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TNO-report

The application of industrial heat pumps in The Netherlands

Final-report

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- process integration

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- PWP Programma Warmtepompen TNO
- Novem B.V.

This project was carried out as in accordance with the Netherlands contribution to Annex XXI, under the title: 'Global environmental benefits of Industrial Heat Pumps'. This Annex XXI forms part of the Implementing Agreement on Advanced Heat Pump Systems (IAAHP) of the International Energy Agency (IEA).

Summary

The work programme entitled 'Implementing Agreement for a programme of research and development on Advanced Heat Pump Systems (IAAHP)' of the International Energy Agency (IEA) includes definitions of international projects in the form of Annexes. Annex 21 is focused on the Global Environmental benefits of industrial Heat Pumps. The Dutch contribution to this project was carried out in two phases. The principal for phase 1 was Novem B.V. Phase 2 was carried out within the framework of the Dutch Heat Pump Implementation Programme (PWP). The results of phase 1 are described earlier in report 93-323. This final report contains the results of phase 1 as well as the results of phase 2. Thus, the phase 1 report (93-323) is lapsed hereafter.

The estimation of the potential for industrial heat pumps has been carried out in this study on the basis of a number of selected reference processes a) for which a usable process description and preferably a pinch study were available and b) which account for a considerable proportion of the primary energy consumption in the industrial sector concerned.

First phase
The first phase of this project was aimed at exploring the potential for heat pumps in following sectors of the Dutch industry:

- The food and drink industry
  - The dairy products industry
  - The sugar and starch industry
  - The beer and malt industry
  - The oils and fats industry
- The paper and cardboard industry
- The textile finishing industry
- The ceramics, glass and brick industry
- The chemical industry
- The base metals industry

The above sectors taken together represent about 85% of industrial energy consumption in The Netherlands. Because of the scarcity of thermal process data, it was hard to evaluate this potential in many cases. This is particularly true of the chemical industry.

In some industrial processes in the Dutch industry it will be necessary to introduce heat pumps in order to bring about a substantial reduction in primary energy consumption. Examples of such industries are the dairy products industry and the sugar and starch industry. Because of the relatively low level of energy prices, however, in many cases this reduction is not yet an attractive proposition from the economic point of view in existing plants.
The (economic) chances for heat pumps are far better in the area of the design and construction of new processes and plants. It often occurs that because of the lack of knowledge and experience of heat pump technology, the technical risk of applying heat pumps in new projects is seen as 'unacceptably' high.

By far the majority of heat pumps are in use in the food and drink industry, especially in evaporation processes which involve only a slight increase in the boiling point. Thermal process analysis is needed to assess the potential for heat pumps. The most widely used form of thermal process analysis is Pinch Technology. The present survey was based not only on the general industrial process literature but also made extensive use of Pinch study reports. At the present time, industrial heat pumps account for less than 5% of the estimated potential.

On the basis of this study the following potentially fruitful applications were found for heat pumps in the Dutch industry:

Table 1 Potential for Heat Pumps in the Food and Drink industry

Sector	**Type HP**	**$P_{condensor}$ [MW]**	**P_{drive} [MW]**	**Number**	**E-savings TJ**	**Emission Reduction CO_2 [ton.10^3/jr]**
Dairy	MVR	450	30	60	10,686	545
	closed cycle	60	20	40	212	11
Sugar	MVR	500	40	8	3,069	157
	close cycle	-	-		-	-
Starch	MVR	200	8	4	2,899	148
	closed cycle	-	-		-	-
Beers	MVR	6	0.3	6	150	7.6
Malt	closed cycle	4	1	6	39	1.9
Oils & Fats	MVR	200	10	pm	4,752	242
	closed cycle	pm	pm	pm	pm	-
Total		1420	108.3	124	21,807	1112.5

Table 2 Potential for Heat Pumps in the rest of industry

Sector	**Type HP**	**$P_{condensor}$ [MW]**	**P_{drive} [MW]**	**Number**	**E-savings TJ**	**Emission Reduction CO_2 [ton.10^3/jr]**
Paper	closed cycle	80	15	20	1,167	59.5
Textile	MVR	-	-	-	-	-
Finishing	closed cycle	4	0.8-1	10 - 15	30	1.5
Ceramics	MVR	-	-	-	-	-
and glass	closed cycle	12[1]	0.5 [2]	3	308	15.7
Chemicals	MVR	1,000	80	pm	22,737	1,159
	closed cycle [3]	36.8	1	6	94.4	48.1
Base	MVR	-	-	-	-	-
materials	closed cycle	pm	pm	pm	pm	pm
Total		1,132.8	96.5	44	25,186	1,283.8

[1] Some of these are heat transformers in the ceramics industry

[2] Drive power of heat transformers not taken into account

[3] Ethylene and ureum production

Second phase
In the second phase of this project, process data of a selected number of processes were gathered and a pinch study of these processes was carried out.
The selection and implementation of a technical and economical attainable heat pumps in these processes was carried out with the IEA/Annex 21 computer programmes (Chalmers/ETA programme and the RCG market assessment speadsheet). The selection of these processes has taken place in cooperation with the National Teams during the 3rd Annex 21 expert meeting, September 1993 in The Netherlands. The following processes are selected:

- Dairy production plant (cheese, milk, whey)
- Textile plant
- Paper production plant
- Building ceramics (bricks, tiles) plant
- Methanol plant
- Ethylene plant (naphta feed)
- Ureum plant
- Starch evaporation plant

In all these processes, except the methanol process, heat pumps are feasible. The feasibility of these heat pumps are calculated with a computer programme, developed within the scope of the Annex 21 project by Chalmers University, Sweden. The meaning of the developed Market Assessment spreadsheet, developed by RCG/Hogler Bailly Inc. within the scope of this project, is limited due to uncertainty about industrial growth, future energy prices and market penetration incentives.

For all these processes, one or two heat pumps were found to have an acceptable pay back period. The results are:

Process	Pinch [°C]	Heat pump type	Condenser capacity [kW]	Pay back period [yr]
Textile	35	GM, CC,[1] Screw R22	6400	3.8
Dairy	71	Absorp, LiBr-H2O, nat. gas	3420	8.6
Dairy	71	TVR	2480	4.8
Paper	86	GM, CC, ECO, TURBO, R114	3830	5.3
Paper	86	Heat Transf LiBr-H2O	1843	9.9
Building Ceramics	52	GM, CC, Screw, R22	470	8.1
Ureum	133	GM, CC, Turbo, H2O	3800	5.1
Ethylene	95	Heat Transformer LiBr-H2O	6676	7.4
Ethylene	95	GM, CC, Turbo, R114	3036	8.1
Methanol	505	No Heat Pump av.		
Starch evaporation	100	MVR	156737	0.5

[1] GM = gasmotor driven
CC = closed cycle
Screw/Turbo = compressor type
ECO = economiser
MVR = mechanical vapour recompression
TVR = thermal vapour recompression

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1 Introduction

The work programme entitled 'Implementing Agreement for a programme of research and development on Advanced Heat Pump Systems (IAAHP)' of the International Energy Agency (IEA) includes definitions of international projects in the form of Annexes. This study is carried out in two phases. The results of phase 1 are described earlier in report 93-323. This final report contains the results of phase 1 as well as the results of phase 2. Thus, the phase 1 report (93-323) is lapsed hereafter.

First phase
This first phase is intended to establish the potential for heat pumps in the Dutch industry. In view of the limited availability of thermal process data - in particular for the chemical industry - this first phase has been exploratory and qualitative. Wherever possible, the potential for heat pumps has been specified by type and capacity.

A number of industrial sectors were selected for assessment of their potential. The selection criterion was specific energy consumption (energy consumption per unit produced). The following industrial sectors were surveyed:
- The food and drink industry
  - The dairy products industry
  - The sugar and starch industry
  - The beer and malt industry
  - The oils and fats industry
- The paper and cardboard industry
- The textile finishing industry
- The ceramic, glass and brick industry
- The chemical industry
- The base metals industry.

Second phase
In the second phase of this project, process data of a selected number of processes were gathered and a pinch study of these processes is carried out.
The selection and implementation of a technical and economical attainable heat pumps in these processes is carried out with the IEA/Annex 21 computer programmes (Chalmers/ETA programme and the RCG market assessment speadsheet). The selection of these processes has taken place in cooperation with other national teams during the 3rd annex 21 expert meeting, September 1993. The following processes in The Netherlands are selected:
- Dairy production plant (cheese, milk, whey)
- Textile plant
- Paper production plant
- Building ceramics (bricks, tiles) plant
- Methanol plant
- Ethylene plant (naphta feed)
- Ureum plant
- Starch evaporation plant

For all these processes, one or two heat pumps were found to have an acceptable pay back period.

What does a heat pump do?

A heat pump 'pumps' heat up from a low and unusable temperature level to a higher, usable temperature level. The energy needed for the 'pump' can be mechanical or thermal. Chapter 3 explains in more detail the working and the large number of types of heat pumps.
Pumping heat generally requires a large investment of capital. For this reason, it is important to establish that there is nowhere else in the process an unnecessary temperature drop in heat flows, and that the source of heat for the heat pump cannot in fact be used elsewhere. The 'pumped' heat must of course be used to advantage, and in so doing reduce the consumption of primary energy, which is the ultimate aim in the application of heat pumps.

One useful aid in the identification of useful heat pump applications is Pinch Technology [A32], which has recently become widely known. This approach charts the heat flows and their quality, and indicates:

a. within what temperature range there are heat deficits which are made up by external heat sources (usually fuel) and
b. within what temperature range there are heat surpluses which are cooled down (often to the atmosphere).

These ranges are separated by the 'pinch temperature', above which there are heat deficits and below which there are heat surpluses. A heat pump must always therefore be 'over the pinch'.

The pinch level and the flow of heat in the vicinity of the pinch are important indicators of the applicability of heat pumps. Pinch studies are moreover not only useful because they indicate the pinch, but also and mainly because every pinch study is based on explicit qualifying and quantifying of the thermal process flows. These are precisely the data which are also required to evaluate the thermodynamic and technical potential of heat pumps. Unfortunately, the pinch studies so far carried out in Netherlands industry - some of which were carried out as part of the Milieu Plan Industrie (MPI) [Environmental Plan for Industry] - are, with only one exception, not available. For these reasons pinch studies carried out abroad (particularly in the USA and the UK) constitute an important source of information for this study.

Testing the potential

The potential for heat pumps can be tested on the basis of four criteria:

Thermodynamic feasibility

A heat pump is thermodynamically feasible when heat is transported by the heat pump over the pinch and when the temperature lift over which heat is transported is not too great (maximum 50 °C). In many cases a pinch study may give the answer. In addition, it may be possible to identify and evaluate possible cheaper alternatives (e.g. conventional heat exchangers) to reduce the primary energy consumption.

Technical feasibility
To fulfil this criterion, the temperature range in which heat is transported must be suitable for heat pumps. From the thermodynamic point of view it may be useful to raise the temperature from 600 °C to 610 °C, but technically speaking this is on the whole not yet possible.
In addition, the condenser and the evaporator must be technically feasible, which can be a problem in highly corrosive or contaminating environments.

Economic feasibility
This is the most complicated and also the most limiting criterion for heat pump applications. Put simply, the benefits of the heat pump must exceed the costs to such an extent that the capital investment is paid back over a reasonable period (for industrial heat pumps the requirement is often a maximum of 5/6 years, but mostly shorter). The investment and the heat factor of the heat pump, the (internal) price of the drive power, plus the energy and capital costs of conventional heat generation are decisive factors.

Industrial sector feasibility
Apart from the above-mentioned criteria, other factors may come into play, such as the cost of back-up facilities, safety, technical risk and environment. Apart from these criteria, the extent to which heat pumps are already applied in the ‘particular’ sector concerned also appears to have a great effect on the acceptance of heat pumps.

From the process, a distinction can be made between in-unit and inter-unit applications. In the case of in-unit applications, the heat pump is located ‘over the unit’. One example is the mechanical vapour recompression applied in evaporators. In the case of inter-unit applications, heat is pumped from general or unit surpluses to benefit another unit or (general) utilities such as low-pressure steam. One example of this is the two heat transformers used in The Netherlands.
Most of the heat pumps successfully applied in industry are in-unit applications, specifically vapour recompression.
In addition, it can be shown that the reduction of primary energy consumption in industry will make the use of heat pumps essential in future: drastic reductions in primary energy consumption can be achieved by using the conventional heat/power installation to deliver the required electricity and high-temperature heat, while pumping up heat in the low-temperature range (<140 °C) by means of heat pumps. This of course only applies if the demand for heat is considerably greater than the demand for power, even after the installation of heat pumps, with the consequent increased demand for electricity and reduced demand for heat. If the demand for power is relatively high as compared with the demand for heat, and the electricity generated in-plant can be sold at a good price, heat surpluses will rapidly ensue. In these circumstances, heat pumps are of course of no advantage. Stimulating heat/power by means of high payback tariffs thus leads in certain cases - where the demand for electricity is high as compared with the demand for heat - to the elimination of heat pumps as a possible solution.

Industrial heat pumps in The Netherlands

The number of industrial heat pumps in The Netherlands is not very great as yet. In the early eighties some effort was made to introduce them, but with the collapse of fuel prices in the mid-eighties heat pump activities were decimated. The exact number of industrial heat pumps is hard to gauge, partly because people are not always aware that what they have on their premises is actually a heat pump. In spite of this, it is possible to surmise that there are at present at least 92 industrial heat pumps in use in The Netherlands. By far the majority are the thermal vapour recompressors in the dairy industry. There are 20 mechanical vapour recompressors, often of high capacity. In addition there are seven compression heat pumps and three absorption heat pumps. There are also two absorption heat transformers.
The industrial sectors where these pumps are installed are the following:

Table 1.1 Industrial heat pump systems in The Netherlands

	MVR	TVR	CHP	AHP	AHT
Food and drink industry	14	60	4	2	0
Paper	0	0	0	0	0
Artificial fertiliser and other chemicals	6	?	2	0	1
Metal	0	0	0	1	1
Textiles	0	0	0	0	0
Others	0	0	3	0	0

The Chalmers/ETA and the RCG/Hagler Bailly computer programmes

Computer programmes to support technical and economic feasibility tests.

In the scope of this IEA Annex 21 project, two computer service programmes were developed. Chalmers ETA developed a programme, focused on thermodynamic and technical feasibility. This programme was used to ‘implement’ different types of heat pumps in several Dutch processes.
Beside this programme, RCG/Hagler Bailly developed a market assessment spreadsheet to calculate the environmental, energetic and economic effects of heat pump application on national scale.

The contents of this report

Chapter two covers the main results of the estimates of potential, both within The Netherlands and abroad. Chapter three covers the operating principle of the main types of heat pumps. Chapters four to nine inclusive cover the potential for heat pumps in the sectors mentioned above, on the basis of the available data, process descriptions and pinch studies.
In chapter 10, the implementation of heat pumps in 8 selected processes with the Chalmers/ETA computer programme is treated of heat.
Chapter 11 contains the experiences with the RCG/Hagler Bailly market assessment spreadsheet.
Finally, the conclusions and recommendations are mentioned in chapter 12.

2 Results of inventories and estimates of potential for industrial heat pumps

Over the years, various inventories and estimates of potential have been carried out, both within The Netherlands and abroad. The principal Netherlands study was the extensive work carried out by E_3T in a large number of sectors. The applicability of heat pumps can be seen to depend to a very large extent on the temperature levels needed for the processes, rather than on the pinch position or the availability of suitable sources. To judge by the very roughly estimated potential for heat pumps in each sector, the database on which this estimate of potential is based was very limited. The conclusion is a potential of 320 open heat pump systems with a total thermal capacity of 1355 MW and a potential of 253 closed heat pump systems with a total thermal capacity of 895 MW. The **penetration** for the year 2000 is estimated at 409 MW for the open systems. The **penetration** of closed systems is estimated at nil(!).

The DOE and EPRI have examined a large number of pinch studies carried out in American companies [A44]. The possible heat pumps which have acceptable payback times in these projects are almost without exception vapour recompressors, almost all mechanical vapour recompressors. The potential in the US is high, which is certainly due in part to the low price of electricity as compared with fuel prices.

3 The principal types of heat pumps and their method of working

Heat pumps can be categorised in a variety of ways.
In the first place, it is possible to distinguish between open and closed systems. Open systems make use of process vapours, while closed systems, as the name implies, consist of a closed circuit in which a working fluid circulates. It is also possible to divide heat pumps by the drive system used: thermal or mechanical. Mechanical systems make use of a compressor to raise the pressure of the working fluid, unlike thermal systems. These use high pressure steam (in the case of open systems), or fluid pumps in combination with absorption/desorption (closed systems) to achieve the desired high pressure.
We give below a more detailed description of the various types of heat pump.
The numerical data refer to the situation in The Netherlands in 1988.

3.1 Open HP systems: mechanical vapour recompression (MVR)

MVR is one of the 'open' systems

The operating principle is as follows:
process vapour is conveyed to a compressor, where the pressure and consequently also the temperature of the vapour is raised. The result of the rise in pressure is that the condensation temperature also rises. The compressed vapour is then condensed, while giving off heat.

The temperature range within which MVRs can be used depends on the physical properties of the process vapour concerned. Since in most applications it is water which is used, the temperature range usually lies between 80 and 200 °C. The temperature lift which can be achieved with 1-stage MVR is about 20 °C.
The efficiency of a system of this kind, defined as the useful heat divided by the compressor power employed, generally lies between 3 and 20 and depends to a very large extent on the temperature lift (the theoretical maximum value of the heat factor at a condenser temperature of 110 °C and a temperature lift of 10 °C is 38.3). In Finland there is an MVR system at a paper plant with a heat factor of 27.8 for a temperature lift of 7 °C. In other words: if the temperature lift is small, the heat factor can be very high!
The costs of a mechanical vapour recompressor can be divided into maintenance costs and purchase and initial installation costs. The latter category amounts to around NLG350 to NLG 400 per kW installed capacity. This compares with an annual operating cost of NLG 3.50 to NLG 4.00 per kW.

Advantages:
- high efficiency (heat factor 10 to 20 where ΔT = 15 to 30 °C);
- can be used up to about 200 °C;
- simple principle;
- simple to integrate into an existing process;
- not excessively high investment costs;
- small heat exchange area.

Disadvantages:
- fouling risks;
- risk of corrosion;
- application limited because of:
  - composition of process vapour (possible presence of inert gases, moisture);
  - nature of the process vapour (are there suitable lubricants, how far from critical point, much overheating etc.);
- compressor may be expensive (as a result of the foregoing);
- small temperature lift.

This type of heat pump is at present the most widely used in industry.

3.2 Open HP systems: thermal vapour recompression (TVR, steam ejector)

The operating principle is as follows:
low pressure process vapour is mixed in the ejector with high pressure steam, so that the pressure of the process vapour is raised. This higher pressure also raises the condensation temperature. The vapour condenses, giving off heat.

Using steam as process of the operating range lies roughly between 60 and 180 °C. The temperature lift is smaller than with mechanical vapour recompression. The TVR has a lower 'off-design' efficiency, i.e. 3 - 10. This can be attributed to the fact that the system is heat-driven.
As far as costs are concerned, the TVR system has a great advantage over other heat pump systems. The initial acquisition costs are in fact only NLG 5 to NLG 10 per kW.

Advantages:
- simple;
- cheap;
- reasonable temperature range;
- no moving parts;
- easy to integrate into existing processes;
- known system.

Disadvantages:
- noisy;
- corrosion, pollution;
- uses a large amount of expensive energy to produce high-pressure steam;
- limited pressure range;
- virtually impossible to use unless steam is the process medium.

The steam ejector is used relatively often for evaporation installations, particularly in the dairy industry, which is why the steam ejector is the most widely used industrial heat pump. In addition, it is often used in combination with or as stand-by for MVR.

3.3 Closed HP systems: the compression heat pump (CHP)

Operating principle

Low-temperature heat is used to evaporate fluid. The resultant vapour is pressurised by means of a compressor. The compressor is driven by an electric or gas motor. The high-pressure vapour is conveyed to a condenser, where it is condensed, giving off heat at a higher temperature (than that of the evaporator). Finally, the resultant fluid passes through an expansion section to reduce its pressure and flows back to the evaporator, thus completing the cycle.
The working fluid is kept separate from the process media, so that the exchange of heat takes place with the aid of heat exchangers.

The temperature range for which compression heat pumps are used is a condenser temperature between about 50 and 100 °C where conventional working fluids are used (R12, R22 and R114). If water is used as the working fluid, higher temperature applications are possible. The temperature lift usually lies between 20 and 40 °C while the COP, defined as the quotient of condenser heat and compressor capacity, varies between 2.5 and 6.
As far as price is concerned, there is a significant difference between gas and electric compression heat pumps (GCHP and ECHP). In the case of an ECHP, the initial purchase must be taken to be NLG 300 to NLG 650 per kW, with initial installation costs of NLG 100 to NLG 250. Maintenance costs come to about NLG 1 to NLG 2.50 per hour. For GCHPs, both the initial purchase and installation costs are about NLG 150 higher, and the maintenance costs are about twice as high as for ECHPs.

Advantages:
- free choice of working fluids;
- no internal contamination of components by the process media;
- safe to operate;
- no corrosion;
- can be applied over a wide range of capacities and temperatures.

Disadvantages:
- expensive compressor;
- conversion of primary to mechanical energy;
- moderate part-load operation (depending on type of compressor);
- large heated surface required in comparison with MVR and TVR.

3.4 Closed HP systems: the absorption heat pump (AHP)

Operating principle

The only difference between the operation of an AHP and a CHP is in the compression phase. A CHP uses mechanical compression, whereas in an AHP ‘thermal compression’ is applied. The vaporised working fluid is conveyed to an absorber where it is absorbed, giving off heat. The resultant mixture is pumped to the generator by a fluid pump (and thus pressurised), where high temperature heat is applied, and the working fluid evaporates out of the solution. The vapour disappears in the direction of the condenser, while the fluid remaining behind in the generator is returned to the absorber via a throttle valve.

The temperatures for which these systems are applied are restricted by the current range of working pairs. Machines using H_2O/LiBr can only operate up to about 130 °C (generator temperature), so that the highest temperature at which useful heat is released is around 100 °C. One working pair which does remain stable at temperatures above 150 °C is NH_3/H_2O. However, if this pair is used in an AHP at generator temperatures in excess of 150 °C, it is not usually efficient.
Because compressing a fluid results in lower losses than vapour compression, the pressure ratio of absorption/adsorption systems can be set at a higher level than for compression systems. As a result, the temperature lift is greater than for compression heat pumps, i.e. 30 to 50 °C. On the other hand the COP (condenser plus absorber heat divided by the applied generator heat) is lower, i.e. around 1.5. The purchase costs are about the same as those of an ECHP, although the initial installation costs are higher (NLG 325.00 to NLG 500.00 per kW installed capacity). The annual operating costs amount to 1% of the purchase price.

Advantages:
- no conversion to mechanical energy;
- simple parts (heat exchangers, fluid pumps);
- low pollution risk;
- good part-load operation;
- low noise;
- flexibility with regard to process changes.

Disadvantages:
- low temperature range;
- corrosion;
- large heat exchange surface;
- slow start-up (it takes a long time for the system to reach the stationary state).

3.5 Closed HP systems: the absorption heat transformer (AHT)

Operating principle

Much the same as AHP. Heat is conveyed to the generator (low pressure section). The vaporised vapour passes to the condenser, where it is condensed. The fluid is pressurised by a fluid pump, conveyed to the evaporator and there vaporised. The high-pressure vapour goes to the absorber and is there absorbed, giving off high-temperature heat.

The temperature range for which the heat transformer is applied is similar to that for the AHP. Here too, therefore, the problem is that the applications are limited by the temperature range of the currently available working pairs.
This means that in the case of H_2O/LiBr systems, the useful heat can be supplied up to a temperature of about 130-140 °C. If however the working pair NH_3/H_2O is used, higher temperatures are possible (theoretically up to about 200 °C). This pair, however, has other disadvantages. Because of the toxicity of ammonia, the heat transformer must be absolutely leakproof.

The temperature lift is about 30 to 40 °C. The costs per kW useful heat are a factor of 1.5 higher than in the case of AHPs.

Advantages:
- see AHP.

Disadvantages:
- see AHP;
- there must be sufficient waste heat (about 2 MW) available at a specified temperature (about 60 to 100 °C).

4 Potential for heat pumps in the food and drink industry

General

There is a great deal of potential for in-unit and inter-unit applications of both open and closed heat pumps in the food and drink industry [A6], [A7], [E4], [E6]. This is mainly due to the fact that the temperature level of the processes is low, the theoretical energy requirement for production very low, and the combination of large heat stream and small temperature lift fairly frequent. A good example of this is the evaporation processes in the dairy, beer and malt sector and the sugar and starch sector. Here again, in-unit applications - such as vapour recompression in evaporators - are almost always more attractive than inter-unit applications.

4.1 Dairy industry

4.1.1 General

Number of concerns established in The Netherlands: 91

Reference processes: - Evaporation of whey and milk
- Drying of powdered whey and powdered milk

Table 4.1 Specific energy consumption of dairy products

	Production ton * 10^3/jr	E-consumption MJ/ton	
		Q [fuel]	E [electricity]
Liquid milk and milk products	1,747	472	172
Butter	290	489	135
Cheese	551	1,688	712
Condensed milk	478	2,045	235
Powdered milk	392	8,989	635
Powdered whey	249	14,184	971
Other dairy products	1,485	554	76

Almost all Netherlands dairy products plants belong to four major concerns, as follows:

1. Friesland (Frico Domo) coöperatie B.A.;
2. Campina melkunie;
3. Nestle Nederland B.V.;
4. Verenigde coöperatieve melkindustrie [Associated co-operative milk industry] Coberco B.A.

The principal (thermal) processes in the dairy industry are as follows:

1. heating (pasteurisation/sterilisation/heat treatment);
2. cooling (storage/process intermediate stage);
3. evaporation;
4. drying.

The energy consumption of the above-mentioned processes can mainly be reduced by:

Heating

- Enhancing degree of regeneration of pasteurising equipment.
- Use of heat pump using as their heat source cooling machine condenser, evaporator condenser or exhaust drying air from drying tower.

Cooling

- Preventing demand for cooling by better pre-heating of product.
- Raising evaporation temperature or reducing condenser temperature (if the condenser heat is not being made use of).

Evaporation

- Mechanical vapour compression, optimization of heating surface and number of stages.

Drying

- Pre-heating of drying air, recovery of heat from flue gases.

Comment:

- A considerable proportion of the cooling in the dairy industry is carried out using groundwater. In view of the levies on groundwater which are to be introduced, this use of groundwater for cooling will have to be replaced by compression cooling, because the waste water streams have too low a temperature (<<90 °C) to be able to drive absorption machines. It goes without saying that a critical examination will have to be carried out to find out whether part of the demand for cooling can be avoided or can be supplemented by cooling towers.

In [E4] there is a detailed discussion of the energy saving potentials of these four main processes. The main processes of heating and cooling occur throughout the production process and in the whole of the dairy industry. The main processes of evaporation and drying are concentrated in a restricted number of concerns. About 50% of the thermal energy consumption of the dairy industry is required for evaporation and drying (about 250. 10^6 nm^3/year). On this basis, evaporation and drying will be used as reference processes for the dairy industry.

4.1.2 Description of reference processes

4.1.2.1 Evaporation of whey and milk

Concentrating milk and whey by evaporation is a commonly used process in The Netherlands dairy industry. Every year about 3.5 million tons of milk are evaporated, about 30% of the total processing of milk. Most milk evaporators are used in the powdered milk industry; evaporation removes 80% of the water from the product before it is turned into powder in the drying tower. In addition, the evaporation process is used in the production of half-cream for coffee and condensed milk. Apart from milk, about 5 million tons of whey are evaporated in The Netherlands. Whey is a by-product in the preparation of cheese and has a low dry matter content. It is evaporated to keep down the costs of further processing and to prepare it for the powdered whey industry. In 1986, the annual energy consumption of all the evaporation plants in The Netherlands dairy industry taken together was 130.8 million nm^3 of natural gas and 39.1 million kWh of electricity.
The energy consumption for evaporation is kept down by making use of the following:
- multi-stage evaporation (generally used in the dairy industry);
- thermal vapour recompression (also widely used);
- mechanical vapour recompression (little used in the dairy industry).

The falling film evaporation system commonly used in the dairy industry consists of several stages, which are all identical as regards their design and operation. The liquid is introduced at the top. It then passes through a baffle plate which ensures that the liquid does not fall straight down through the downpipe to the bottom, but that it flows in the form of a film down the walls of the downpipe. The proper functioning of the installation and its efficiency (usually expressed as kg steam per kg water extracted, between 0.1 and 0.2 for most evaporation installations) depends to a very large extent on the proper division of the liquid and thus on the size of the apertures and the position of the baffle plate. While it is in the downpipes, water is evaporated from the liquid. The liquid is heated by vapour which condenses on the outside of the pipes. Below each stage the concentrate is separated from the product vapour in the vapour separator. The concentrate is then pumped to the following stage. The product vapour from the separator is conveyed to the vapour space of the following stage and there condenses on the downpipes. In this way, the heat applied at the previous stage is recovered. The vapour from the last stage is condensed in a condenser.

In the case of combined flow multi-stage evaporation – as is usual in the dairy industry – the pressure and consequently the evaporation temperature of the entire installation declines, so that there is always driving force available for the vapour flow. The energy consumption of an evaporation installation is roughly speaking in inverse ratio to the number of stages.

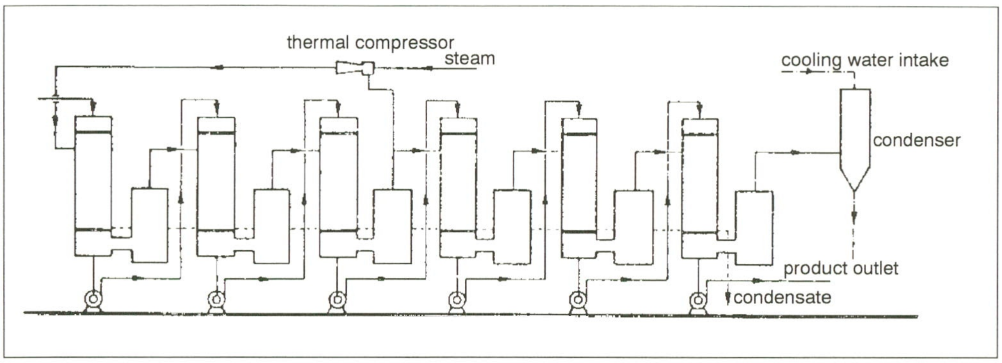

Figure 4.1 Six-stage combined flow evaporation with thermal vapour recompression

Compression of the product vapour produced is one way of reducing steam consumption in an evaporation installation. Because of the low investment costs, thermal compression is widely used in The Netherlands dairy industry. Using high pressure steam (8 - 16 bar), the thermal compressor or steam ejector compresses part of the low pressure vapour (usually obtained from stage 3 or 4 in the common used six-stage evaporator).

The figure below shows a single-stage evaporator in which mechanical vapour recompression is applied. In this installation, all the heat is recovered by compressing the product vapour and returning it to the vapour space of the stage. The evaporation of milk and whey gives rise to low temperatures and pressures, so that the streams of vapour are very voluminous. For this reason, fans, are used to maintain a relatively high pressure ratio e.g. Roots blowers. The main advantage of these blowers is their low purchase price since they are mass-produced. One commonly applied pressure ratio is 1.25 which for the temperature range found in evaporators amounts to a temperature increase of 5 K. This is why compressors of this kind can be used for only one stage.

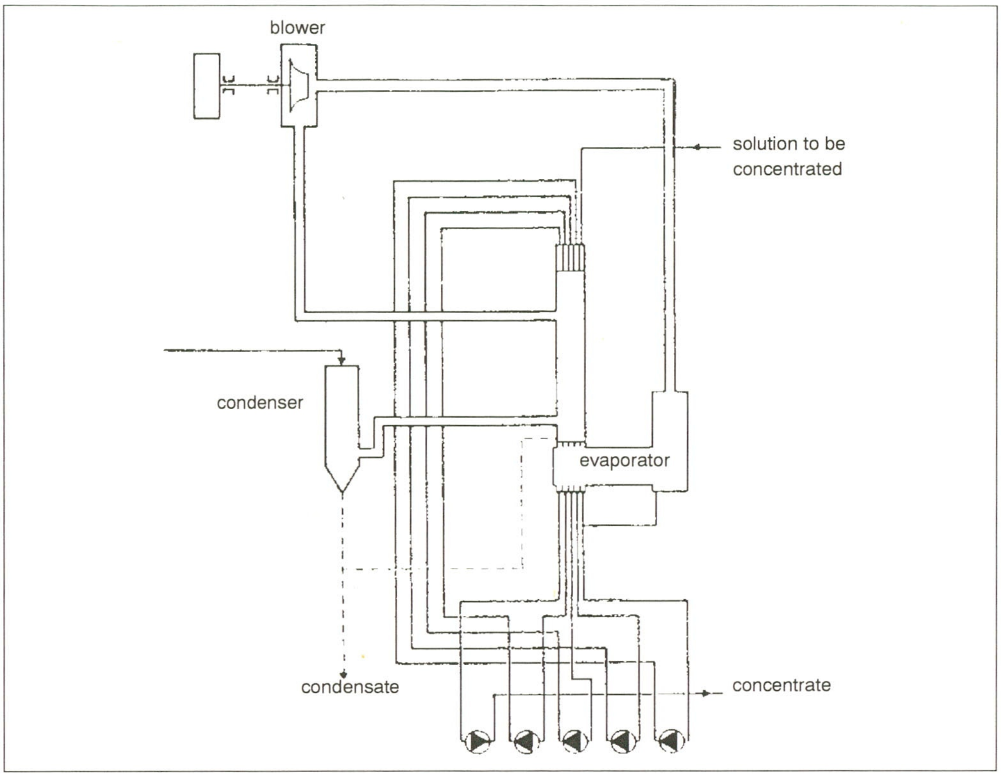

Figure 4.2 Single-stage multi-pass evaporator with mechanical recompression

In order to obtain a sufficiently concentrated product, the stage is subdivided into sections through which the product passes in succession. Since it is necessary to achieve a large rise in the boiling point, a normal one or two-stage evaporation installation with thermocompression is installed downstream.

Stork Friesland [E6] has made a number of calculations comparing various types of evaporator which have to achieve the same evaporation result. The table below compares different evaporator variants (single-stage MVR, six-stage MVR with TVR, single-stage MVR with two following stages with TVR) for various concentration ratios and intake capacities.

Table 4.2 Comparison of various evaporation systems

	MVR	TVR	MVR + 2 TVR	TVR
Evaporation route [% dry matter]	5.5-28	5.5-28	5.5-50	5.5-50
Water evaporation kg/h	40,179	40,179	44,500	44,500
Steam consumption kg/h	550	3,777	1,480	4,265
Electric power:				
– pumps (kW)	45	69	71	76
– blower (kW)	503	-	501	-
Primary energy consumption m^3 gas/h	225	325	307	360
Investment %	146	161	175	173
Energy costs fl/h	76.86	72.08	96.89	81.16
Energy costs fl/ton water	1.91	1.79	2.17	1.82
Evaporators with intake capacity of 50 ton/h				

	MVR	TVR	MVR + 2 TVR	TVR
Evaporation route [% dry matter]	5.5-28	5.5-28	5.5-50	5.5-50
Water evaporation kg/h	24,107	24,107	26,700	26,700
Steam consumption kg/h	330	2,400	893	2,690
Electric power:				
– pumps (kW)	32	46	42	50
– blower (kW)	302	-	307	-
Primary energy consumption m^3 gas/h	137	207	187	232
Investment %	100	122	128	131
Energy costs NLG/h	45.65	46.06	56.96	51.44
Energy costs NLG/ton water	1.89	1.91	2.13	1.92
Evaporators with intake capacity of 30 ton/h				

It is noticeable that MVR for the low concentration ratio represents both a lower investment cost and a lower primary energy consumption. This primary energy consumption of MVR systems declines still further if combined heat and power (cogeneration) is used. The difference in primary energy consumption between evaporators with MVR and 2 TVR and evaporators with TVR is less marked.

The costs of an evaporation installation are made up of investment, energy, drainage and product losses, maintenance and cleaning costs. The cost of steam-raising equipment is not included. This means that MVR is considerably more advantageous when a new system is being installed, particularly if the electricity required for the compressor is generated by combined heat and power. The installation should preferably be large enough for gas turbines to be used for generating the electricity. The flue gases from the turbine can then be used to heat the drying air in the spray tower, which is at a relatively high temperature (about 200 - 220 °C).

4.1.2.2 Drying of milk and whey powder

In The Netherlands, about 600 10^6 kg of water is extracted from the drying of milk and whey powder. This is done almost without exception in spray dryers. The total energy consumption amounts to 105 . 10^6 nm^3 natural gas/year and 80 . 10^6 kWh/year. The specific energy consumption per kg of water extracted amounts to 0.17 nm^3 natural gas and 0.13 kWh. The specific energy consumption is therefore many times higher (about 10 times) than for evaporation. The figure below shows the configuration of a spray dryer.

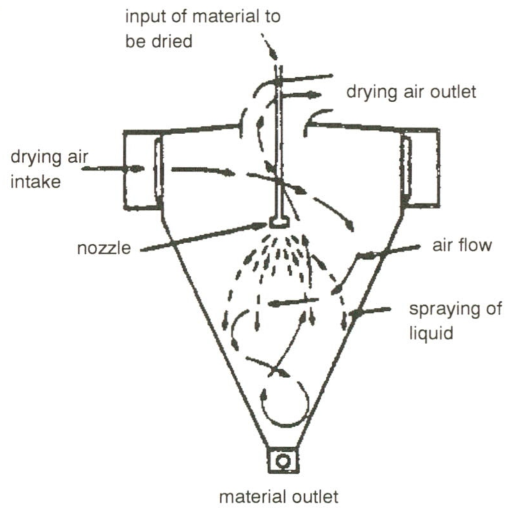

Figure 4.3 Spray dryer

The fresh drying air is at a temperature of about 210 - 220 °C, while the extracted drying air is at a temperature of about 90 °C with a moisture content of 50 g/kg (dew point 38 °C). Large savings can be achieved if heat is recovered from the exhaust air to pre-heat the drying air [E4].

4.1.3 Applications for heat pumps in the reference processes

The application of in-unit heat pumps in evaporation processes has already been discussed in 4.1.2. The drop in temperature of the drying air in spray dryers is so great that application of heat pumps is not attractive for thermodynamic reasons.

Altering the drying process could perhaps reduce this drop in temperature, but measures of this kind do not come within the scope of the present project. The spray drying process is however of interest for inter-unit heat pumps.
Moreover, at the present time considerable quantities of groundwater [A12] are used for cooling purposes in the dairy industry (about 31 million m^3/year). Groundwater levies make it necessary to look for alternatives. It is possible that it will be possible in this case to employ compression cooling machines and make effective use of the heat from the condenser. The temperature of the exhaust heat flows would appear to be too low in the dairy industry to drive absorption cooling machines [E5].

4.1.4 Process integration in the dairy industry

The grand composite curve of a dairy plant [E5] indicates that the pinch temperature lies 'within' the temperature range for the evaporation process, 'within' the temperature range for the drying process and 'within' the temperature range for the pasteurisation/sterilisation process. The cooling process lies entirely below the pinch [E5].
The application of mechanical vapour recompression to the evaporator reduces both the heating and the cooling requirements of the plant. The large quantity of heat released in the (latent) drying air flow and mechanical cooling to a temperature of about 30 - 40 °C can be pumped up by means of closed heat pumps to a level above the pinch, for example for use in pasteurisers. Moreover, the production of steam in a dairy plant can be virtually eliminated if a combined heat-power installation with a gas turbine is installed: the flue gases from the gas turbine can be used to generate drying air, while the electricity generated can also be used to drive the compressor in the evaporation installation. There is still a certain amount of fresh steam needed for the evaporator, possibly generated by means of a small exhaust gas boiler. There is also a possible requirement for hot water which cannot be met at all times by the existing heat pumps. A hot-water boiler has to be installed for this purpose.
The exergy balance for this option shows that the greatest reduction in exergy losses is due to the lack of natural gas → steam conversion and natural gas → dry air conversion [E5].

4.1.5 Potential for heat pumps in the dairy industry

MVR in evaporators

As Jansen has shown [E4], there is a reasonable potential for heat pumps in The Netherlands dairy industry. In view of the location of the pinch, the only possibility is for power-driven heat pumps. The ratio of power demand/heat demand changes to such an extent that it is perfectly possible to extract heat for drying air from the flue gases of a gas turbine.

In The Netherlands there are at the present time about 60 evaporators with a total intake capacity of 7000 10^6 kg/year. About 60 vapour recompression systems with a total electric capacity of about 30 MW can be installed. The payback times are of the order of 1 to 2 years. At present, there are only three MVR installations in the dairy industry.

Heat recovery from exhaust drying air

Exhaust drying air contains heat which can be used in part directly and in part via heat pumps for pasteurisation/sterilisation.
The latent Heat of the exhaust drying air can be raised to about 80 °C) by means of closed heat pumps. This heat can be used for pasteurisation and sterilisation and cleaning. The potential is estimated at about 20 MW (mechanical). The small number of hours of operation of the system, however, makes the payback time unacceptably long, ten years or more.

Using the condenser heat from cooling machines

In [E4] it is shown that the heat from cooling machines can be pumped up to a desired temperature level for pasteurisation/heat treatment. There is a potential of about 15 MW (mechanical) heat pump capacity in the dairy industry for making use of this heat from cooling machines. Here too however the payback time is very long, around 15 years [E4]. This is due to the large temperature lift and the fact that the number of hours of operation of the cooling installations is limited (about 1000 - 1500 hours/year).
If groundwater cooling has to be replaced by cooling derived from cooling machines, then it is worthwhile designing these cooling machines as heat pumps - i.e. usefully employing the condenser heat at a higher temperature. On the basis of a useful heat take-up of 10 MJ/m^3, a total groundwater consumption of 31 million m^3 per year and an operating time of 4500 hours per year, this represents a cooling capacity of 19 MW. At locations where groundwater is much used for cooling and there is a demand for heat at 60 - 90 °C, there is a potential for (two-stage) heat pumps.

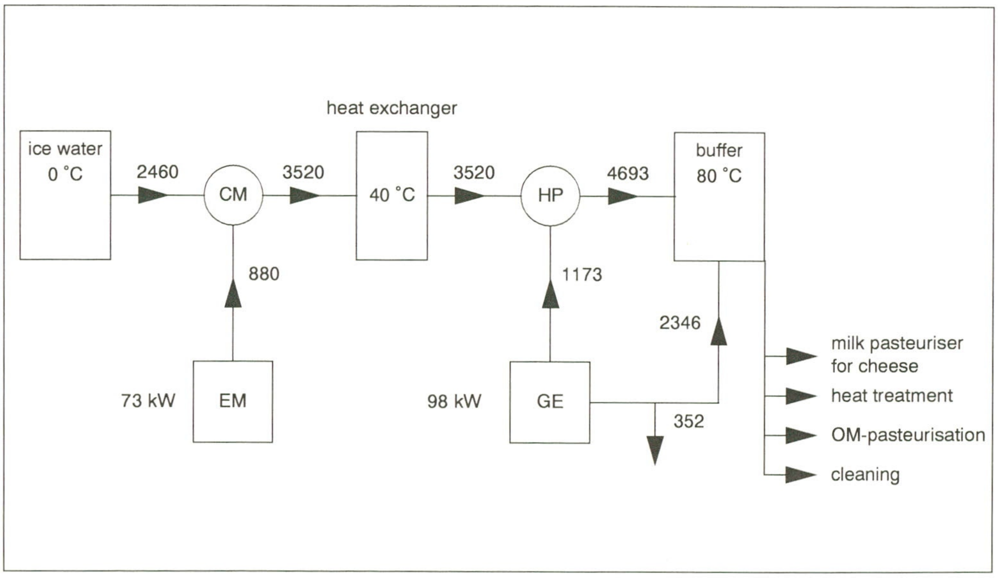

Figure 4.4 A heat pump and a cooling machine in cascade (heat quantities in kWh/day)

The above potential for mechanically driven heat pumps will have a considerable effect on the heat/power demand of dairy plants, leading to a demand for more power and less heat. The application of combined heat and power will consequently become (more) attractive because:

a. the useful input of heat from the heat-power system remains guaranteed (current heat: power ratio = 10 : 1 in the dairy industry as a whole [E4]), and
b. there is less and less need to purchase electricity.

Table 4.3 Potential for heat pumps in the dairy industry

	Number	Total P-condensor [MW]	Total P-drive [MW]
Inter-unit MVR evaporators	60	400 - 500	30
Inter-unit Closed HP (Heat source: exhaust drying air →) (Heat source: product cooling →)	40	60	20

4.2 Sugar and Starch industry

4.2.1 General

Number of concerns established in The Netherlands: 1.

Reference processes:
- Evaporation of clear juice (sugar)
- Crystallisation to form sugar
- Evaporation of starch

Table 4.4 Specific energy consumption of sugar and starch

	Production ton $*$ 10^3/jr	E-consumption MJ/ton	
		Q [fuel]	E [electricity]
Beet sugar	900	8,195	660
Potato starch	500	5,190	1,525
Maize starch	450	1,790	810
Wheat starch	200	2,350	950

Beet sugar

There are in The Netherlands six plants where beet sugar is produced. These plants belong to two concerns (Suikerunie and CSM). In 1988 6.7 million tons of beet were processed in The Netherlands, yielding 0.99 million tons of white sugar. The total processing capacity amounts to 3000 tons an hour overall, which with continuous operation represents a season of about three months. The season runs from September to December. The processing capacity of the plants ranges from 250 to 550 tons of beet per hour. The sugar industry is highly energy-intensive.

Starch

The Netherlands starch-producing industry numbers eight plants. A distinction can be made between the potato starch plants (four, all AVEBE), three maize starch plants, and one wheat starch plant. Maize and wheat are mostly imported (USA), while potatoes are usually supplied by contract growers (mainly around Groningen). A large proportion of the starch produced is further processed into derivatives. The potato starch industry is the most energy-intensive sector (see table). Just like the sugar industry, it is seasonal, and therefore only produces starch immediately after harvest time.

4.2.2 Description of reference processes

4.2.2.1 Evaporation of clear juice

The main production process for sugar is made up six stages in all. We shall focus here on the reference process: evaporation of clear juice. In addition to the main production process there are a number of auxiliary processes, such as pulp drying, carbonation, pulp drying and waste water treatment.

Juice extraction and purification

The beets are cut up and the majority of the sugar is then extracted by hot water. By compressing the cut-up pieces, still more sugar is extracted. The remaining material, in the form of pulp, is removed and used mainly for cattle feed.

Juice concentration and crystallisation

The separation of the sugar from the clear juice is carried out in two stages. First the juice is concentrated by evaporation so that it just fails to crystallise. This is done in multi-stage evaporators which are driven by steam obtained from the combined heat and power installations usually employed in the sugar industry.

Energy consumption of the evaporation process

In the sugar industry, combined-flow evaporators are the only kind used. The evaporators consist of four or five stages. The consumption of steam per kg water extracted amounts to about 0.4 to 0.45 kg steam per kg extracted water. The absolute pressure of the steam falls from 3.5 - 4 bar to about 0.6 - 0.7 bar. The clear juice is thickened by the addition of about 15% dry matter until it reaches about 70% dry matter (syrup).
In The Netherlands sugar industry, no mechanical vapour recompression systems are used, nor even any thermal vapour recompression systems. The specific energy consumption of evaporation is relatively high (0.4 to 0.45 kg/kg). The final condensate (about 90 °C) is used to supply the heat demand for various purposes in the plants.

4.2.2.2 Crystallisation to form sugar

The syrup obtained as described above is then further evaporated and crystallised. This is usually carried out by boiling. This boiling process is done batchwise and is usually carried out in three stages. The basic process for one stage is as follows:

- The syrup is thickened in the boiling pan until it is supersaturated, after which small sugar crystals are produced by the addition of powdered sugar.
- The pan is topped up with syrup and the boiling process continues. The end product is known as the 'massecuite'.
- The massecuite is centrifuged, separating out the sugar crystals. The massecuite from the second and third stages (three-stage configuration) is passed through a cooling crystalliser before being centrifuged.

