by its very nature introduces the latest process integration techniques into the design office.

SuperTarget has been written specifically for the windows graphical user interface. The menu allows to enter and manipulate process plant data, so as to obtain information about energy, capital and shaftwork targets. Both grassroots design and retrofit situations can be handled. In addition, SuperTarget has a full range of facilities to handle total site projects, unless there are no models for other components but the heat exchangers, and phase changes can't be handled easily. Lastly, a highly interactive heat exchanger network design capability is provided. This includes network simulation, sensitivity analysis and optimisation.

The main menu resides at the top of the screen and provides access to most of its functions.

The **File menu** enables the user to execute a number of file handling operations or to set-up the windows printer.

The **Edit menu** provides access to SuperTarget data editors. These allow the user to input new data, modify existing data, scale existing data, delete data and write data reports.

The Stream data editor provides a spreadsheet facility for the input and editing of stream data. SuperTarget allows the definition of segmented stream data to represent a variation of Mass Flow Specific Heat (MCP) with temperature. That is, a simple stream can be split into separate segments, each with a constant MCP. This is particularly useful for representing the super-heating and sub-cooling sections of vaporising or condensing streams. The stream data is arranged in a table, with one per segment. The fields where the stream data is displayed laid horizontally and are used as follows:

No.: Number of the row.
Type: The stream type is either hot or cold.
Stream name: Names should be unique within a data file.
TS and TT: Supply temperature of the stream and target temperature of the stream. An error will be reported if the two values are equal. There is no special treatment of a condensing or vaporising stream; it should simply be represented by a close TS and TT and a large CP. A temperature difference of one degree is recommended for a constant temperature stream.
DH and MCP: These two fields provide alternative ways of defining the heating or cooling duty of a segment. One of the fields must be specified. To some extent they are dependent upon each other, and upon the segment TS and TT values, so some automatic calculations occurs.

HTC: This field is used to supply a film coefficient for the stream. If a local value is not required then the string "None" appears instead.

ΔT: This field is used to supply a local difference of temperature (ΔT) contribution for the segment. If a local value is not required then the string "Global" appears instead. In this case the temperature will be shifted by ΔTmin/2.

Capital Cost Law: This field is used to attach capital costlaws to stream segments, for use in the calculation of heat exchanger costs for range targeting and the capital targets report.

Below the Stream data editor, there are three more editors: the Utility data editor, the Cost data editor and Project data editor. These editors provide spreadsheet facilities for the input and editing of utility data, capital cost data and general information relating to projects, respectively.

The **Point menu** provides functions to explore the interaction between a set of process heat sinks, heat sources and available utilities, at a given minimum approach temperature (ΔTmin). It also provides the facilities needed to evaluate point targets for energy, area, capital cost and so on.

Upon selecting the option "Set Process ΔTmin" the user will be prompted to supply a new value of ΔTmin. This can either be done directly, by supplying ΔTmin itself; or indirectly, by supplying the total amount to be used of either hot or cold utility.

The point menu provides access to several different graphs, which fall into two types. The first type are those which don't display utility use:

- Composite curves.
- Shifted composite curves.

The second type are those which do:

- Grand composite curve (utility data is optional).
- Balanced composite curves.
- Balanced grand composite curve.
- Single step utility placement.
- Extract grand composite curve (utility data is optional).

Other information is also provided by the point menu, such as the energy report, the utility report, the capital report, the problem table and the CP matrix.

The **Exergy menu** provides the facilities needed to evaluate exergy losses in the process and the heat exchanger network. It provides access to functions which allow the point targeting graphs to be viewed using Carnot Factor, rather than temperature, as the Y axis co-ordinates. The exergy routines allow the engineer to derive the shaftwork targets for a process. In addition, the utility loads for different temperature levels can be specified and the shaftwork targets calculated for the new configuration. The exergy composite curves, balanced exergy composite curves and the exergy grand composite curve are shown, and the user can also obtain separate targets for the network exergy loss, the process exergy loss and the utility exergy loss.

The **Site menu** provides access to a set of functions for performing a total site analysis of a complete manufacturing site. These functions allow the user to explore the integration of separate plants via the site wide heat and power utilities. This provides the information needed to obtain overall targets for the fuel use, power import and flue gas emissions of the site. The capability to handle multiple files is provided, together with the ability to interactively change utility loads and study their impact on the total site analysis.