The first stage produces the end product. The second and third stage process the discharged material from the preceding stage. The sugar from these stages is dissolved in syrup and recirculated to the first stage. The material discharged from the third stage is removed as molasses (Baloh [E8], pages 80-90).

Crystallisation is a complex process from the heat technology point of view, because on the one hand heat is absorbed by the evaporation process and on the other hand, heat is generated, the crystallisation heat. The dry matter content of the syrup ranges from 68% to 91% before centrifuging. After centrifuging, the dry matter content is 99%. The consumption of steam is about 0.9 kg steam per kg water evaporated. Baloh's diagram below (Figure 4.5) illustrates the exergy balance of crystallisation. The crystallisation process uses steam at about 1.2 bar. The product vapour is condensed at about 0.2 to 0.3 bar. The boiling pan is over the pinch. In The Netherlands, there is no vapour recompression, although there is in Switzerland (Zuckerfabrik Aarberg [E9], [E10].

4.2.2.3 Evaporation of potato starch

After cleaning, the potatoes are ground down in a number of stages, resulting in a mixture of starch, liquor (about 80% of the weight of the potatoes) and fibres. The starch is usually extracted from this mixture by means of hydrocyclones.

The separation of the mixture of starch, fibres and liquor in stages, through a number of hydrocyclones, gives rise to an extraction process, during which the heavier starch separates out from the lighter liquor and potato residue. The liquor on top of the potato residue is then removed by decanting.
The resulting waste water is partly returned to the extractor as process water, and partly evaporated to produce a thick syrup (protamylase, cattle feed). AVEBE has three evaporators which extract about 200 tons of water per hour. Two of these evaporators are 9-stage combined-flow evaporators, which use 8 to 9 tons per hour of 10 bar steam [E13]. One of the evaporators is a three-stage system with MVR for the first stage. Here too, the capacity is about 200 tons of water extracted per hour [E14].

In 1986, Cerestar of Sas van Gent installed a vapour recompressor of 1.34 MWe on a two-stage counter-current starch evaporator. The mass flow over the compressor is 35.7 tons/hour [E13]. The heat factor is 16.2 (according to Carnot: 29.7). The compressor is connected to both stages. Part of the compressed vapour is further compressed by an ejector for the purposes of a pressure releasing evaporator further downstream, in which the final desired dry matter content is achieved.

4.2.3 Applications for heat pumps in the reference processes

In all the processes described, vapour recompression can be used as an in-unit application, but it is only worthwhile if this vapour compression occurs ‘over the pinch’. Here too, vapour recompression is the heat pump application with the shortest payback period. In addition, it may be possible to recover latent heat from dryers, in particular starch dryers, by means of closed heat pumps, and use it for hot water heating (inter-unit application).

4.2.4 Process integration in the sugar/starch industry

Baloh [E8] indicates that the consumption of fuel in a traditional sugar plant can be greatly reduced, provided that considerable investments can be contemplated. He demonstrates that by applying vapour recompression in the clear juice evaporator and the crystalliser, and using a gas turbine, the ‘water turnover’ via steam can be reduced by a factor of ten. In view of the size of the investments, this solution is probably only attractive for new sugar beet factories. The following investments are the minimum required:

- Vapour recompressors over the evaporator and crystalliser, the latter with a high pressure ratio (1 : 3). At the Aarberg sugar refinery, this was done years ago (1946), because cheap hydro-electric power was available.
- An evaporator with a low pressure ratio, i.e. a relatively large heating surface.
- A gas turbine with an auxiliary steam boiler.

According to Baloh [E8], the primary energy consumption of his reference process can be reduced by over half by the application of the above measures. The diagrams below show the changes in the exergy balance. This solution is perhaps also of interest to the starch industry.

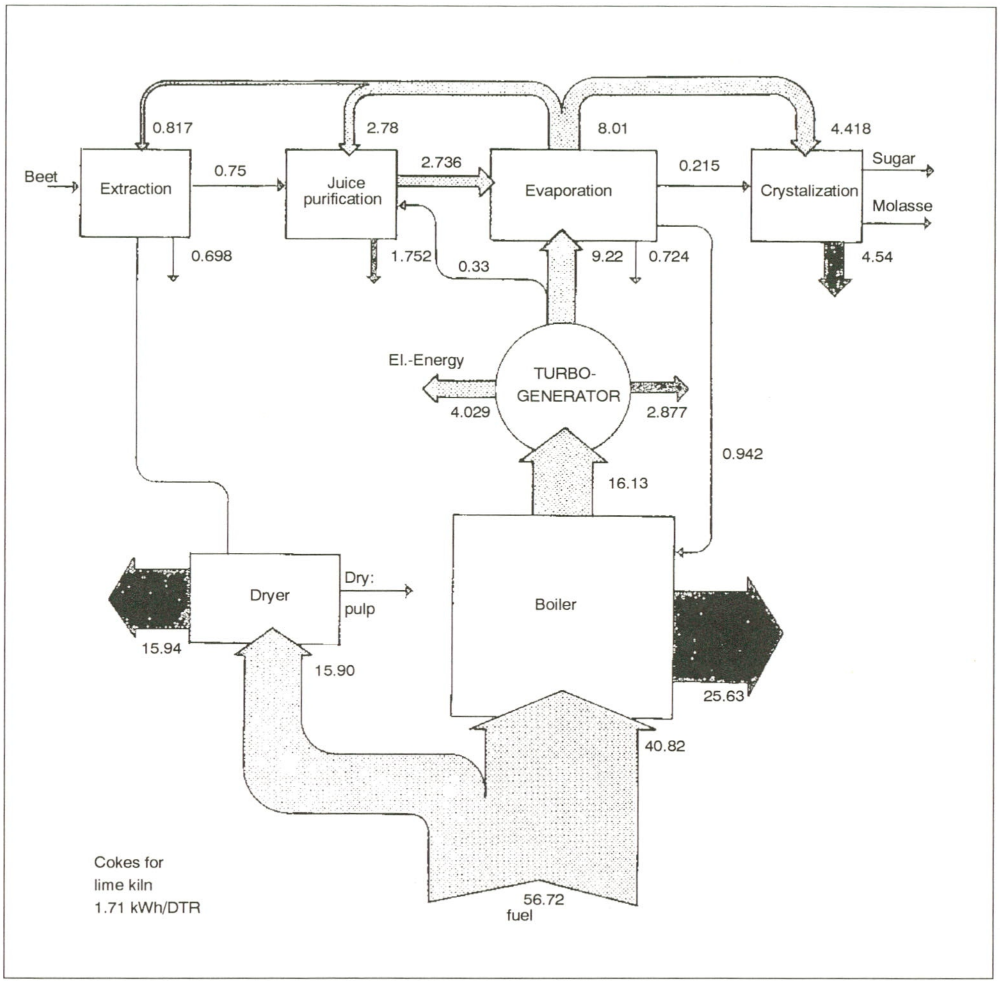

Figure 4.5 Exergy balance of conventional sugar refinery (kWh/DTR)

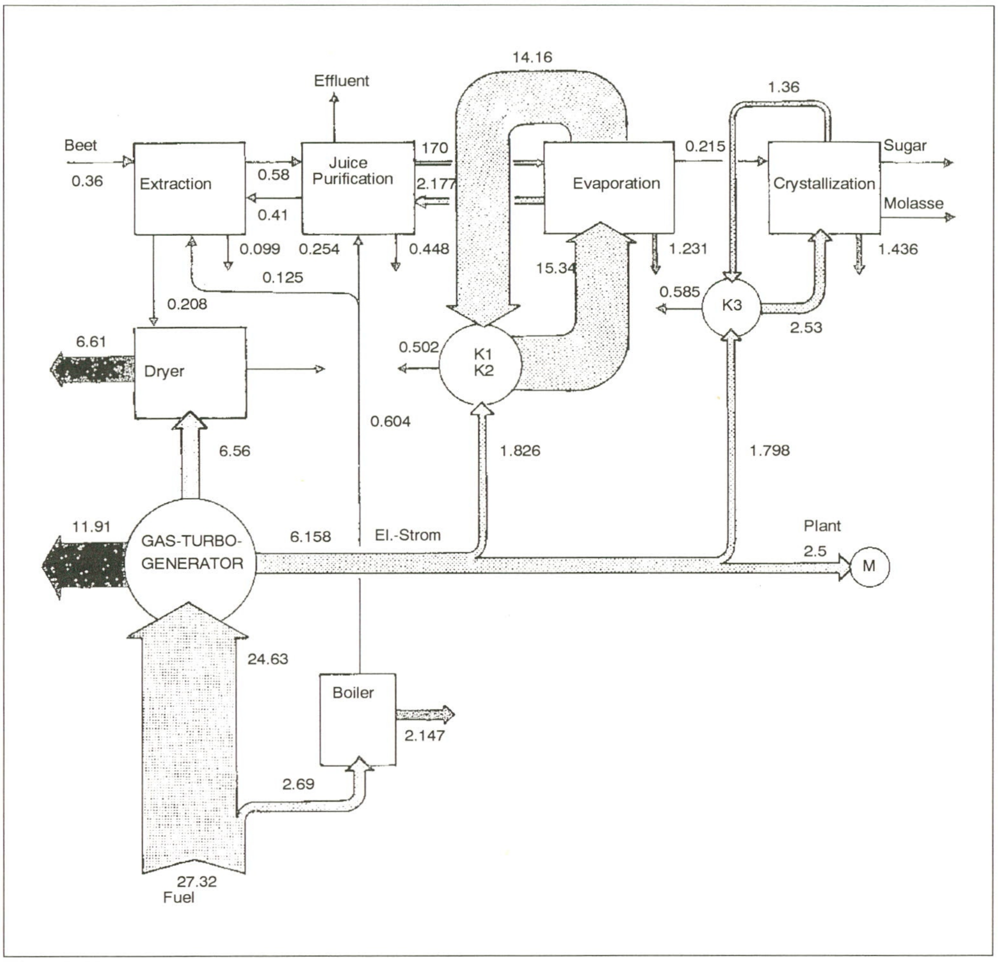

Figure 4.6 Exergy balance of optimised sugar reginery (kWh/DTR)

4.2.5 Heat pump potential in the sugar/starch industry

MVR in evaporators and crystallisers

If all sugar plants in The Netherlands were to operate on the Baloh principle, there would be an MVR potential of about 40 MWe. In the starch industry the potential for MVR is about 8 MWe.

Heat recovery from exhaust drying air

There is possibly potential for closed inter-unit heat pumps which can make use of the latent heat from drying installations. In many cases, however, the process pinch is so high in comparison with the dew point that it is probably not an attractive proposition. However, if the temperature difference between dew point and pinch is small [E7], this is not so. At this stage, it is not possible to arrive at any potential for closed heat pumps in this sector.

Table 4.5 Heat pump potential in the sugar/starch industry

	P condensor [MW]		P drive [MWe]	
	Sugar	Starch	Sugar	Starch
MVR	500	200	40	8
Closed HP	-	-	-	-
Number of MVR	8	4		
Number of closed HP	-	-	-	-

4.3 Beer and Malt industry

4.3.1 General

Number of concerns established in The Netherlands: 17.

Reference process: - Boiling (evaporating) of wort.

Table 4.6 Specific energy consumption beer and malt

	Production 10^3 ton/jr	E-consumption MJ/ton	
		Q [fuel]	E [electricity]
Beer	2,000	1,301	358
Malt	172	2,750	432

4.3.2 Description of the reference process

In the brewing of beer, a solution containing sugar among other things, which is known as the wort, is boiled in a copper. During this process, the water content is reduced by about 10%. In the classic process, steam is fed into the jacket round the copper. The condensed steam gives off heat and the wort evaporates, with the resultant water vapour being vented off to the atmosphere.

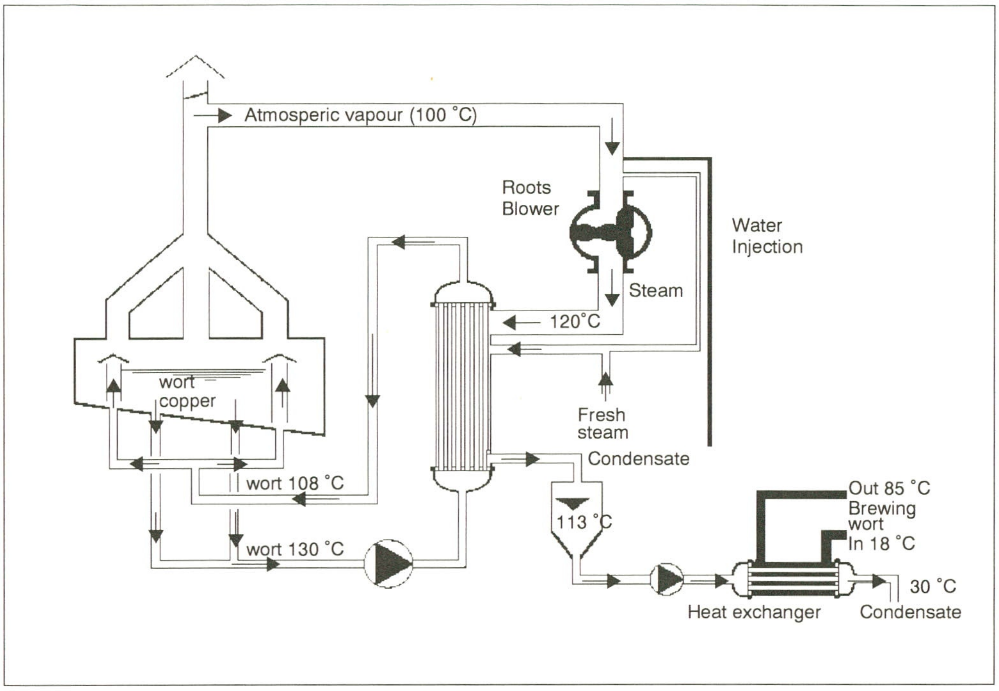

Figure 4.7 Diagram of the wort boiling process

At breweries abroad, but also at one brewery in The Netherlands, vapour recompression is used to reduce the energy consumption of the wort boiling process. If the resultant vapour is recompressed to a higher pressure (and thus a higher temperature), heat can be recovered by allowing the resultant vapour at above atmospheric pressure to condense in a heat exchanger in which the 'fresh' wort is heated. Because coppers are not pressurised, the intake side of the compressor receives additional steam.

4.3.3 Applications of heat pumps in the reference process

See above.

4.3.4 Process integration in the beer and malt sector

A brewery in The Netherlands recently carried out a pinch study. However, this pinch study has not been made available to IMET-TNO. For this reason, we looked for and found a foreign brewery pinch study. The brewery of Tetley Walker Ltd. in Warrington was provided with information by Linnhoff March [E17]. The following figure gives the grand composite curve for this process. It was found that the primary energy consumption could be considerably reduced by heat exchange. It was also shown that wort boiling takes place far above the pinch and is therefore not of interest. In addition to heat exchange (mainly above the pinch, which in this process is at 17.5 °C) combined heat and power and decentralised heat generation are considered to be worthwhile options.

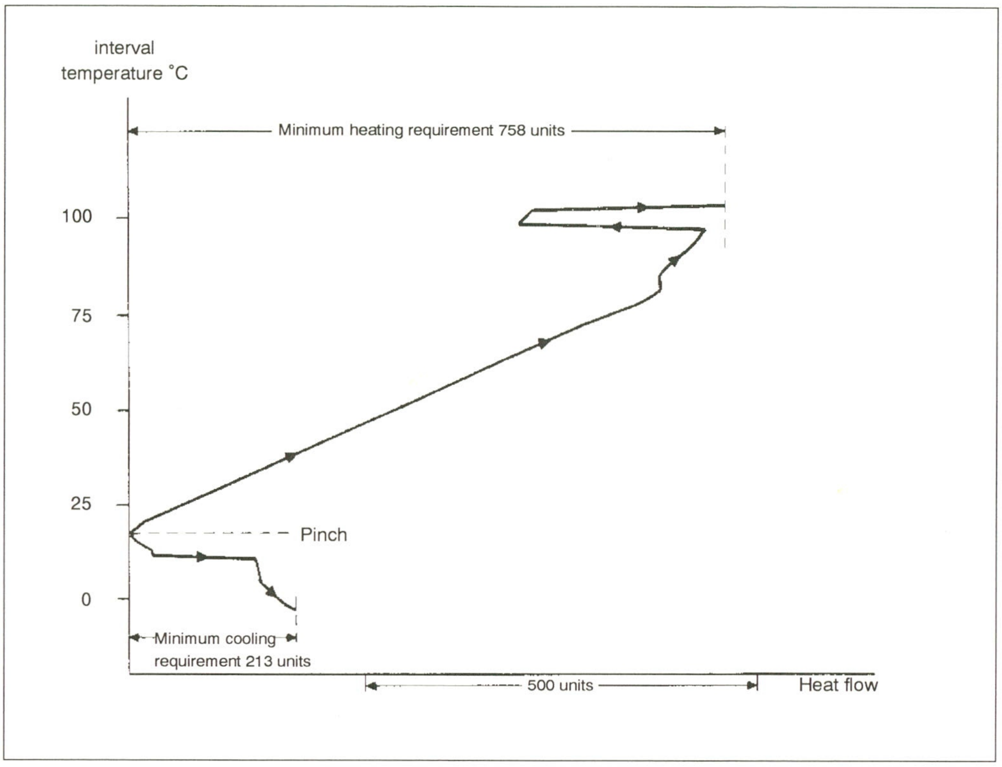

Figure 4.8 Grand composite curve Tetley Walker Ltd. brewery

4.3.5 Heat pump potential in the beer and malt sector

It is not known whether the wort boiling process in Netherlands breweries also lies entirely above the pinch. If this is so, the opportunities for vapour recompression are nil. On the other hand, it is hard to imagine that the important stage of transition from water to vapour is so far away from the pinch. The question is to what extent the grand composite curve of [E17] results from the process being batchwise. It will be claimed that almost all the raw materials intake can be heated by means of the outgoing product flow. At the present time there is in the brewery sector one wort copper equipped with mechanical vapour recompression. In the recent past, Heineken Nederland [E18] had a 50 kW vapour recompressor. However, this has been decommissioned, together with its copper.
The brewery sector uses groundwater for cooling, about 6.5 million m^3 per year. If this cooling is to be (partially) replaced by cooling machines, they can perhaps be designed from the outset as heat pumps, i.e. making efficient use of the heat from the condenser. This represents a potential of about 4 MWth for closed heat pumps. The sales potential will however have to be critically studied.

Table 4.7 Heat pump potential in the beer and malt sector

	Number	P condenser [kW]	P drive [kW]
MVR wort coppers	6	6,000	300
Closed HP	6	4,000	1,000

4.4 Edible oils and fats industry

4.4.1 General

Number of plants in The Netherlands: 14.

Reference processes:
- Pressing oil from soya beans - hexane extraction;
- Extraction of animal fats

Table 4.8 Specific energy consumption in the oils and fats industry

		Production ton/jr	E-consumption MJ/ton [fuel + electricity]
Products:	Raw olie soya oil	518,000	766
	soya meal	2275,000	902
	animal fats	200,000	3,830

4.4.1.1 Producers and products

In The Netherlands, the products that are made in the edible oils and fats industry can be divided into four groups: margarine, oils, fats and sauces. These products are made at about thirty production plants. The table below gives an overview of the products, made by the various manufacturers.

Table 4.9 Producers in the edible oils and fats industry

Producer	**Product**			
	Margarine	**Oil**	**Fat**	**Sauces**
ADM		X		
V.d. Bergh & Jurgens	X			
Bosland			X	
Brinkers	X			
Cargill		X		
Conimex				X
v. Dijk Food Products	X			X
Loders Croklaan (Unilever)		X		
Remia	X			X
Romi	X			
Smilde			X	
Ten Kate			X	
Topvet			X	
Unimills (Unilever)		X		
Waterlander			X	

Total capacity for the whole sector was 4235 thousand tons. In the report mentioned above, another division into products was made, so it is not possible to give more detailed figures.

4.4.1.2 Process description

Up till now no detailed process data are available at TNO-ME. Via Novem B.V. an effort was made to get the results of process integration studies, performed in this sector. Novem is willing to help, but could not yet succeed to get permission to pass on the results to TNO. The process data described in this chapter are based on schemes and figures from a handbook [E16]. Additional information was supplied by TNO Voeding.
Section 4.4.1.1 through 4.4.1.5 describe the seed-oil milling process, resulting in crude oil. The section 4.4.16 describe the refining of crude oil.

The oil can be processed in the following ways:

fat : hardening
margarine : making emulsions
oil : crushing, fractionating, refining and hardening
sauces : making emulsions

The raw materials that are used in The Netherlands most frequently are soya beans and sunflower seeds.

The following processes in the oil production can be distinguished:

- *Cleaning of beans and seeds*
- *Size reduction*
- *Extraction of oil from the beans and seeds*
- *Refining*

The oil can be used for the production of margarines and sauces.
This requires the following actions:

- *Crystallization*
- *Cooling*
- *Making emulsions*

Figure 4.9 shows the process tree for oil.
A more detailed description is given in the following sections. Since detailed data are not available, the description is rather qualitative.

4.4.1.3 Cleaning and drying of beans and seeds

First the stones and lumps are removed from the seeds and beans by means of sieves, sifters and aspirators. Subsequently, the seeds are dried with steam of 2 to 3 bar. Next, in case of sunflower seeds, the seeds are decorticated. If soya beans are used, their front ends are dehulled. Figure 4.9 shows schematically the cleaning process. The energy needs of these sub-processes are included.

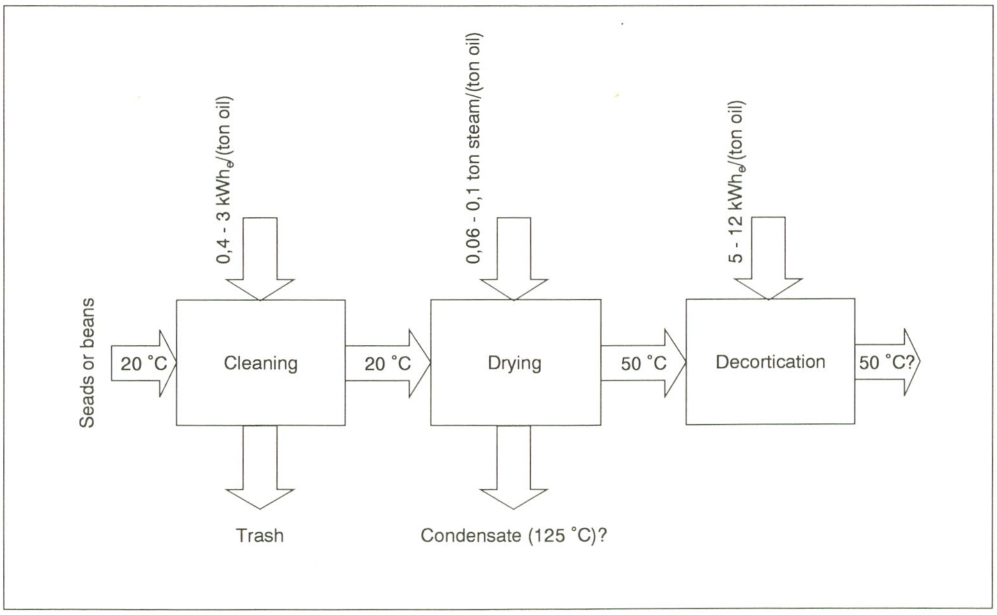

Figure 4.9 Process tree for oil production

4.4.1.4 Size reduction and primary fat separation

Figure 4.10 shows the process tree of size reduction.
Next to the cleaning process the beans are being crushed. The crushing is followed by cooking and conditioning with the help of 3 bar steam. Then the beans, or what is left of them, are being pre-pressed. This process takes place in an expeller. Some crude oil is pressed out of the seeds in this way. One part of the cake, which is formed by pre-pressing is broken and the pieces are fed into a batch extractor. The other part is pressed again.

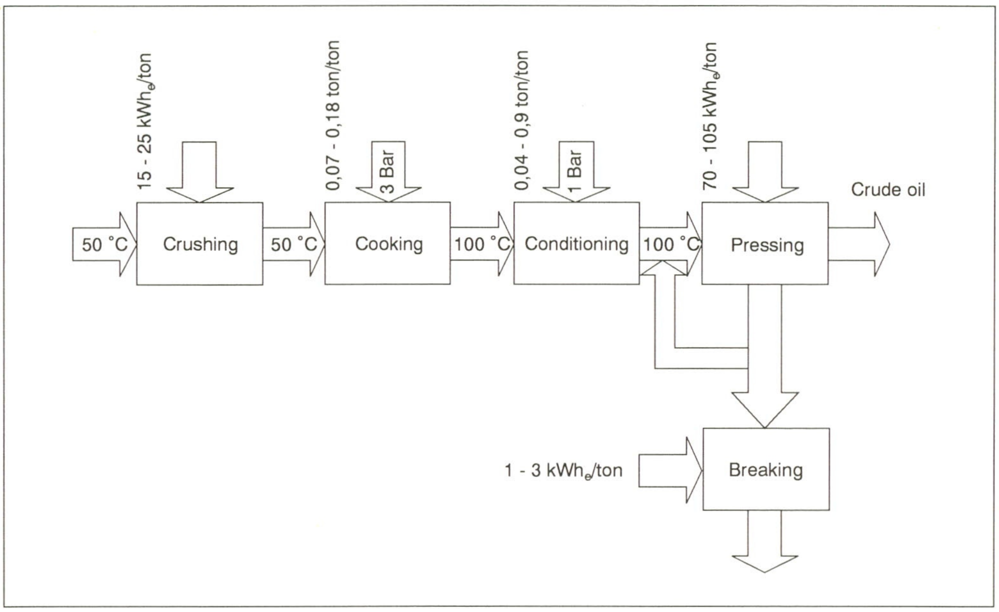

Figure 4.10 Process tree for size reduction

4.4.1.5 Extraction

By means of hexane crude oil is extracted from beans and seeds. Before extraction can take place, the hexane has to be preheated. The extraction process provides two products: meal and a mixture of crude oil and hexane. The meal is ground, dried and, if necessary, cooled. The mixture has to be distilled in order to separate the solvent (hexane) and the crude oil. Subsequently the crude oil is degummed.

4.4.1.6 Refining

The product of the seed-oil milling process is crude degummed oil. In that way it is not yet suited for consumption, so the next step in the production process is refining of the crude oil. There are two possibilities: physical and caustic refining. The first is for crude oil that already is rather pure. Caustic refining is applied when the crude oil contains more impurities.

Physical refining consists of the following sub-processes (see figure 4.12). First the crude oil is mixed with concentrated phosphoric acid. The temperature at which mixing takes place is 70 °C to 90 °C. The next step is bleaching with bleaching earth at 90 to 120 °C. Finally the oil is deodorized by means of high pressure steam (temperature 240 to 270 °C).

Caustic refining is more complex than physical refining. Some extra process-steps are included. The crude degummed oil is neutralized with caustic at a temperature of about 70 to 90 °C. Just as with physical refining, the mixture is then bleached and finally deodorized.

In [E16] an indication is given of the energy that is required to produce oil and margarine. The steam has to be supplied on four pressure and temperature levels.

4.4.2 Description of reference processes

4.4.2.1 Pressing of oil from soya beans - Hexane extraction

Oil-bearing vegetable products are mechanically pressed to reduce the oil content to about 15-25%. After this the oil content is further reduced by extraction to about 1%. In the case of the most commonly occurring seeds, hexane is used as the extraction medium in a counter-flow process. The extraction residue is conveyed via a heated screw conveyor, in which some of the hexane present evaporates off, to a ‘toaster’. In this, at a temperature of about 100 °C, the hexane is thoroughly removed by direct and indirect steam heating. The remaining residue can be used as cattle feed. The oil-in-hexane solution is separated into oil and solvent at a number of stages in the process by stripping and evaporation - the hexane vapour extracted from the toaster is used to evaporate hexane from the oil/hexane mixture. Atmospheric evaporators and vacuum film evaporators are used for this purpose. The hexane vapours released are indirectly condensed with water.
The mixture of oil and hexane (the ‘miscella’) contains roughly 75% hexane and 25% oil. A high proportion of the condensation heat of the hexane is now removed by cooling water. It is possible that this heat can be recovered for use in the process.

4.4.2.2 Extraction of animal fats

The raw fat is brought to a temperature of 130 °C by indirect steam heating at a pressure of 10 kPA. The fat is melted and dried by agitation and heating (the water evaporates through the combination of temperature and pressure) and the material breaks down into fat and crackling. These are then separated by screening. The fat is decanted and centrifuged, the solid particles still present in the fat being separated out. The crackling is conveyed to a screw press so that the fat can be pressed out. The crackling is then ground down into meal.
The fat is then usually refined.

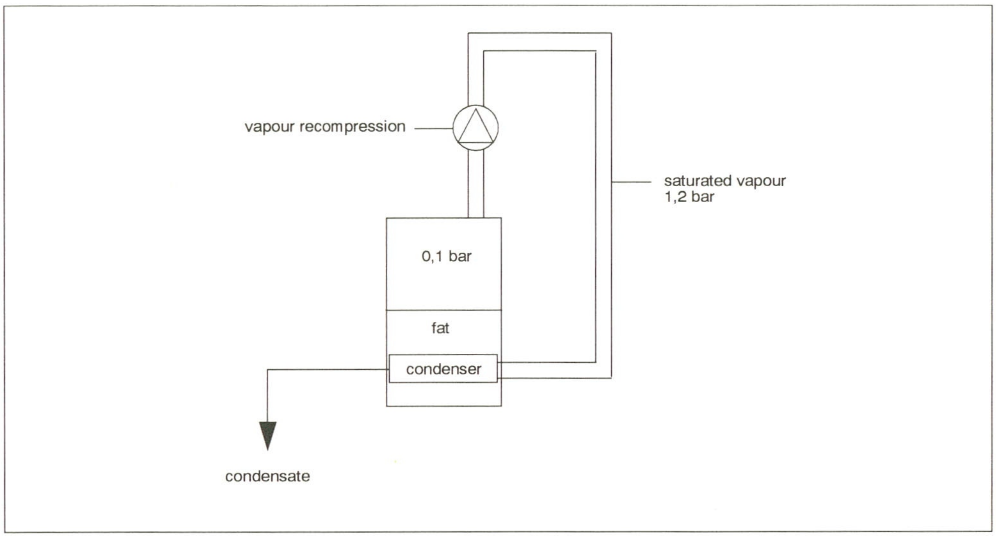

Figure 4.11 Diagram of fat melting/drying

4.4.3 Applications for heat pumps in the reference processes

In the hexane extraction process, hexane vapour can possibly be mechanically recompressed to recover (condensation) heat at a higher temperature. The pinch of the hexane extraction process is about the atmospheric condensation temperature of hexane, so that the recompression takes place above the pinch.

Vapour recompression can also be applied in the melting and drying of animal fat. In fact, a vapour recompressor is already present, in the form of a vacuum pump. On the other hand, there is a heat requirement of about 90 to 100 °C to melt the fat. This heat requirement can be largely covered by the condensing water vapour (Figure 4.11).

4.4.4 Process integration in the oils and fats industry

Linnhoff March carried out a pinch study in 1986 for Van den Bergh & Jurgens Ltd. in Bromborough, U.K. [E15]. In this plant the following edible oil and fat processes are carried out:

- Storage above ambient temperature (50 - 70 °C);
- Filtration and neutralisation;
- Catalytic hydrogenation in batch reactors (180 °C);
- Deodorisation by steam stripping (240 - 260 °C);
- Fractional crystallisation of certain undesirable components.

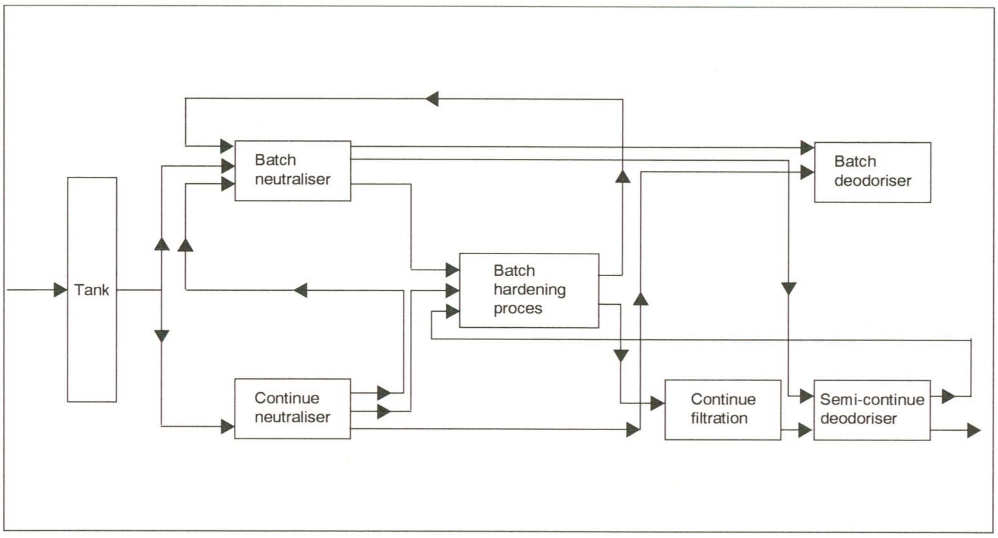

Figure 4.12 Vegetable fats refining process

The (not 'sharp') pinch for this process is about 57.5 °C. The DTmin has been set at 35 °C. By making changes to and extending the heat exchanger network, about £500,000 per year can be saved on energy costs. The estimated investment amounts to about £1,000,000. Heat pumps and combined heat and power are not regarded as options [E14].

4.4.5 Heat pump potential in the oils and fats industry

The heat pump potential for this sector cannot be quantified at this stage. The most important current application of heat pumps is mechanical recompression of methanol vapour, at a plant in The Netherlands. The temperature lift, throughput and pressure ratio of this recompressor are however not known.

There is probably a reasonable potential for heat transformers, because many products are condensed. In Japan in particular, heat transformers are used in the chemical industry and the edible oils and fats industry to generate low pressure steam by means of condensation heat (around 80 - 90 °C). This is of course only of value where there are no surpluses of low pressure steam.

The Linnhoff March study [E15] reveals that after installing an extensive heat exchanger network in order to recover the maximum possible heat internally, there are large surpluses of steam at the plant in question, at a temperature of about 75 °C. On the other hand, there are process flows which are cooled down from a high temperature (250 °C) above the 'near pinch' of 162 °C, in order to heat up process flows from 80 °C to 155 °C. This could also happen (in part) for the abovementioned 75 °C surpluses if a heat transformer was used.

5 Heat pump potential in the paper and card board sector

5.1 General

Number of plants: 32.

Reference process: - Production of paper and card.

The paper and card board sector can be divided into seven sub-sectors, which in 1991 produced 2.8 million tons of paper (Novem 1992). The product breakdown is as follows:

1. Writing and drawing paper (30%)
2. Solid cardboard (25%)
3. Corrugated cardboard (20%)
4. Newsprint (10%)
5. Sanitary tissue (5%)
6. Packaging cardboard (5%)
7. Other (5%)

In The Netherlands the total specific primary energy consumption per ton net saleable product is 11.7 GJ (VNP 1992). The specific energy consumption depends on the product, and varies from 8 GJ (solid cardboard) to 17 GJ (toilet tissue). Subdividing the specific primary energy consumption per net ton saleable product gives the following result:

1. Sanitary tissue (17 GJ/ton);
2. Newsprint (16 GJ/ton);
3. Packaging cardboard (13 GJ/ton);
4. Writing and drawing paper (11 GJ/ton);
5. Corrugated cardboard (8.5 GJ/ton);
6. Solid cardboard (8 GJ/ton).

Generally speaking, paper production makes use of two forms of energy: steam and electricity. In the particular case of the production of toilet tissue, gas is also used as energy source (for the Yankee dryer). The consumption of electricity varies very greatly from one sector to the other, being affected by the scale of production, alternation between products and raw material preparation. As far as the present study is concerned, electricity consumption is of less interest, and attention will be focused on the use of thermal energy (steam and gas). Variations in the use of thermal energy are far less significant than variations in electricity consumption. If conversion losses are left out of account, the thermal energy consumption is as follows:

1. Writing and drawing paper (8.5 GJ/ton);
2. Packaging cardboard (7.5 GJ/ton);
3. Sanitary tissue (7 GJ/ton);
4. Newsprint (6.5 GJ/ton);
5. Corrugated cardboard (6 GJ/ton);
6. Solid cardboard (5.5 GJ/ton).

The proportion of the energy consumption taken up by the drying process is by far the greatest at around 80%.

In the papermaking sector, a number of energy optimization studies have been carried out, with the possible application of heat pumps being considered in the light of 'pinch' studies. The pinch of a process is the temperature level at which the heat demand of the process flows exactly equals the supply of heat. Above the pinch, extra heat must be provided by the utilities, while below the pinch the utilities have to remove surplus heat. It can be seen from the foregoing that when designing production processes, efforts must be made on the one hand to prevent heat above the pinch from being removed by cooling, or on the other hand heat being supplied below the pinch. In this area, heat pumps have a special part to play, since they can always be used to upgrade heat below the pinch, which in principle has to be removed by cooling, to a level above the 'pinch' where there is a net demand for heat.

5.2 Description of reference processes

The heart of a paper mill is the papermaking machine. It consists of the following main sections:

- Flow box.
  The raw material (a dilute suspension of fibres) is spread evenly over the entire width of the machine.
- Screening section.
  This is the section where the sheet is formed and the majority of the water removed.
- Press.
  By pressing the sheet between rolls, part of the water remaining after the screening section is removed.
- Dryer section.
  By means of evaporation carried out by drying cylinders, the moisture content is reduced to the desired final level.
- Calendar.
  Specific surface finishes can be applied to the paper by calendering.
- Pope reel.
  The continuous sheet of paper is wound into reels.

The drying cap

Since the drying process occupies such a prominent position in the energy consumption picture, it is worthwhile considering it in greater detail.

The evaporation of the moisture from the paper sheet is mostly carried out with the aid of drying cylinders, which are internally heated by steam. The heat supplied not only helps to dry the paper but also offsets losses of heat to the atmosphere. If we take a portion of the paper sheet of size dA, the following applies

$$\mathbf{Q_{steam} = Q_{paper} + Q_{loss}}$$

in which Q_{steam} is the energy given off by the steam, Q_{paper} is the useful energy which on the one hand increases the temperature of the paper and on the other evaporates water, and Q_{loss} represents the losses of energy by convection and radiation to the atmosphere.

In the following sections we shall consider separately each of the three values from the above equation.

Q_{steam}

The transfer of heat in the dryer to a section of paper of surface area dA is as follows:

$$Q_{steam} = \int_{t_{in}}^{t_{out}} U_1 (t) \, (T_s - T_p (t)) \, dA \; dt$$

in which U_1 (t) is the total heat transfer coefficient which is a function of time (=position in the dryer); T_s is the steam temperature and T_p (t) the paper temperature in the vicinity of the steam cylinder. T_p (t), like U_1 (t), depends on the position in the dryer.

The total heat transferred depends on the time the paper stays in the dryer, in other words on the length of the dryer and the speed at which the paper sheet moves. A higher production speed can easily be offset by making the dryer proportionately longer.

The heat transferred from the steam increases as the temperature difference between steam and paper increases. Generally speaking, the steam temperature can be compulsorily fixed, whereas the paper temperature depends on a large number of variables.

The heat transferred can also be increased by increasing the total heat transfer coefficient. This a function of a number of heat resistances which are connected in series ($1/\alpha$), as follows:

$$U_1 = \frac{1}{\left(\frac{1}{\alpha_1} + \frac{1}{\alpha_2} + \ldots + \frac{1}{\alpha_n} \right)}$$

The heat resistances in question are those of:
1. the transit zone from the steam to the cylinder;
2. the cylinder wall;
3. the layer of air between the cylinder wall and the paper sheet;
4. any correction terms necessitated by contamination.

Any reduction in one of the heat resistances cited must always be considered in relation to the others. For instance, reducing the heat resistance of the wall is of no use if the total heat transfer coefficient is subordinate to the resistance of the transit zone between steam and cylinder.

Q_{loss}

The heat transferred from the steam is not necessarily usefully employed. Part of it is lost to the atmosphere. The heat losses can be expressed by the following formula:

$$Q_{\text{loss}} = \int_{t=0}^{t=t} U_2(t)\,(T_p(t) - T_a)\,dA\,dt$$

in which U_2 is the total heat transfer coefficient, $T_p(t)$ the paper temperature and T_a the temperature beneath the steam dome.

The heat losses decline as the temperature difference between the paper and the atmosphere declines. Generally speaking, the ambient temperature can be compulsorily set. In order to reduce losses, every effort should be made to raise the temperature under the steam dome to the highest possible level.

To minimise heat losses, it is also possible to endeavour to reduce the heat transfer coefficient. If we assume that the paper is not covered by felt (provisionally), this heat transfer coefficient is made up of a number of heat resistances linked in parallel ($1/\alpha$), hence:

$$U_2 = \left(\frac{1}{\alpha_1} + \frac{1}{\alpha_2} + \dots + \frac{1}{\alpha_n}\right)$$

The heat resistances concerned take account of radiation and convection losses. At normal temperatures under the steam dome, radiation losses are relatively small in comparison with convention losses.

As a general rule, it may be said that efficiency is enhanced by small quantities of flushing air at a relatively high temperature.

Q_{paper}

The useful energy is the energy which contributes to the heating up of the wet paper and evaporation of the water. For a surface of area dA, the formula can be set out as follows:

$$Q_{\text{paper}} = \sum_{i = p,w} [(m \cdot C_p)_i \cdot dA \cdot \Delta T_i] \;+ g \cdot L \cdot dA$$

The first term on the right-hand side represents the warming up of the wet paper sheet; the second term the evaporation. According to the theory of drying, the rate of evaporation (g) is equal to:

$$g = \frac{dm}{dt} = \frac{1}{\beta^{-1} + Z} \cdot (c'_p - c_a)$$

in which β^{-1} is the resistance of the water in the paper as it passes into the atmosphere and Z the diffusion resistance of the water in the paper. The force which drives the water into the atmosphere is represented by the term (c'_p - c_a). This is the difference between the water concentration of the surface of the paper (c'_p) and of the environment (c_a).

To what extent the internal diffusion resistance or the external transition resistance determines the speed of water transport is not as yet known. It is caused among other things because there are reputedly three sorts of water in the wet paper:

- water in the voids between the fibres;
- water absorbed by the fibres;
- bound water [1].

It should be pointed out in this connection that in many industrial drying processes, the diffusion resistance predominates.

If we next consider the driving force behind the transport of water (c'_p - c_a), instead of working (and/or calculating) with concentrations, it is also possible to use partial vapour pressure. The driving force can be maximised by on the one hand increasing the partial vapour pressure at the surface of the paper and on the other hand reducing the ambient vapour pressure.

If the transition resistance $1/\beta$ predominates, the partial vapour pressure in the main air and at the surface of the paper are closely linked. A high moisture content in the drying air results in a high surface temperature for the paper and a corresponding high partial vapour pressure.

If the internal water transport in the paper is decisive for the drying speed, a higher partial vapour pressure beneath the steam dome results in a higher paper temperature. This will facilitate the internal transport of water, with the result that the effect on the evaporation speed is only slight.

On the basis of the foregoing it can be concluded that the drying process benefits from small quantities of flushing air at a relatively high temperature. For practical reasons, however, there are definite limits for the temperature and moisture content of the drying air beneath the drying cap. In that case the only result is flushing with relatively dry and warm air.
Depending on the type of paper and machine, the moisture content (on a wet basis) of the paper sheet entering the drying section lies between 45% and 70%. This corresponds to a quantity of water per kg of dry paper of between 0.8 to 2.3 kg, a reduction in the absolute moisture content of 1% (on a wet basis) equal to a reduction in the relative moisture content of something under 5%. Or, as stated by Van Bergen et al. [F10]: for every percentage point more water on entering the drying section, the steam consumption rises by 5%.

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[1] Bound water constitutes only 1% of the moisture content and is not usually removed

5.3 Potential applications for heat pumps and process integration in the paper and card board sector

In the introduction it has already been stated that a special role is reserved for heat pumps. In any event, they can be used to upgrade heat below the pinch, which in principle has to be removed by cooling, to a level above the 'pinch', where there is a net demand for heat. [1]

Van Dalen [F7] carried out a pinch study at Parenco, Renkum. The study is relevant insofar as it shows that the pinch level is to a very large extent dependent on the boundary conditions specified for the process [2]. Unfortunately the study is not representative of the paper industry in The Netherlands, since Parenco is the only paper producer using wood as a raw material.

Linnhoff March [F1] describe the results of a pinch study of three papermaking machines. The results are summarised in Figures 5.1 and 5.2. Figure 5.1 shows for each temperature level the enthalpy of the heating and cooling process flows ('composite curves'). The pinch lies where the curves meet. The 'grand composite curve' is plotted (Figure 5.2) on the basis of the 'composite curves', showing the net enthalpy surplus for each temperature. The pinch is the point where the net surplus is equivalent to nil.

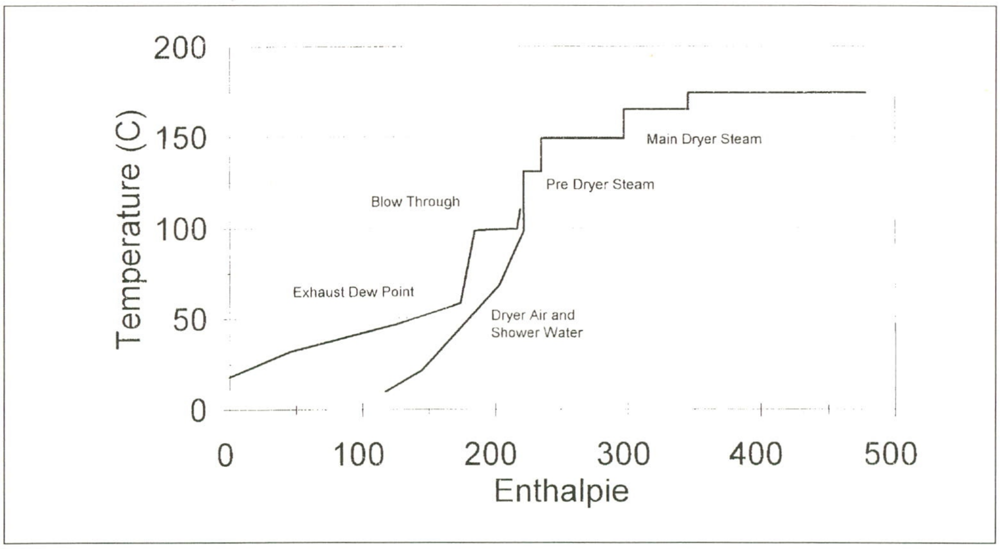

Figure 5.1

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[1] There is no point is using heat pumps between temperatures which are either all entirely below or entirely above the pinch temperature

[2] If it is a requirement that the flow of air from the drying cap should be cooled down to 25 °C, the pinch lies at 77 °C. This corresponds with the temperature at which the water vapour/air mixture becomes available inside the top part of the drying cap. If however it is accepted that the air flow from the drying cap is removed at a temperature of 45 °C, the pinch lies at 25 °C, which is the temperature to which the process water and well water are heated up.

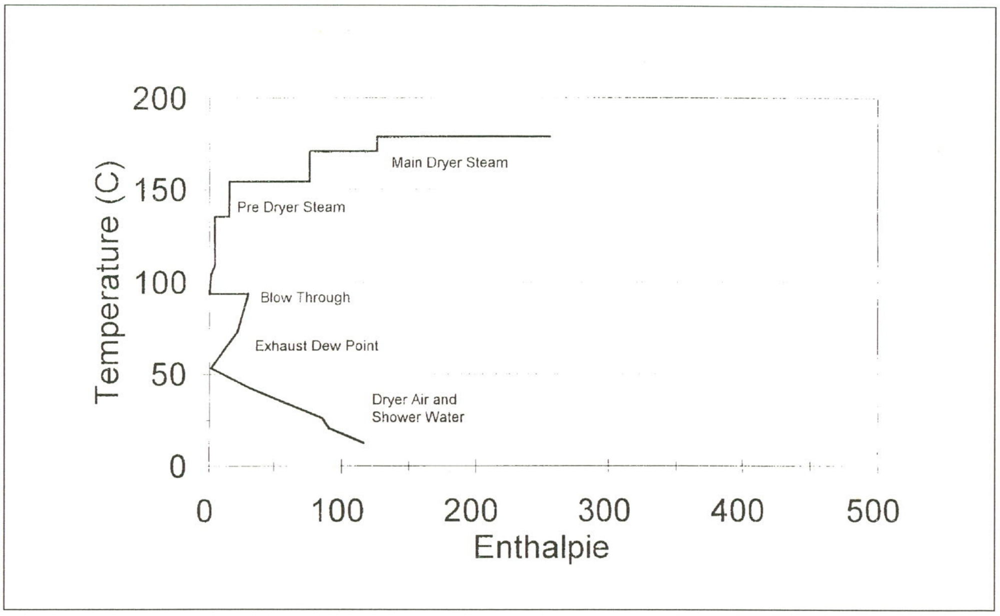

Figure 5.2

The Linnhoff March study [F1] shows a pinch on the steam side of the dryer, and a near-pinch at the drying cap exhaust. For the time being, we shall assume that something similar also occurs in papermaking machines in The Netherlands.
There is in any case no reason to believe that the situation is any different in principle in The Netherlands. For heat pump applications, this should in theory mean that heat at 50 °C must be pumped up to 100 °C. In principle, this is possible, but heat pumps with such a large temperature lift are not yet available.

In view of the foregoing, a study by Friedel et al. [F9] is of interest. They investigated to what extent heat pumps could be used to recover heat from drying air. They developed a heat pump system whereby steam (1.35 bar, 110 °C) was produced from drying air at 80 °C. In the first phase of this project, various heat pump and heat transformer concepts were analysed. The results are shown in the following table (Table 5.1). The second phase incorporates a two-stage absorption heat pump of 100 kW, which came up to expectations. It is not clear whether the heat pump concept described here also pumps heat over the pinch.

Table 5.1

		Feasibility (3)	Energy-saving potential (1)	Costs (2)	Result
Heat pumps	Compression-HP				
	a (mech. compressor) R114	++	-	--	(13)
	b (therm. Compressor) H_2O	-	--	++	(11)
	Two-stage absorption (2 Absorbers, 2 Desorbers)	+	+	o	(16)
	Absorption-Compression	o	+	-	(11)
	Resorption-Compression				
	a 1-stage	--	+	--	(3)
	b 2-stage	--	+	--	(3)
	Absorption-Resorption-Compression	--	o	--	(2)
Heat transformers	Two-stage Absorption (with thermal noise)	o	o	-	(10)
	Absorption-Compression	--	+	-	(5)
	Absorption-Resorption	o	o	-	(10)

++	very good
+	good
o	satisfactory
-	fairly satisfactory
--	not satisfactory

In the Linnhoff March 'pinch' studies, no account is taken of the pressing process: the mechanical removal of water in the papermaking machine. The rule of thumb generally applied is that for every percent dry matter gained in the pressing section, the energy consumption of the drying section falls by about 4-5%. The pressing process is enhanced by using hot rather than cold process water. Efforts are being made to achieve this, on condition however that this heating is not achieved at the expense of increased steam consumption. In practice the process water is heated up in a scrubber with the wet drying air from the drying cap. The wet drying air is at a temperature of about 55 °C. Pumping up this temperature by a few degrees would therefore have major indirect consequences for the steam consumption.

The 'pinch' studies do not therefore give the whole picture. There would appear to be possibilities for heat pumps at the outlet of the drying cap. These possibilities are closely bound up with the effect of the temperature of the process water on the pressing process. In cardboard production, this effect is more marked than in the case of paper. All of the foregoing is currently under study.

In all cases, heat pumps will have to compete on both price and technical grounds with the use of steam.

5.4 Potential for heat pumps in the paper and card board sector

Installing heat pumps must only be considered if optimum use is already being made of heat exchangers; in other words, only where a 'good' drying cap has been installed. We give below a calculation of the enthalpy flows relating to the recovery of heat from the wet drying air of a large Dutch paper mill. The results are shown in the table. The first three columns of the table give the temperature, humidity, specific enthalpy and the total enthalpy flow of the wet drying air:

- at the entry point of the heat exchanger cross current (HE in);
- at the entry to the scrubber;
- at the exit from the scrubber.

The table shows that at the exit from the scrubber only 5 MW (21% of the total enthalpy flow) has been recovered; 1.2 MW has been transferred to the drying air, while 3.8 MW has been transferred to the process water. This 21% corresponds to the 17% mentioned in the study by Friedel et al. [F9].

The table also shows what the results would be if a heat pump were to be installed downstream of the scrubber. The recovery of heat from the drying cap is then increased by 9 MW, reaching a total of 14 MW (nearly 60%).

Table 5.2

	HE in	HE out/ scrubber in	Scrubber out/HP in	HP out
Temperature (C)	82	62	59	48
Humidity (%)	42.5	100	100	100
Spec. Enthalpy (kJ/kg)	535	508	433	247
Enthalpy flow (MW)	23.8	22.6	18.8	9.8
Yield (MW)		1.2	3.8	9.0

In 1991 2.8 million tons of paper were produced in The Netherlands. On the basis of 8000 hours of operation per year, this represents a production figure of 350 tons per hour. If the production of toilet tissue and special papers is left out of account, an output of 315 tons per hour is suitable for the application of a heat pump. This is about 9 times the hourly production of one of the larger Dutch paper mills. In other words, if a heat pump were to be installed in all papermaking machines, it would be possible to recover over 80 MW of heat. On the basis of an estimate of 2 heat pumps in the ten largest plants, this would amount to 20 machines per plant with an average condenser capacity of 4 MW.

6 Potential for heat pumps in textile finishing

6.1 General

Number of concerns: 41

Reference process: - Drying process for cloth on cylinder dryers or tenters

In 1986, the textile finishing industry produced 60 million kg of cloth with a specific thermal energy consumption of 54 MJ/kg and a specific electrical energy consumption of 4.3 MJ/kg.

The most important textile finishing processes are bleaching, dyeing, printing and drying of cloth. In addition to mechanical treatments such as singeing and starching, the wet processes (destarching, boiling, bleaching, dyeing, printing and finishing) together with their subsequent drying are the core of the textile finishing process.

Apart from good housekeeping, energy-saving measures at the process level can be divided into two categories:
- Measures to reduce the throughput of water and air.
- Heat recovery.

One very important part of the energy consumed by the textile finishing process is the exhaust vapour from dryers, tenters, steamers and printing machines.

6.2 Description of reference processes

Textile is usually dried in cylinder dryers or tenters. Cylinder dryers consists of a number of adjacent steam heated cylinders. The textile to be dried is usually fed to the cylinders in such a way that the top surface and the underside of the cloth are in alternate contact with the drying cylinders. Tenters are drying machines in which the textile is stretched out over its entire width and conveyed in this position through a heated chamber. The heat is transported by air. The tenter can be heated directly or indirectly.
Both of these drying processes extract moist air and take in fresh drying air. Energy savings can be achieved by reducing the drying air deficit and/or recovering heat from the exhaust drying air. There are numerous tenters and cylinder dryers in The Netherlands textile industry. The drying process is the most energy-intensive unit operation in the textile finishing industry.

6.3 Applications for heat pumps in the reference processes

Heat from exhaust drying air can be recuperated and exploited for use in the fresh drying air. It is of course only possible to exploit the latent heat in the exhaust drying air if the moisture in the drying air is condensed. This is also of importance for the cleaning of the drying air: condensation removes most of the pollutants, odour and minute pieces of textile fibre. Generally speaking, the drying air is initially recuperated by exchange with the fresh drying air. The heat pump is inserted ‘over’ this heat exchanger. Possibly the condenser heat can also be used for other purposes.

6.4 Process integration in the textile finishing industry

TENSA carried out a pinch study for a textile mill in North Carolina, USA [D3]. The pinch there was about 40 °C. A (low!) Dtmin of about 5.5 °C was maintained. The heat exchanger network developed on the basis of this study has a payback time of less than one year and reduces the primary energy flow by 11.4 MW. Particularly close attention was paid to the implementation of a double closed heat pump which pumps up heat from the wet washer circuit to about 110 °C for preheating the drying air for the tenters. The payback time for these heat pumps is about 3.2 years. It should be pointed out in this connection that the ratio of the price of electricity to the price of gas in the USA is about 2.5 (MJ/MJ), whereas this ratio is about 5.52 in The Netherlands.

6.5 Heat pump potential in the textile finishing industry

There are about 40 textile finishing plants in The Netherlands. About 35 million kg of water must be evaporated from the 60 million kg of cloth produced. Closed heat pumps with a total condenser capacity of about 4 MW can be installed, probably in about 10 of the 15 largest concerns in the sector. Apart from heat recovery, these heat pumps also provide flows of drying air from which the moisture has been condensed, which is of importance from the pollution (and odour) point of view.

7 Potential for heat pumps in the building ceramics industry, the brickmaking industry and the glass industry

7.1 The ceramics industry

7.1.1 General

Number of concerns: 72.

Reference processes: - Brick firing;
- Brick drying.

The production of roofing tiles and bricks amounts to 2400 10^3 tons per year, with a specific fuel consumption of 3100 MJ/ton.
The electricity consumption amounts to 165 MJ/ton, principally for transporting products and gas flows.

The ceramics sector - particularly the building ceramics subsector - is highly energy intensive. In addition, the share of energy in the added value is high (25 to 35%).
The principal processes in the building ceramics industry are shaping, drying and firing. Drying accounts for about 40% of the specific energy consumption (energy consumption per ton of finished product), firing about 60% and shaping about 1 to 2%.

In the early eighties, large sums were invested in this sector to reduce energy costs. These investments had a marked effect on specific energy consumption. In recent years, further major investments have been made in production equipment, especially tunnel kilns. Although these investments were mainly aimed at improving the quality of products and increasing productivity, they were almost always accompanied by a reduction in the specific energy consumption which was sometimes considerable. Many of these investments received support as part of the demonstration project scheme of the Ministry of Economic Affairs.

7.1.2 Description of the reference processes

Drying

Before the bricks can be fired their moisture content must be brought down from 20-30% to 0.5-1%. This is done in chamber driers. The drying air is heated by gas burners and exhaust air from the kiln. The required temperature varies from 40 °C at the start of the drying cycle to about 95 °C at the end of the drying cycle, which lasts from about 30 to 50 hours.

In many cases - particularly older kilns - large quantities of cooling air are extracted. This extraction is direct extraction from the product cooling process, and is necessary for technical reasons. It is obvious that this heat should then be used for the drying process.
The temperature of the heat supplied is well above the required temperature. Considerable exergy nullification occurs. Sometimes the heat surpluses from the kiln are partly used for the drying process but strictly speaking they are not beneficially employed. This type of the process structure leads to less economical dryer designs.
For various reasons which we shall not go into here, the newest designs of kiln are aimed at keeping the generated cooling air inside the kiln to the maximum possible extent, which nowadays is technically perfectly feasible.
Generating heat for drying air, therefore, has to be done using fuel. Reducing the energy consumption of drying installations can be achieved in part by recovery of the heat from the exhaust drying air. The tangible heat can be recovered by recuperative methods. Recovery of latent heat can possibly be achieved by means of heat pumps.

Firing

Thanks in part to improved insulation, the present generation of tunnel kilns is much more economical in energy than the older types. The relative share of the total losses represented by the losses via the flue gases is therefore higher. The temperature of the flue gases is such that it is sufficient for drying the product. For some types of clay, it is possible to carry out a good part of the drying using flue gases from the kiln. This means that the kilns are extremely economical. Indirect cooling of flue gases is however expensive owing to the occurrence of corrosion phenomena. In addition, it is difficult to condense out the flue gases against the flow of air. The flue gases can be condensed out to a very large extent with the aid of a scrubber cooled by a cooling tower, which helps to promote optimum heat recovery. From the environmental point of view this is also highly desirable: the process in fact combines flue gas purification and heat recovery.

7.1.3 Applications for heat pumps in the reference processes

A very large amount of latent heat can be recovered from drying air and flue gases and used for drying air pre-heating. The current process systems in the ceramics industry, whereby heat from the kiln is extracted for the dryer result in large surpluses of low-temperature heat (<100 °C)[1)] and there is consequently no potential for heat pumps.

This can however change if:
a. wet flue gas purification is applied and
b. the kiln and the dryer are completely uncoupled.

[1)] In ceramics processing it is in any case advantageous to make a distinction between directly exchangeable heat and indirectly exchangeable heat.
External heat flows just above the pinch which are not directly exchanged are of little value. Process improvement is mainly directed at preventing these heat flows.

If wet flue gas purification is applied, there is a large source of heat at about 40 - 55 °C, which with closed heat pumps at 70 - 90 °C can be used for the drier. The latent heat in the exhaust drying air can perhaps also be pumped up to the desired level of 85 - 90 °C.

7.1.4 Process integration in the building ceramics industry

TNO-ME is currently executing a process integration study for the building ceramics industry. The pinch of the process elements lies in the vicinity of the dew points of the flue gases from the kiln and the exhaust drying air. Heat pumps are therefore appropriate if the heat (if required!) is pumped up from a temperature around these dew points to a level above the pinch, especially for the purpose of preheating drying air.

7.1.5 Heat pump potential in the building ceramics industry

In the long term: about 20 MW thermal at 10 locations.
In the short term: 1 demonstration project making use of the condensation heat from flue gases for preheating drying air by means of a closed heat pump. In this demonstration project, the kiln and dryer must already be uncoupled and wet flue gas purification must already be installed, and of course no heat surpluses in the 70 - 90 °C zone must be available.

7.2 The sand-lime brick industry

7.2.1 General

Number of concerns: 11.

Reference process: - Curing of sand-lime bricks in autoclaves.

The overall annual production amounts to 1.44 thousand million Waal size equivalents (WSE). The specific gas consumption amounts to 16.62 nm^3/1000 Waal size equivalents and the specific electricity consumption 18.14 kWh/1000 Waal size equivalents.

7.2.2 Description of the reference process

The sand lime brick production process is a batch process. The raw materials are sand, unslaked lime and water. These are mixed in certain proportions and then shaped in hydraulic presses into bricks, blocks or other elements. During the mixing process, the unslaked lime reacts with water and gives off heat. The compressed 'raw' product thus reaches a temperature of about 50 °C. The bricks are then cured in autoclaves by steam at about 15 bar. Under the effect of this steam, a reaction is initiated between the lime which has by now been slaked $Ca(OH)_2$ and sand SiO_2. The result is that these reactants bond together to form calcium hydrosilicates which give the product its characteristic white colour and strength.

In modern installations the heat from exhaust steam is almost all recovered. This is done by releasing steam from one autoclave into the other, thus lowering both pressure and temperature. High pressure condensate is flashed, and the major part of the condensate (the clean part) is used as boiler feedwater. Heat is recovered indirectly from the contaminated condensate.

A high proportion of the energy losses arises through accumulation in the finished products. This proportion represents about 40% of the total fuel consumption in modern plants. Heat recovery is not used to preheat products. In the long term, vapour recompression may become an attractive proposition if the product can be preheated to curing temperature.

7.2.3 Applications for heat pumps in the reference process

In the plants in The Netherlands low pressure steam is still vented off. This exhaust steam is also used to preheat feedwater. To be any use, the steam must be at a pressure of at least 4 bar. This might possibly be raised from the above-mentioned exhaust steam with the aid of a heat transformer.

7.2.4 Process integration in the sand-lime brick industry

So far as is known, not a single pinch study has been carried out in the sand-lime brick industry. It is possible that (much) more heat can be exchanged between the finished product and the 'green' products.

7.2.5 Heat pump potential in the sand-lime brick industry

Probably a few heat transformers, each of about 2-5 MW.

7.3 The glass industry

7.3.1 General

Number of concerns: 9.

The specific energy consumption amounts to about 4 to 5.5 MJ/kg for hollow glass and 5 to 7 MJ/kg for flat glass. The electricity consumption amounts to about 1 MJ/kg.

Glass production in The Netherlands can be divided into four groups:
- Hollow glass (packaging, tableware, light bulbs);
- Flat glass (windows);
- Glass fibre (textile and plastics reinforcement);
- Glass wool and glass fleece (stiffening, insulation).

Glass production in The Netherlands amounts to about 980,000 tons. By product weight, it can be divided up as follows:

— Hollow glass:	73%
— Flat glass:	15%
— Glass fibre, glass wool and glass fleece:	10%
— Pressed and blown glass:	2%

About 50% of the glass used for packaging and 10 to 20% of flat glass is recycled.

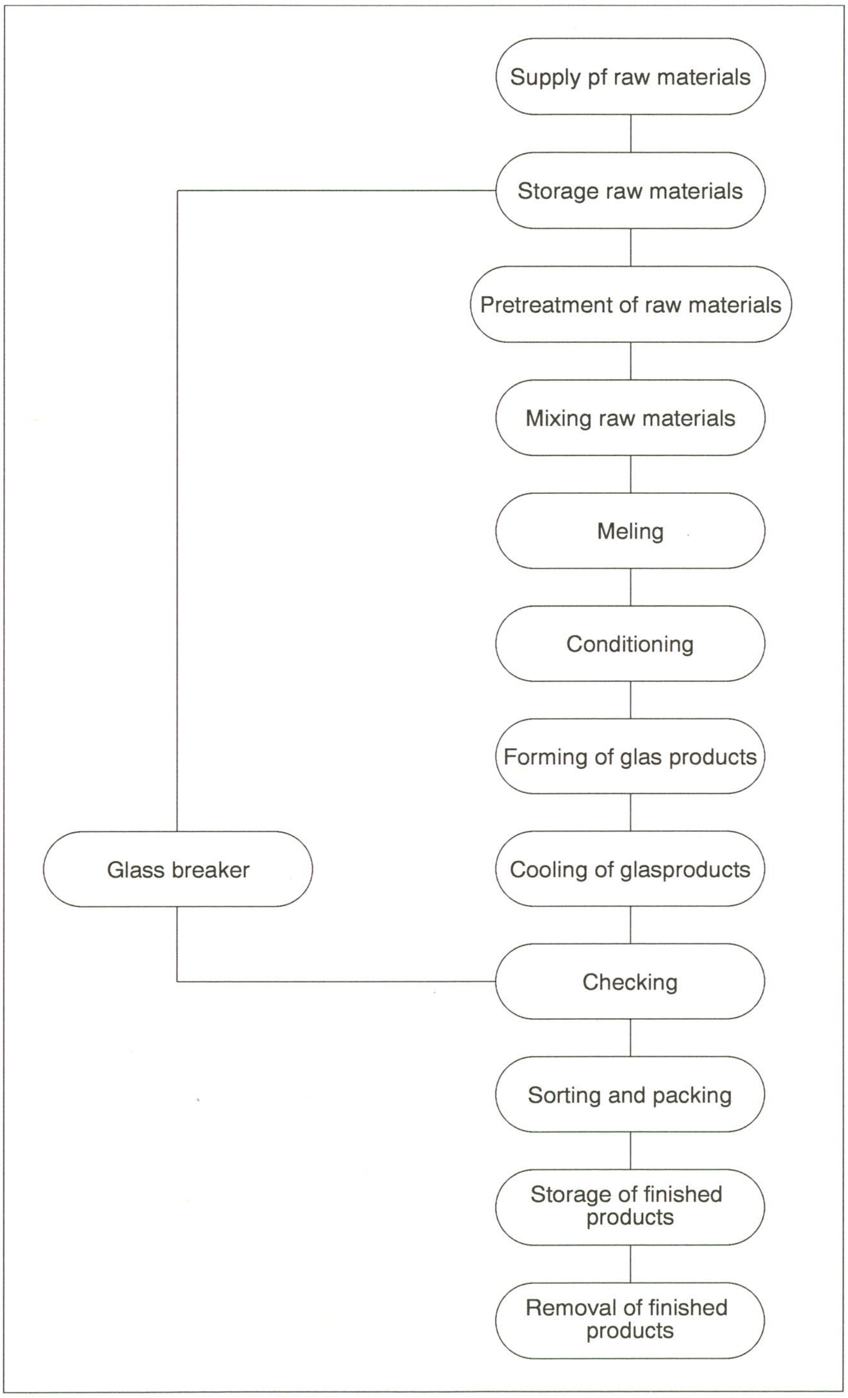

Figure 7.1 Production of flat and packing glass

A saving of about 20% of the thermal energy consumption is possible if heat recovery is applied. The possibilities for recuperative/regenerative recovery by means of heat exchangers are so great that it makes no sense from the thermodynamic point of view to use heat pumps. Moreover, the temperature level is so high that it is technically impossible to apply heat pumps. There is no potential for heat pumps.

8 Potential for heat pumps in the chemical industry

8.1 General

The chemical industry accounts for almost half of total industrial energy consumption in The Netherlands. The chemical industry can very roughly be divided into the following main sectors:

- The agricultural fertiliser industry (ammonia, urea, nitric acid and calcium ammonium nitrate);
- Organic chemical base materials (including olefins, aromatics and derivatives);
- Inorganic chemical base materials (salt, phosphorus, silicon carbide and metal oxides and their derivatives);
- The synthetic resins industry.

Table 8.1 Energy consumption per main sector

	Consumption [TJ]	Share [%]
Agricultural fertilisers	100.2	18.7
Organic base materials	353.2	65.8
Inorganic base materials	42.6	7.9
Synthetic resins	8.1	1.5
Other chemicals	32.2	6.0
Total Chemicals	536.3	100

8.2 Potential for heat pumps in the artificial fertiliser industry

Number of concerns: 9.

Reference processes:
- Sulphuric acid production, followed by Nitric acid production
- Ureum production

Table 8.2 Specific energy consumption

Product	**Production [10^3 ton]**	**Specific energy consumption**	
		Q [MJ/ton]	**E [MJ/ton]**
Ammonia	2,621	35,330	-169
Calcium ammonium nitrate	1,753		250
Nitric acid	2,100	?	95
Urea	833	3,000	300
Other	6,667	360	240

Ammonia production therefore accounts for over 90% of the energy consumption.

8.2.1 Description of sulphuric acid process

Molten sulphur is oxidised to form SO_2. The combustion gases are cooled in a multi-bed catalytic converter and oxidised to form SO_3. SO_3 then reacts with water to form sulphuric acid. All these processes are exothermic. They produce steam and electricity for the entire plant.

Phosphates and sulphuric acid are then reacted in a vacuum reactor to give 28% nitric acid (P_2O_5) and gypsum. The reaction heat is used for steam-raising. The nitric acid is separated out from the gypsum by washing it out in counter-current with water [C3]. The nitric acid is recycled above the reactor. The 28% nitric acid can be concentrated to 52% nitric acid in a two-stage vacuum evaporator.

8.2.2 Description of the Ureum process

Process description

This chapter gives a short description of the process. The appendix contains a process flow diagram and the temperature - heat flux relation of main streams of an urea plant with a capacity of 200,000 MTA.
As the Stamicarbon CO_2 stripping process covers more than 50% of the worlds urea technology in operation, this process is chosen for a representation of energy management. The mass flows, temperatures, energy streams, and flow diagrams are deducted from literature.

Urea is produced at high pressure (145 bar) from carbon dioxide and ammonia, via the intermediate ammonium carbamate. The ammonium carbamate is then dehydrated to urea. Both reactions are equilibrium reactions. For total feed conversion the feed components have to be recycled to extinction. As the reaction, carbamate gives urea plus water, goes to equilibrium, as little as possible water should be recirculated to the dehydration reactor.

In the CO_2 stripping process the unreacted carbamate is removed from the urea by stripping with CO_2. This is possible without pressure reduction by lowering the partial pressure of the ammonia by introduction of the CO_2. As a result the carbamate decomposes to CO_2 plus ammonia. These gases are stripped with the fresh CO_2 feed from the urea - water solution.

The discussed process is a stand alone process. If the urea plant is combined with downstream plants, like melamine, with interplant recycle streams, an other process might be more advantageous. In the given process the main equipment operates at about the same pressure. Vaporization, condensation and gravity are the main circulation driving forces. An ammonia yet brings the condensate from the reactor system vent scrubber back into the carbamate condensor.

Two strippers and an urea hydrolyser are installed for clean-up of the waste water before disposal to the sewer. Some air has to be introduced to the system to oxidise the traces of H_2, possible present in the CO_2 feed, and to protect the stainless equipment by passivation.

Flowsheet description, see figure 8.2

The main feature of the urea by the carbon dioxide stripping process is, that the unconverted carbamate is decomposed into the basic components, and these are stripped from the urea solution, without reduction in pressure, and consequently without the need for mechanical pumps or compressor in the synthesis recycle loop. CO_2 (18.6 t/h) and air (3 t/h) are compressed to 145 bar. H_2 is selectively oxidised to prevent the formation of a possible hazardous mixture of CO_2 and ammonia in the system.

The mixture of CO_2, N_2 and some remaining oxygen is fed to the carbamate stripper. In this stripper the majority of the unconverted carbamate is removed from the urea water solution. This is done by equilibrium shift by partial pressure reduction caused by the addition of the CO_2. The addition of the CO_2 to the reactor effluent and consequently partial pressure reduction of the ammonia shifts the equilibrium towards CO_2 and $2NH_3$ decomposing the carbamate, and stripping of the resulting gases. The heat required for the decomposition is delivered by condensing 23 bar steam, available from the partly back pressure, partly vacuum condensing of the steam turbine drive of the CO_2 compressor.

The stripper is executed as a falling film heat exchanger. The urea - carbamate - water solution flows from top to bottom along the heat exchanger tubes wall. The fresh CO_2 and the CO_2 and ammonia from the decomposed carbamate and the inert gases flow upwards through the centre of the tubes. The heat required for the decomposition is delivered by the condensing steam on the shell side of the exchanger.

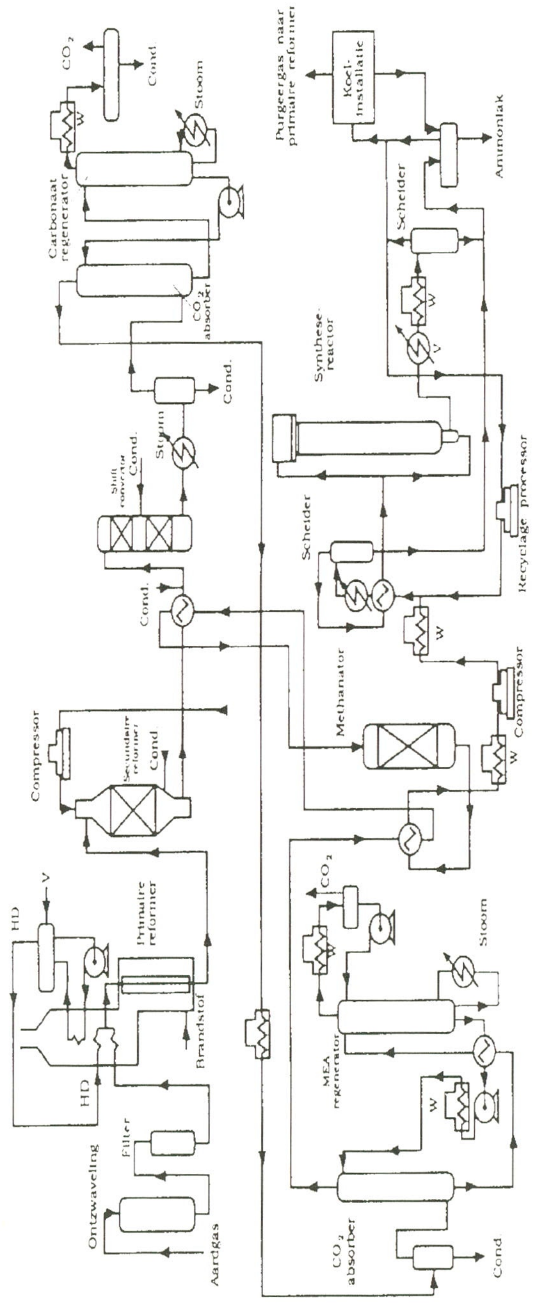

Figure 8.1 The Ureum process

Passing through the stripper the gases are also heated from 160 °C to 185 °C. The stripper gases are mixed with 14.3 t/h fresh ammonia and a recycle stream moved by the fresh ammonia with the help of a yet. The recycle stream contains ammonia, CO_2, water, carbamate and a small amount of urea. The mixed stream is cooled down to some 154 °C and is fed to the carbamate condensor. The carbamate condensor is cooled by generating 3.5 bar steam. At this lower temperature and high ammonia partial pressure, the CO_2 and ammonia condense to carbamate. The outlet temperature is some 170 °C. This product enters a vessel with an extended residence time, roughly one hour.

The carbamate is converted to urea absorbing heat. Unconverted CO_2 and ammonia condense to carbamate, the overall result is a slight temperature tise. Some 60% of the carbamate is converted into urea. The conversion to urea rate depends on the total water content in the outlet of the reactor which shifts the equilibrium into the wrong direction. The water results from the reaction water, and the recirculated water. It is obvious that a low water containing recycle stream is important.

From the top of the urea reactor the urea - carbamate - water solution flows back to the carbamate stripper. The unreacted and inert gases leave the reactor at the top and are condensed/absorbed in the vent scrubber, with water carbamate recycle stream.The inert gases are cooled and vented and the condensate recycled by means of the ammonia driven yet to the carbamate condensor.

The bottom of the stripper containing urea, water and some not decomposed carbamate is flashed to 3.5 bar and fed to the second carbamate stripper. In this second stripper, the remaining carbamate is decomposed and removed from the urea - water solution. The second stripper is reboiled by LP steam. The bottom temperature is some 140 °C, the top temperature is some 135 °C. The top gases together with the vent gases from the water clean-up section, condense to carbamate in the second carbamate condensor and cooled to 75 °C. The resulting mixture is scrubbed with circulation water in the scrubber which is also provided with a cooling loop.

The urea water solution is heated, melted and flashed to 0.4 bar. The flashed gases are condensed together with the condensibles in the recycle gases from the second stripper, in the vacuum condensor. To remove the last traces of unconverted gases the urea is again heated and flashed to 0.04 bar, the gases are again condensed. The uncondensibles are removed with the vacuum yets.

The liquid urea is pumped into a prilling tower and dryed, cooled and solidified into prills with ambient air. The liquid products from the vacuum systems, for the majority water, are collected and pumped to the water clean-up system. The water is cleaned in two stripping towers and one urea hydrolyser. The remaining urea in the water is hydrolysed to carbamate, the carbamate is decomposed and the resulting gases are stripped.

The cleaned water is cooled and the excess disposed off. A small stream is used for scrubbing of the prilling air and recycled to the second carbamate condensor, together with the top product from the second carbamate stripper.

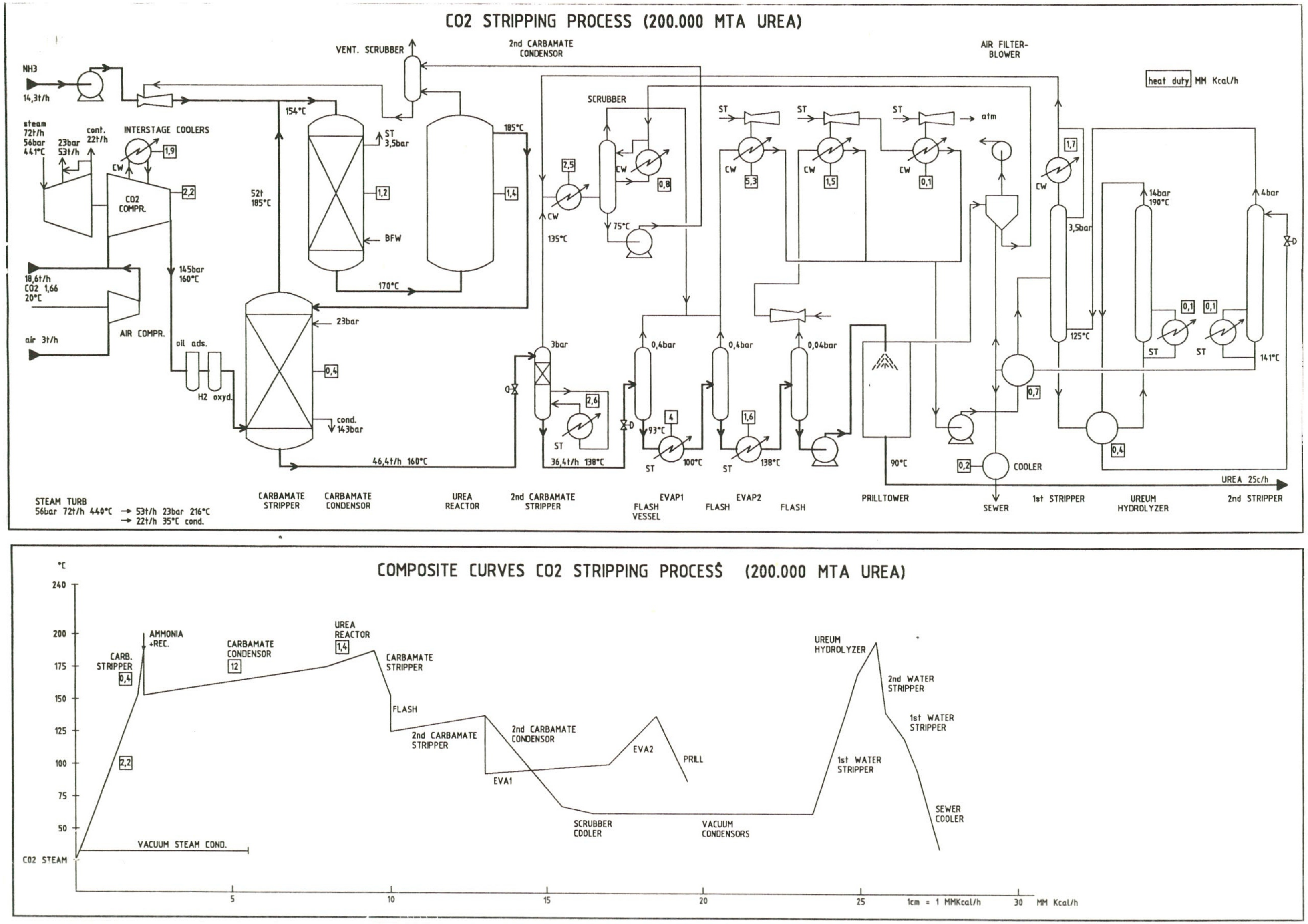

Figure 8.2 The CO_2 striping process

8.2.3 Applications for heat pumps in the sulphuric acid processes

In the sulphuric acid process, a heat pump can be applied: the reaction of SO_3 with water to give sulphuric acid takes place below the pinch (96 °C) of the sulphuric acid process. With the aid of a heat transformer, this reaction heat can be converted into low-pressure steam (3 bar) just above the pinch. The temperature lift is considerable (about 40 °C).
The pinch for the phosphoric acid process is too low for a heat transformer (54 °C), and the temperature lift is too great (about 40 °C) for compression heat pumps [C3]. Process changes which bring about a reduction in the required temperature lift might perhaps make it an attractive proposition to apply recompression of the low-pressure vapour given off by the product.

8.2.4 Applications for heat pumps in the Ureum process

The available thermal data of the Ureum process are sufficient to make a quantitative approach to make an evaluation with the Chalmers Annex 21 programme, see 10.6

8.2.5 Process integration in the agricultural fertiliser industry

The sulphuric acid process gives rise to large surpluses of low-temperature heat, in particular the reaction heat arising from the formation of sulphuric acid from SO_3 and water. This heat can be pumped up to give low-pressure steam. It is however also possible to recover this heat recuperatively for preheating of nitric acid during the evaporation process. If a heat transformer is used, the low-pressure steam generated can be used as a concentration medium in the nitric acid evaporators [C4].

The composite curves and a grand composite curve of the Ureum process are available, see 10.6.

8.2.6 Potential for heat pumps in the agricultural fertiliser industry

Insufficient information is available to make it possible to give an estimate for the potential for heat pumps in The Netherlands artificial fertiliser industry. At the present time - as far as is known - no heat pumps are applied in the artificial fertiliser industry.
It may be expected that there is a reasonably large potential for heat transformers in this sector of industry, but the profitability is low because of the very low internal price of low-pressure steam.

From the Ureum process, the potential for heat pumps is about 10.7 MW_{th}. For the other subsectors, insufficient information is available to make it possible to give an estimate for the potential for heat pumps. At the present time as far as known - no heat pumps are applied in the artificial fertilizer industry. It is possible that there is a reasonably large potential for heat transformers in this sector of industry.

8.3 Production of organic chemical base materials

Number of concerns: 55.

Reference process:
- Butane distillation;
- Naphtha distillation;
- Ethylene production;
- Methanol production.

8.3.1 Description of reference processes

8.3.1.1 Butane destillation

d n-butane from a mixture of butanes is carried out in a distillation column [C13]. The condenser temperature is 55.5 °C, the reboiler temperature 73.3 °C, and the temperature of the feedstock is 49.4 °C.

8.3.1.2 Naphta distillation

Light and heavy fuel oil is fractionated in a splitter using a light naphtha feedstock at 93.3 °C. The reboiler temperature is 132.5 °C and the condenser temperature 56.6 °C. At the plant described, there is a second splitter which divides naphtha into a light naphtha fraction and an unspecified bottom product. The feedstock temperature is 126.6 °C, the condenser temperature 37.7 °C (top product temperature: 133.3 °C!) and the reboiler temperature 188.3 °C.

8.3.1.3 Ethylene production

For the production of ethylene, propylene and butadiene thermal cracking of nafta, LPG and petroleum condensate is applied. Nafta is routed to a furnace with steam, where the cracking process takes place. Thermal cracking proceeds by reactions in which radicals are formed. In order to protect the furnace dimethyl disulphide is added. Directly after cracking the product stream is separated in four main streams: cracking residu, cracking oil, cracking gasoline and a gas mixture containing lower olefins.

The gas mixture is compressed and fed to a washing tower to remove carbon dioxide and hydrogen sulphide using lye as washing agent. The gas is fed to molecular sieves to remove water and subsequently fed to the distillation section. There gas components are separated. First methane is removed and then the gas is separated in a cold (DSM: up to -165 °C) and hot distillation section into ethylene, ethane, acethylene, propene, propane, propyn, propadiene and a C4 fraction. Ethane is cracked in the ethane furnace at 830 °C. The C4 fraction is purified downstream in a separate section.

The C5-C10 fraction, the so called pyrolysis gasoline, is separated in three fractions by means of distillation: the first fraction is a C5 non-aromatic fraction, from which dicyclopentadiene is recovered by means of dimerisation and distillation. The C6-C9 fraction is used for benzene production and the C9+ fraction is a.o. processed to aromatic oil.

Extraction of butadiene from the C4 fraction
Butadiene can be recovered from the C4 fraction obtained by cracking of nafta by means of extractive distillation. Therefore the C4 fraction is fed to an absorber column, where butadiene is absorbed. In the SHELL process acetonitrile is used. Thereupon butenes that might be present are removed by stripping and subsequently separated. From the middle of the stripper column a side stream is withdrawn, containing butadiene and heavier compounds. This flow is fed to a scrubber for separation of butadiene. The butadiene is further purified. The bottom flow is recycled from the scrubber to the stripper. The solvent is regenerated.

At DOW the separation of butadiene from the C4 fraction proceeds as follows:
- The C4 fraction coming from the cracker is routed to a reactor in which some by-products are hydrogenated with hydrogen. As a result a heavy oil fraction is produced that is returned to the cracking installation. The main stream is separated from the C4 fraction using distillation with acetonitrile (ACN). In a stripper subsequently ACN and butadiene are separated. ACN is reused and butadiene is purified.

In this chapter a 500,000 MTA ethylene production plant with naphtha feed is described. Its corresponding appendix contains flow diagrams and temperature - heat flux diagrams.

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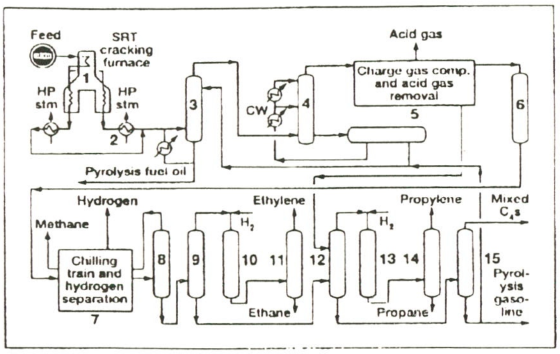

Ethylene

Application: To produce polymer-grade ethylene (99.95 vol%). Major byproducts are propylene (chemical or polymer-grade), a butadiene-rich C_4 stream and C_6 to C_8 aromatics-rich pyrolysis gasoline.

Description: In the pyrolysis section, hydrocarbon feedstock is preheated and cracked in the presence of steam in tubular SRT (short residence time) pyrolysis furnaces (1). The resultant products exit the furnace at 1,400°F to 1,600°F and are rapidly quenched in the transfer line exchangers (2) that generate high pressure steam.

Furnace effluent, after quench, flows to the gasoline fractionator (3) where the heavy oil fraction is removed from the gasoline and lighter fraction (liquids cracking only). Final cooling of furnace effluents is accompanied by a direct water quench in the quench tower (4).

Raw gas from the quench tower is compressed in a multi-stage centrifugal compressor (5) to greater than 500 psig. Hydrocarbons condensed in the first charge compression stages are returned to the quench tower while those condensed in the latter stages are stripped and sent to the depropanizer (12).

The compressed gas is then dried (6) and chilled. Hydrogen is recovered in the chilling train (7), which feeds the demethanizer (8). The bottoms from the demethanizer go to the deethanizer (9).

Acetylene in the deethanizer overhead is hydrogenated (10) or alternately, the acetylene can be removed by solvent extraction and recovered. The ethylene-ethane stream is fractionated (11) and ethane leaving the bottom of the ethylene fractionator is recycled and cracked to extinction.

The deethanizer bottoms and stripper bottoms from the charge compression system are depropanized (12). Methylacetylene and propadiene in the depropanizer overhead are hydrogenated using LCI's L-B Fining process—a selective, liquid phase hydrogenation step (13). The depropanizer bottoms is separated into mixed C_4 and light gasoline streams (15). Polymer-grade propylene is recovered in a propylene fractionator (14).

Yields: Data for various feedstocks to maximize ethylene are:

					Gas oils			
Feedstock	Ethane	Propane	n-Butane	Full range naphtha	Atm. Light	Heavy	Vacuum	Hydrocrackate
Ethylene, wt%	84.0	45.0	44.0	34.4	28.7	25.9	22.0	30.2
Propylene, %	1.4	14.0	17.3	14.4	14.8	13.6	12.1	13.3
Butadiene, wt%	1.4	2.0	3.0	4.9	4.8	4.9	5.0	5.1
Aromatics, wt%	0.4	3.5	3.4	14.0	19.6	13.3	8.5	13.2

Energy consumption: State-of-the-art designs have energy consumptions of 3,300 kcal/kg of ethylene produced for ethane cracking to 5,500 kcal/kg of ethylene produced for gas oil feedstocks. Compressor power is 0.6 to 0.7 kW per kg of ethylene produced.

Commercial plants: Approximately 45% of the world's ethylene plants use Lummus' ethylene technology. Many existing units have been significantly expanded (above 150% of nameplate) using LCI's MCET (maximum capacity expansion technology) approach.

Licensor: ABB Lummus Crest, Inc.

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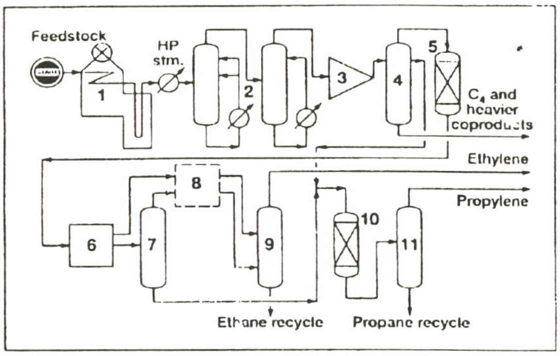

Ethylene

Application: To produce polymer-grade ethylene and propylene by thermally cracking paraffinic feedstocks (ethane through hydrocracked residue). Derived olefinic and aromatic products are produced, purified and recovered. Two main process technologies are used:

1. USC (ultra selective cracking)—Pyrolysis and quench systems
2. ARS (advanced recovery system)—Cold fractionation/refrigeration.

Designs have been incorporated to meet environmental restrictions.

Description: Beds are sent to USC cracking furnaces (1). Contaminants removal may be installed upstream. Cracking heat may be supplied by gas turbine exhaust. Pyrolysis occurs under the temperature-time control specific to the feedstock and product requirements. Rapid quenching preserves high olefin yield and generates high-pressure waste heat steam. Lower temperature waste heat is recovered in the downstream quench oil and quench water towers (2). Pyrolysis fuel oil and gasoline distillate are fractionated. Cracked gas (C_4 and lighter) is then sent to compression (3) and pressured to meet fractionation needs. Acid gas removal system is included.

ARS minimizes refrigeration energy by using the techniques of dephlegmator gas chilling (exclusive arrangement with Air Products) and distributed distillation. C_2 and lighter components as well as C_4 and heavier components are separated in the low fouling front-end dual pressure depropanizer (4). Overhead vapor is hydrogenated to remove acetylene (5) and is routed to the ARS (6), where two C_2 streams of varying composition are produced. Hydrogen and methane are separated overhead.

The heavier C_2 stream is deethanized (7) and C_2 overhead passes to the ethylene-ethane fractionator (9). The lightest bottoms stream (C_2s only) is routed to the ethylene-ethane fractionator (10). Polymer-grade ethylene product is sent overhead from the ethylene-ethane fractionator.

C_3s are combined and hydrogenated to remove methyl acetylene and propadiene (10). Polymer or chemical-grade propylene is then produced overhead from the C_3 superfractionator (11).

C_4 and heavier coproducts are further separated in a sequence of distillation steps. Ethane and propane are typically recycle cracked. Refrigeration is supplied by cascade ethylene/propylene systems.

Specific advantages of ARS technology are: 1. Reduced chilling train refrigeration load in the dephlegmator, 2. Simultaneous chilling/prefractionation in the dephlegmator, 3. Reduced methane content in feed to demethanizer, 4. Deethanizer bypassing, 5. Dual feed ethylene fractionator (lower reflux ratio) and 6. Resulting refrigeration demand reduction (approx. 75%).

Economics: Ethylene yields range from 57% (ethane, high conversion) to 28% (heavy hydrogenated gas oils). Corresponding specific energy consumptions range from 3,000 kcal/kg to 6,000 kcal/kg.

Commercial plants: Over 100 ethylene units have been built by Stone & Webster. Expansion techniques based on ARS technology have achieved up to 70% capacity increase.

Licensor: Stone & Webster Engineering Corp.

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Figure 8.3 Description of the ethylene process

The data given are composed from literature data and experience obtained in start-up and operation of various ethylene plants with naphtha or combined naphtha - LPG feed. The data are fitted to a 500,000 MTA production unit with some optimizations included. The data are based on plants built in the era 1960 through 1980, being the construction period of naphtha crackers in The Netherlands. Many improvements are possible but have not in all cases been executed by lack of economic incentive.

Most plants operating in The Netherlands are suited to co-crack LPG, this is not taken into consideration.

The most important part of the ethylene production units are the reactors, called cracking furnaces. The cracking takes place in the cracking coils, located in the radiation box. The lay-out of the coils and the shape of the radiation boxes are different for the various furnace types. Feedstock costs represent some 80% of the total cost for olefin production. The product slate from a given quality feedstock depends on the residence time in the cracking coils (type of furnace) and on the hydrocarbons partial pressure (steam dilution). The shorter residence time furnaces give the higher olefins yields, and a higher total product yield, however, at the expense of the production of pyrolysus gasoline (benzene precursors).

The value of by-products in most cases is higher than the feedstock costs, with exception of the produced fuel. Therefore the required product slite differs from site to site and is depended on the downstream plants configuration. The balance are given for moderate yields as practised in most plants operating in The Netherlands.

As the cracking is highly endothermic and requires elevated temperatures (800 - 900 °C), heat integration is very important. However, heat integration is limited by the high investment costs and consequently the required high plants reliability. Combustion air preheating and high pressure steam superheating are very well known means for heat efficiency improvement, however, application to existing furnaces is not always economically defendable.