The **New menu** provides functions which are used to locate the optimum value of the minimum approach temperature for a new process design. The analysis considers energy requirements, utility usage, heat exchanger surface area and various costs over a range of ΔTmin values. The optimum value can then be chosen based upon criteria such as minimum total cost.

The **Retrofit menu** provides functions which are used to locate the optimum value of the minimum approach temperature for a retrofit process design. The analysis considers energy reduction, area efficiency, changes in the amount of heat exchanger surface area, cost savings and pay back periods over a range of ΔTmin values. The ΔTmin value can then be chosen to satisfy constraints such as a given pay back period or a given level of investment.

The **Network menu** provides various tools for the synthesis and analysis of network structures, in order to satisfy the energy and capital targets for a chosen value of ΔTmin. This part of SuperTarget does not perform automatic network design. Instead, the tools are available to locate and size various network matches.

The main user interface for the design of heat exchanger networks is the Network Grid. This window displays the current heat exchanger network in the standard pinch technology grid diagram format. This allows the user to visualise the current state of the network design. The interactive environment provides the tools for graphically placing heat exchanger matches, stream splits and stream mixers.

SuperTarget runs in two models: design mode and simulation mode. The design mode is the model which allows a network to be evolved heat exchanger by heat exchanger. Once a match has been specified it can be checked that the design is still on course towards achieving the energy and capital targets by using the "remaining problem analysis". The simulation mode is the model in which a network can be input as a set of heat exchanger duties or areas together with the heat exchanger topology. This mode allows analysis of the network behaviour using sensitivity techniques and the network temperature controller.

The **Tools menu** provides a selection of simple tools for use by the engineer. These include a calculator and a heat exchange calculator. The menu also provides access to a window for changing system configurations options.

Discussion of the SuperTarget program.

SuperTarget has been used in this project as a tool to apply Pinch Technology in the studied processes. Generally, it can be said that the program is quite useful in the way it helps the engineer to attack the problem of the complex heat recovery systems easily and clearly.

But, like everything in this life, SuperTarget has got its own advantages and disadvantages which are going to be discussed in the following lines.

The first problem that can be found is the requirements for the software and hardware for running SuperTarget. If we look at SuperTarget User Guide we can find out that the minimum recommended hardware specifications are an 80486 or Pentium CPU with maths co-processor and 8 MB RAM. Despite this recommendation, more memory should be used or the program could crash very often just when trying to make some calculations upon setting process ΔTmin.

One big advantage of the program is that it runs with Windows 95. This implies an easy way to work where we can access to all its functions from the main menu and easily introduce the data, run the calculations, make the grid, etc. Evenmore, the Help menu provides access to SuperTarget's comprehensive help facilities, which are very good organised and explained and it really helps the user to understand how to work with SuperTarget.

As it already has been said, SuperTarget is a useful tool for handling complex systems with many hot and cold streams to couple, in the same way that Pinch Technology is a good methodology for analysing these very big processes. But this systematic way of working that Pinch Technology and SuperTarget apply could not be that useful for much simple processes which could be analysed better with other tools like heat balance programs, for example, IPSEPRO, ASPEN, or Gatecycle.

The program is designed to handle heat transfer between heat exchangers and other component models are still missing. Because of that, it is difficult to model temperature changes caused by expansion or compression. Beside that, it is impossible to model mass transfer and the user is forced to find out a methodology for handling this phenomena.

In the following lines, the needs of a Pinch Technology program and the tools which would make such a software almost perfect are shown [26]:

A Pinch Technology program must have:

- Number of pinches more than one.
- Condensation and boiling.
- Compatible to Windows 95.
- Display the exact values.
- Copy possibility.

A Pinch Technology program should have:

- Excel-Sheets for data-input.
- Steam table included.
- Tool for defining different kinds of heat exchangers.

A Pinch Technology program could be:

- Compatible to simulation program.

- Compatible to CAD.

Supertarget has got all the requirements which are completely necessary for a Pinch Technology program: it can work with more than one pinch, runs with Windows 95, displays the exact values, it is possible to copy, and the condensation and boiling processes can be handled.

Referring to the requirements that a Pinch Technology program should have, SuperTarget has got just one of those three: excel-sheets for input-data. On the other side, there are not steam table and any tool for defining different kind of heat exchangers.

None of the requirements that a Pinch Technology program could have are followed by SuperTarget version 3.1. Maybe the last version SuperTarget 4.0 is able to be compatible to CAD and to simulation programs. At least, this new version is compatible to ASPEN.

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