For separation of the reactor effluents, high pressures (40 bar) and low temperatures (sub zero) are required. Extended compressing, cooling and refrigeration systems are needed. These systems require high duty driving machinery. The most practised integration of a gas turbine combined with an off-gas steam superheater/boiler and steam turbines is given. Also integration of the cooling and refrigeration systems is given to the most practised extent.

Flowsheet description of the ethylene process

8.3.1.3.1 Hot section

The naphtha from storage is preheated with returning steam condensates to some 100 °C and fed to the convection section of the furnaces. In counterflow with the flue gases, the feed is preheated to some 400 °C, and mixed with dilution steam. High pressure boiler feed water already preheated and deairated is further preheated to boiling temperature, in the intermediate part of the convection section. The naphtha feed together with the dilution steam is further preheated to the cracking starting temperature, some 630 °C. The steam oil ratio depends on the naphtha feed composition and on the value of the product slate. An average of 0.55 is used in this study.

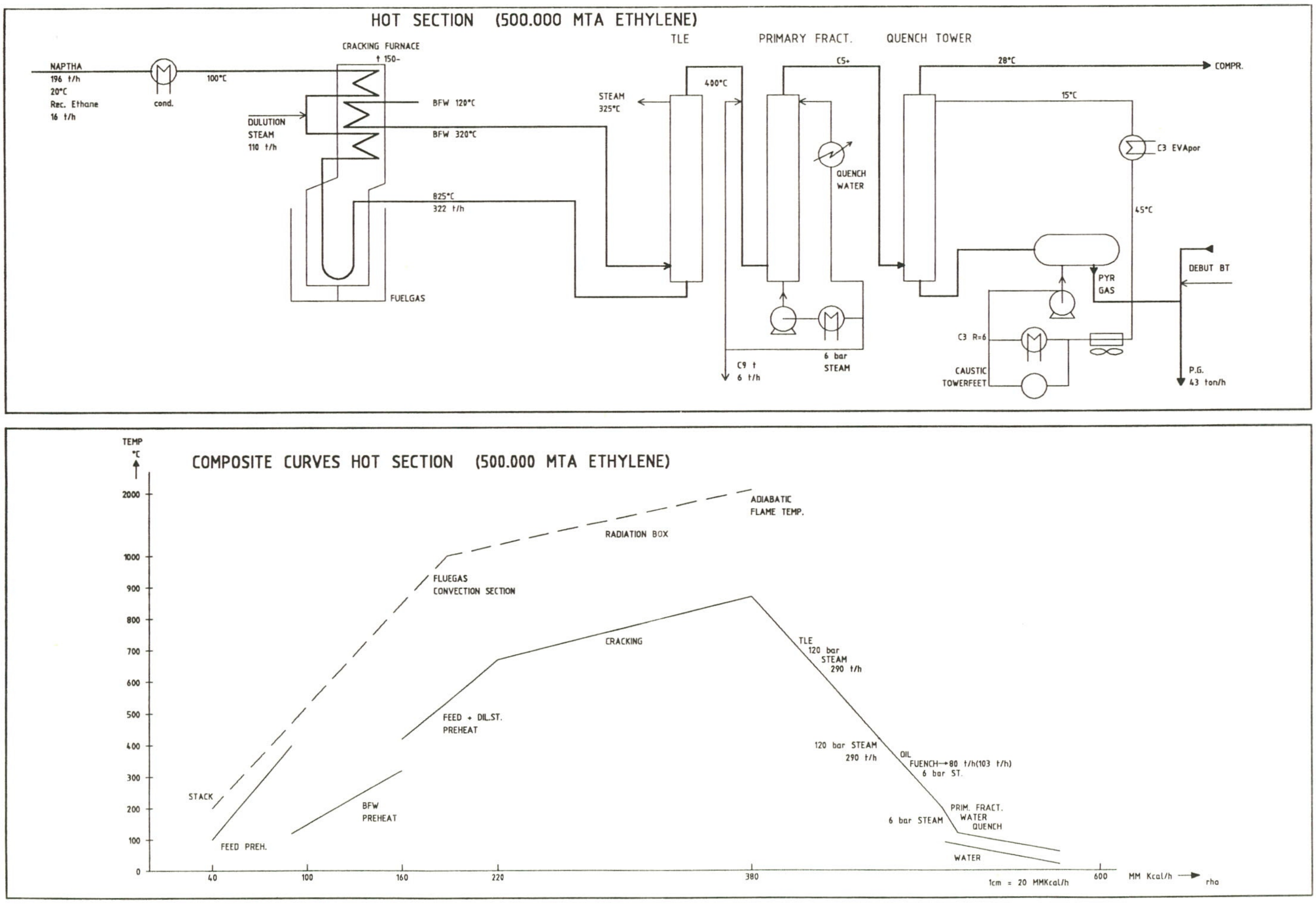


Figure 8.4 Hot section ethylene process

The steam - oil mixture enters the cracking coils, heat for cracking is supplied by radiation. As the cracking proceeds the temperature increases to some 830 °C. Condensation of olefins to less valuable products like heavy oils and pyrolysus gasoline is relatively fast at coil outlet conditions, therefore the effluent has to be cooled rapidly. For this purpose Transfer Line Exchangers are installed close to the furnaces outlets. The product is cooled to some 400 °C, generating high pressure steam. The TLE's outlets are collected into a transfer line and transported to the primary fractionator.

Before entering the primary fractionator the product is quenched by injection of heavy oil produced in the furnaces, and for this purpose collected and circulated. Heavy products condense and are dissolved in the heavy oils. The product and quench oil mixture enters the primary fractionator, where the product is further cooled down by injection of quench oil and a closed gasoil circulation loop. The quench and gasoil circulating loops are cooled by generating LP (dilution steam). In this system heavy oils are condensed and separated from the cracked gases, and circulated. A bleed stream makes the balance and is used as fuel oil. The gases leave the top of the fractionator with a temperature of some 100 °C.

The gases are fed to the water quench tower where the gasoline and the majority of the dilution steam is condensed with circulating quench water. The quench water is used for reboiling, excess heat is removed by cooling water. The quench tower top temperature is 15 to 35 °C depending on the cooling water temperature. Basically the excess heat in the hot section is used for:
a. Generating high pressure steam (90 - 120 bar).
b. Generating low pressure steam (dilution steam 6 bar).
c. For driving distillation columns.

8.3.1.3.2 Cracked gas compression section

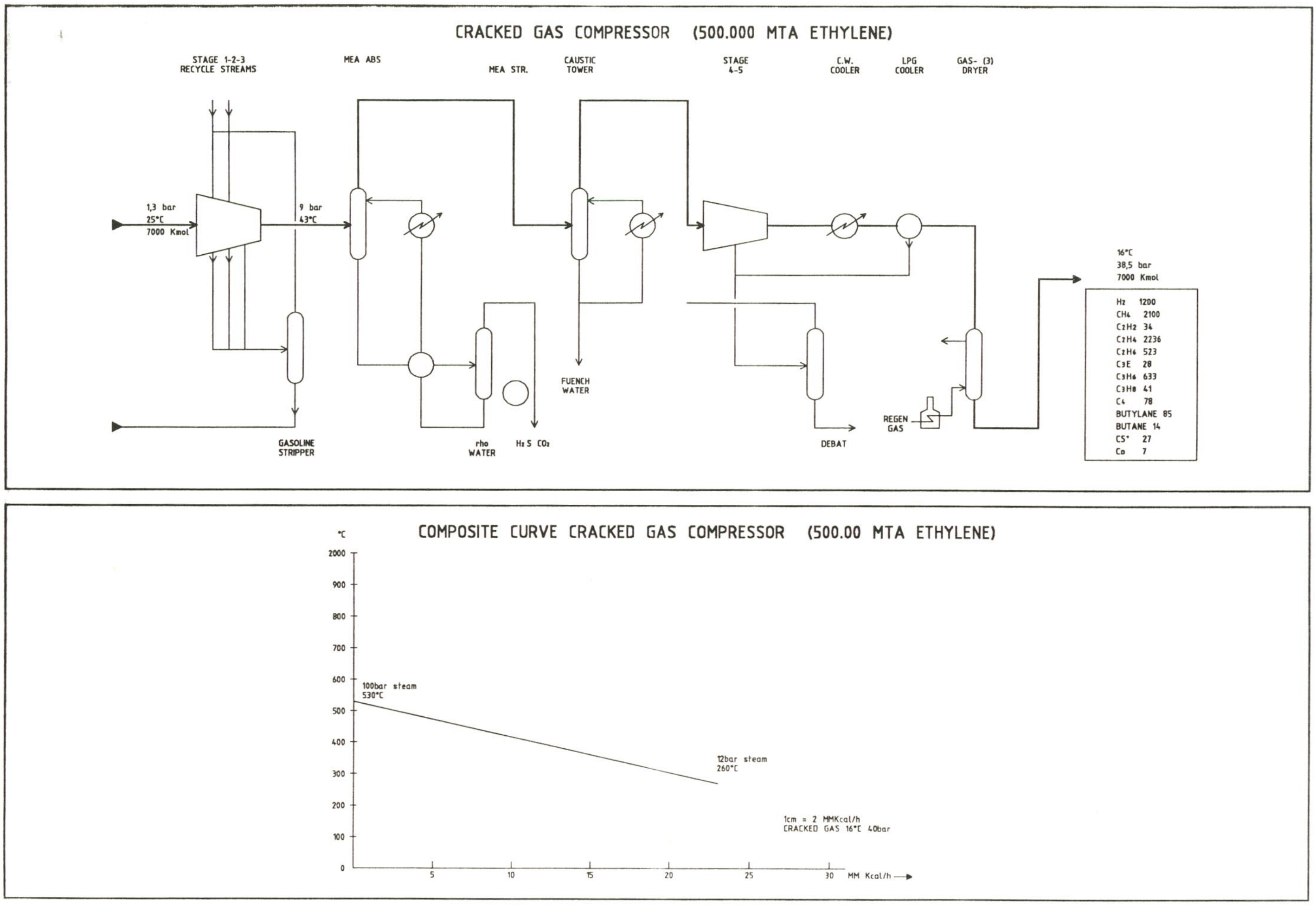


Figure 8.5 Cracked gas compressor ethylene process

The cracked gas from the quench tower is compressed in 5 stages from a slight overpressure to 40 bar. The stages are provided with interstage coolers and gas liquid separators. The condensates from the first three stages is collected and stripped in the gasoline stripper. The gases are recycled to the compressor, the liquids collected in the gasoline storage. The condensates of the last stages are collected and fed to the debutanizer. Between stage three and four a MEA wash and/or caustic scrubbing are installed to remove sulphur components and CO_2. The compressor discharge is also cooled with cooling water. Adsorbers are used to remove the last traces of water present in the cracked gas. The cracked gas compressor is driven by a high pressure steam turbine. The turbine is partly back pressure operated, balanced by partly vacuum condensing.

8.3.1.3.3 Cryogenic gas separation

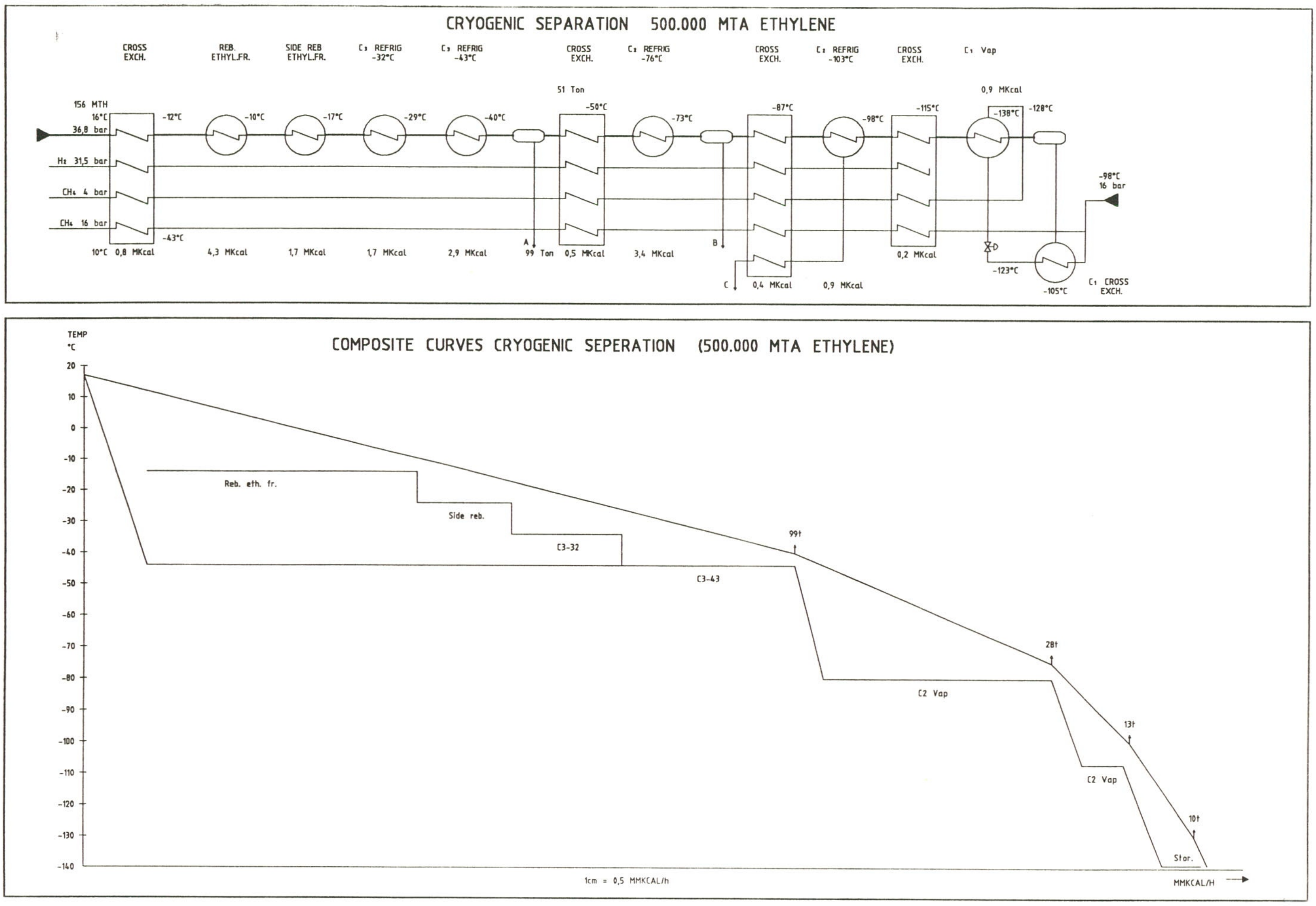


Figure 8.6a Cryogenic separation ethylene process

In the cryogenic gas separation hydrocarbon gases are condensed, an impure hydrogen stream is the end product. The condensates are separated in four gas liquid separators at -40, -73, -77, and -128 °C. These condensates are fed to the primary demethanizer. The topproduct of the demethanizer is high pressure methane. This is partly expanded. The two methane streams together with the hydrogen stream are cross exchanged in four multiple plate heat exchangers with the cracked gas feed, and leave the system at some 10 °C. Cooling of the cracked gas is also realised by reboiling the ethylene fractionator. Refrigeration from outside is supplied by two propylene vaporizers and two ethylene vaporizers. A methane expansion/evaporating cooler provides the lowest temperatures, needed for condensation of methane from the hydrogen rich stream.

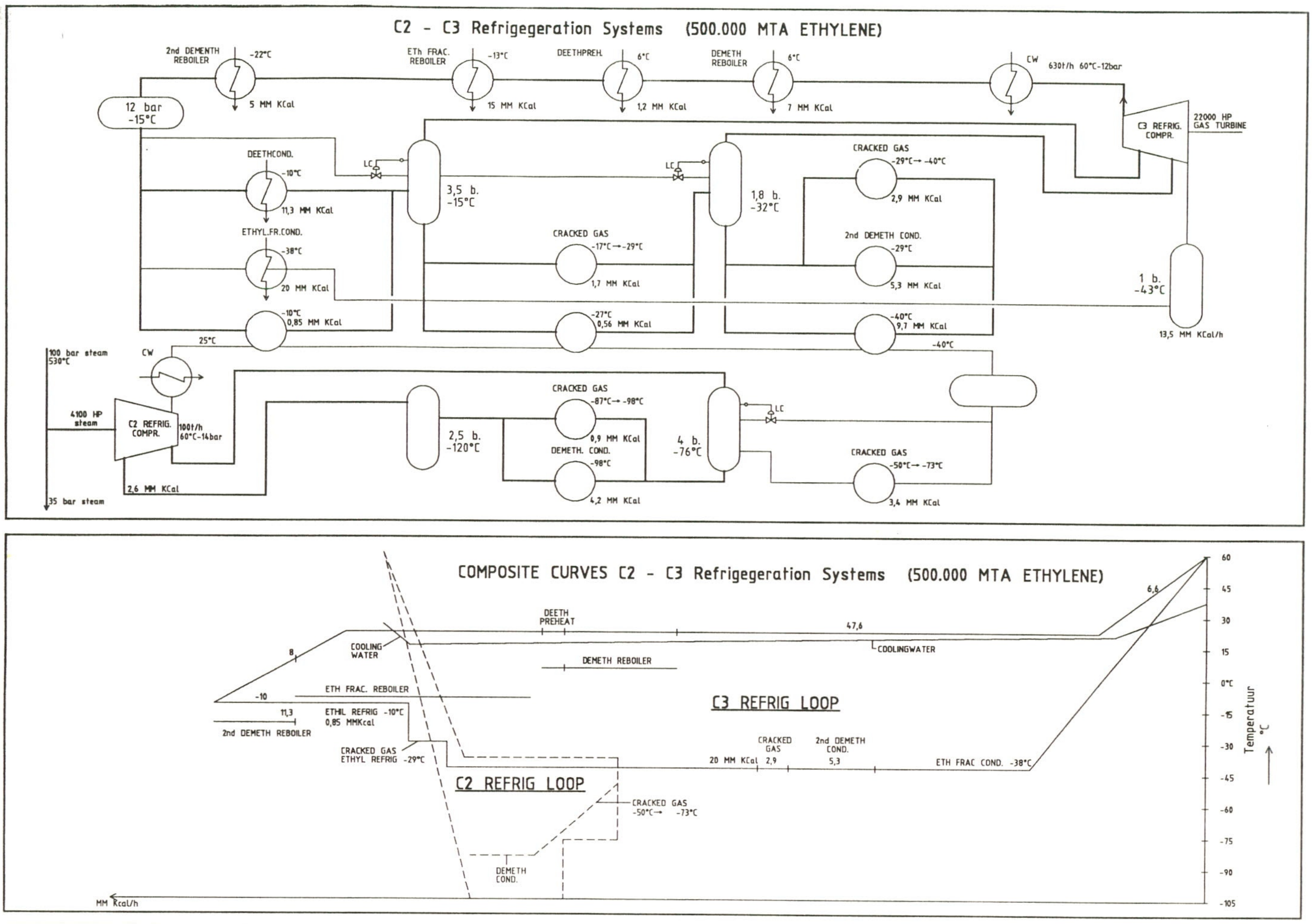


Figure 8.6b Refrigeration systems ethylene process hydrogen rich stream

8.3.1.3.4 Separation - purification

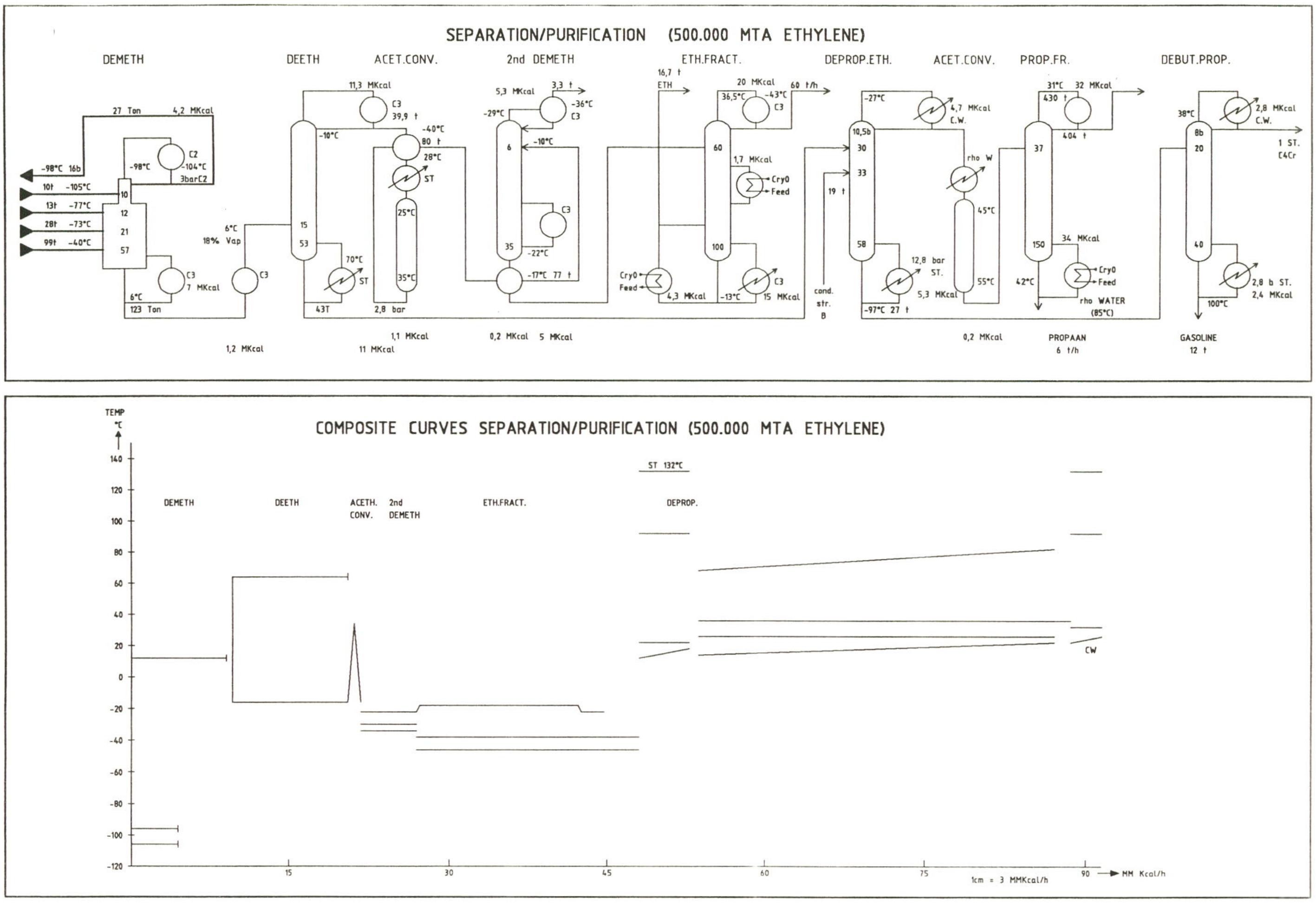


Figure 8.7 Separation/purification ethylene process

Primary demethanizer
The four liquid streams from the cryogenic gas separation are fed to the first demethanizer at four different locations. Each feed point matching the feed tray composition. High pressure methane is produced as top product. Hydrocarbons C2+ are removed in the bottom. The column is reboiled by condensing propylene refrigeration gases, and condensed by ethylene refrigeration at the lowest temperature level (-102 °C).

Deethanizer
The bottom product of the primary demethanizer is fed to the deethanizer. In the deethanizer the C2 fraction is separated from the C4+ fraction. The column is reboiled with 3.5 bar steam and condensed with propylene refrigeration at -10 °C.

Acetylene convertors
The C2 fraction is catalytically hydrotreated to hydrogenate the acetylenes.

Second demethanizer
When impure hydrogen is used for hydrotreating the C2 fraction, a second demethanizer is needed for removing methane and traces of CO and H2, from the C2 fraction. The second demethanizer is reboiled and condensed by means of the propylene refrigeration system.

Ethylene fractionator
The ethylene fractionator separates the ethylene from the ethane. Reboiling and condensing is performed by the propylene refrigeration system.

Depropanizer
The bottom product from the deethanizer is fed to the depropanizer. The depropanizer separates the C3 fraction from the C4+. The column is reboiled with LP steam and condensed with cooling water.

C3 fraction hydrotreaters
To maximise propylene production the C3 fraction is catalytically hydrotreated.

Propylene fractionator
The propylene fractionator separates the propylene from the propane. The column is reboiled by quench water, and condensed by cooling water.

Debuthanizer
The bottom product of the debuthanizer is fed to the debutanizer. The debuthanizer separates the C4 fraction from the C5+ gasoline. The column is reboiled with LP steam and condensed with cooling water.

Ethylene and propylene refrigeration systems
The ethylene and propylene refrigeration systems provide heating and cooling at sub zero temperatures. To minimise the required shaft power, the ethylene and propylene refrigeration systems are highly integrated with each other, and with the separation and purification systems. The working pressures of the various pieces of equipment and the various pressures and temperature levels of the evaporation of propylene and ethylene have carefully to be fitted. To optimize the plants total energy balance, the propylene refrigerating compressor is driven by a gas turbine, the waste heat is used for superheating the high pressure steam generated in the TLE's. The ethylene refrigeration compressor is driven by a steam turbine.

8.3.1.4 Methanol production

In reformers natural gas is converted with steam into synthesis gas in the presence of a nickel catalyst. The synthesis gas is subsequently compressed and fed to the methanol reactor. Methanol is synthesized under mild conditions (relatively low pressure) using a copper based catalyst. By cooling of the product stream the methanol is condensed. Unconverted gas components are recycled to the reactor.

The liquid methanol is thereupon purified by distillation. In the first distillation column light components, like dimethyl ether, are removed, while in the second column methanol is separated from higher boiling compounds.

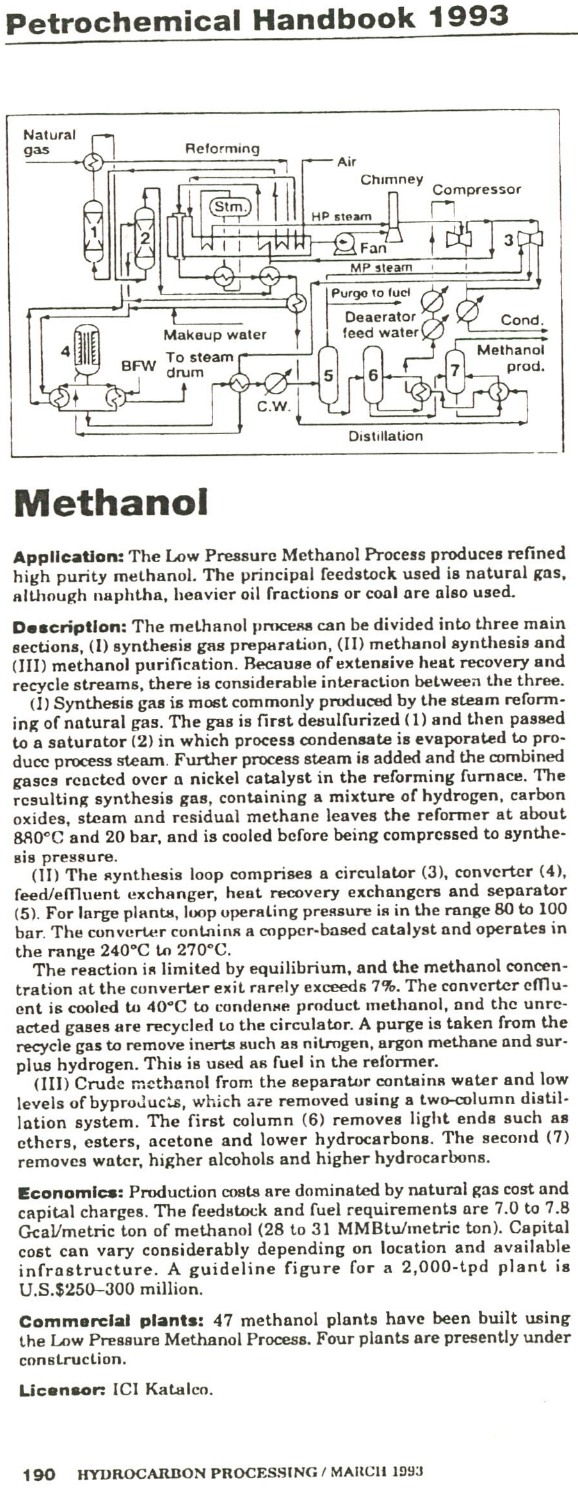
This chapter contains a short description of the methanol production process. In the appendix a process flow diagram and the temperature - heat flux relation of main streams of a methanol plant with a capacity of 740,000 MTA are given.
The primary step in the synthesis of methanol is the generation of synthesis gas, which consists of hydrogen and carbon monoxide. For synthesis gas generation several processes are available, basically using either or both the steam reforming and the partial oxidation route. Since these processes are energy consuming, optimization of its process configurations has drawn major attention in the last two decades.

In this report the conventional steam reforming process has been studied, as it represents the most common synthesis gas generation route. From an energetical point of view however the composition of the synthesis gas generated by steam reforming is not optimal. With the given C/H ratio of natural gas and additional hydrogen obtained by decomposition of process steam, the H_2 surplus is such that the stoichiometric number SN, which is defined as $(H_2\text{-}CO_2)/(CO+CO_2)$, is between 2.7 and 3. This is much higher than 2.0, which is the optimum value for methanol synthesis. The surplus hydrogen requires additional compression energy and behaves as a ballast gas in the synthesis loop. It has to be discharged with the purge gas.

Flowsheet description

Natural gas is preheated in the convection bank of the reformer box and desulphurised using zinc oxide. The gas is mixed with medium pressure steam and routed to the reformer, that is situated in the downfired furnace box.

In the tubular reformer natural gas and steam are converted into synthesis gas at 20 bar in the presence of a nickel catalyst. The heat required for the endothermic reaction is supplied by radiation during combustion of a mixture of natural gas and purged gas from the synthesis loop, outside the vertically positioned reformer tubes. Flue gas from the furnace, augmented with auxiliary firing, is used for boiling and superheating steam and preheating the feedstock. Steam raised in the reformer convection bank is used for driving the turbine drives of the compressor and synthesis loop circulator. Finally flue gas is used for preheating the combustion air used in the burners.



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Methanol

Application: The Low Pressure Methanol Process produces refined high purity methanol. The principal feedstock used is natural gas, although naphtha, heavier oil fractions or coal are also used.

Description: The methanol process can be divided into three main sections, (I) synthesis gas preparation, (II) methanol synthesis and (III) methanol purification. Because of extensive heat recovery and recycle streams, there is considerable interaction between the three.

(I) Synthesis gas is most commonly produced by the steam reforming of natural gas. The gas is first desulfurized (1) and then passed to a saturator (2) in which process condensate is evaporated to produce process steam. Further process steam is added and the combined gases reacted over a nickel catalyst in the reforming furnace. The resulting synthesis gas, containing a mixture of hydrogen, carbon oxides, steam and residual methane leaves the reformer at about 880°C and 20 bar, and is cooled before being compressed to synthesis pressure.

(II) The synthesis loop comprises a circulator (3), converter (4), feed/effluent exchanger, heat recovery exchangers and separator (5). For large plants, loop operating pressure is in the range 80 to 100 bar. The converter contains a copper-based catalyst and operates in the range 240°C to 270°C.

The reaction is limited by equilibrium, and the methanol concentration at the converter exit rarely exceeds 7%. The converter effluent is cooled to 40°C to condense product methanol, and the unreacted gases are recycled to the circulator. A purge is taken from the recycle gas to remove inerts such as nitrogen, argon methane and surplus hydrogen. This is used as fuel in the reformer.

(III) Crude methanol from the separator contains water and low levels of byproducts, which are removed using a two-column distillation system. The first column (6) removes light ends such as ethers, esters, acetone and lower hydrocarbons. The second (7) removes water, higher alcohols and higher hydrocarbons.

Economics: Production costs are dominated by natural gas cost and capital charges. The feedstock and fuel requirements are 7.0 to 7.8 Gcal/metric ton of methanol (28 to 31 MMBtu/metric ton). Capital cost can vary considerably depending on location and available infrastructure. A guideline figure for a 2,000-tpd plant is U.S.$250–300 million.

Commercial plants: 47 methanol plants have been built using the Low Pressure Methanol Process. Four plants are presently under construction.

Licensor: ICI Katalco.

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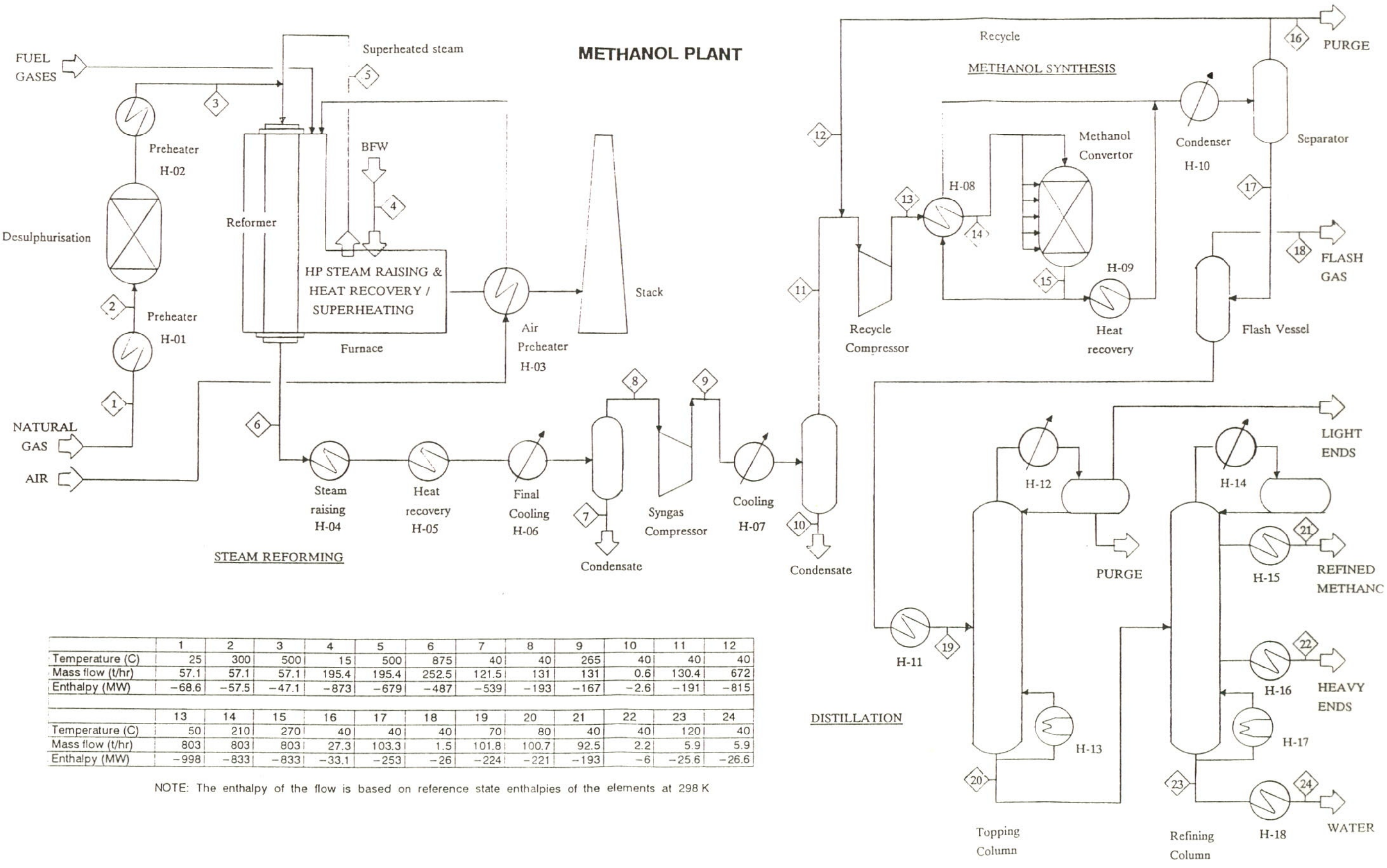
Figure 8.8 Description of the ethylene process

Hot reformed gas is first heat exchanged against boiling feed water, thereby raising more steam. It is thereupon heat exchanged against preheated boiler feed water. Some further heat from the reformed gas is used to preheat the water being fed to the deaerator. The remaining, nonuseful heat is rejected to cooling water, while condensating the surplus steam supplied to the reformer. The synthesis gas is subsequently compressed in a centrifugal compressor and mixed with the loop circulating gas for compression to the pressure of the synthesis loop (about 100 bar). The synthesis gas passes the loop heat interchanger (H-08), where it is heated to the reaction temperature by effluent gas from the converter. Part of the cold feed gas is intermediately fed to the converter in order to absorb exothermal reaction heat.

Methanol is synthesized under mild conditions, i.e. at relatively low pressure and 240 - 270 °C using a copper based catalyst. By cooling of the product stream, ultimately using cooling water, the crude methanol is condensed. Crude methanol is separated from the remaining loop gases in the separator. Unconverted gas components are recycled to the reactor, while part of the flow is purged. The purge is used as fuel in the furnace.



	1	2	3	4	5	6	7	8	9	10	11	12
Temperature (C)	25	300	500	15	500	875	40	40	265	40	40	40
Mass flow (t/hr)	57.1	57.1	57.1	195.4	195.4	252.5	121.5	131	131	0.6	130.4	672
Enthalpy (MW)	−68.6	−57.5	−47.1	−873	−679	−487	−539	−193	−167	−2.6	−191	−815

	13	14	15	16	17	18	19	20	21	22	23	24
Temperature (C)	50	210	270	40	40	40	70	80	40	40	120	40
Mass flow (t/hr)	803	803	803	27.3	103.3	1.5	101.8	100.7	92.5	2.2	5.9	5.9
Enthalpy (MW)	−998	−833	−833	−33.1	−253	−26	−224	−221	−193	−6	−25.6	−26.6

NOTE: The enthalpy of the flow is based on reference state enthalpies of the elements at 298 K

Figure 8.9 Flowsheet of the methanol process

Crude methanol is refined by distillation in two stages. In the first distillation column, the so called topping column, light components like dimethyl ether and dissolved gases are removed, while in the second column, the refining column, methanol is separated from higher boiling compounds, i.e. water and some heavy alcohols.

8.3.2 Applications for heat pumps in the reference processes

In the butane fractionation process, the difference in temperature between the condenser and the reboiler is so small that it is worthwhile recompressing the vaporised top product so that the condensation heat of the top product is released at a temperature which is sufficiently high for the reboiler. This is a potential successful application for MVR (payback time: 4.1 years [C19]). This is an example of an in-unit application for an MVR.
Recompression of the top product from the second naphtha cracker (133.3 °C) means that the condensation heat of this top product can be used for the reboiler of the first naphtha cracker. This MVR has a payback time of 1.7 years. For application of heat pumps in the ethylene process and the methanol process, see chapter 10. The potential for closed cycle heat pumps in the ethylene industry is 26 MW. There is no potential for heat pumps in the methanol process, see chapter 10.

8.3.3 Process integration in the manufacture of base organic chemicals

In this sector, much work is being done on process integration, more in fact than in any other sector. It is tailormade for process integration. In many cases the internal exchange of heat can be achieved economically by using heat exchanger networks.
There are numerous possibilities for heat pumps, particularly in and between distillation columns, in which recompression of top products is worthwhile in order to fulfil the heat requirement of reboilers in the same or other columns. The payback time of these columns is short, particularly where the internal power tariff is low thanks to combined heat and power systems. Up to the present, however, heat exchanger (networks) have been in the lead as compared with heat pumps because of the short payback times. In a number of cases, the limits of internal exchange have been reached, and the heat pump is the most obvious choice for reducing the consumption of primary energy.

8.3.4 Heat pump potential in the manufacture of base organic chemicals

The potential for MVR has been estimated by [A7] at about 100 to 200 units with a thermal capacity of about 500 MW each.
The basis for this estimate is not clear. This particular sector of industry is in any case extremely reluctant to provide information about the heat regulation of its processes. Although many energy saving measures have been adopted, it remains a fact that it is in this sector that the largest – absolute – saving can be achieved. The potential for closed cycle heat pumps is unknown.

8.4 Inorganic base chemicals manufacture

Number of concerns: ?

Reference processes:
- Production of titanium dioxide
- Salt evaporation

8.4.1 Description of the reference processes

Titanium dioxide

A pinch study was carried out in a titanium dioxide factory by the Energy and Process Integration Services department of Harwell Laboratories, UK. Titanium dioxide is mainly used as a pigment in the dyestuffs industry. The figure below depicts the process:

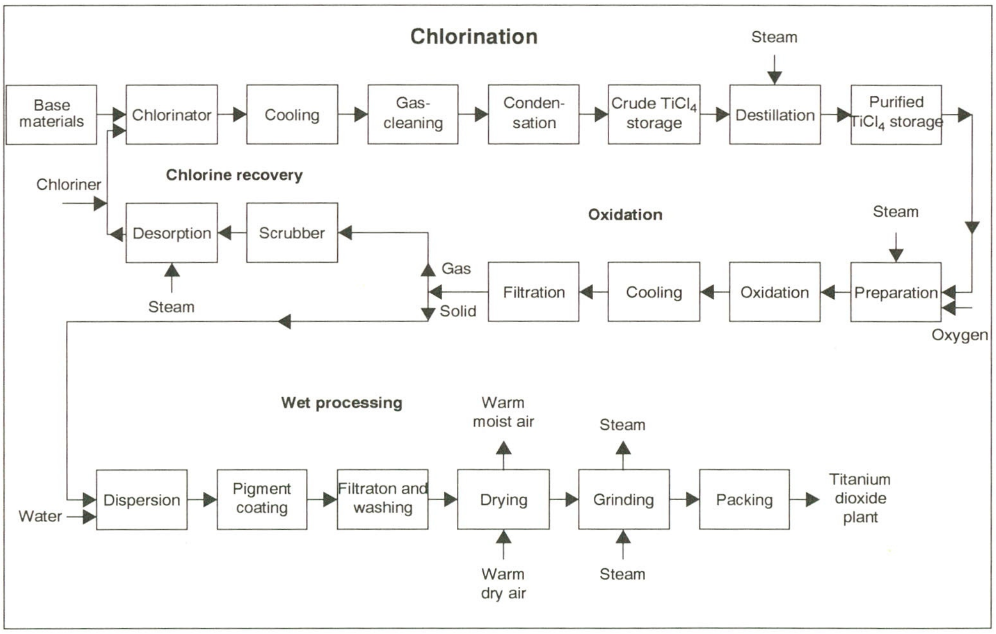


Figure 8.10 Block diagram of Tioxide plant

The process goes through the following stages:

The titanium ore is converted into titanium tetrachloride ($TiCl_4$) in a high-temperature fluid bed reactor, after which the $TiCl_4$ is condensed and purified.
Next, the titanium chloride is oxidised to form pure titanium dioxide in a high-temperature reactor. Solid and gaseous products are separated out by filtration. Chlorine gas is recovered from the gaseous products by means of an absorption/desorption process and then returned to the fluid bed reactor.

The solids are passed through a dispersion of water in order to give the product the desired properties. After this, it is dried and ground.
Virtually all the process heat is supplied in the form of (20 bar) steam.

Salt

The salt evaporation process is carried out in multi-stage evaporators. So far as is known no thermal or mechanical vapour recompression is applied in The Netherlands, although this would result in a reduction in the primary energy consumption.

8.4.2 Applications for heat pumps in the reference processes

Titanium oxide

As at present carried out, the titanium dioxide process does offer the possibility of heat recovery, but not through heat pumps. The grand composite curve of the final process stage, the wet treatment plant, is not 'sharp' enough in the vicinity of the pinch, which means that the temperature lift is too great for the application of heat pumps.

Salt

In The Netherlands salt industry power is generated by means of STEG (Steam and Gas Turbine) units. There appears to be a surplus of low-pressure steam, probably because the STEG units are oversized (a considerable part of the electricity is sold off) and energy-saving measures. In view of this situation, there is absolutely no inducement to recompress the product vapour with electricity generated by the last (low-pressure) steam turbine stage.

8.4.3 Process integration in the manufacture of base inorganic chemicals

In this sector of industry too, there is considerable interest in process integration. The measures taken mostly affect internal heat exchange. In the reference process in the Harwell study [C2], heat from the $TiCl_4$ cooler was conveyed to the stripping column (for reboiling). The heat released by the cooling of the oxide can be used for pre-heating the feedstock. In addition, by exchanging heat from the top product of the stripping column with the feedstock for the column, considerable savings are possible in the chlorine recovery plant. The temperature difference between the condenser and the reboiler of the stripper is about 35 °C, which is on the high side for a temperature lift.

8.4.4 Heat pump potential in the manufacture of inorganic chemical raw materials

Not enough information is available from the Dutch inorganic chemical industry to permit an estimate of the potential for heat pumps. At the present time, so far as is known, no heat pumps are applied in the inorganic chemical raw materials industry.

There is probably quite a large potential for heat transformers in this sector of industry, but the profitability is low because of the very low internal price of low-pressure steam.

MVR can be applied in a number of cases, especially in stripping and distillation columns with a small temperature difference between condenser and reboiler, linked together above the pinch.

In the salt industry there is a reasonable potential for MVR. In view of the present surpluses of low-pressure steam and the presence of excessively large STEG units, the only potential is in new plants.

8.5 The synthetic resins industry

Number of concerns: 24.

Reference processes: - Production of polybutadiene

8.5.1 Description of reference process

This process involves the polymerisation of butadiene monomer with the aid of toluene [C12]. Butadiene, the base material, is first dried and then cooled to 23 °C. After this it is mixed with toluene and cooled in an (ammonia) cooling machine down to -2.7 °C. This mixture is then conveyed to a reactor, where the exothermic polymerisation reaction takes place. The reactor is cooled with ammonia. On emerging from the reactor, the mixture is heated and volatile components (butadiene monomer and toluene) are flashed out (at about 150 °C). This takes place in three stages, at each of which the temperature rises. The vapours from the three flash drums are collected and condensed (90% toluene, 10% butadiene monomer and a little polybutadiene). The polybutadiene liquid is then stripped of water and toluene by steam. The wet toluene is dried and returned to the process. The bottom product from the strippers, polybutadiene, is filtered and dried to form the end product.

8.5.2 Applications for heat pumps in the reference processes

The above-mentioned report cites possible applications for two MVR systems with a short payback time. Toluene/water vapour is compressed and used to raise fresh steam for the strippers. The payback times are 0.9 and 2 years respectively. The mechanical capacity of these MVR systems is 183 kW and 2200 kW respectively.

8.5.3 Process integration in the synthetic resins industry

The process pinch lies in the region of 92 °C. It is referred to as a 'sharp' pinch (small DT and large heat flows).
For this reason the use of the above-mentioned MVR installations would be fully justified.

8.5.4 Heat pump potential in the synthetic resins industry

Not enough information is available from the Dutch synthetic resins industry to make it possible to estimate the potential for heat pumps. At the present time - so far as is known - no heat pumps are applied in the synthetic resins industry.

There is probably a reasonable potential for MVR in this sector of industry, particularly in the area of steam strippers. There are possibly also applications for heat transformers. In the plant studied in the United States, however, the payback times for heat transformers were too long (about 9 years).

9 Potential for heat pumps in base metals

9.1 General

The base metals sector is divided up as follows:
- pig iron and steel industry;
- steel piping plants;
- wire-drawing and cold rolling mills;
- non-ferrous metals industry.

As far as energy consumption is concerned, by far the largest share goes to the primary metal industry. Steel and aluminium production taken together account for over 98% of the thermal and 85% of the electrical energy consumption [A4]. The three concerns active in this field in The Netherlands are Hoogovens, Aluminium Delfzijl and Pechiney. More detailed information about the energy consumption of the base metals industry is to be found in Table 9.1.

Table 9.1 Specific energy consumption - base metals

	Thermal energy consumption		**Electricity consumption**	
	Total (TJ)	**Specific (MJ/ton)**	**Total (TJ)**	**Specific (MJ/ton)**
Blast furnace steel	83,360	16,345	5,290	1,037
Electric steel	793	3,448	709	3,083
Steel pipe manufacture	475	-	108	-
Other processes (rolling mills etc.)	570	-	324	-
Primary aluminium	1,209	4,545	14,210	53,421
Primary zinc	54	276	2,874	14,663
Non-ferro metal-smelting	637	-	30	-
Total	87,098	n/a	23,545	n/a

Heat pumps would be applied to raise heat from too low a temperature to a level at which the heat can be used. For this reason it is mainly the use of thermal energy which is interest in the present investigation.
This report only touches on the industrial processes for the manufacture of steel and aluminium, because these two processes account for the majority of the energy consumption in this sector.

9.1.1 Description of reference processes

Steel

The production process for steel can be divided into a number of stages. Figure 9.1 shows in diagrammatic form how this process is structured.

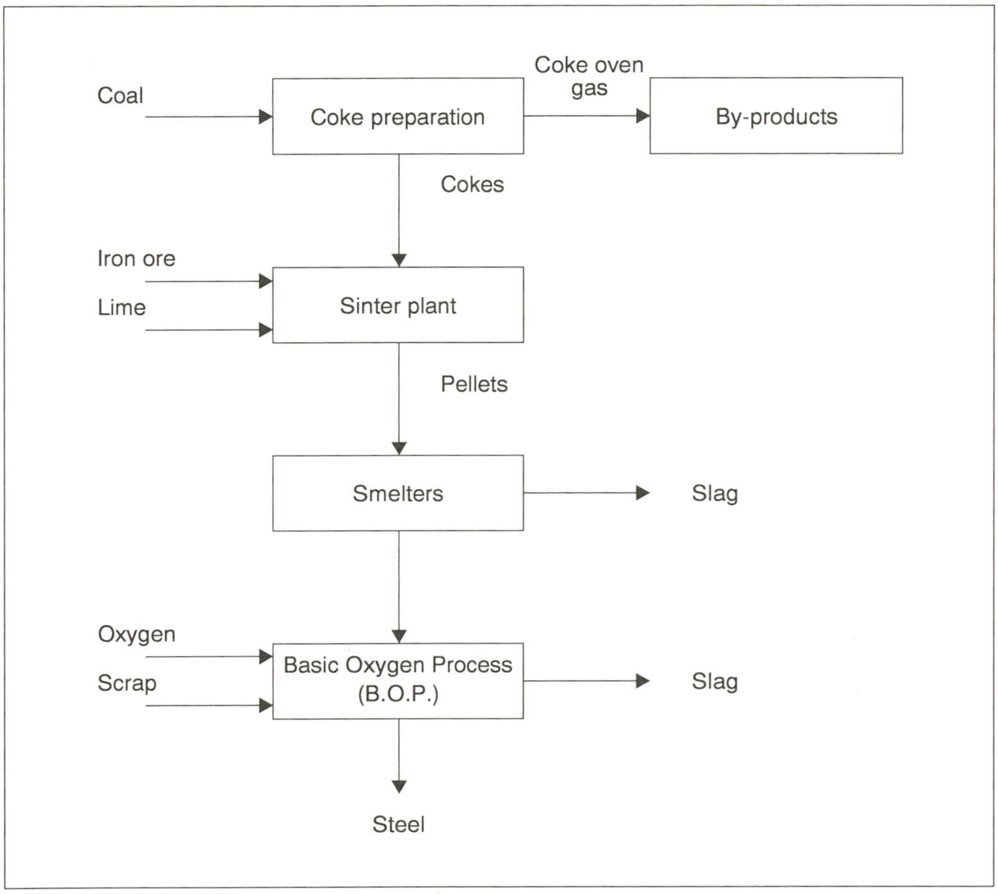


Figure 9.1 Steel production process

First of all, coal is converted into coke in the coke ovens. This is done by heating the coal to 800-850 °C, thus eliminating volatile components. These gases yield a number of by-products (including ammonium sulphate), after which the gas is used to fire the coke ovens, and to provide heat for other processes. The cokes go to the sintering plant, where particles of iron ore, coke and lime are compressed together to form pellets, which are then conveyed to the smelter furnaces. The ore in the pellets contains iron oxide which is reduced by the coke to give liquid iron. The sulphur present is bound by the lime.

After the liquid pig iron has been produced from the ore, further processing is needed to make steel from the iron. For this purpose, the quantity of carbon in the iron must be reduced from 4-4.5% to 0.1-1.5%. The process most commonly applied nowadays

is the basic oxygen process, whereby a proportion of scrap (maximum 25%) is added to the pig iron. Oxygen is blown through this mixture at a high temperature, with the result that part of the carbon present in the iron oxidises and forms CO. Other components such as manganese and silica are also removed during this process.
The steel is poured into moulds in a foundry. After this it is further processes in rolling mills, steel pipe-making plants, wire-drawing mills, etc.
Another method of manufacturing steel is the electro-steel process. Here too pig iron is mixed with scrap. In this case, however, the percentage of scrap can be much higher than for the basic oxygen process (up to 100% scrap). In this process, the mixture of scrap and pig iron is melted by the formation of an arc between electrodes and the mixture.

Aluminium

Figure 9.2 shows a diagrammatic representation of aluminium manufacture. Alumina is separated by electrolysis into aluminium and oxygen. The aluminium goes to the smelters, where it is mixed with scrap and alloyed. After this it is moulded into blocks and sheets and further processed. As can also be seen from the diagram, the surplus heat is removed by air and cooling water.

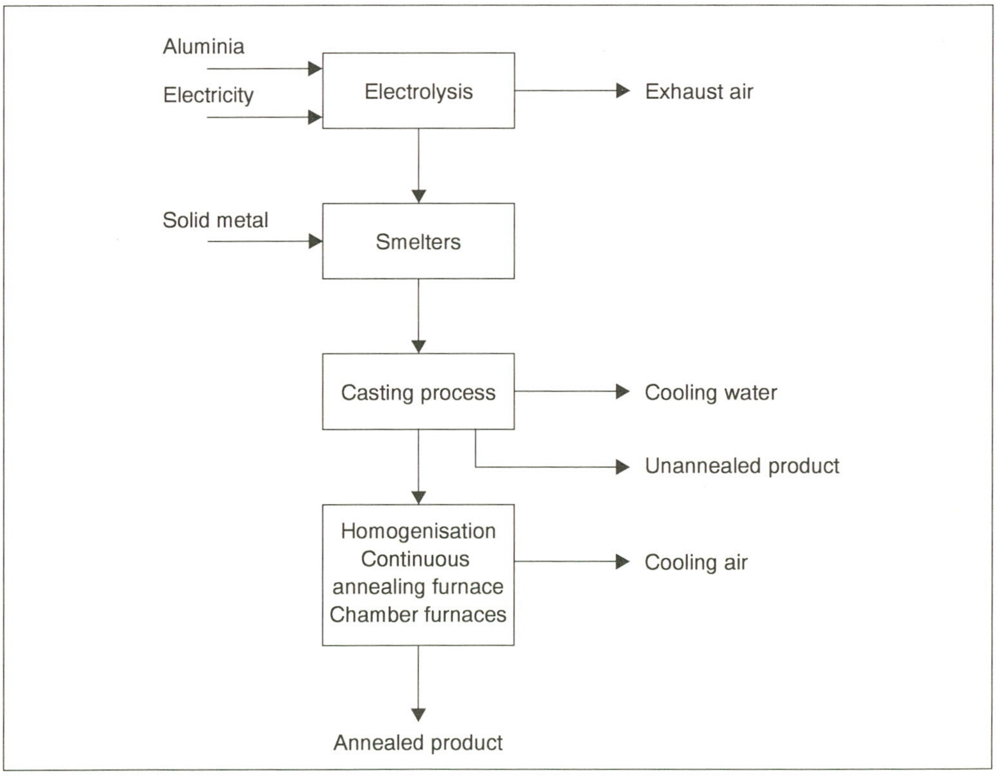


Figure 9.2 Aluminium production process

9.2 Process integration in the base metals industry and possibilities for heat pumps

The possible applications for heat pumps mainly reside in processes where there is a transition from the liquid phase to the vapour phase or vice versa. These processes are characterised by a large difference in enthalpy with a small variation in temperature. In this section we shall investigate the possibilities for the application of heat pumps.

9.2.1 Steel

Application of heat pumps in the steel industry appears to be a lost cause, because of the high temperatures used in this sector. When we study the potential, however, the pinch temperature of the individual sections of the processes is of great importance. Although information is not available on this subject from the Dutch steel industry, it is possible to arrive at an estimate. In 1987 and 1988 pinch studies were carried out in the British steel industry [B1, B2]. Heat pumps were not the only possibility mentioned in these studies. For every production unit the cold and hot flows were listed and composite curves plotted. The British Steel Corporation (BSC) discovered that the pinch temperatures of some units were surprisingly low. Table 9.2 gives these figures. Since some units consist of several plants, there may be more than one pinch temperature.

Table 9.2 Pinch temperatures for BSC steelmaking

Production unit	Pinch-temperature (°C)
Coke ovens	57, 59
By-products	102, 120
Sinter plant	> 1,000
Smelters	134
Basic oxygen process	> 1,000
Rolling mills	825
Combined heat and power unit	33

If the pinch temperatures alone are considered, there are definite possibilities for the application of heat pumps, both in the smelters and the coke ovens, and in the plant where by-products are obtained. Unfortunately, the studies do not give any details of enthalpies, so that nothing can be said about the capacity of any heat pumps. It is by their capacity that the application of heat pumps stands or falls.

Applications in The Netherlands

In The Netherlands, Hoogovens IJmuiden possesses an efficient heat transformer. This heat transformer raises residual heat from the hot rolling mill from about 90 °C to over 130 °C. This heat is used to raise low-pressure steam. The working pair is LiBr/water and the usable capacity amounts to 4.1 MW.
It is not known whether this transformer is entirely in line with the rules of pinch technology. If we examine the data from British Steel Corporation, the pinch temperature for the rolling mills is 825 °C, and a heat demand of 130 °C would have to be entirely met by higher temperature residual heat. It is however possible that this heat cannot be exploited, perhaps for reasons of safety. Another possibility is that the two concerns are not fully comparable. Be that as it may, in any case Hoogovens found it worthwhile to install a heat transformer.

9.2.2 Aluminium

It is impossible to say anything about the possibilities in the aluminium industry. The temperatures of the various furnaces are all very high, so that the chances for the application of heat pumps appear to be small. In the previous paragraph, however, it was shown that the furnace temperature is not per se the pinch temperature. More detailed information is therefore necessary to enable us to determine whether the application of heat pumps is worthwhile.

9.3 Heat pump potential in the base metals industry

Steel

There are definite possibilities for applying heat pumps in the steel industry. Hoogovens IJmuiden already has a heat transformer. In addition, a pinch study for British Steel Corporation (BSC) shows that the pinch temperatures for some processes are low. The following pinch temperatures were recorded for BSC:

- Coke oven: 57 and 59 °C;
- By-products: 102 and 120 °C
- Smelters: 134 °C.

However, without additional information, the potential cannot be quantified.

Aluminium

The opportunities in the aluminium industry appear slight, on account of the high temperatures and the high proportion of electrical energy consumed. At this stage, however, there is insufficient information for us to be able to say with certainty that application of heat pumps in this sector has no future.

10 Heat pump implementation in several selected processes in the Dutch industry

10.1 Introduction

In phase 2 of this project, the thermal data of eight Dutch processes have been gathered:

- A Textile Plant[1)]
- A Dairy (Whey, milk, cheese) Plant
- A Paper Production Plant
- A Building Ceramics (Bricks, Tiles) Plant
- A Ureum Process (200.000 MTA)
- An Ethyle Plant (500.000 MTA)
- A Methanol Plant (740.000 MTA)
- A Starch evaporation Plant

With these thermal process data, calculations are made with the IEA/Annex 21 computer programme, developed by Chalmers University, see appendix 5. The first step of calculation is making composite curves using the thermal data. From these composite curves a grand composite curve is made and a minimum heat demand curve.

The Annex 21/Chalmers/ETA programme contains the data of 50 commercial available heat pumps. With the option 'integration' it is possible to combine a selected heat pump and a selected process.

The Chalmers/ETA programme is based on Pinch Technology. From the thermal data, the programme builds composite curves and a grand composite curve of the process. From these curves, a first thermodynamic evaluation of heat pumps is possible.
A very useful feature of the programme is the minimum heat demand curve. This curve gives the diminuation of the heat demand as a function of the global DT min, the temperature difference between the hot and the cold composite curve. Implicitely, this curve gives the effect of an increase of (internal) heat exchanging on the heat (and cooling) demand of a process. In some case, the heat demand decreases dramatically by diminuation of the global DT min. In that cases, relatively large energy savings are achieved with heat exchangers. After heat exchanger implementation, heat pumps are taken into account. In some other cases, the DTmin doesn't seem to influence the heat demand. In that case conventional heat exchangers are possibly not very economical, and heat pump implementation has good possibilities.
The programme contains an extensive list of commercial heat pumps. The user of the programme can combine these heat pumps with the process, conform the Pinch Rule for heat pumps: The heat source of the heat pump must be beneath the pinch, the sink above the pinch, thus pumping heat from the surplus area to the deficiency area. In a lot of cases, the implementation of heat pumps requires additional heat exchangers. The programme calculates the number of heat exchangers. The chosen implementation can be evaluated both technically and economically.

[1)] This data came from the U.S. textile industry. This process is nevertheless representative for the Dutch textile industry.

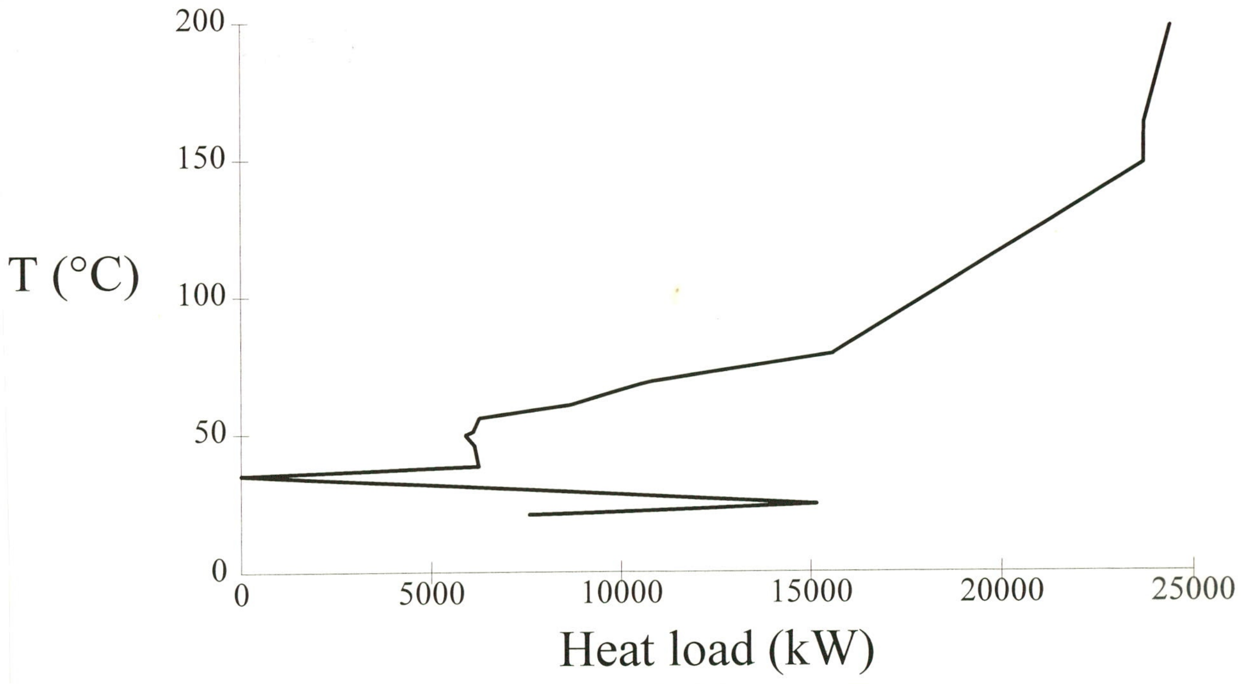
The capacity of the heat pump, the driving energy, the COP, the number of additional heat exchangers, the decrease of heat demand as a percentage of the total heat demand, the pay back period, annual profit, capital and maintenance costs are calculated

RCG/Hagler/Bailly Inc. has developed a spread sheet to evaluate the effects of the combination of the individual Heat Pump integration results on the national energy balance and the emissions on national scale, see appendix 6.

As said in the introduction, it was very difficult to get results of Pinch studies of Dutch processes. Only eight individual integration studies are gathered and implemented in the Chalmers/ETA and the RCG/Hagler/Bailly Inc. programmes. In some cases, the results of the integration are contra-intuitive and not conform the industrial experiences of heat pump implementations in The Netherlands. From an economical point of view, only heat pumps with a pay back period shorter than ten years are taken into account.

10.2 Heat pump implementation in the textile process

The thermal data of this study came from a U.S. Pinch study. In The Netherlands, no Pinch study was carried out in the textile industry. The process, described in [D3] is similar to the Dutch processes in the textile industry. This plant is much larger than the regular Dutch plants.



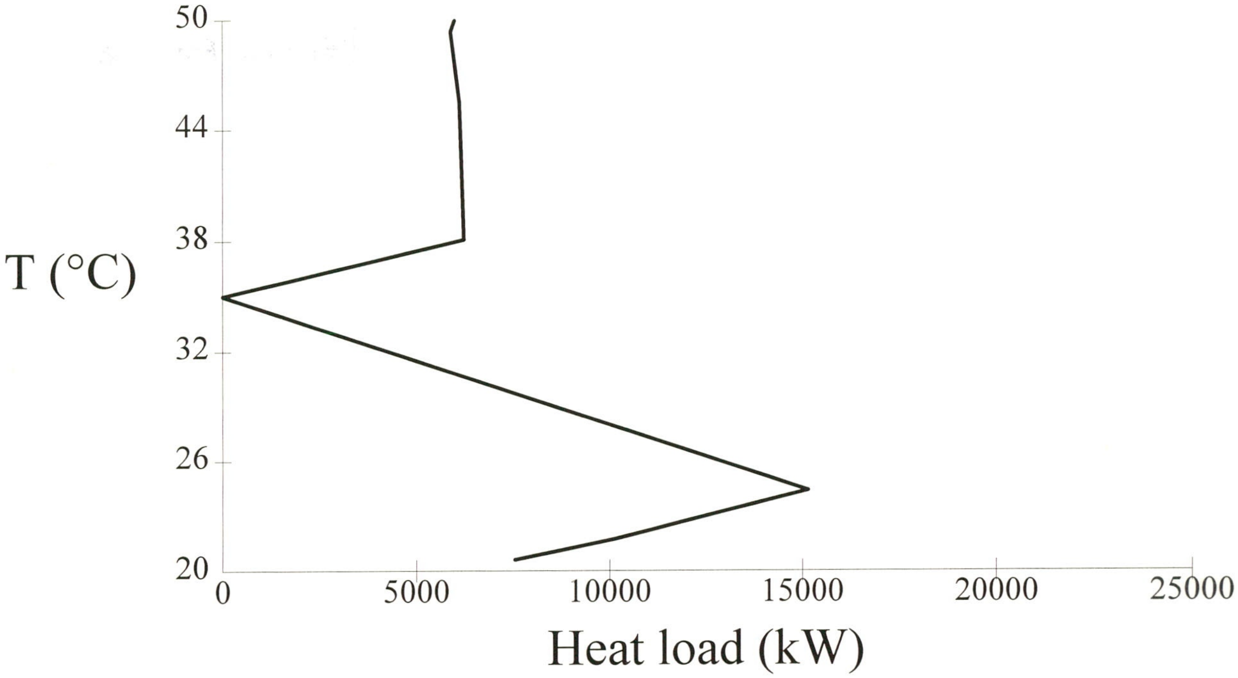


Figure 10.2.1 Grand Composite Curve of a Textile Plant

Figure 10.2.1 gives the grand composite curve of this process.
From this grand composite curve, it is easily seen that a compression heat pump is appropriate. Before that, implementation of conventional HE's is advisable to achieve a DTmin of 10 °C, as can be seen from figure 10.2.2, where the heat demand of this process is depicted as a function of ΔTmin.

Possible heat pumps are a 6300 kW gas motor driven compression heat pump with screw compressor and R22 as working fluid and a 6200 kW gas motor driven compression heat pump with turbo compressor and R114 as working fluid. The pay back time of the R22/screw combination is attractive, see table 10.2.1 and table 10.2.2. The turbo/R114 has a relative long pay back period, see table 10.2.3 and table 10.2.4.

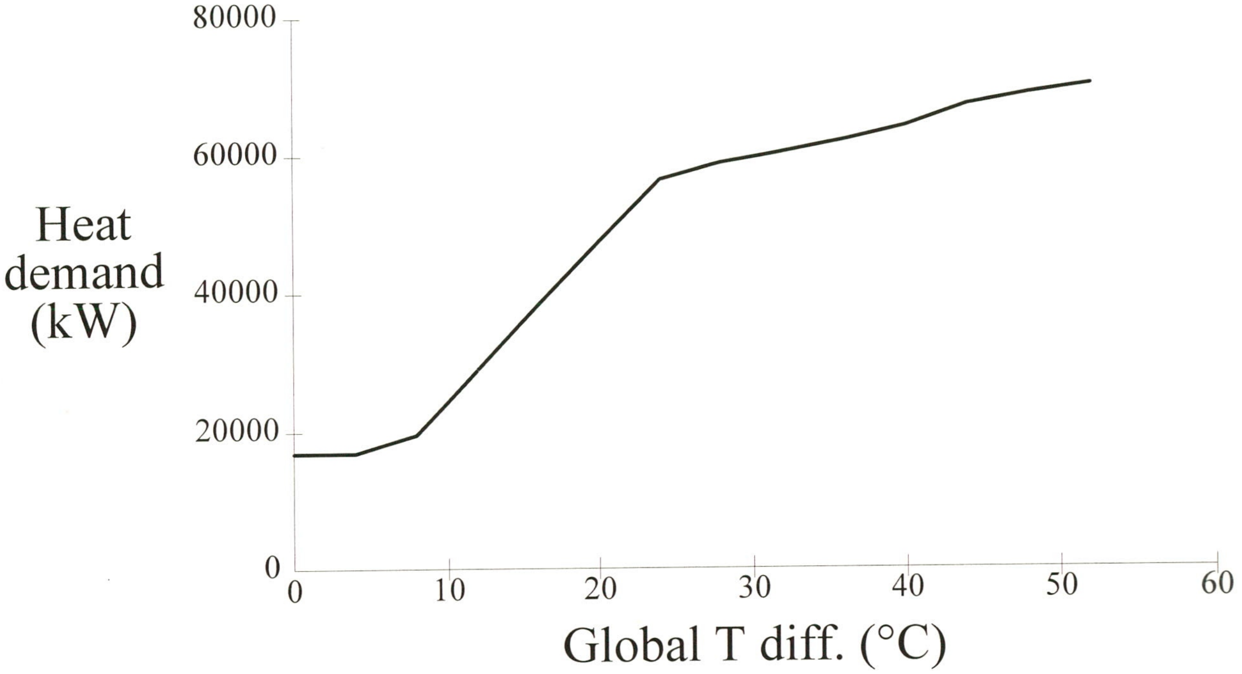
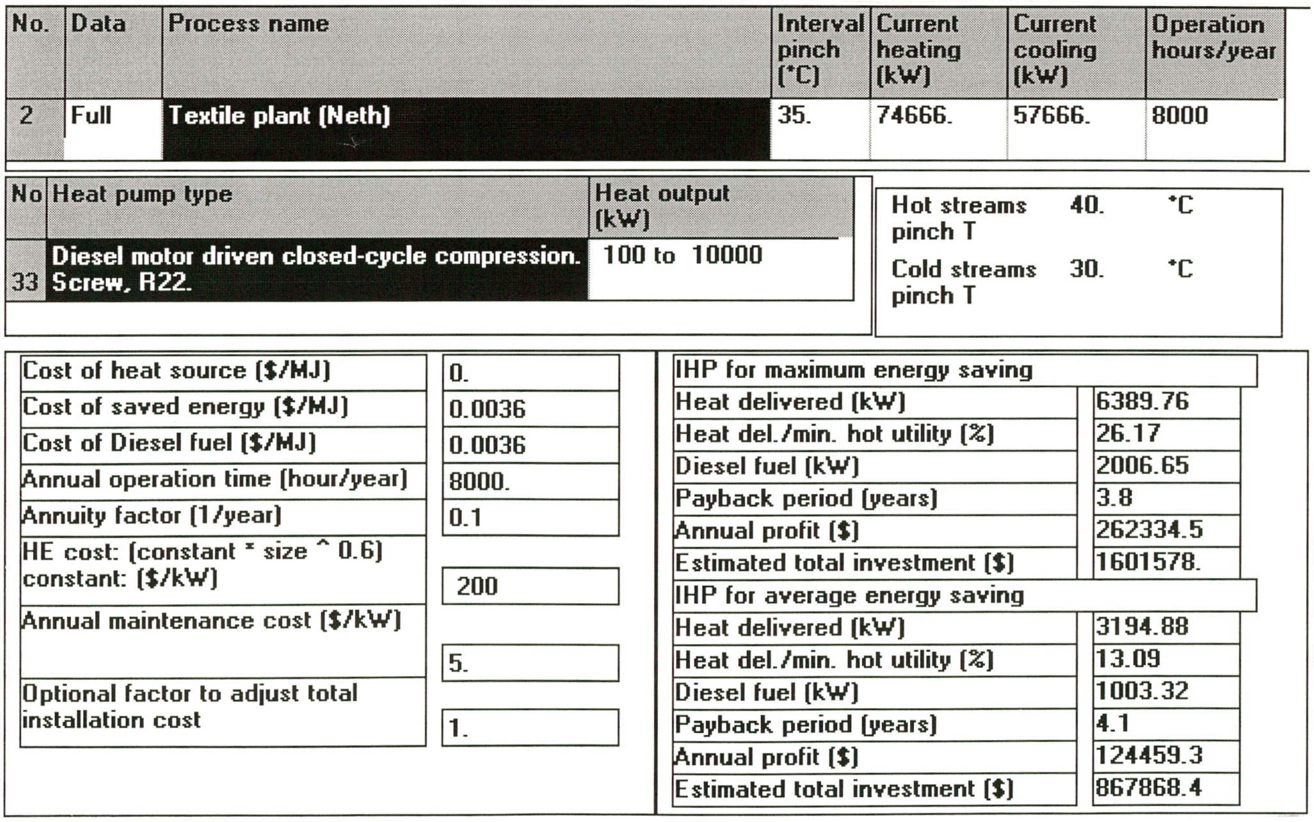


Figure 10.2.2 Minimum heat demand of a textile plant

Table 10.2.1



No.	Data	Process name	Interval pinch (°C)	Current heating (kW)	Current cooling (kW)	Operation hours/year
2	Full	**Textile plant (Neth)**	35.	74666.	57666.	8000

No	Heat pump type	Heat output (kW)
33	**Diesel motor driven closed-cycle compression. Screw, R22.**	100 to 10000

Hot streams pinch T	40.	°C
Cold streams pinch T	30.	°C

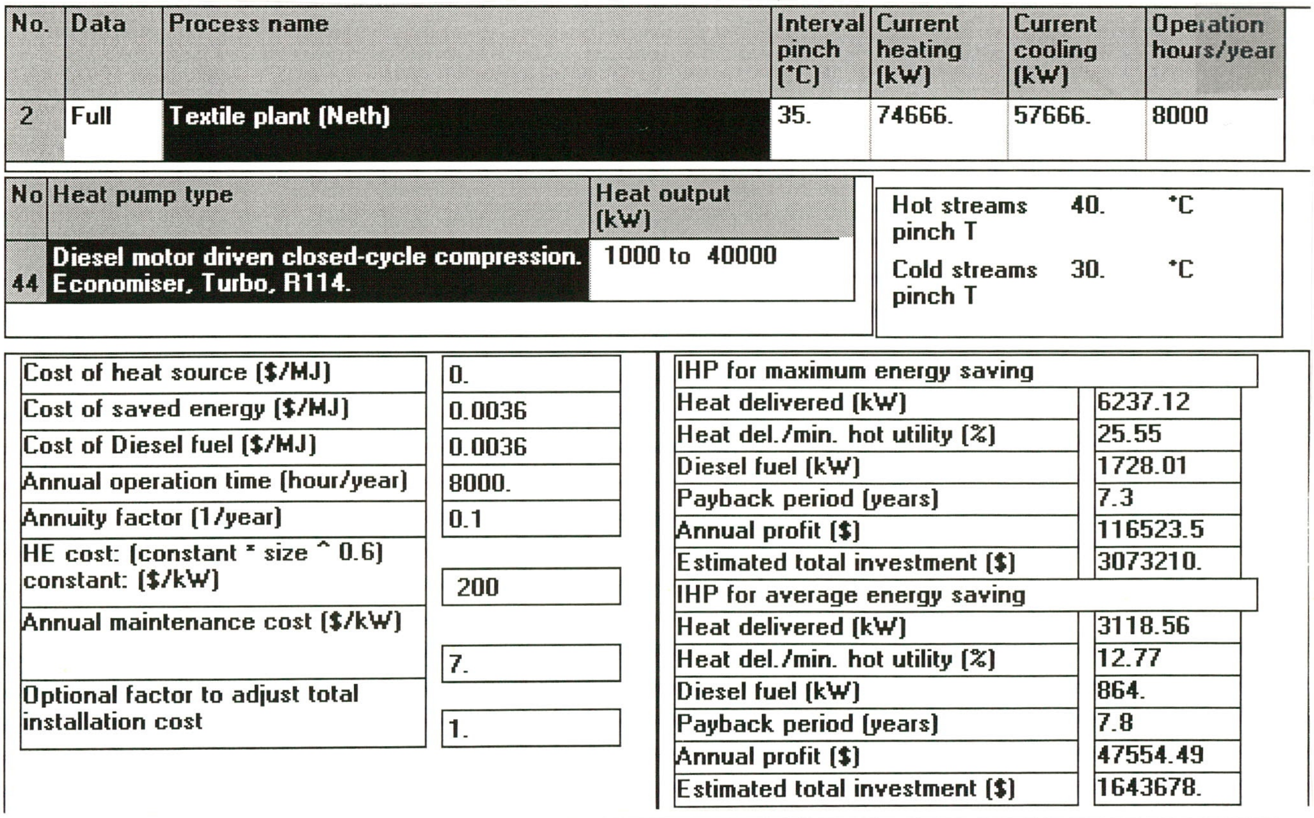
Cost of heat source ($/MJ)	0.
Cost of saved energy ($/MJ)	0.0036
Cost of Diesel fuel ($/MJ)	0.0036
Annual operation time (hour/year)	8000.
Annuity factor (1/year)	0.1
HE cost: (constant * size ^ 0.6) constant: ($/kW)	200
Annual maintenance cost ($/kW)	5.
Optional factor to adjust total installation cost	1.

IHP for maximum energy saving	
Heat delivered (kW)	6389.76
Heat del./min. hot utility (%)	26.17
Diesel fuel (kW)	2006.65
Payback period (years)	3.8
Annual profit ($)	262334.5
Estimated total investment ($)	1601578.
IHP for average energy saving	
Heat delivered (kW)	3194.88
Heat del./min. hot utility (%)	13.09
Diesel fuel (kW)	1003.32
Payback period (years)	4.1
Annual profit ($)	124459.3
Estimated total investment ($)	867868.4

Table 10.2.2

Results valid for process no 2 and IHP no 33	Maximum saving.	Average saving.
Annual heat delivered by the heat pump (MJ)	184025000.	92012520.
Annual Diesel fuel consumption (MJ)	57791420.	28895710.
Annual value of heat delivered ($).	662490.13	331245.06
Annual cost of Diesel fuel. ($)	208049.09	104024.55
Annual cost of source energy ($).	0.	0.
Estimated heat pump installtion cost ($).	1365658.25	708486.75
Estimated number of additional heat exchangers.	8.	6.
Estimated cost of additional heat exchangers ($).	235919.5	159381.7
Estimated annual maintenance cost ($).	31948.79	15974.4
Payback period (years).	3.8	4.1
Annual profit ($).	262334.5	124459.3
COP (-).	3.18	3.18
Delivering temperature (°C)	55.85	55.85
Extraction temperature (°C)	31.28	31.28

Table 10.2.3



No.	Data	Process name	Interval pinch (°C)	Current heating (kW)	Current cooling (kW)	Operation hours/year
2	Full	Textile plant (Neth)	35.	74666.	57666.	8000

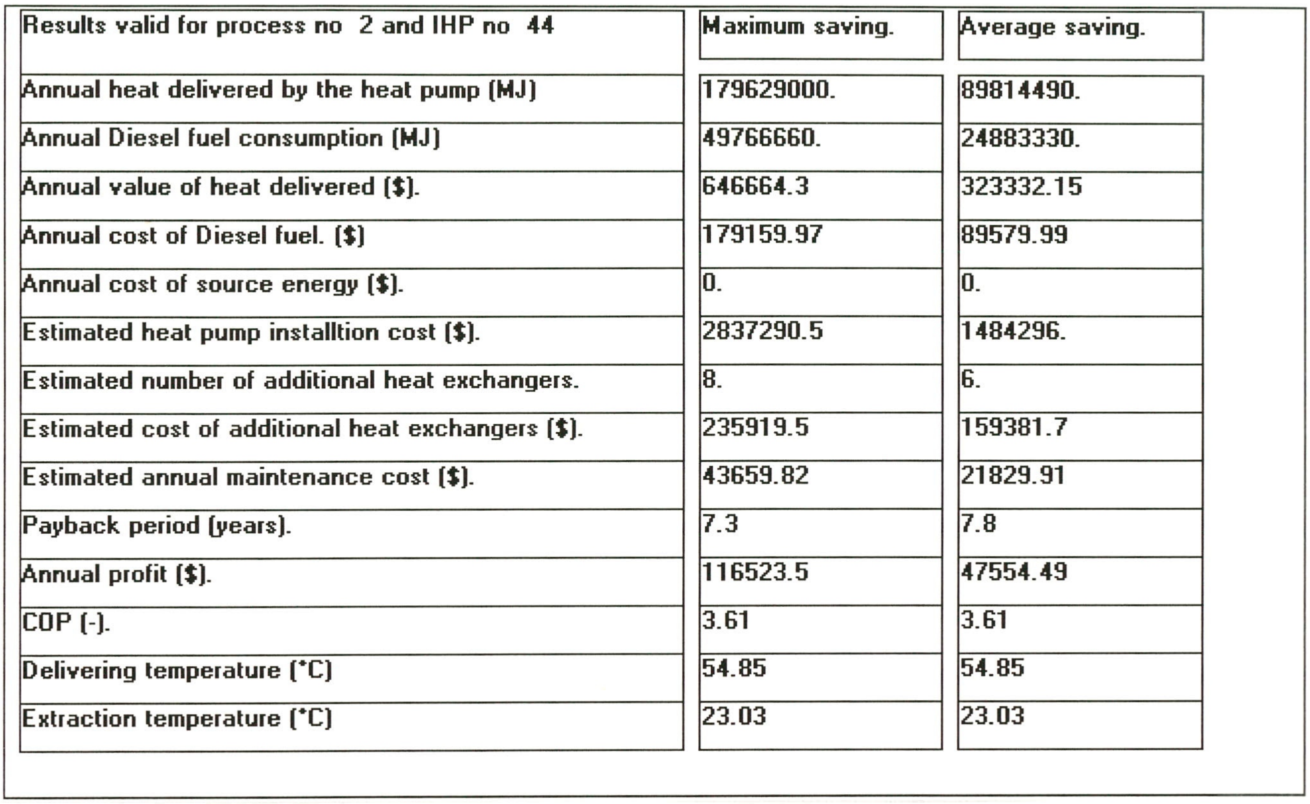
No	Heat pump type	Heat output (kW)
44	Diesel motor driven closed-cycle compression. Economiser, Turbo, R114.	1000 to 40000

Hot streams pinch T	40.	°C
Cold streams pinch T	30.	°C

Cost of heat source ($/MJ)	0.
Cost of saved energy ($/MJ)	0.0036
Cost of Diesel fuel ($/MJ)	0.0036
Annual operation time (hour/year)	8000.
Annuity factor (1/year)	0.1
HE cost: (constant * size ^ 0.6) constant: ($/kW)	200
Annual maintenance cost ($/kW)	7.
Optional factor to adjust total installation cost	1.

IHP for maximum energy saving	
Heat delivered (kW)	6237.12
Heat del./min. hot utility (%)	25.55
Diesel fuel (kW)	1728.01
Payback period (years)	7.3
Annual profit ($)	116523.5
Estimated total investment ($)	3073210.
IHP for average energy saving	
Heat delivered (kW)	3118.56
Heat del./min. hot utility (%)	12.77
Diesel fuel (kW)	864.
Payback period (years)	7.8
Annual profit ($)	47554.49
Estimated total investment ($)	1643678.

Table 10.2.4



Results valid for process no 2 and IHP no 44	Maximum saving.	Average saving.
Annual heat delivered by the heat pump (MJ)	179629000.	89814490.
Annual Diesel fuel consumption (MJ)	49766660.	24883330.
Annual value of heat delivered ($).	646664.3	323332.15
Annual cost of Diesel fuel. ($)	179159.97	89579.99
Annual cost of source energy ($).	0.	0.
Estimated heat pump installtion cost ($).	2837290.5	1484296.
Estimated number of additional heat exchangers.	8.	6.
Estimated cost of additional heat exchangers ($).	235919.5	159381.7
Estimated annual maintenance cost ($).	43659.82	21829.91
Payback period (years).	7.3	7.8
Annual profit ($).	116523.5	47554.49
COP (-).	3.61	3.61
Delivering temperature (°C)	54.85	54.85
Extraction temperature (°C)	23.03	23.03

10.3 Heat pump implementation in a Dairy production (Cheese, whey, milk) plant

With the Chalmers programme, it is impossible to evaluate a process with several (near) pinches, as appear in multi stage evaporators in the Dairy industry. Only one heat pump with sink above the 'highest pinch' and source beneath the 'lowest pinch' is implementable. Figure 10.3.1 gives the grand composite curve of this process.

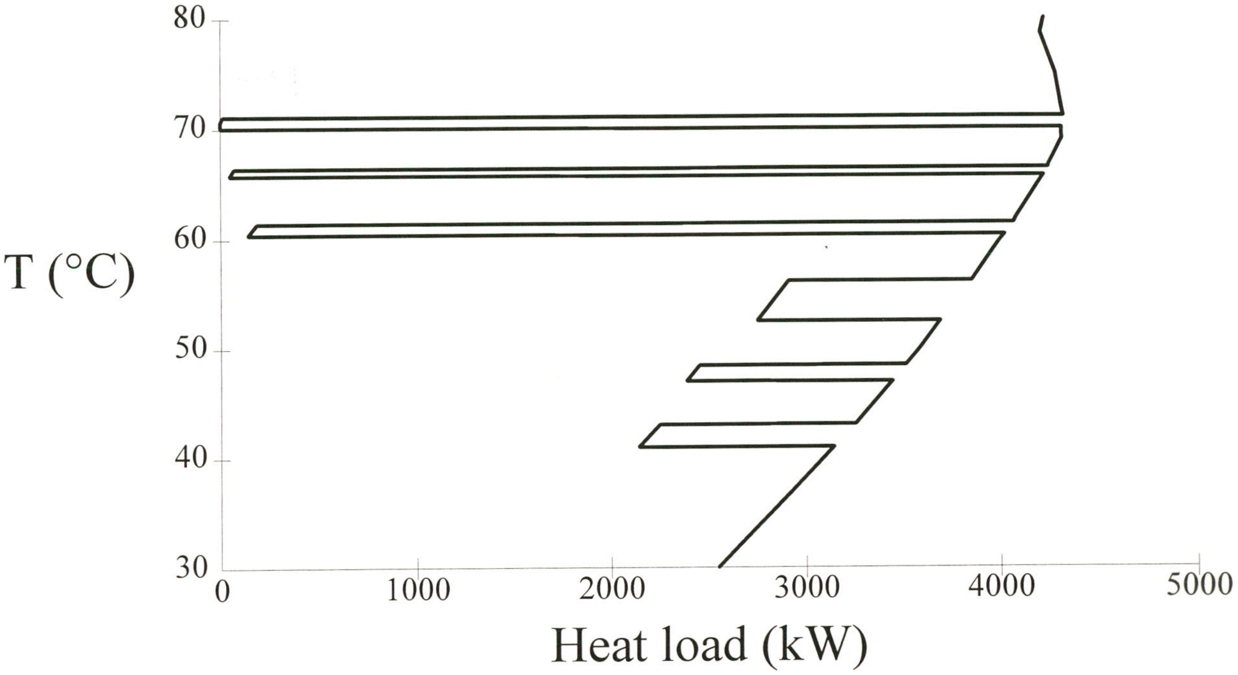


Figure 10.3.1 The grand composite curve of the dairy plant

Process data came from a relatively large Dutch plant. Figure 10.3.2 gives the heat demand curve. In this case, decrease of the global DTmin by conventional internal heat exchange is very profitable. After that, heat pumps can further decrease the energy consumption.
Two types of heat pumps are evaluated, a thermal vapour compression system and an absorption heat pump. The exchange between the (near) pinches in the top of the GCC is assumed to be served by a conventional multi stage evaporator process.
The Pay Back Period of the thermal vapour compressor - very conventional in the Dairy industry - seems to be very long, 4.8 years. Regretfully, the expected mechanical vapour compressor doesn't fit 'due 'programmafout' to temperature limitations'.
In fact, MVR is a good and realised option in the Dutch Dairy industry by this temperature regimes!
Table 10.3.1 and table 10.3.2 give the technical and economical data of the thermal vapour recompressor. Figure 10.3.3 shows the pay back period (PBP) of the TVR.

In some case, there is a minimum Pay Back Period at a certain temperature lift, see figure 10.3.3.

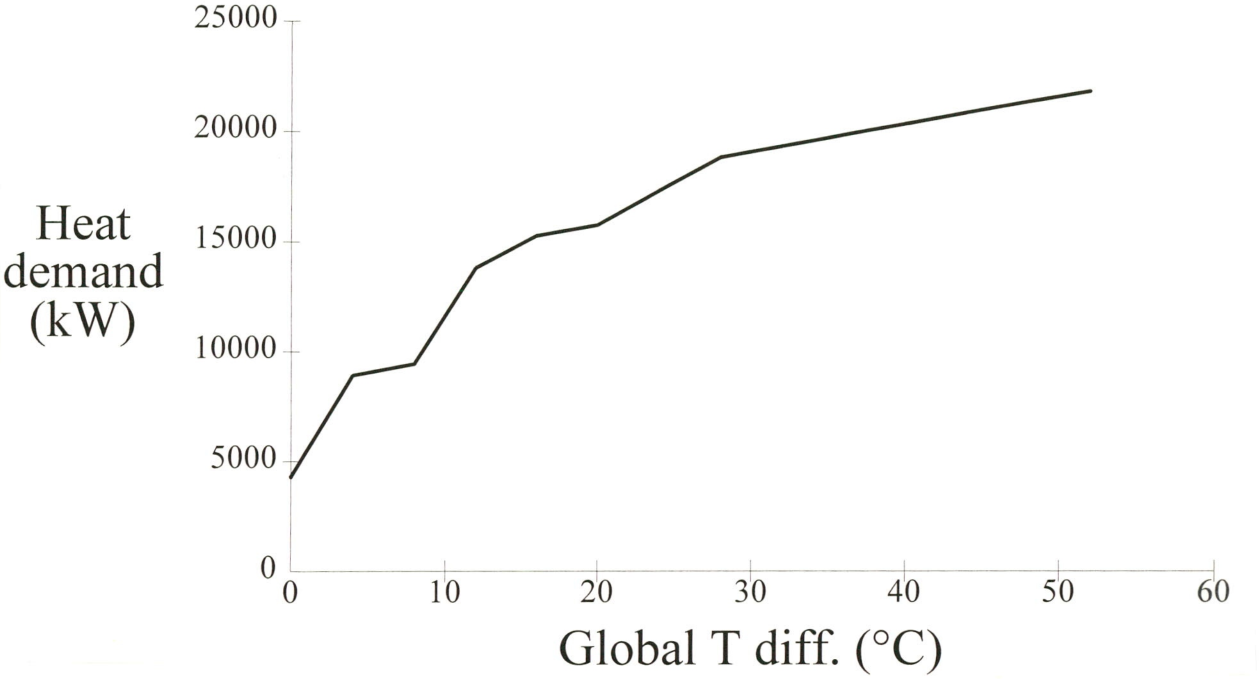


Figure 10.3.2 The head demand curve of the dairy plant

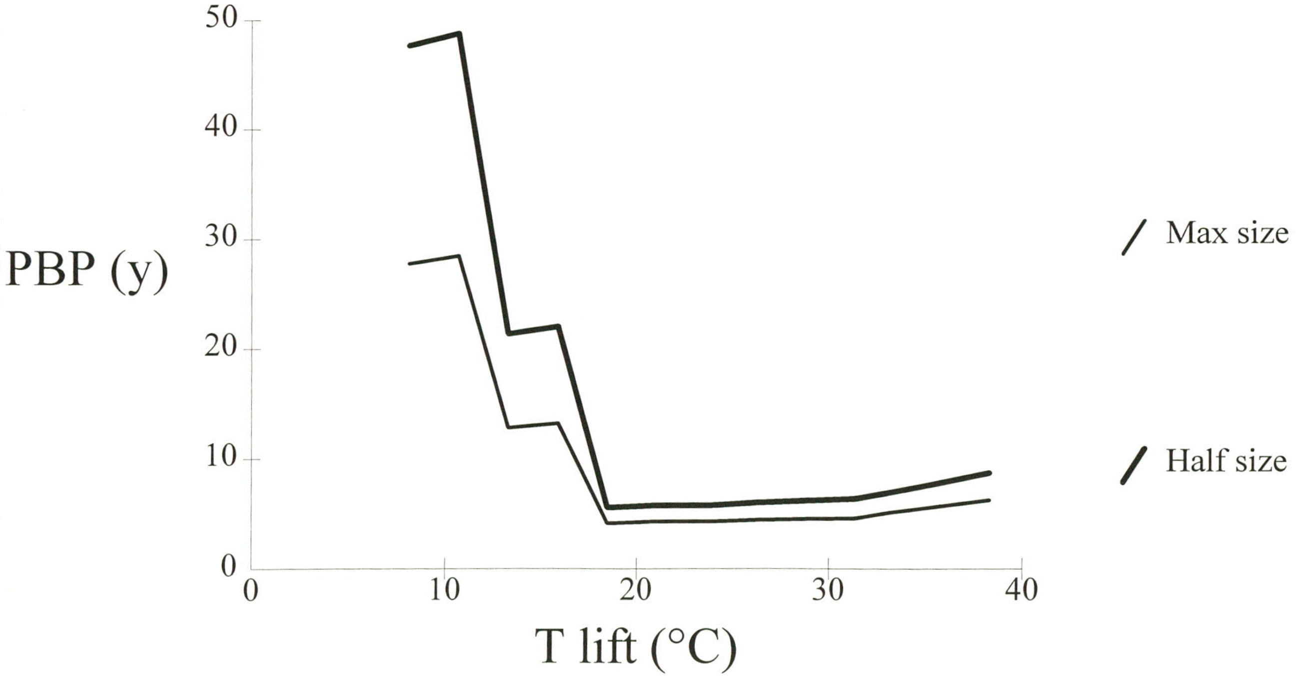


Figure 10.3.3 The PBP curve of the TVR in the dairy plant

The second heat pump is an absorption heat pump. With this heat pump, the heat recovery is larger than with the thermal vapour recompressor due to a higher temperature lift. The pay back period is longer than the TVR pay back Period.

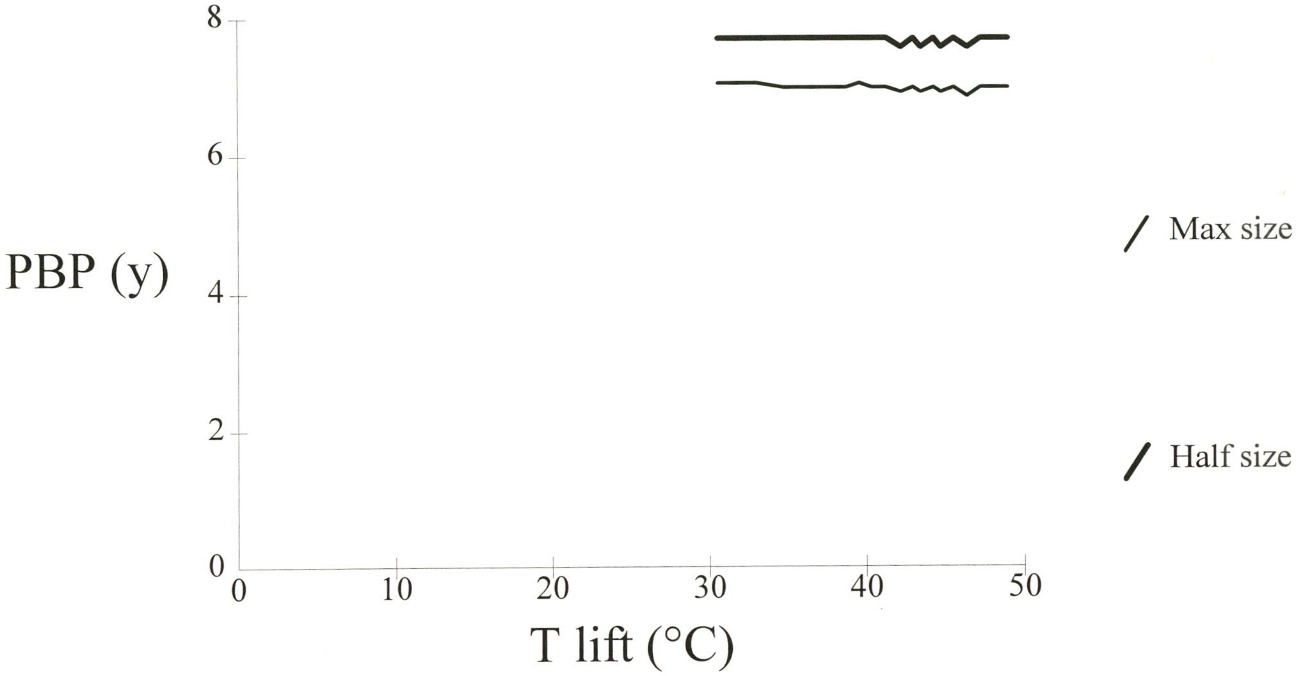
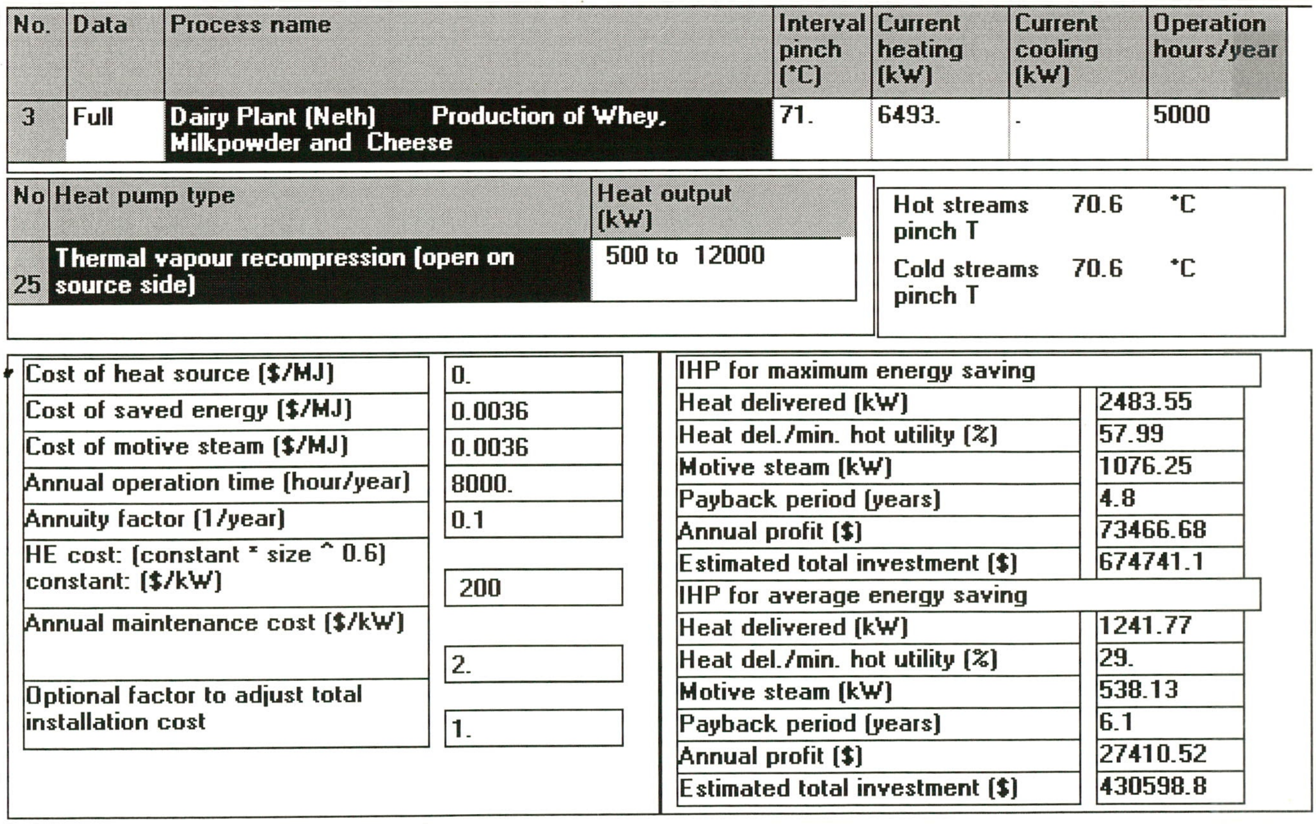


Figure 10.3.4 The BPB curve of the absorption heat pump in the dairy plant

Table 10.3.1



No.	Data	Process name	Interval pinch (°C)	Current heating (kW)	Current cooling (kW)	Operation hours/year
3	Full	Dairy Plant (Neth) Production of Whey, Milkpowder and Cheese	71.	6493.	.	5000

No	Heat pump type	Heat output (kW)
25	Thermal vapour recompression (open on source side)	500 to 12000

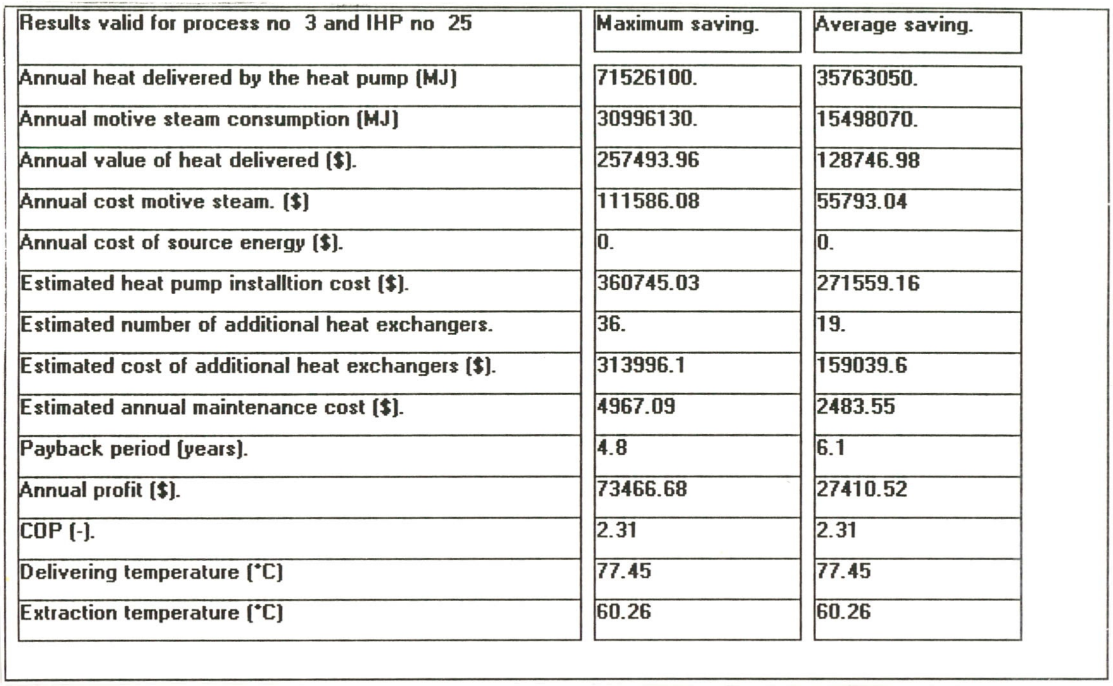
Hot streams pinch T	70.6	°C
Cold streams pinch T	70.6	°C

Cost of heat source ($/MJ)	0.
Cost of saved energy ($/MJ)	0.0036
Cost of motive steam ($/MJ)	0.0036
Annual operation time (hour/year)	8000.
Annuity factor (1/year)	0.1
HE cost: (constant * size ^ 0.6) constant: ($/kW)	200
Annual maintenance cost ($/kW)	2.
Optional factor to adjust total installation cost	1.

IHP for maximum energy saving	
Heat delivered (kW)	2483.55
Heat del./min. hot utility (%)	57.99
Motive steam (kW)	1076.25
Payback period (years)	4.8
Annual profit ($)	73466.68
Estimated total investment ($)	674741.1
IHP for average energy saving	
Heat delivered (kW)	1241.77
Heat del./min. hot utility (%)	29.
Motive steam (kW)	538.13
Payback period (years)	6.1
Annual profit ($)	27410.52
Estimated total investment ($)	430598.8

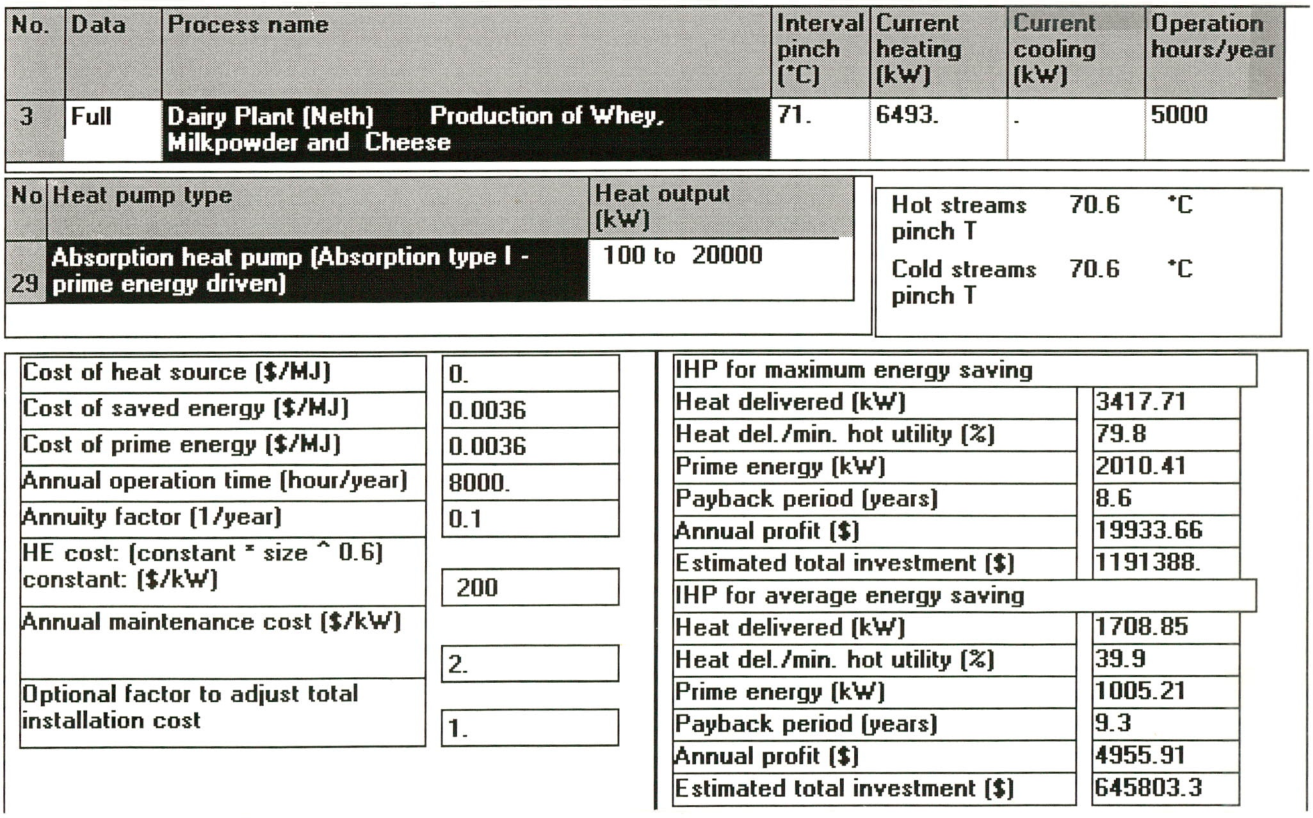
Table 10.3.3 and table 10.3.4 give the technical and economical data of the absorption heat pump. The PBP of the absorption heat pump is not influenced by the lift, see figure 10.3.4.

Table 10.3.2



Results valid for process no 3 and IHP no 25	Maximum saving.	Average saving.
Annual heat delivered by the heat pump (MJ)	71526100.	35763050.
Annual motive steam consumption (MJ)	30996130.	15498070.
Annual value of heat delivered ($).	257493.96	128746.98
Annual cost motive steam. ($)	111586.08	55793.04
Annual cost of source energy ($).	0.	0.
Estimated heat pump installtion cost ($).	360745.03	271559.16
Estimated number of additional heat exchangers.	36.	19.
Estimated cost of additional heat exchangers ($).	313996.1	159039.6
Estimated annual maintenance cost ($).	4967.09	2483.55
Payback period (years).	4.8	6.1
Annual profit ($).	73466.68	27410.52
COP (-).	2.31	2.31
Delivering temperature (°C)	77.45	77.45
Extraction temperature (°C)	60.26	60.26

Table 10.3.3



No.	Data	Process name	Interval pinch (°C)	Current heating (kW)	Current cooling (kW)	Operation hours/year
3	Full	Dairy Plant (Neth) Production of Whey, Milkpowder and Cheese	71.	6493.	.	5000

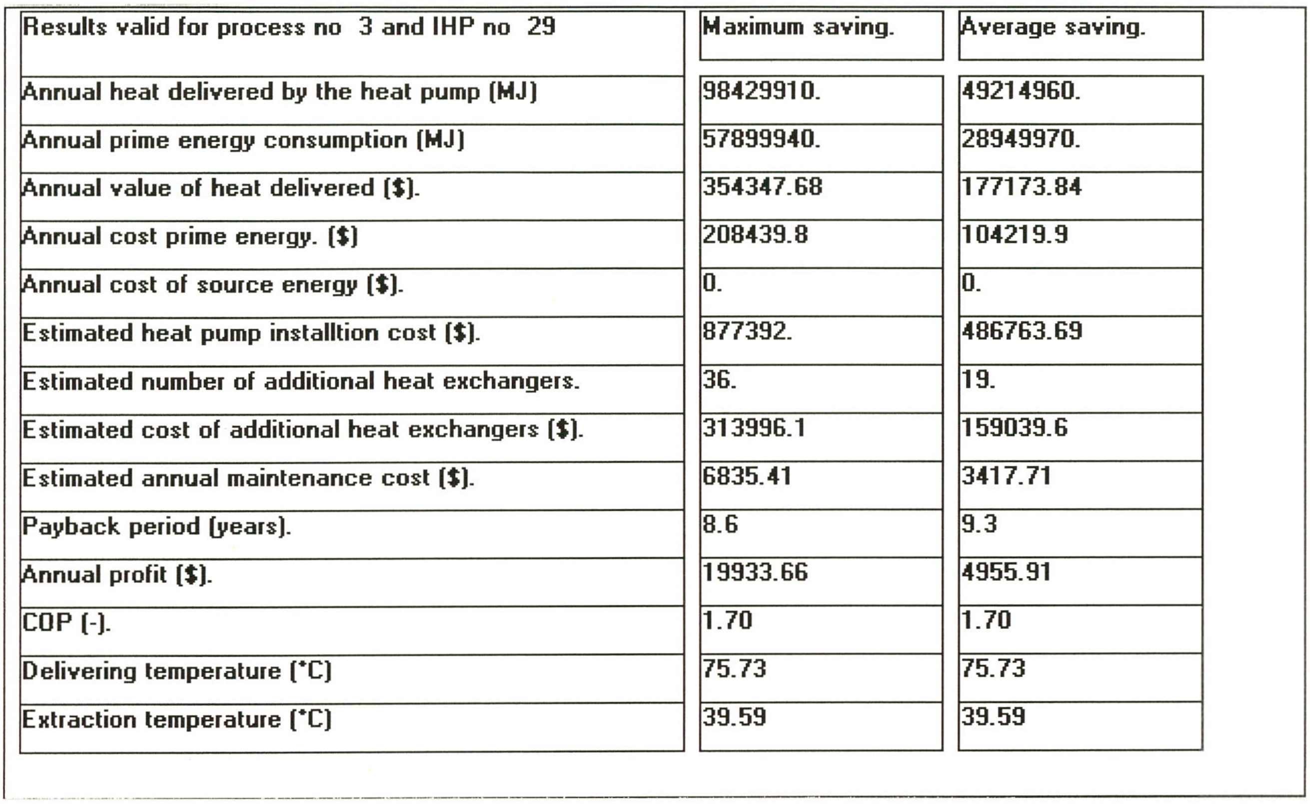
No	Heat pump type	Heat output (kW)
29	Absorption heat pump (Absorption type I - prime energy driven)	100 to 20000

Hot streams pinch T	70.6	°C
Cold streams pinch T	70.6	°C

Cost of heat source ($/MJ)	0.
Cost of saved energy ($/MJ)	0.0036
Cost of prime energy ($/MJ)	0.0036
Annual operation time (hour/year)	8000.
Annuity factor (1/year)	0.1
HE cost: (constant * size ^ 0.6) constant: ($/kW)	200
Annual maintenance cost ($/kW)	2.
Optional factor to adjust total installation cost	1.

IHP for maximum energy saving	
Heat delivered (kW)	3417.71
Heat del./min. hot utility (%)	79.8
Prime energy (kW)	2010.41
Payback period (years)	8.6
Annual profit ($)	19933.66
Estimated total investment ($)	1191388.
IHP for average energy saving	
Heat delivered (kW)	1708.85
Heat del./min. hot utility (%)	39.9
Prime energy (kW)	1005.21
Payback period (years)	9.3
Annual profit ($)	4955.91
Estimated total investment ($)	645803.3

Table 10.3.4



Results valid for process no 3 and IHP no 29	Maximum saving.	Average saving.
Annual heat delivered by the heat pump (MJ)	98429910.	49214960.
Annual prime energy consumption (MJ)	57899940.	28949970.
Annual value of heat delivered ($).	354347.68	177173.84
Annual cost prime energy. ($)	208439.8	104219.9
Annual cost of source energy ($).	0.	0.
Estimated heat pump installtion cost ($).	877392.	486763.69
Estimated number of additional heat exchangers.	36.	19.
Estimated cost of additional heat exchangers ($).	313996.1	159039.6
Estimated annual maintenance cost ($).	6835.41	3417.71
Payback period (years).	8.6	9.3
Annual profit ($).	19933.66	4955.91
COP (-).	1.70	1.70
Delivering temperature (°C)	75.73	75.73
Extraction temperature (°C)	39.59	39.59

10.4 Heat pump implementation in a paper production plant

This process, based on a pinch study of a relatively large Dutch paper plant, has a relatively sharp pinch at 84 °C, see figure 10.4.1. The minimum heat demand curve - figure 10.4.2 - is relatively flat. The relative effect of heat exchanging (= decreasing the DTmin) on the minimum heat demand is low: Heat pumps are direct applicable.

Two heat pumps have a pay back period shorter than 10 years:
- a heat transformer;
- a gas engine driven closed cycle heat pump with R114 as working fluid and a turbo compressor.

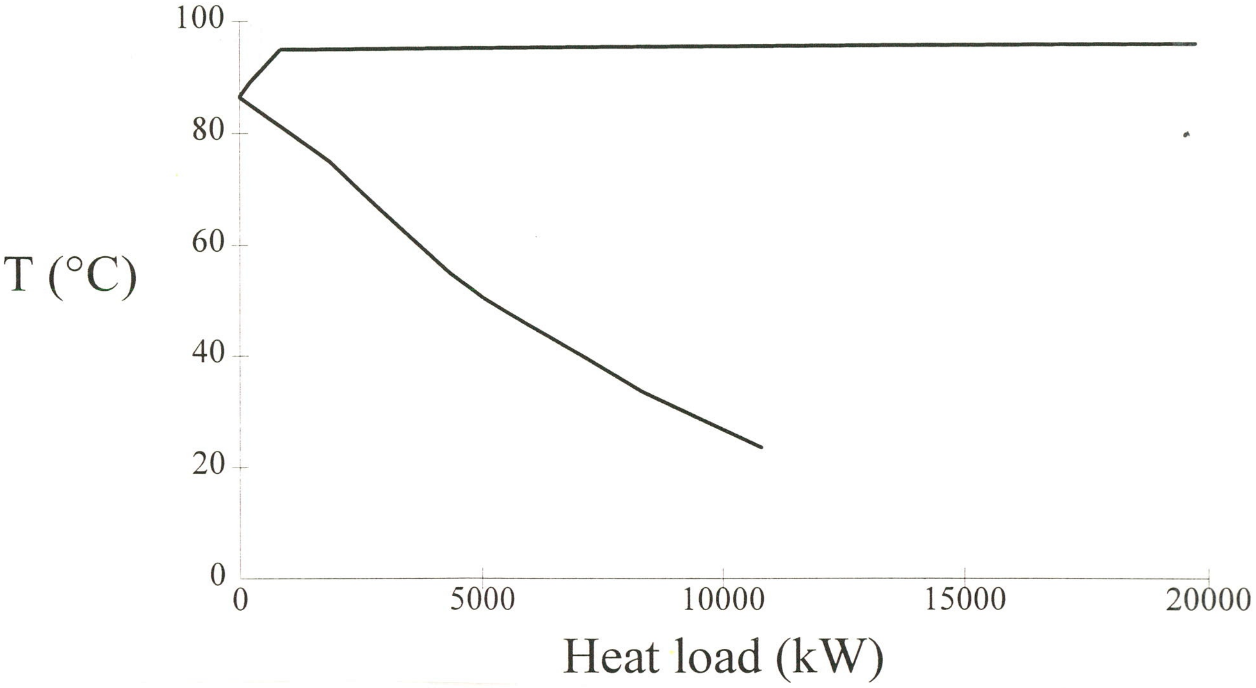


Figure 10.4.1 Grand composite of the paper production process

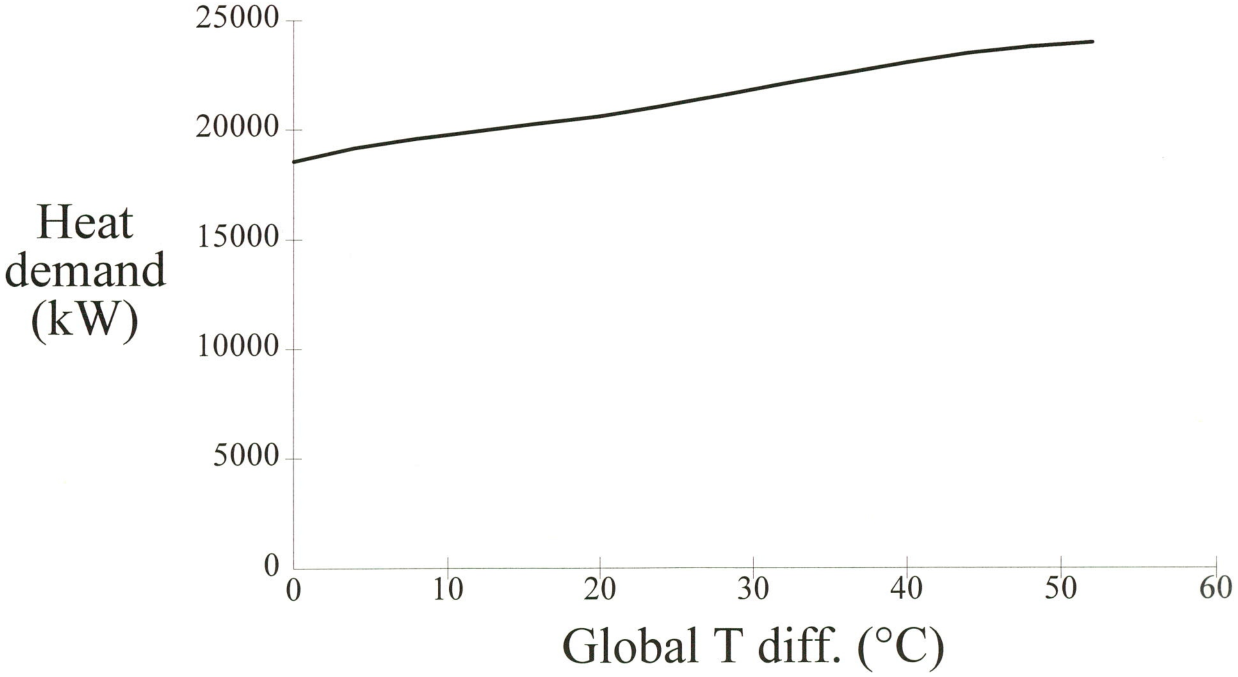
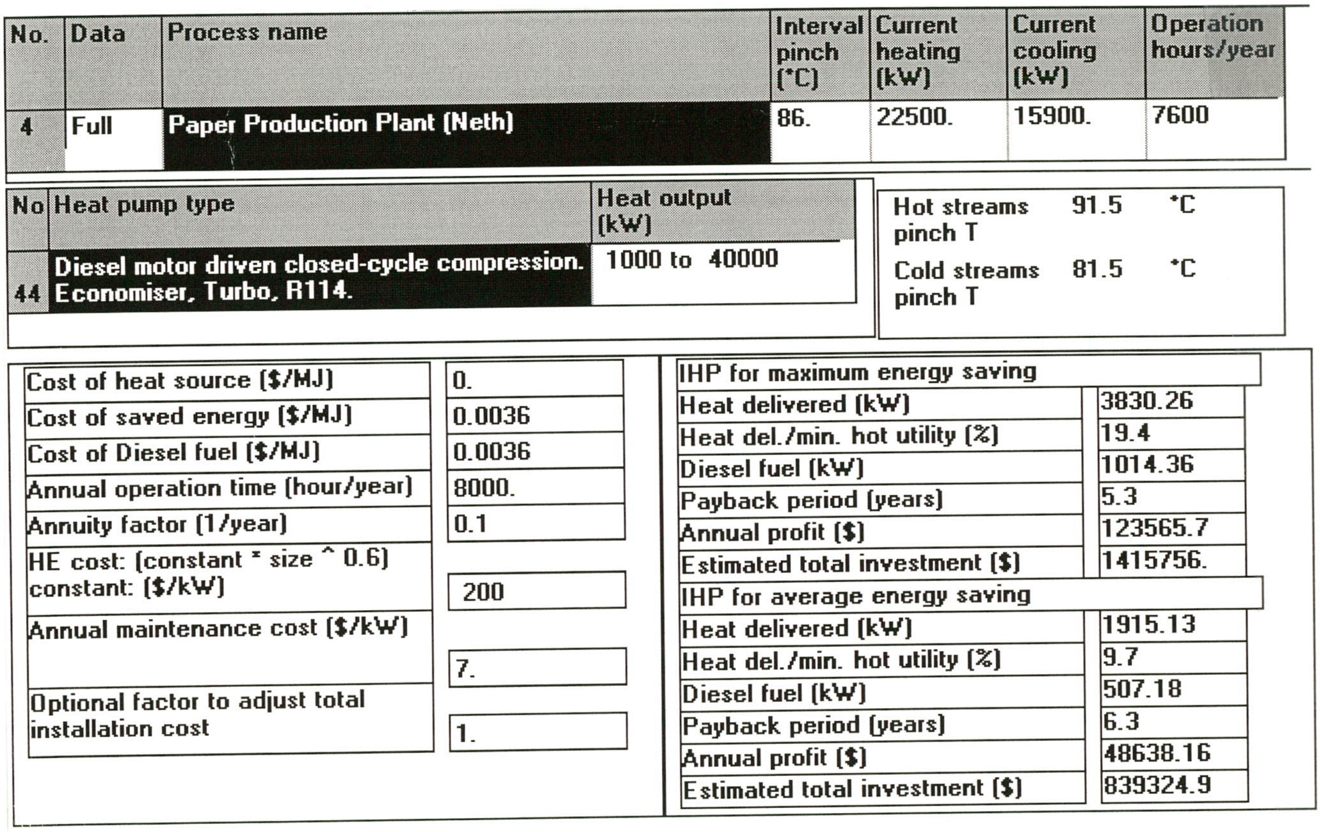


Figure 10.4.2 Heat demand curve of the paper production process

The gas engine heat pump has a relatively short Pay back period of 5.3 years. The temperature lift is relatively large, see table 10.4.1 and 10.4.2.

The heat transformer has a very low driving temperature: 65 °C ! Worldwide no reference is made to heat transformers with such low driving heat temperatures. It is unlikely that such a heat pump can be realized.

Table 10.4.1



No.	Data	Process name	Interval pinch (°C)	Current heating (kW)	Current cooling (kW)	Operation hours/year
4	Full	Paper Production Plant (Neth)	86.	22500.	15900.	7600

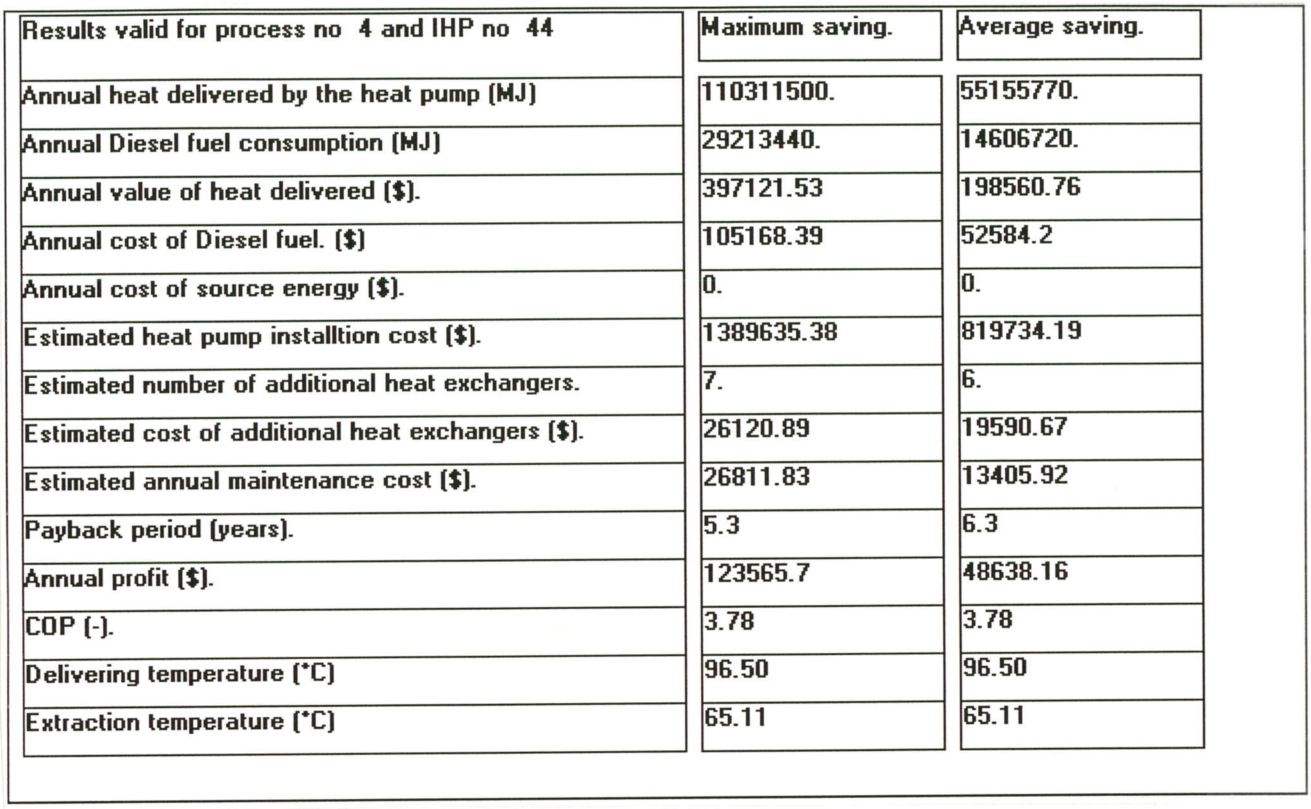
No	Heat pump type	Heat output (kW)
44	Diesel motor driven closed-cycle compression. Economiser, Turbo, R114.	1000 to 40000

Hot streams pinch T	91.5	°C
Cold streams pinch T	81.5	°C

Cost of heat source ($/MJ)	0.
Cost of saved energy ($/MJ)	0.0036
Cost of Diesel fuel ($/MJ)	0.0036
Annual operation time (hour/year)	8000.
Annuity factor (1/year)	0.1
HE cost: (constant * size ^ 0.6) constant: ($/kW)	200
Annual maintenance cost ($/kW)	7.
Optional factor to adjust total installation cost	1.

IHP for maximum energy saving	
Heat delivered (kW)	3830.26
Heat del./min. hot utility (%)	19.4
Diesel fuel (kW)	1014.36
Payback period (years)	5.3
Annual profit ($)	123565.7
Estimated total investment ($)	1415756.
IHP for average energy saving	
Heat delivered (kW)	1915.13
Heat del./min. hot utility (%)	9.7
Diesel fuel (kW)	507.18
Payback period (years)	6.3
Annual profit ($)	48638.16
Estimated total investment ($)	839324.9

Table 10.4.2



Results valid for process no 4 and IHP no 44	Maximum saving.	Average saving.
Annual heat delivered by the heat pump (MJ)	110311500.	55155770.
Annual Diesel fuel consumption (MJ)	29213440.	14606720.
Annual value of heat delivered ($).	397121.53	198560.76
Annual cost of Diesel fuel. ($)	105168.39	52584.2
Annual cost of source energy ($).	0.	0.
Estimated heat pump installtion cost ($).	1389635.38	819734.19
Estimated number of additional heat exchangers.	7.	6.
Estimated cost of additional heat exchangers ($).	26120.89	19590.67
Estimated annual maintenance cost ($).	26811.83	13405.92
Payback period (years).	5.3	6.3
Annual profit ($).	123565.7	48638.16
COP (-).	3.78	3.78
Delivering temperature (°C)	96.50	96.50
Extraction temperature (°C)	65.11	65.11

Figure 10.4.3 gives the PBP period curve of the gas engine driven heat pump. This curve has a minimum at 31 °C. Figure 10.4.4 the PBP & capacity curve of the heat transformer. The PBP of the transformer decreased with higher capacity and larger temperature lift. What we see on figure 10.4.4 appears to be a very frequent phenomena by implementing heat pumps: the implementable heat pump capacity grows with a larger temperature lift. As a result of a non-proportional Heat Pump cost per kW, larger heat pumps have lower specific costs. In spite of a lower COP at higher lifts, the combination of the facts mentioned gives a shorter pay back period at larger temperature lifts!
Table 10.3.3 and table 10.3.4 show the technical and economic data of the transformer.

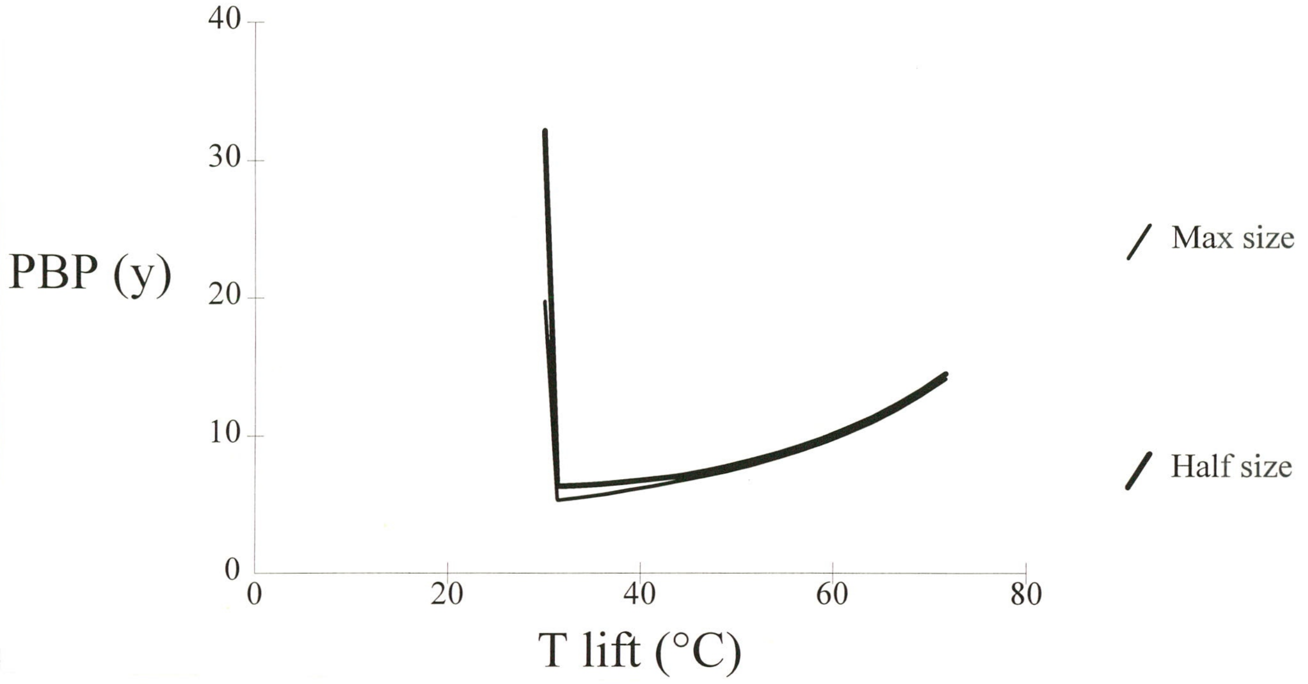


Figure 10.4.3

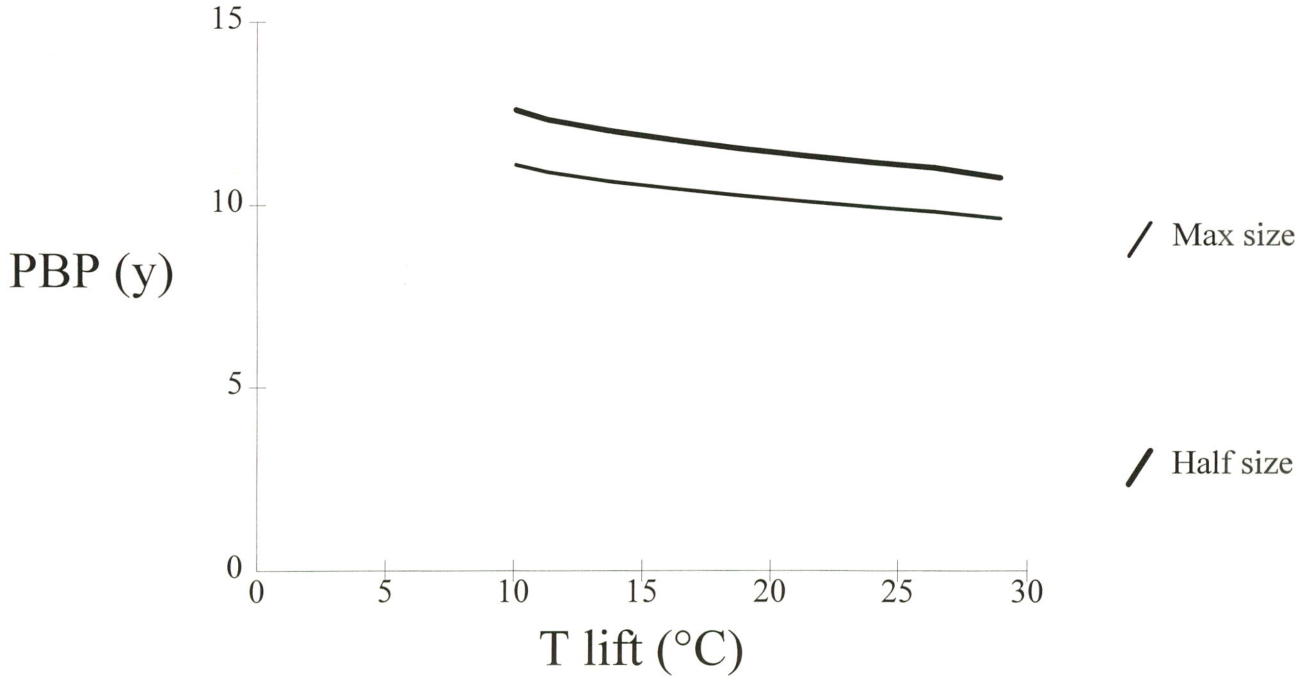
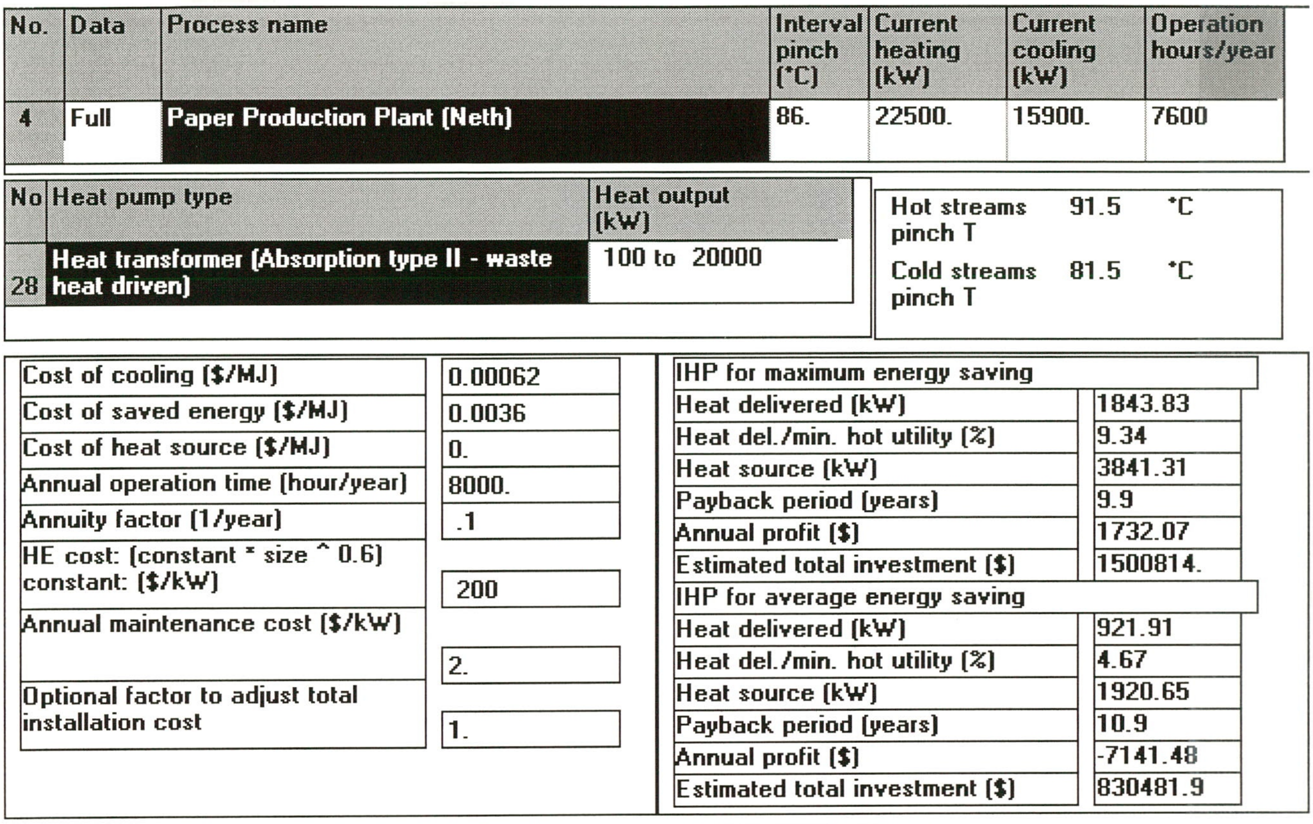


Figure 10.4.4

Table 10.4.3



No.	Data	Process name	Interval pinch (°C)	Current heating (kW)	Current cooling (kW)	Operation hours/year
4	Full	Paper Production Plant (Neth)	86.	22500.	15900.	7600

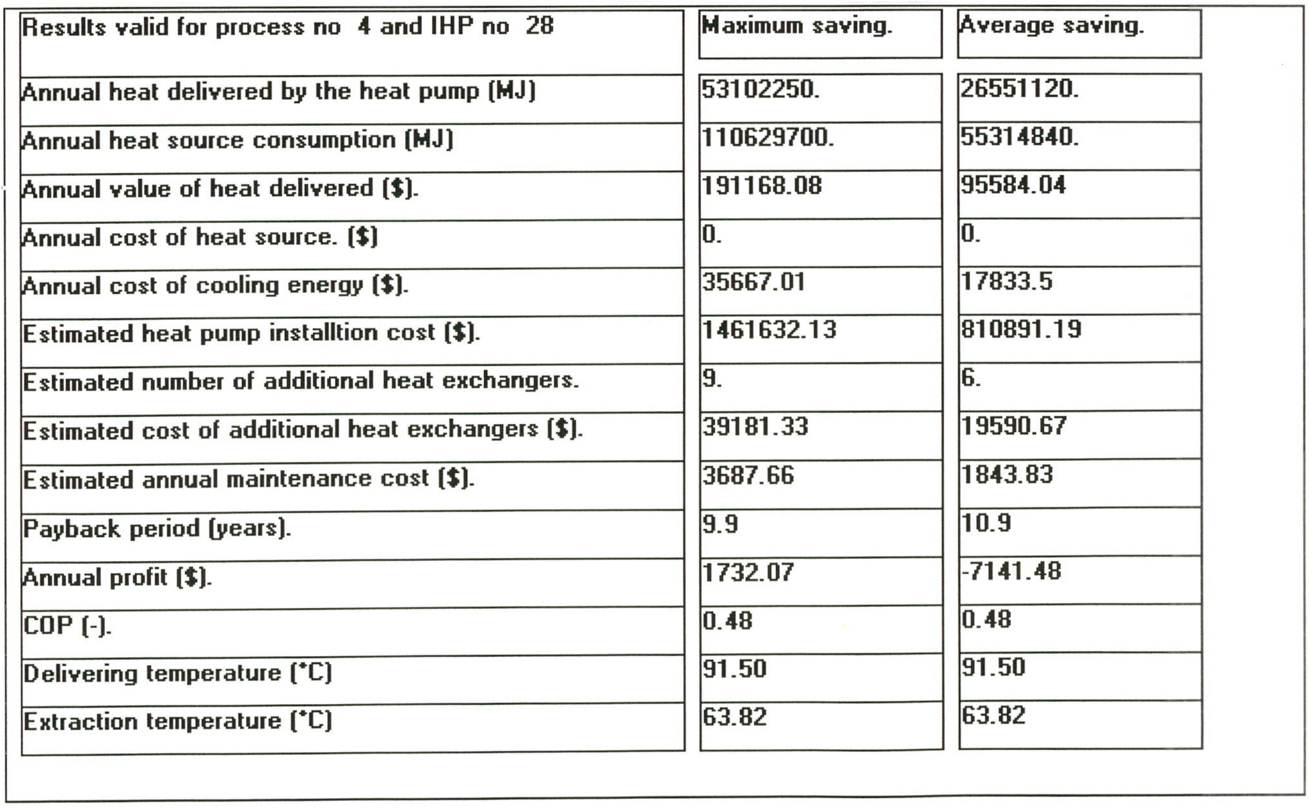
No	Heat pump type	Heat output (kW)
28	Heat transformer (Absorption type II - waste heat driven)	100 to 20000

Hot streams pinch T	91.5	°C
Cold streams pinch T	81.5	°C

Cost of cooling ($/MJ)	0.00062
Cost of saved energy ($/MJ)	0.0036
Cost of heat source ($/MJ)	0.
Annual operation time (hour/year)	8000.
Annuity factor (1/year)	.1
HE cost: (constant * size ^ 0.6) constant: ($/kW)	200
Annual maintenance cost ($/kW)	2.
Optional factor to adjust total installation cost	1.

IHP for maximum energy saving	
Heat delivered (kW)	1843.83
Heat del./min. hot utility (%)	9.34
Heat source (kW)	3841.31
Payback period (years)	9.9
Annual profit ($)	1732.07
Estimated total investment ($)	1500814.
IHP for average energy saving	
Heat delivered (kW)	921.91
Heat del./min. hot utility (%)	4.67
Heat source (kW)	1920.65
Payback period (years)	10.9
Annual profit ($)	-7141.48
Estimated total investment ($)	830481.9

Table 10.4.4



Results valid for process no 4 and IHP no 28	Maximum saving.	Average saving.
Annual heat delivered by the heat pump (MJ)	53102250.	26551120.
Annual heat source consumption (MJ)	110629700.	55314840.
Annual value of heat delivered ($).	191168.08	95584.04
Annual cost of heat source. ($)	0.	0.
Annual cost of cooling energy ($).	35667.01	17833.5
Estimated heat pump installtion cost ($).	1461632.13	810891.19
Estimated number of additional heat exchangers.	9.	6.
Estimated cost of additional heat exchangers ($).	39181.33	19590.67
Estimated annual maintenance cost ($).	3687.66	1843.83
Payback period (years).	9.9	10.9
Annual profit ($).	1732.07	-7141.48
COP (-).	0.48	0.48
Delivering temperature (°C)	91.50	91.50
Extraction temperature (°C)	63.82	63.82

10.5 Heat pump implementation in a building Ceramics Plant

In The Netherlands, there are a lot of Building Ceramic Plants. Fig 10.5.1 gives the grand composite curve of a representative process. The *a priori* potential for heat pumps is small due to relative small heat recovery chances around the pinch. The practical DTmin is relatively high; it can be deminished by heat exchanging in the drying section. After that - DTmin shrinking to 10 °C - the heat demand can be lowered with a small heat pump . Fig 10.5.2 gives the minimum heat demand curve.

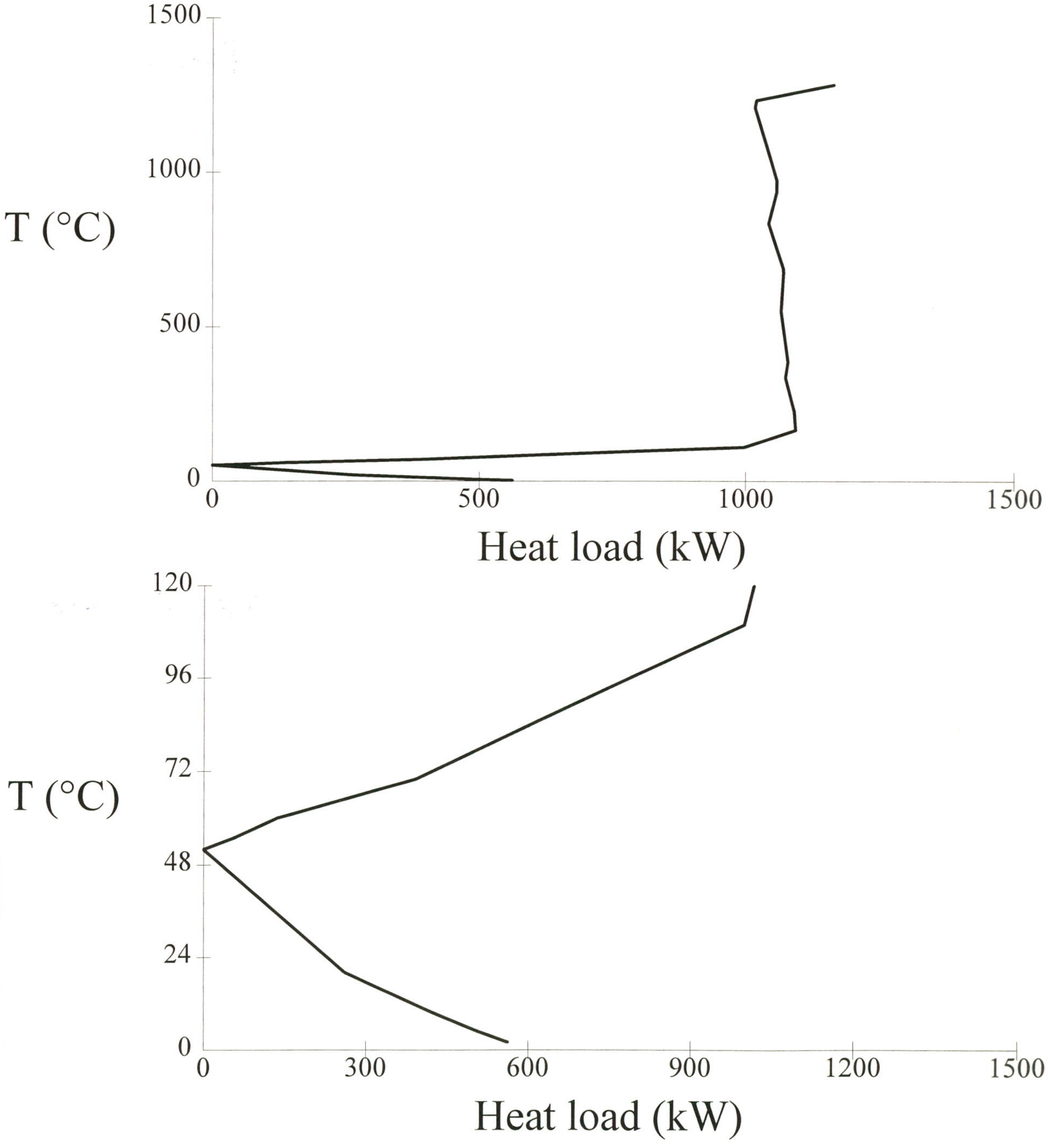


Figure 10.5.1 Grand composite curve of the building ceramics plant

Before implementation of heat pumps, the DTmin has to be reduced to 10 °C. After that, heat pumps are not feasible.

With a DTmin of 50 °C, a gas motor driven heat pump is feasible see table 10.5.1, table 10.5.2 and figure 10.5.3. The investment is nevertheless much higher than the option to reduce the DTmin with conventional heat exchangers.

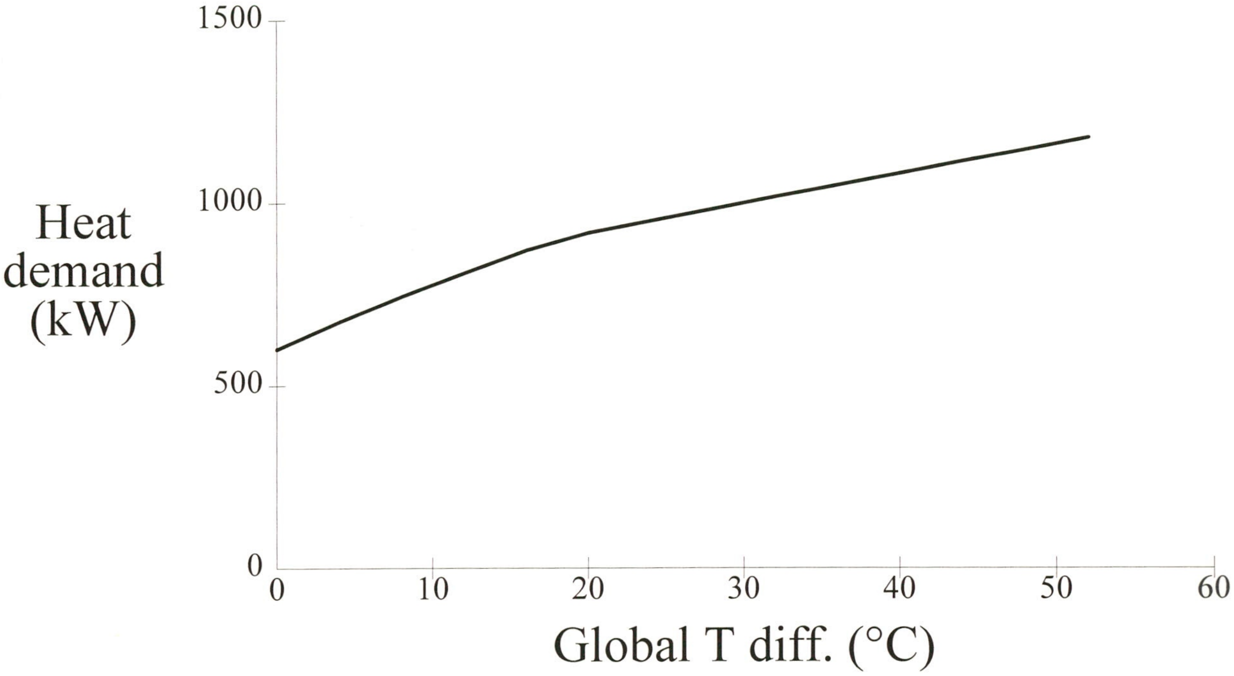


Figure 10.5.2 Grand composite curve of the building ceramics plant

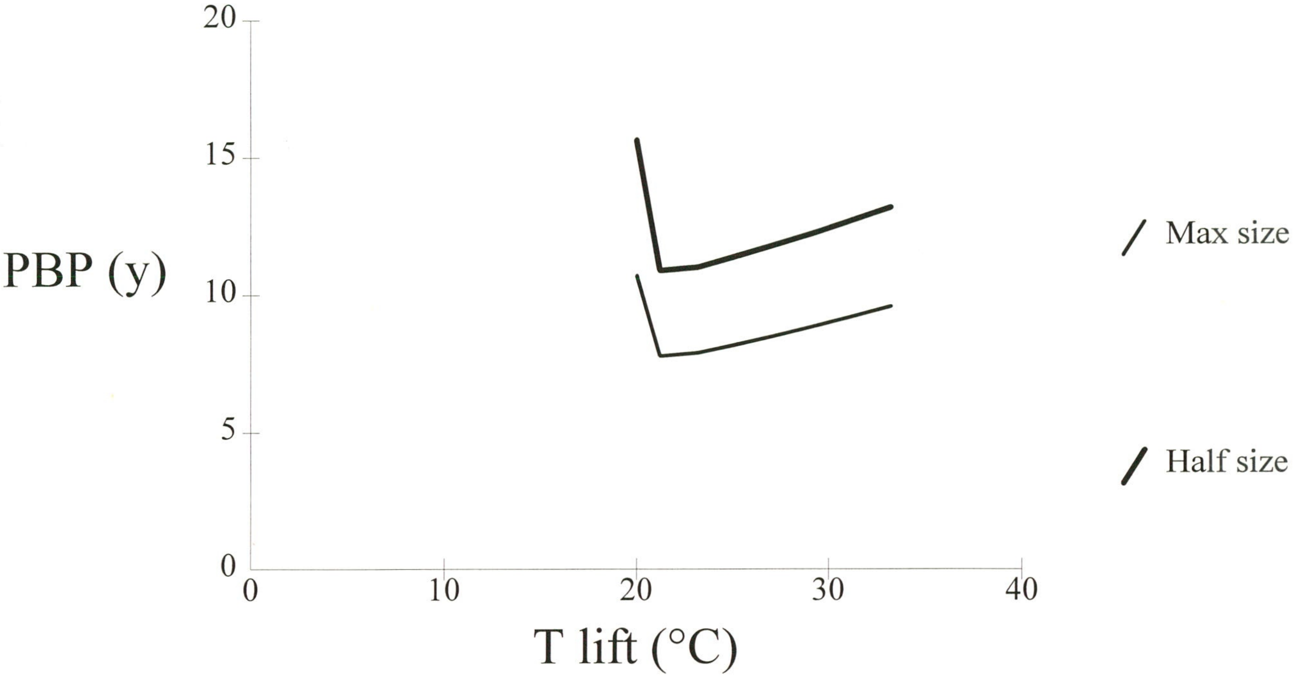
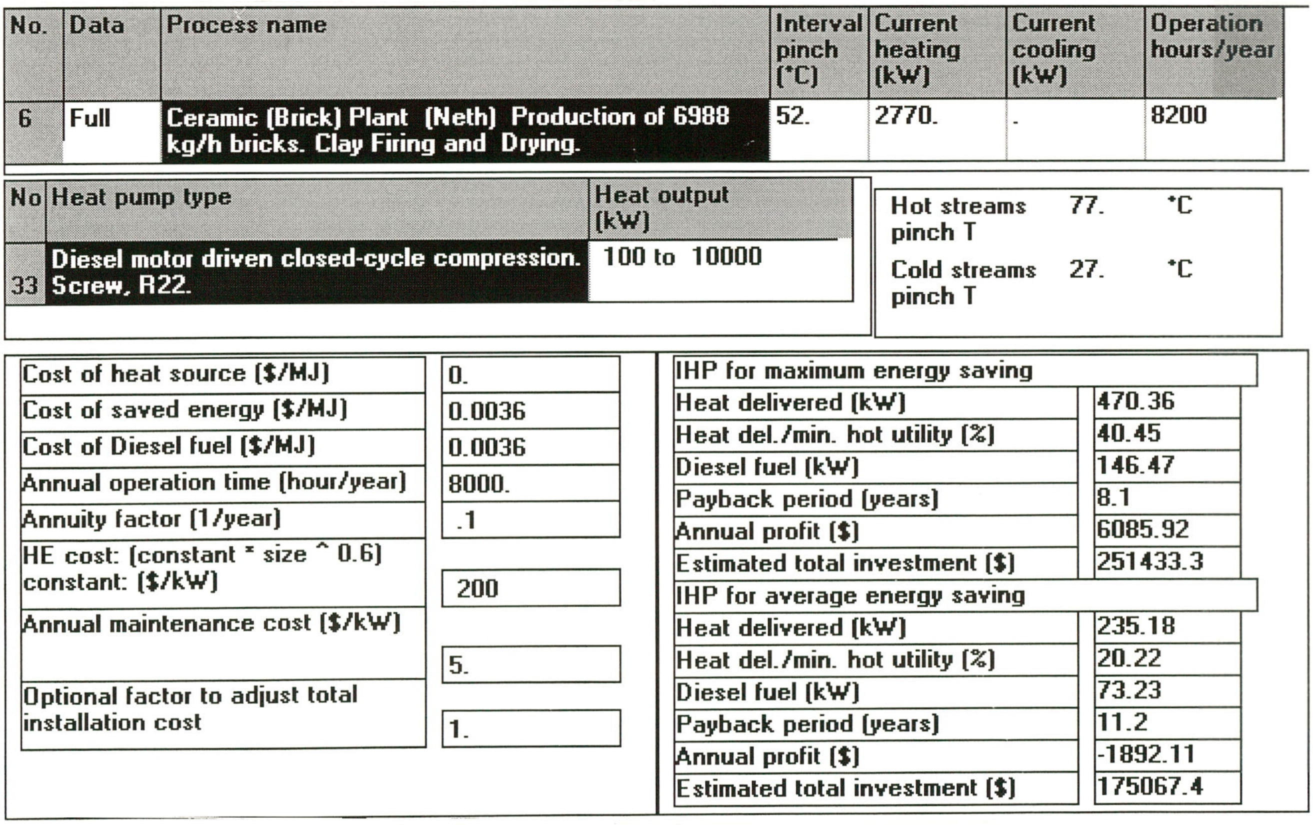


Figure 10.5.3 The PBP curve of the GM heat pump in the building ceramics plant

Table 10.5.1



No.	Data	Process name	Interval pinch (°C)	Current heating (kW)	Current cooling (kW)	Operation hours/year
6	Full	Ceramic (Brick) Plant (Neth) Production of 6988 kg/h bricks. Clay Firing and Drying.	52.	2770.	.	8200

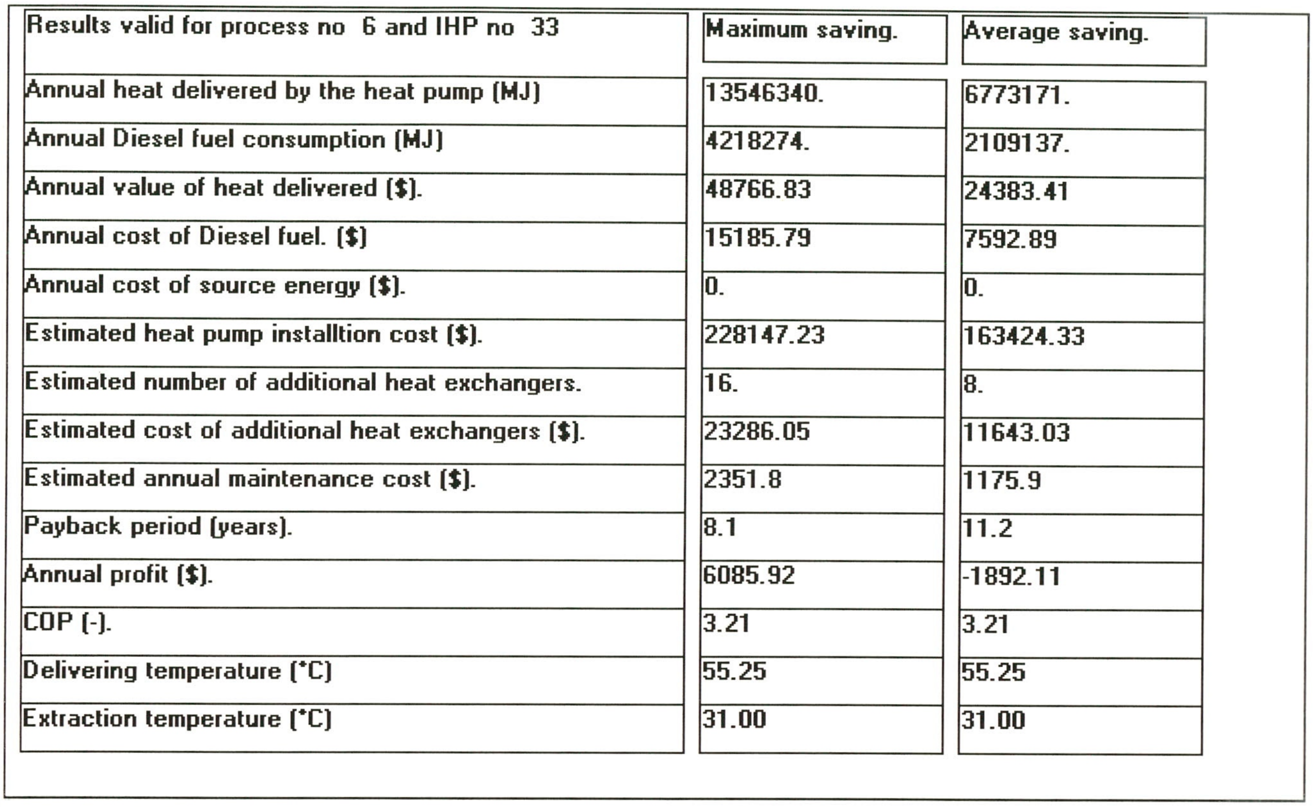
No	Heat pump type	Heat output (kW)
33	Diesel motor driven closed-cycle compression. Screw, R22.	100 to 10000

Hot streams pinch T	77.	°C
Cold streams pinch T	27.	°C

Cost of heat source ($/MJ)	0.
Cost of saved energy ($/MJ)	0.0036
Cost of Diesel fuel ($/MJ)	0.0036
Annual operation time (hour/year)	8000.
Annuity factor (1/year)	.1
HE cost: (constant * size ^ 0.6) constant: ($/kW)	200
Annual maintenance cost ($/kW)	5.
Optional factor to adjust total installation cost	1.

IHP for maximum energy saving	
Heat delivered (kW)	470.36
Heat del./min. hot utility (%)	40.45
Diesel fuel (kW)	146.47
Payback period (years)	8.1
Annual profit ($)	6085.92
Estimated total investment ($)	251433.3
IHP for average energy saving	
Heat delivered (kW)	235.18
Heat del./min. hot utility (%)	20.22
Diesel fuel (kW)	73.23
Payback period (years)	11.2
Annual profit ($)	-1892.11
Estimated total investment ($)	175067.4

Table 10.5.2



Results valid for process no 6 and IHP no 33	Maximum saving.	Average saving.
Annual heat delivered by the heat pump (MJ)	13546340.	6773171.
Annual Diesel fuel consumption (MJ)	4218274.	2109137.
Annual value of heat delivered ($).	48766.83	24383.41
Annual cost of Diesel fuel. ($)	15185.79	7592.89
Annual cost of source energy ($).	0.	0.
Estimated heat pump installtion cost ($).	228147.23	163424.33
Estimated number of additional heat exchangers.	16.	8.
Estimated cost of additional heat exchangers ($).	23286.05	11643.03
Estimated annual maintenance cost ($).	2351.8	1175.9
Payback period (years).	8.1	11.2
Annual profit ($).	6085.92	-1892.11
COP (-).	3.21	3.21
Delivering temperature (°C)	55.25	55.25
Extraction temperature (°C)	31.00	31.00

10.6 Heat pump implementation in the ureum process

The grand composite curve of the ureum process, figure 10.6.1, seems to be ideal for a high temperature absorption heat pump due to a relatively high temperature lift and a large sink/ small source combination. Further reduction of the DTmin by means of conventional heat exchanging is not very useful, see the minimum heat demand curve, figure 10.6.2.

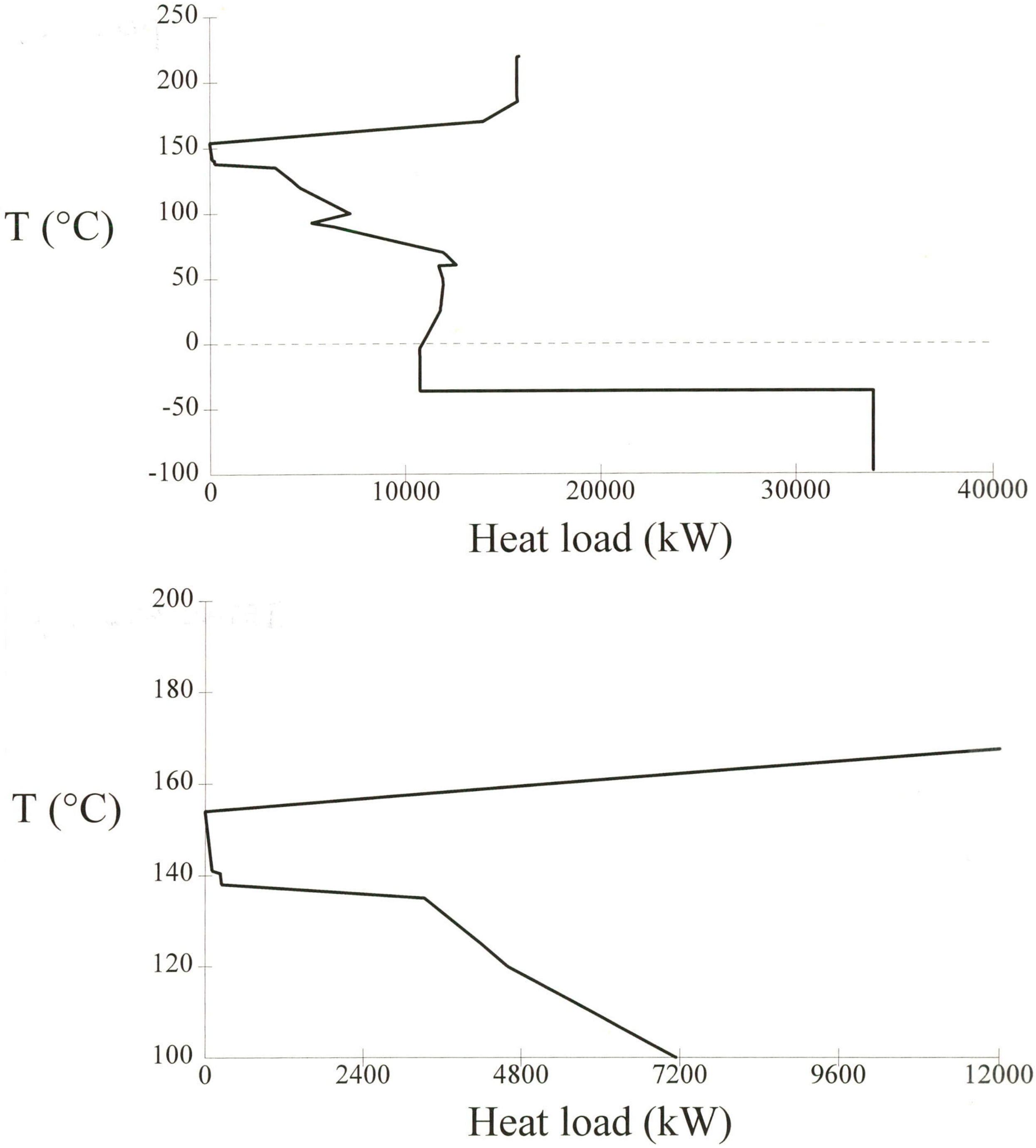


Figure 10.6.1 Grand composite curve of the Ureum process

With the Chalmers/ETA programme, it was not possible to implement an absorption heat pump, due to temperature limitations of the chosen AHP in this programme. For this reason, a closed compression heat pump with screw compressor and water as working fluid was implemented. A PBP of 5.1 year could be realized, see table 10.6.1 and table 10.6.2. Figure 10.6.3 shows the PBP curve. It has a minimum near 35 °C.

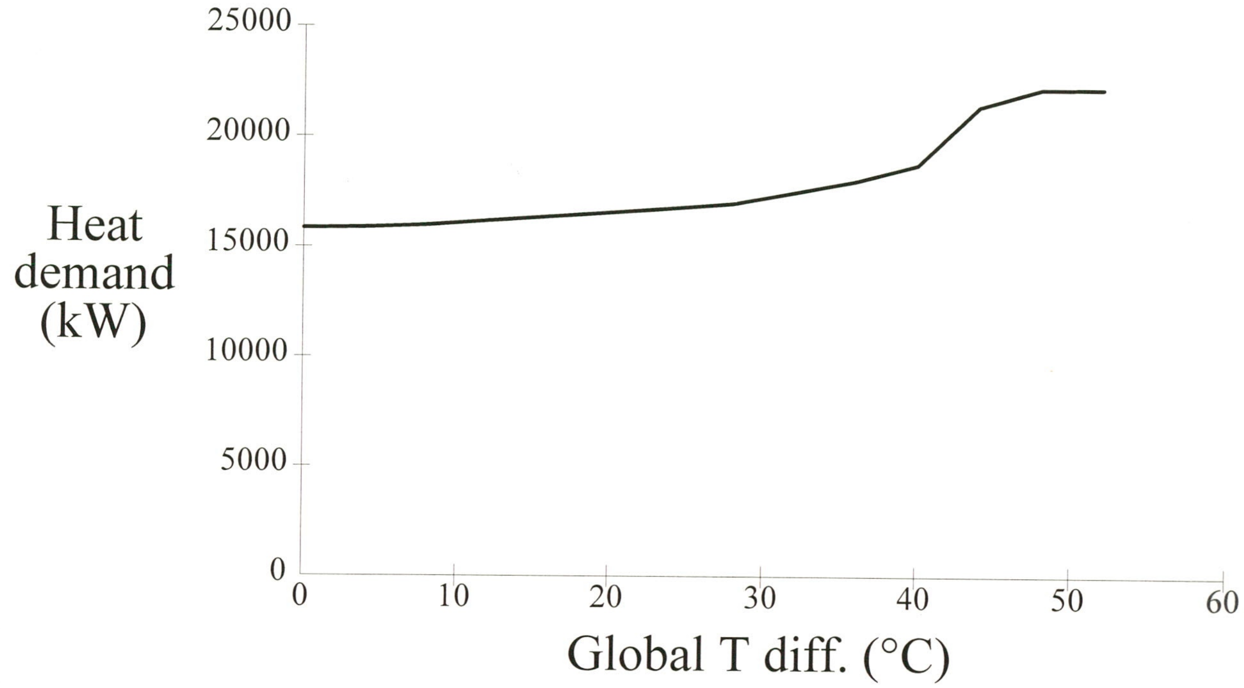


Figure 10.6.2 Heat demand curve of the Ureum process

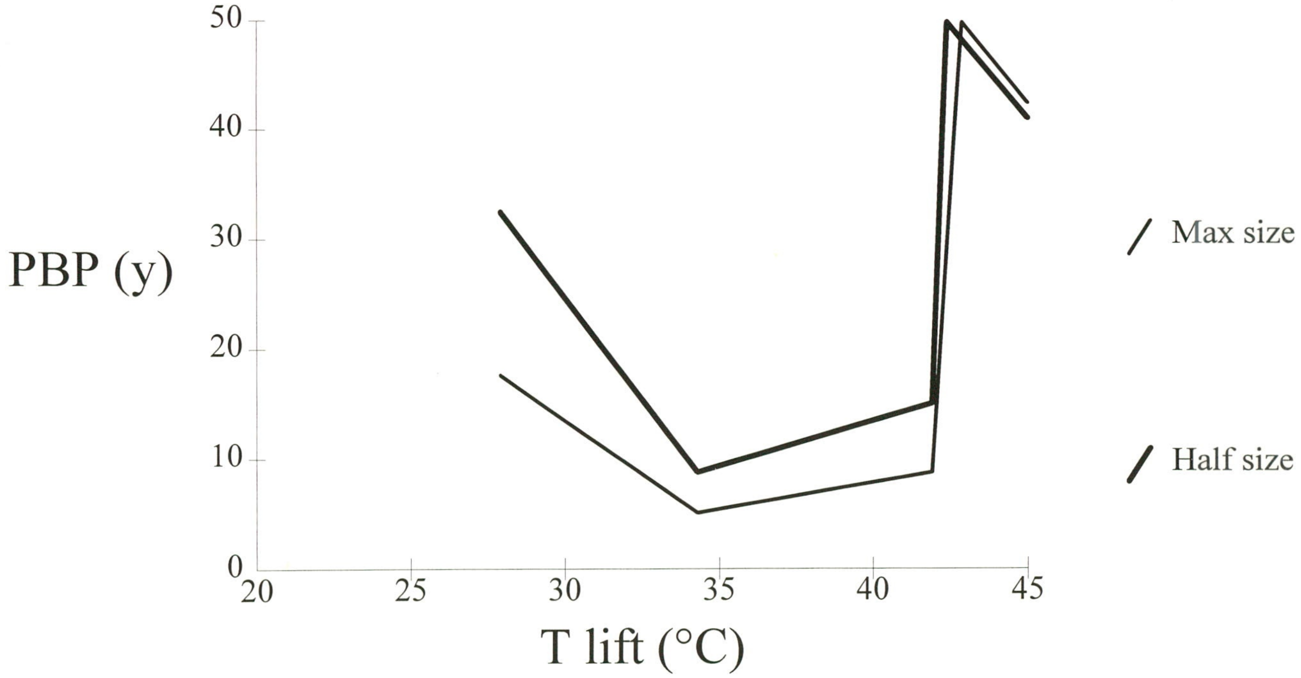
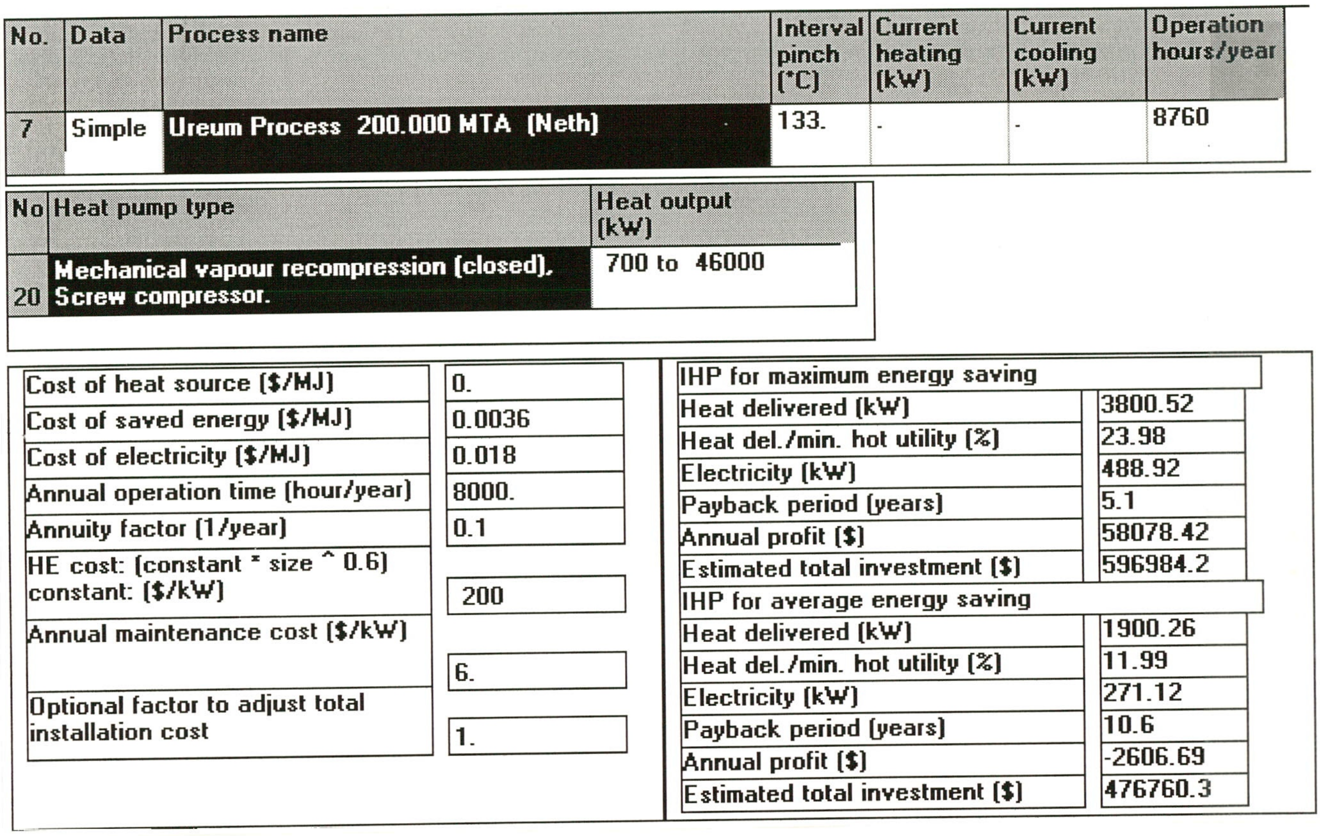


Figure 10.6.3 The PBP curve of the closed cycle heat pump with water as working fluid in the ureum process

Table 10.6.1



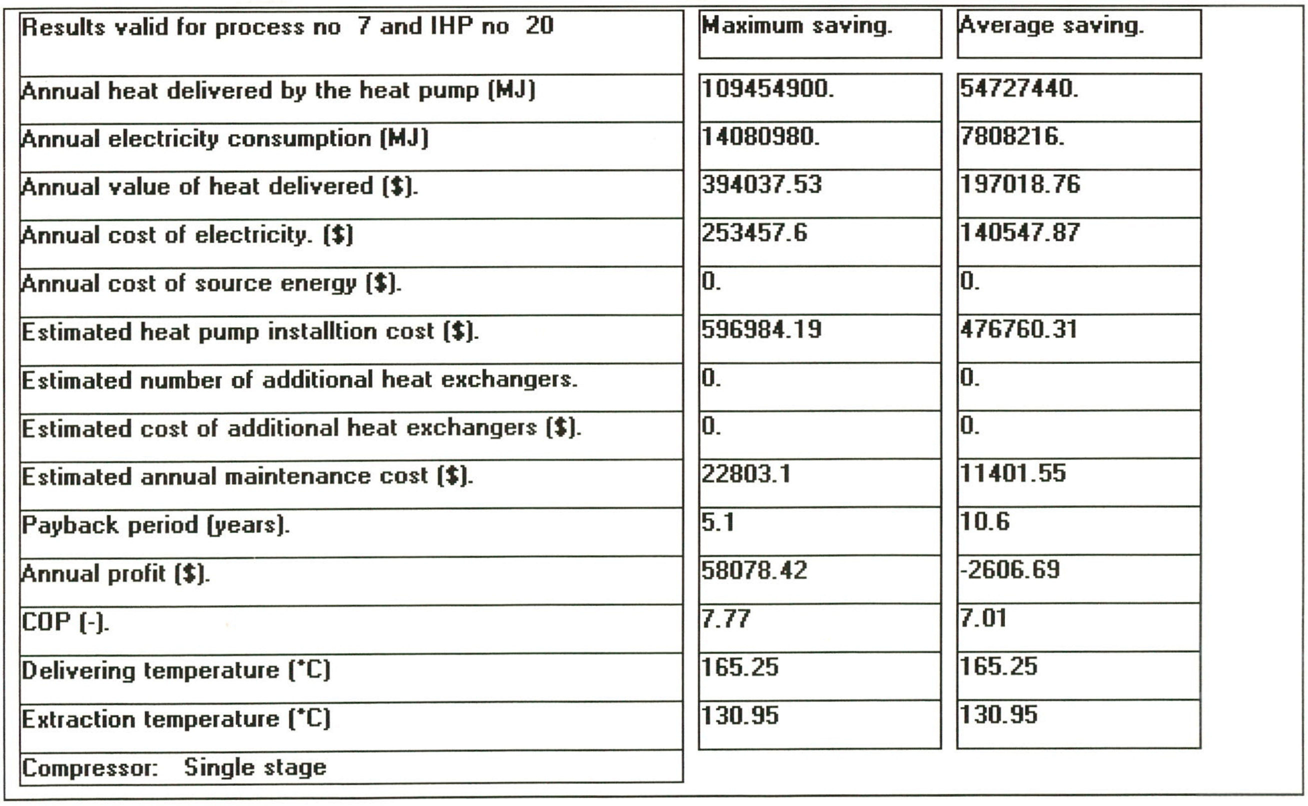
No.	Data	Process name	Interval pinch (°C)	Current heating (kW)	Current cooling (kW)	Operation hours/year
7	Simple	Ureum Process 200.000 MTA (Neth)	133.	-	-	8760

No	Heat pump type	Heat output (kW)
20	Mechanical vapour recompression (closed), Screw compressor.	700 to 46000

Cost of heat source ($/MJ)	0.
Cost of saved energy ($/MJ)	0.0036
Cost of electricity ($/MJ)	0.018
Annual operation time (hour/year)	8000.
Annuity factor (1/year)	0.1
HE cost: (constant * size ^ 0.6) constant: ($/kW)	200
Annual maintenance cost ($/kW)	6.
Optional factor to adjust total installation cost	1.

IHP for maximum energy saving	
Heat delivered (kW)	3800.52
Heat del./min. hot utility (%)	23.98
Electricity (kW)	488.92
Payback period (years)	5.1
Annual profit ($)	58078.42
Estimated total investment ($)	596984.2
IHP for average energy saving	
Heat delivered (kW)	1900.26
Heat del./min. hot utility (%)	11.99
Electricity (kW)	271.12
Payback period (years)	10.6
Annual profit ($)	-2606.69
Estimated total investment ($)	476760.3

Table 10.6.2



Results valid for process no 7 and IHP no 20	Maximum saving.	Average saving.
Annual heat delivered by the heat pump (MJ)	109454900.	54727440.
Annual electricity consumption (MJ)	14080980.	7808216.
Annual value of heat delivered ($).	394037.53	197018.76
Annual cost of electricity. ($)	253457.6	140547.87
Annual cost of source energy ($).	0.	0.
Estimated heat pump installtion cost ($).	596984.19	476760.31
Estimated number of additional heat exchangers.	0.	0.
Estimated cost of additional heat exchangers ($).	0.	0.
Estimated annual maintenance cost ($).	22803.1	11401.55
Payback period (years).	5.1	10.6
Annual profit ($).	58078.42	-2606.69
COP (-).	7.77	7.01
Delivering temperature (°C)	165.25	165.25
Extraction temperature (°C)	130.95	130.95
Compressor: Single stage		

10.7 Heat pump in the ethylene process

Figure 10.7.1 gives the grand composite curve of the ethylene plant, figure 10.7.2 a detail of this curve around the pinch.
A decrease of DTmin (with conventional heat exchangers) seems to be not very attractive, see figure 10.7.3.

A heat transformer seems to be very attractive due to the relative small sink and a large source with sufficient temperature level. Table 10.7.1 and table 10.7.2 give the results A PBP of 7.4 years is attainable. The PBP of the heat transformer (capacity: 6676 kW) decreases at higher temperature lifts, due to a larger capacity at large lift and a very slight influence of the lift on the COP.

Apart from the heat transformer, two types of heat pumps are feasible, a closed cycle heat pump with water as working fluid (capacity: 4800 kW) and a gas motor driven closed cycle heat pump (capacity: 3036 kW). Table 10.7.3 and table 10.7.4 give the technical and economic data.

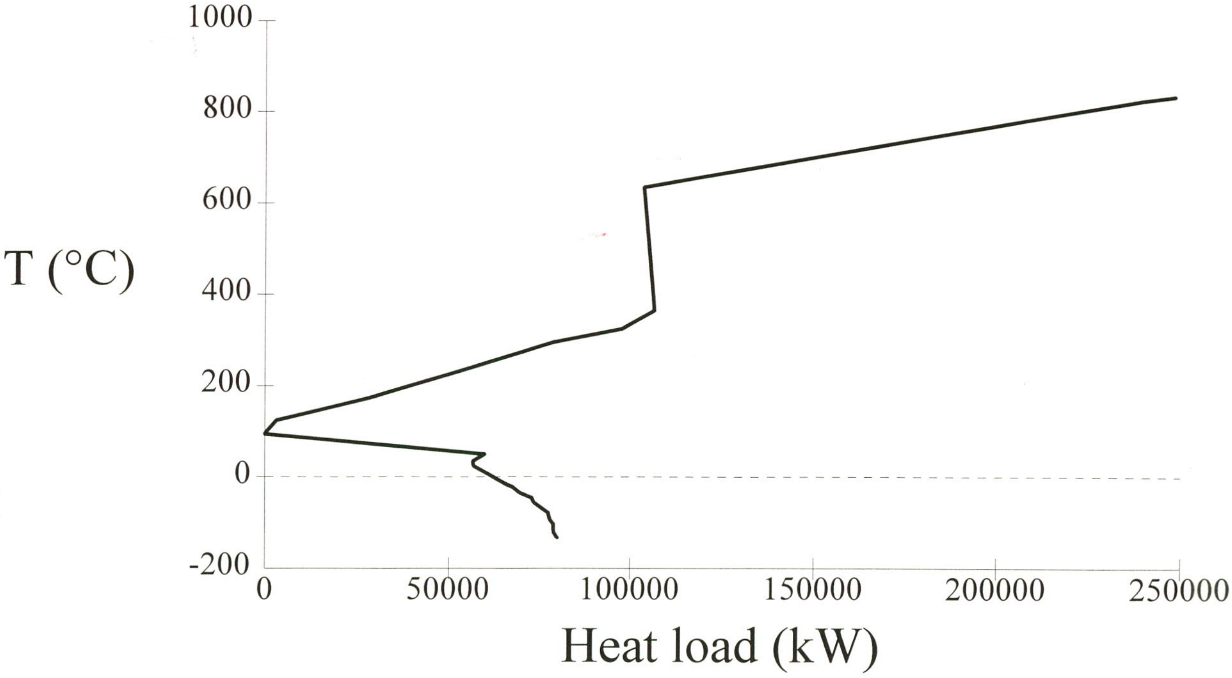


Figure 10.7.1 The grand composite curve of the ethylene plant

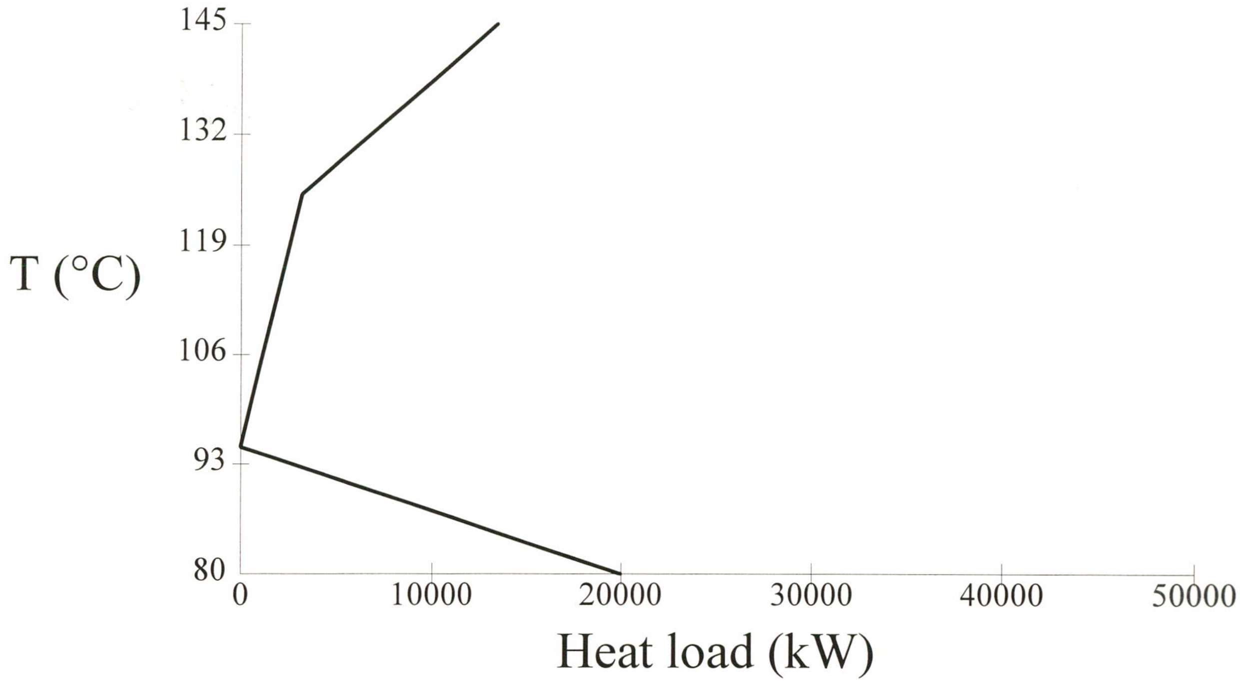


Figure 10.7.2 Detail of the GCC around the pinch

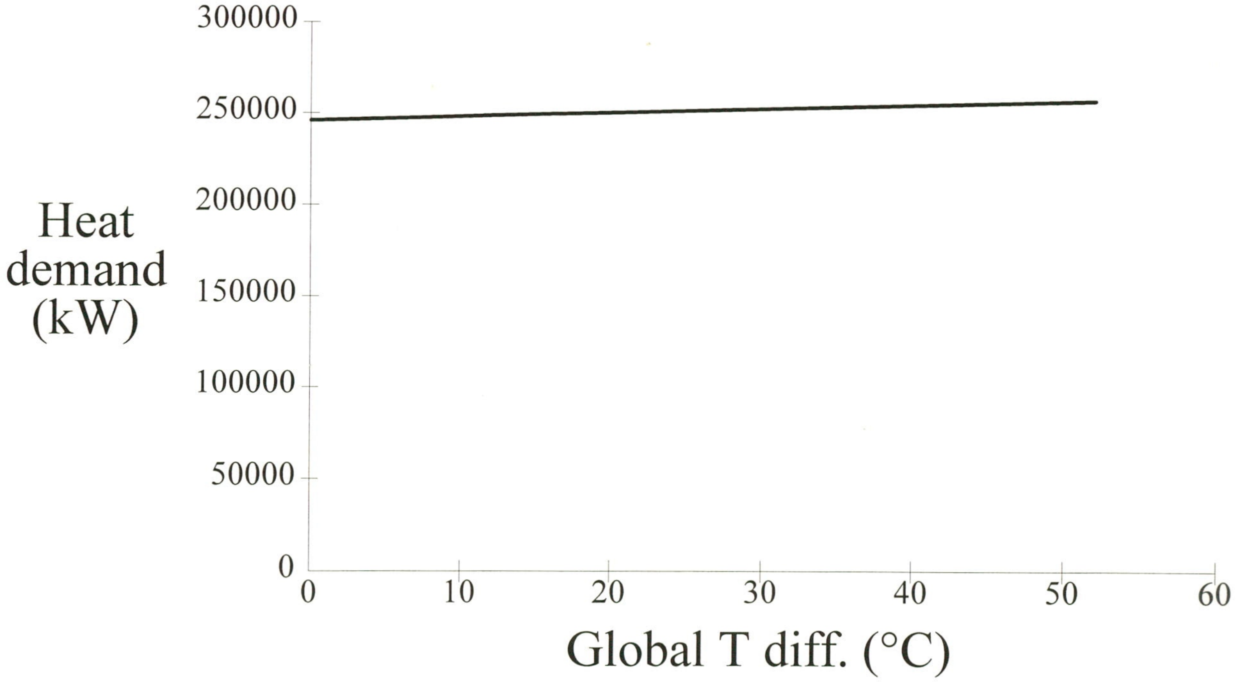


Figure 10.7.3 The head demand curve of the ethylene plant

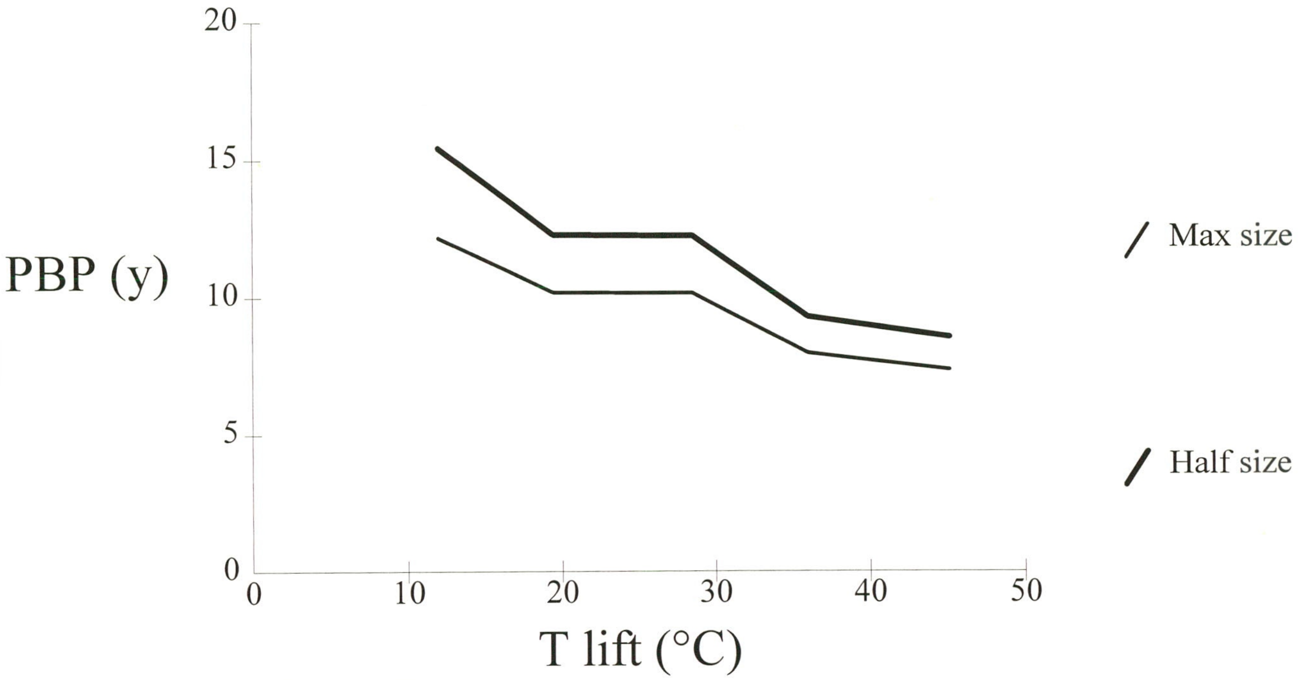
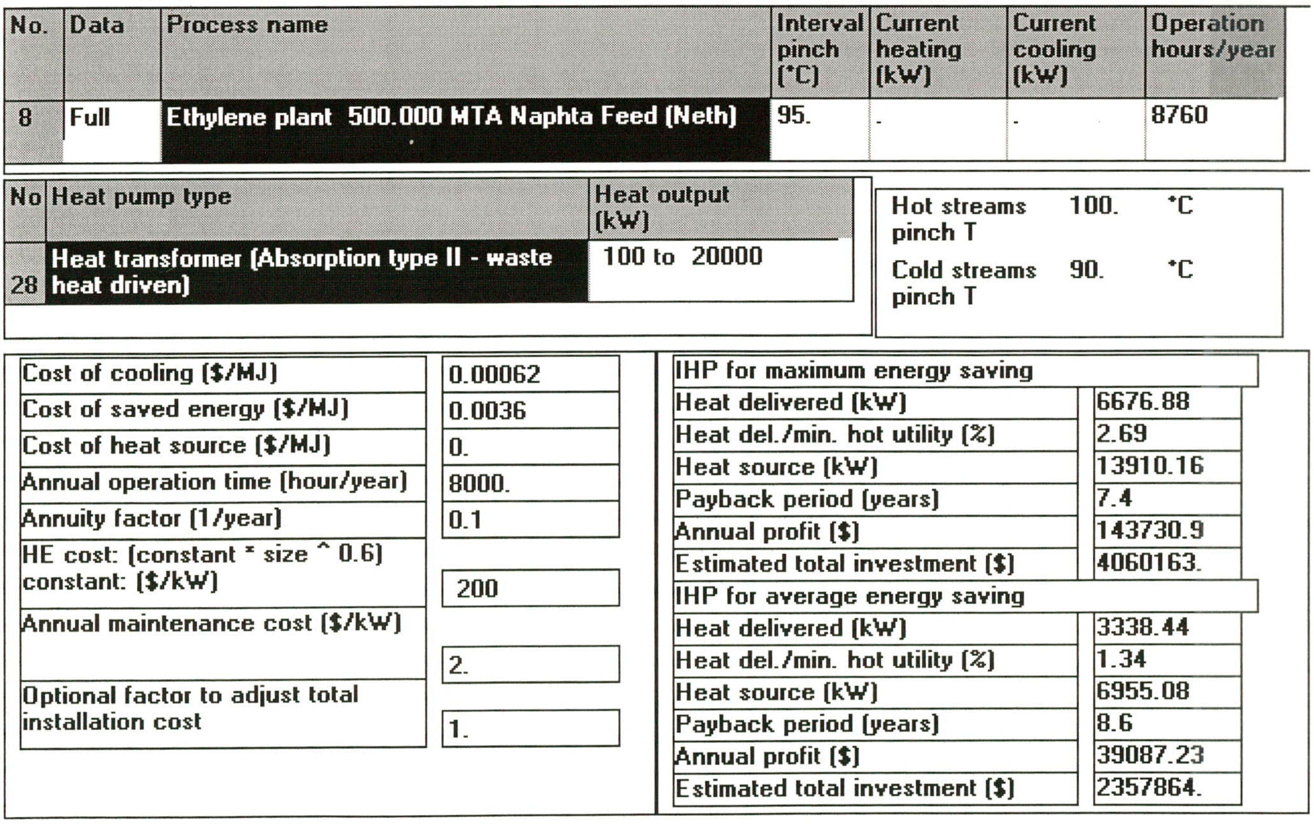


Figure 10.7.4 The PBP curve of the heat transformer in the ethylene plant

Table 10.7.1



No.	Data	Process name	Interval pinch (°C)	Current heating (kW)	Current cooling (kW)	Operation hours/year
8	Full	Ethylene plant 500.000 MTA Naphta Feed (Neth)	95.	-	-	8760

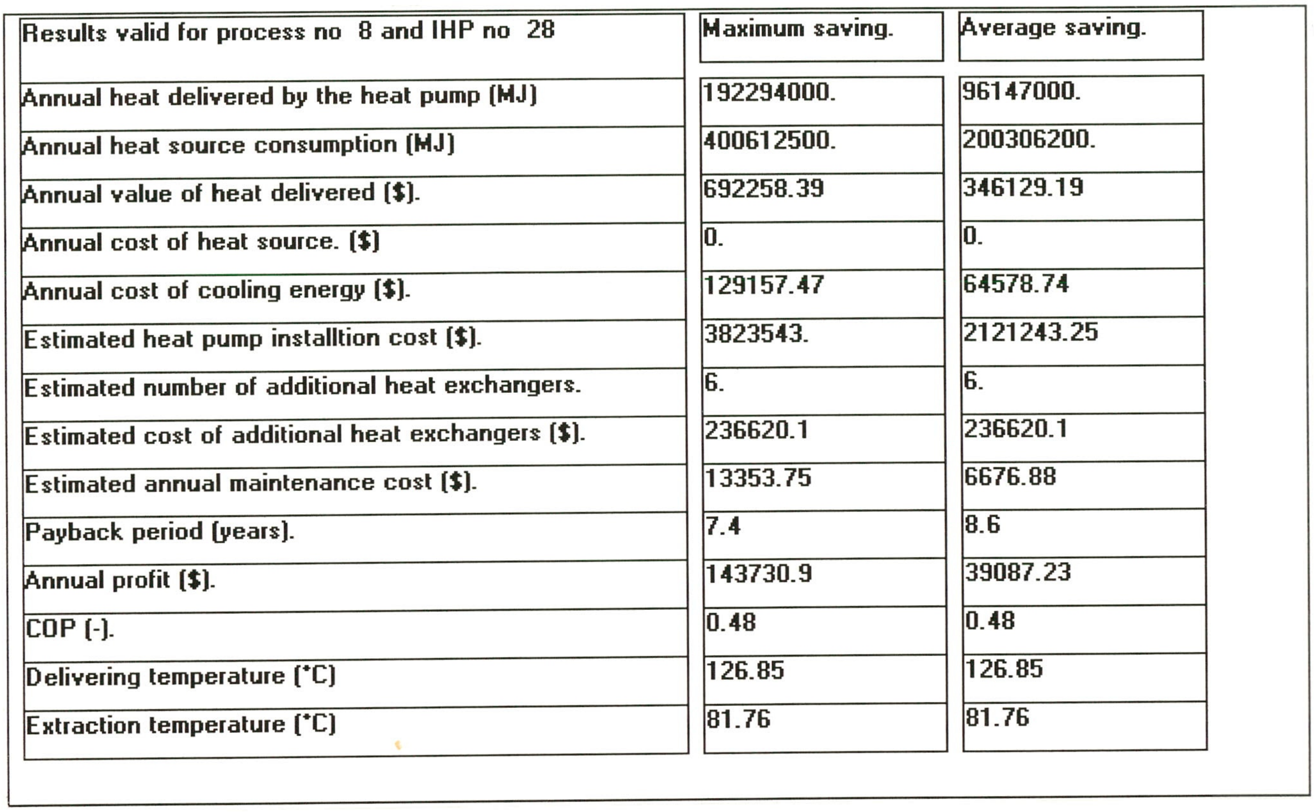
No	Heat pump type	Heat output (kW)
28	Heat transformer (Absorption type II - waste heat driven)	100 to 20000

Hot streams pinch T	100.	°C
Cold streams pinch T	90.	°C

Cost of cooling ($/MJ)	0.00062
Cost of saved energy ($/MJ)	0.0036
Cost of heat source ($/MJ)	0.
Annual operation time (hour/year)	8000.
Annuity factor (1/year)	0.1
HE cost: (constant * size ^ 0.6) constant: ($/kW)	200
Annual maintenance cost ($/kW)	2.
Optional factor to adjust total installation cost	1.

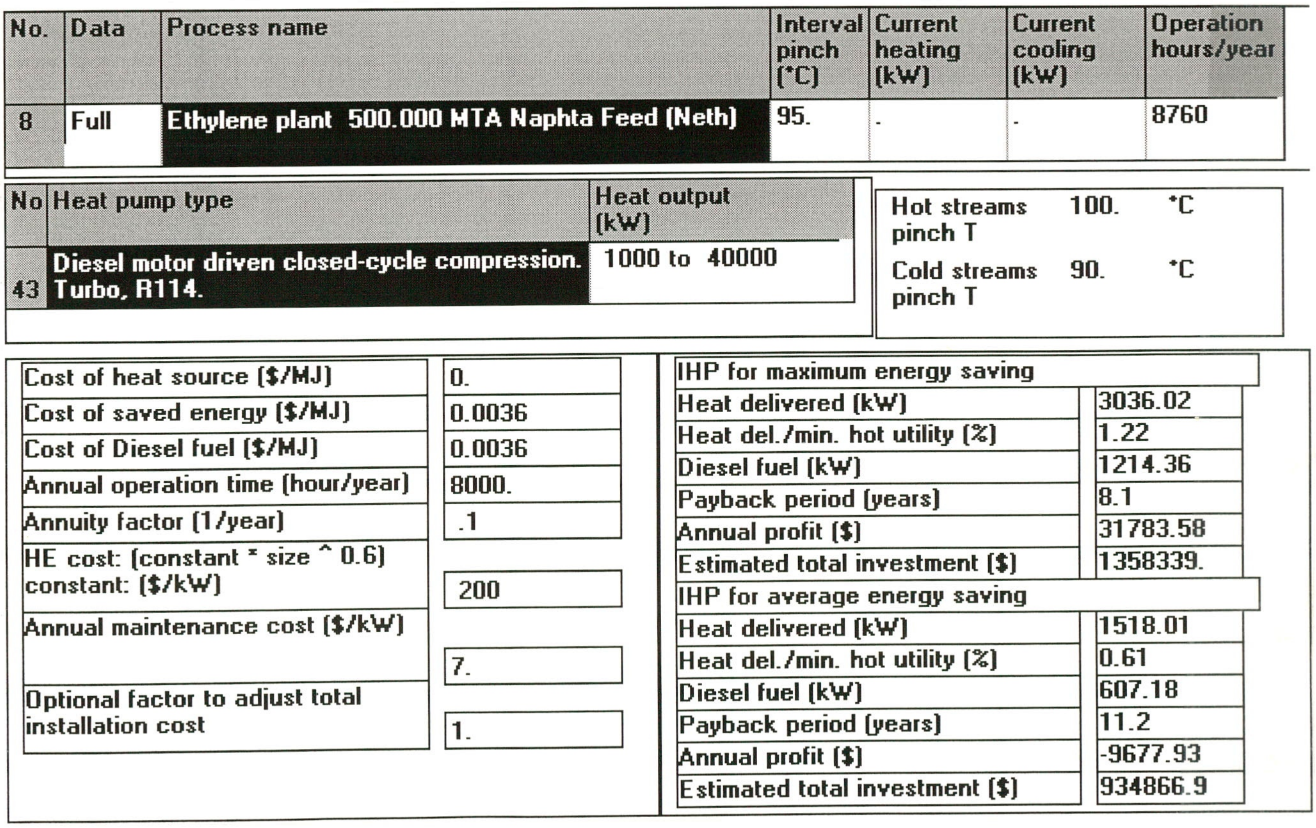
IHP for maximum energy saving	
Heat delivered (kW)	6676.88
Heat del./min. hot utility (%)	2.69
Heat source (kW)	13910.16
Payback period (years)	7.4
Annual profit ($)	143730.9
Estimated total investment ($)	4060163.
IHP for average energy saving	
Heat delivered (kW)	3338.44
Heat del./min. hot utility (%)	1.34
Heat source (kW)	6955.08
Payback period (years)	8.6
Annual profit ($)	39087.23
Estimated total investment ($)	2357864.

Table 10.7.2



Results valid for process no 8 and IHP no 28	Maximum saving.	Average saving.
Annual heat delivered by the heat pump (MJ)	192294000.	96147000.
Annual heat source consumption (MJ)	400612500.	200306200.
Annual value of heat delivered ($).	692258.39	346129.19
Annual cost of heat source. ($)	0.	0.
Annual cost of cooling energy ($).	129157.47	64578.74
Estimated heat pump installtion cost ($).	3823543.	2121243.25
Estimated number of additional heat exchangers.	6.	6.
Estimated cost of additional heat exchangers ($).	236620.1	236620.1
Estimated annual maintenance cost ($).	13353.75	6676.88
Payback period (years).	7.4	8.6
Annual profit ($).	143730.9	39087.23
COP (-).	0.48	0.48
Delivering temperature (°C)	126.85	126.85
Extraction temperature (°C)	81.76	81.76

Table 10.7.3



No.	Data	Process name	Interval pinch (°C)	Current heating (kW)	Current cooling (kW)	Operation hours/year
8	Full	Ethylene plant 500.000 MTA Naphta Feed (Neth)	95.	-	-	8760

No	Heat pump type	Heat output (kW)
43	Diesel motor driven closed-cycle compression. Turbo, R114.	1000 to 40000

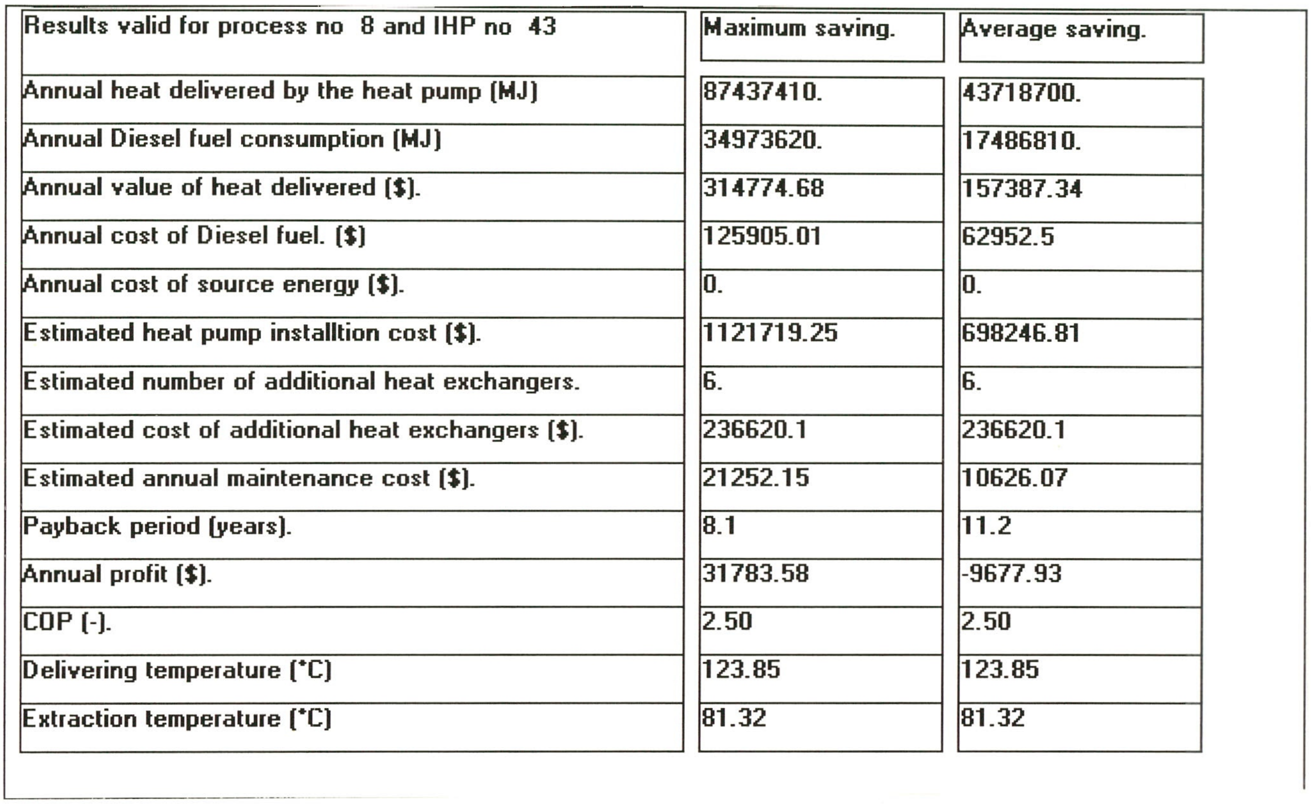
Hot streams pinch T	100.	°C
Cold streams pinch T	90.	°C

Cost of heat source ($/MJ)	0.
Cost of saved energy ($/MJ)	0.0036
Cost of Diesel fuel ($/MJ)	0.0036
Annual operation time (hour/year)	8000.
Annuity factor (1/year)	.1
HE cost: (constant * size ^ 0.6) constant: ($/kW)	200
Annual maintenance cost ($/kW)	7.
Optional factor to adjust total installation cost	1.

IHP for maximum energy saving	
Heat delivered (kW)	3036.02
Heat del./min. hot utility (%)	1.22
Diesel fuel (kW)	1214.36
Payback period (years)	8.1
Annual profit ($)	31783.58
Estimated total investment ($)	1358339.

IHP for average energy saving	
Heat delivered (kW)	1518.01
Heat del./min. hot utility (%)	0.61
Diesel fuel (kW)	607.18
Payback period (years)	11.2
Annual profit ($)	-9677.93
Estimated total investment ($)	934866.9

Table 10.7.4



Results valid for process no 8 and IHP no 43	Maximum saving.	Average saving.
Annual heat delivered by the heat pump (MJ)	87437410.	43718700.
Annual Diesel fuel consumption (MJ)	34973620.	17486810.
Annual value of heat delivered ($).	314774.68	157387.34
Annual cost of Diesel fuel. ($)	125905.01	62952.5
Annual cost of source energy ($).	0.	0.
Estimated heat pump installtion cost ($).	1121719.25	698246.81
Estimated number of additional heat exchangers.	6.	6.
Estimated cost of additional heat exchangers ($).	236620.1	236620.1
Estimated annual maintenance cost ($).	21252.15	10626.07
Payback period (years).	8.1	11.2
Annual profit ($).	31783.58	-9677.93
COP (-).	2.50	2.50
Delivering temperature (°C)	123.85	123.85
Extraction temperature (°C)	81.32	81.32

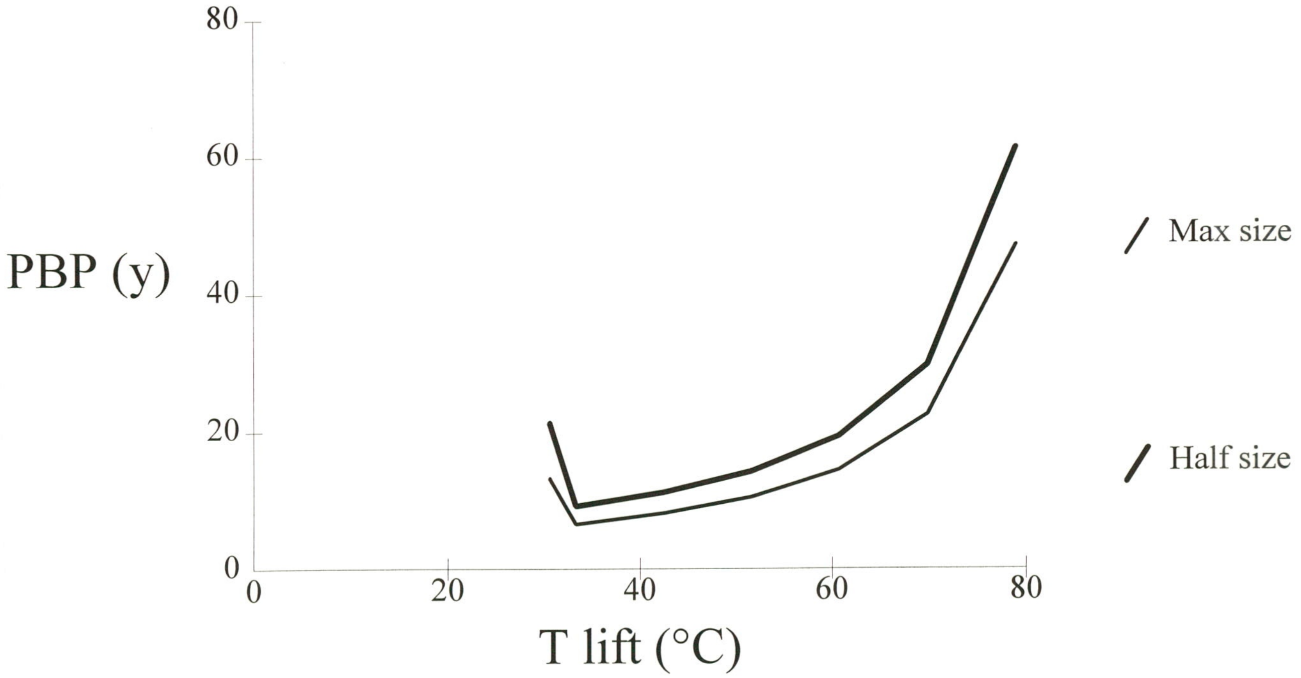


Figure 10.7.5 The PBP of the GM heat pump in the ethylene plant

10.8 Heat pump implementation in the methanol process

Due to a very high pinch temperature, heat pumps are not feasible in a methanol plant, see figure 10.8.1.

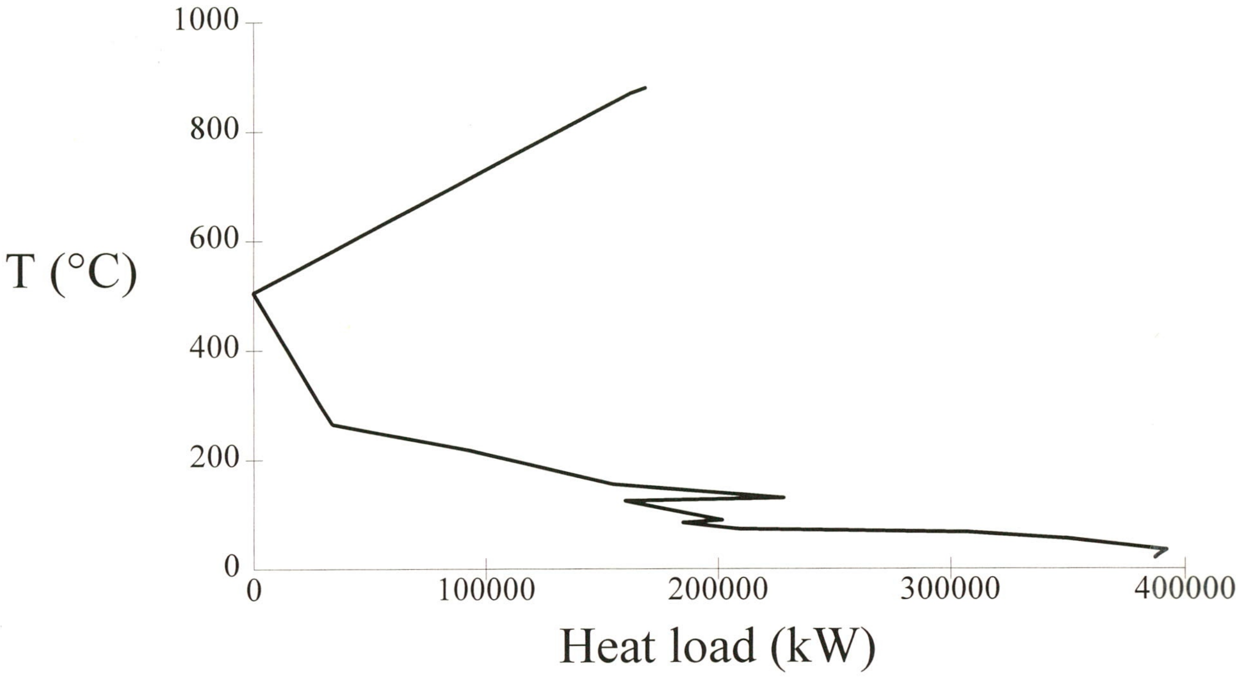


Figure 10.8.1 The grand composite of the methanol process

10.9 Heat pump implementation in the Starch evaporation process

Figure 10.9.1 gives the grand composite curve of a starch evaporation plant. Figure 10.9.2 gives the minimum heat demand curve of this process. A mechanical vapour recompression seems to be very trivial as well as very attractive. This is a good example of an ideal application of MVR.

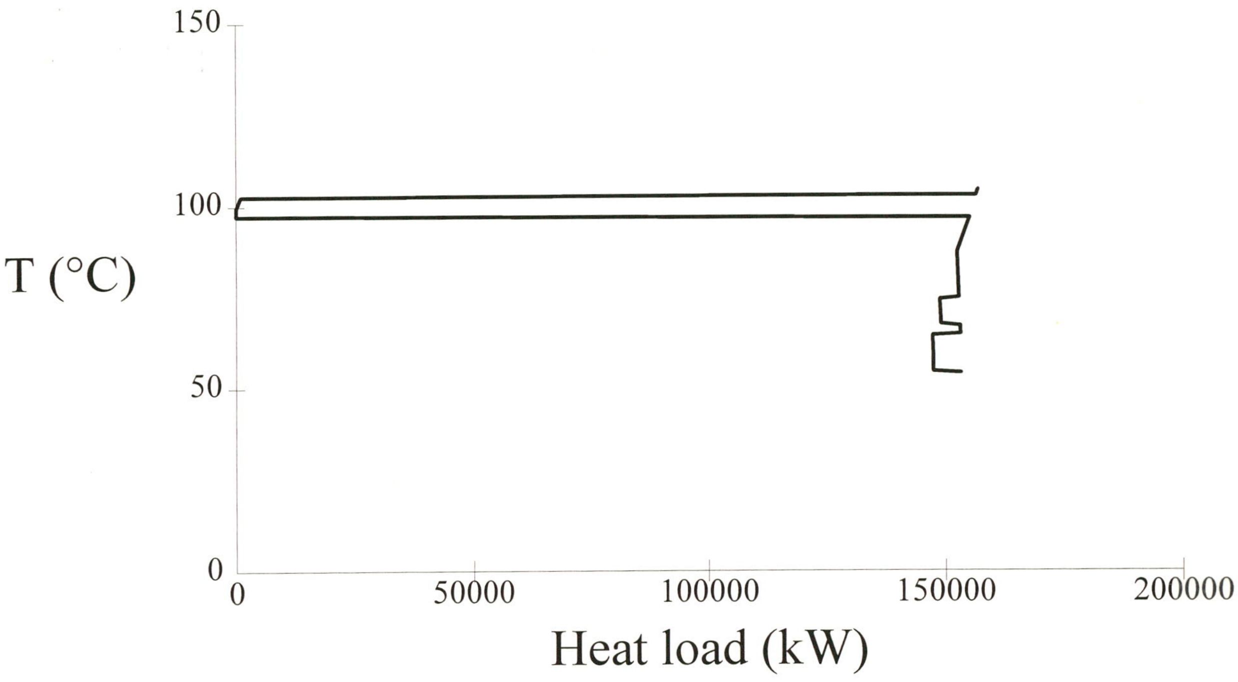


Figure 10.9.1 The grand composite curve of the starch evaporation process

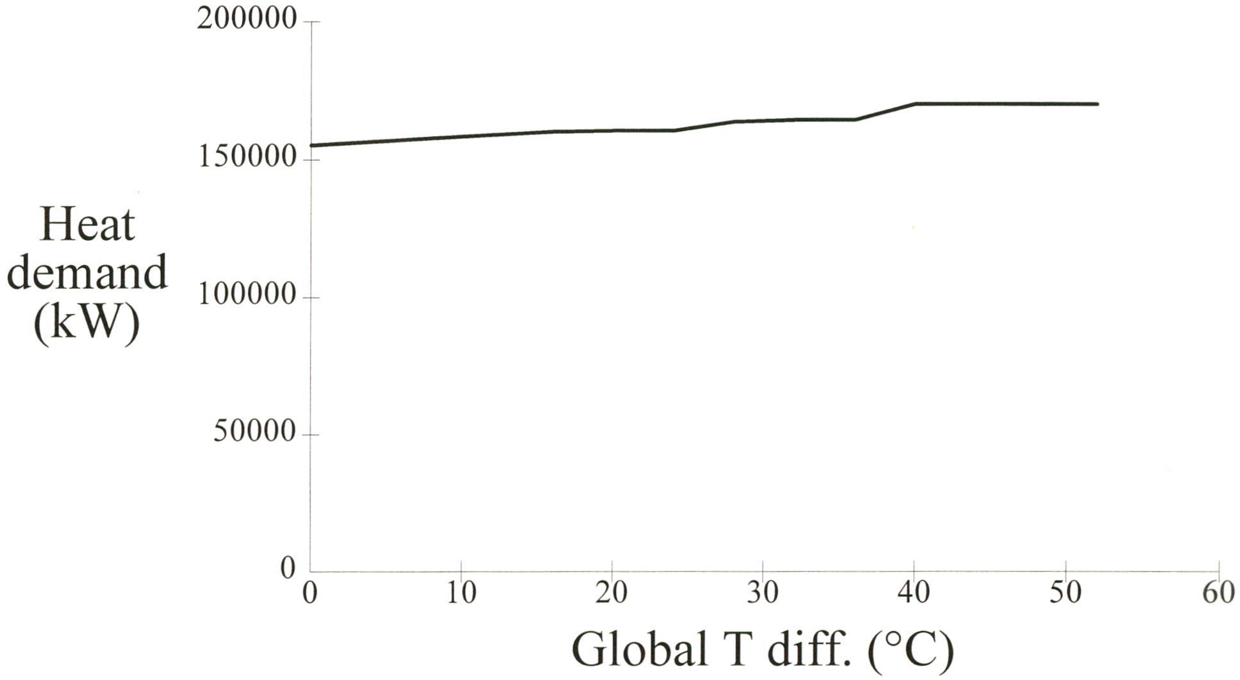


Figure 10.9.2 The heat demand curve of the starch evaporation process

Figure 10.9.3 gives the PBP curve and table 10.9.1 and 10.9.2 give the economic data of this heat pump. The PBP curve is given by figure 10.9.3.

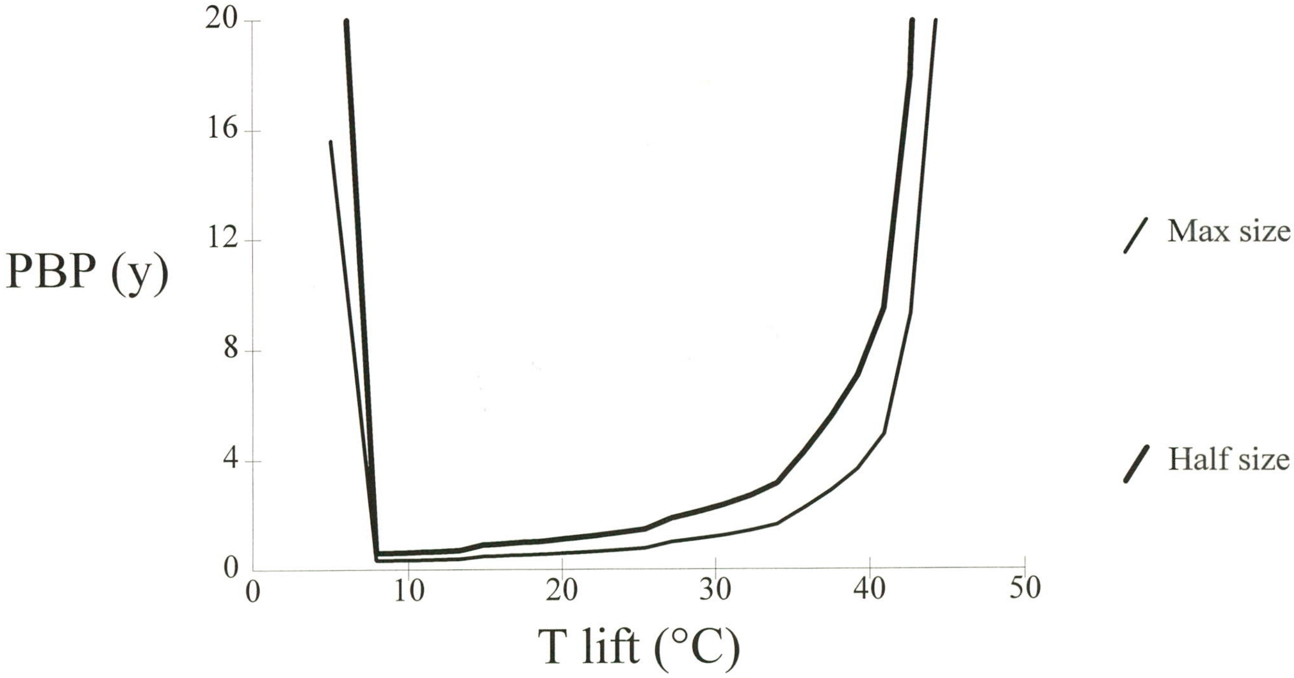
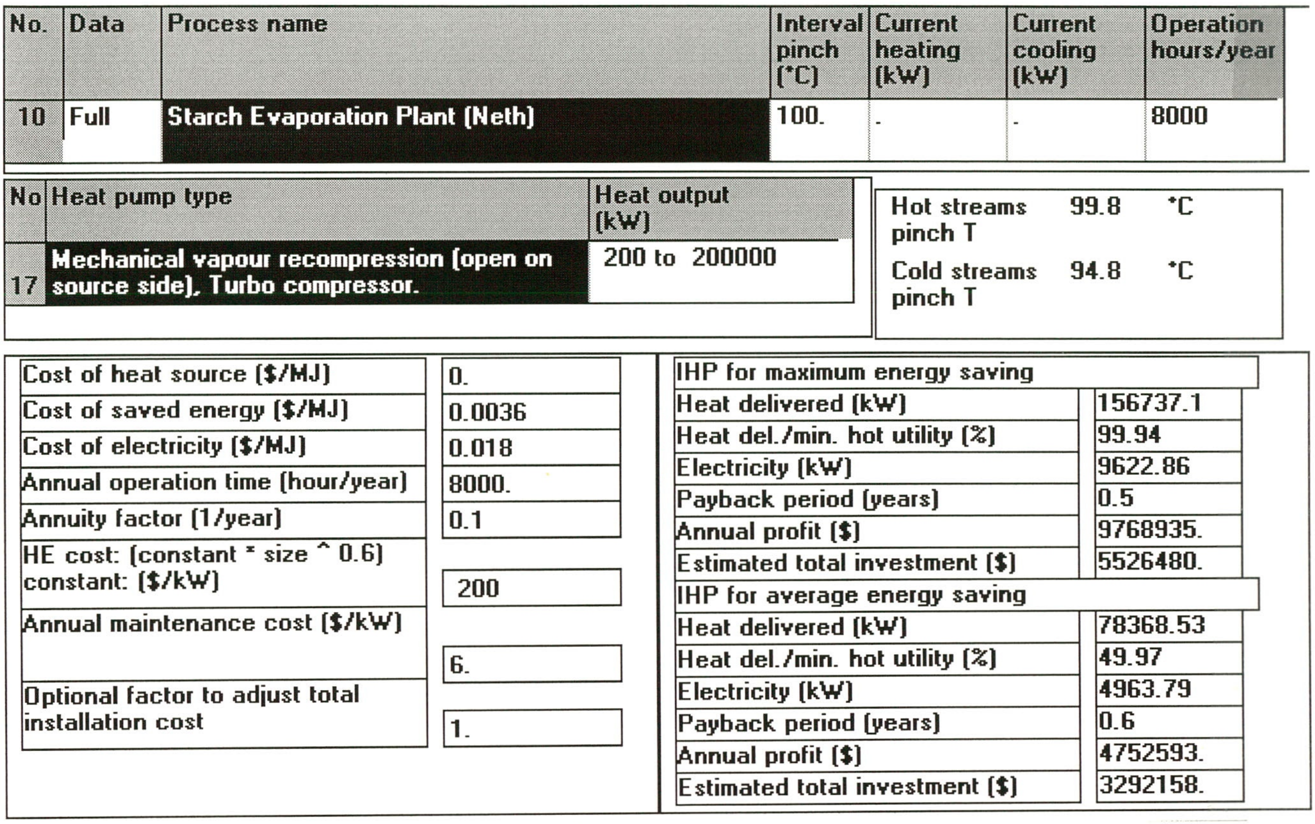


Figure 10.9.3 The PBP curve of the MVR in the Sarch evaporation process

Table 10.9.1



No.	Data	Process name	Interval pinch (°C)	Current heating (kW)	Current cooling (kW)	Operation hours/year
10	Full	Starch Evaporation Plant (Neth)	100.	.	.	8000

No	Heat pump type	Heat output (kW)
17	Mechanical vapour recompression (open on source side), Turbo compressor.	200 to 200000

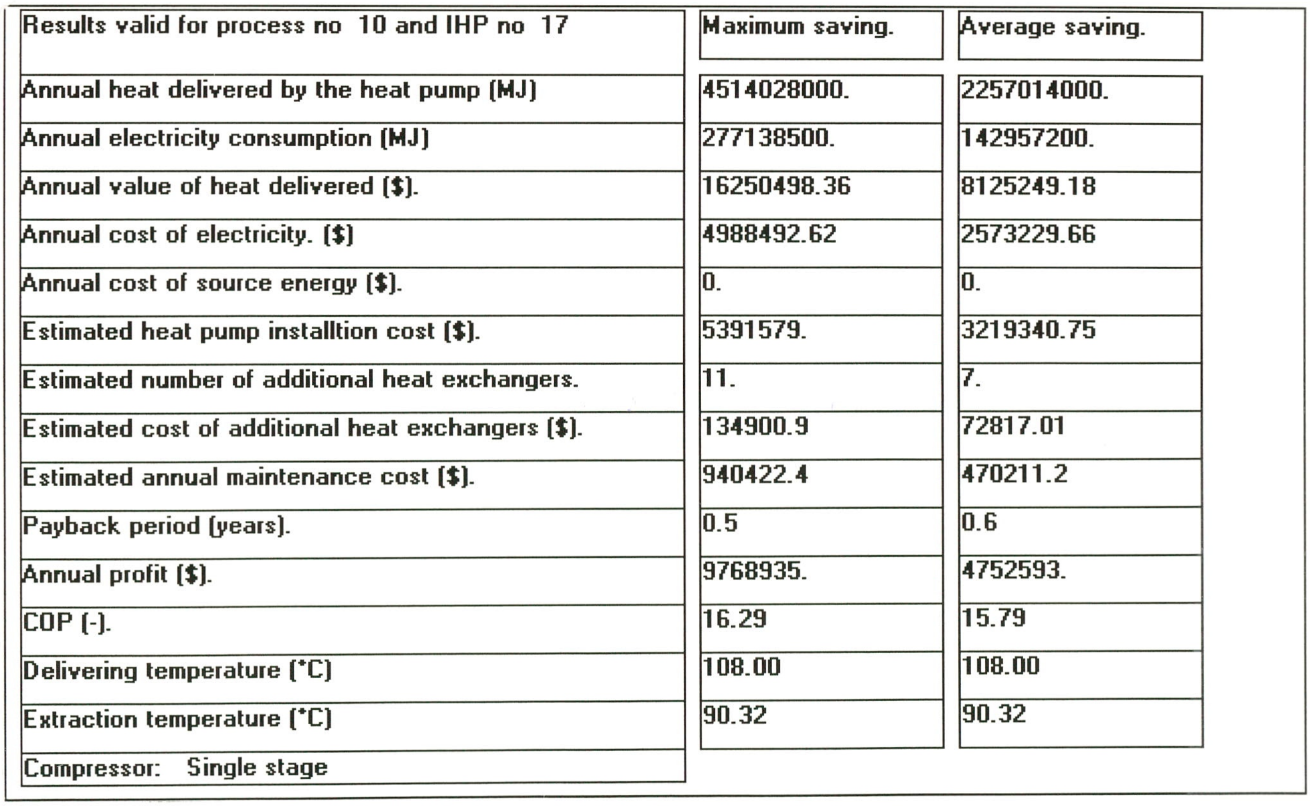
Hot streams pinch T	99.8	°C
Cold streams pinch T	94.8	°C

Cost of heat source ($/MJ)	0.
Cost of saved energy ($/MJ)	0.0036
Cost of electricity ($/MJ)	0.018
Annual operation time (hour/year)	8000.
Annuity factor (1/year)	0.1
HE cost: (constant * size ^ 0.6) constant: ($/kW)	200
Annual maintenance cost ($/kW)	6.
Optional factor to adjust total installation cost	1.

IHP for maximum energy saving	
Heat delivered (kW)	156737.1
Heat del./min. hot utility (%)	99.94
Electricity (kW)	9622.86
Payback period (years)	0.5
Annual profit ($)	9768935.
Estimated total investment ($)	5526480.

IHP for average energy saving	
Heat delivered (kW)	78368.53
Heat del./min. hot utility (%)	49.97
Electricity (kW)	4963.79
Payback period (years)	0.6
Annual profit ($)	4752593.
Estimated total investment ($)	3292158.

Table 10.9.2



Results valid for process no 10 and IHP no 17	Maximum saving.	Average saving.
Annual heat delivered by the heat pump (MJ)	4514028000.	2257014000.
Annual electricity consumption (MJ)	277138500.	142957200.
Annual value of heat delivered ($).	16250498.36	8125249.18
Annual cost of electricity. ($)	4988492.62	2573229.66
Annual cost of source energy ($).	0.	0.
Estimated heat pump installtion cost ($).	5391579.	3219340.75
Estimated number of additional heat exchangers.	11.	7.
Estimated cost of additional heat exchangers ($).	134900.9	72817.01
Estimated annual maintenance cost ($).	940422.4	470211.2
Payback period (years).	0.5	0.6
Annual profit ($).	9768935.	4752593.
COP (-).	16.29	15.79
Delivering temperature (°C)	108.00	108.00
Extraction temperature (°C)	90.32	90.32
Compressor: Single stage		

11 Market assessment of industrial heat pumps in The Netherlands

RCG/Hagler Bailly Inc. has developed a market assessment worksheet for industrial heat pumps. The main target of this worksheet is to fix the effect of heat pump implementation on:

- Net energy savings.
- Net energy costs.
- Emission reductions.

The market Assessment is based on the following data:

General

- Energy price data.
- Emissions data per type of fuel.
- Electricity generation data (e.g. fuel mix).
- Market penetration data.

Process

- Industrial process data.
- Estimated number of plants.
- Estimated industry growth.
- Total process heat demand.
- Energy mix for process heat demand.
- Projected yearly reductions on total process heat demand.
- projected process heat demand by CHP, waste heat recovery boilers and incinerators.

Heat pump

- Heat pump data from the Chalmers/ETA programme:
  - Heat pump type (up to five types per process).
  - Annual profit ($).
  - Pay back (years).
  - Energy delivered (GJ/year).
  - Drive energy delivered (GJ/year).

The combination of these data gives for every defined process the net energy savings (MJ, $) and the reduction of SO_x, NO_x, CO_2, CO, and CH_4 emissions.

Heat pump implementation in the methanol plant is not possible, see chapter 10. For this reason, there is no heat pump market potential in this process.
Due to the small number of ethylene plants (3) and urea plants (2), the market assessment spreadsheet cannot fix a market potential. In fact, there is a market potential for this processes

The meaning of this market assessment spreadsheet is very limited. Strictly, it is impossible to fix the market potential for heat pumps, because:

- The resulted data are very sensitive for the industrial growth, the energy prices and marked penetration incentives based on profit/payback level. This data – if available – are far from reliable.

- The diffusion rate approach is based on the law of large numbers. The diffusion rate approach (rate at which use approaches maximum penetration) results thus in very low heat pump capacity in scarce plants. In general, just the large plants with good opportunities for - large, continu running - heat pumps are scarce!

Figures 11.1 to 11.5 give the Dutch net energy savings and the Dutch projected emission reductions of Dairy production, paper production, starch evaporation, textile finishing and building ceramics. With the market assessment spreadsheet, there is no potential found for urea production plants, methanol plants and ethylene plants, due to low plant numbers in the Netherlands. For methanol, there is no potential, but, for urea and ethylene plants heat pumps are possible and feasible, see chapter 10.

Appendix 3 gives a full output sheet of the market assessment sheet.

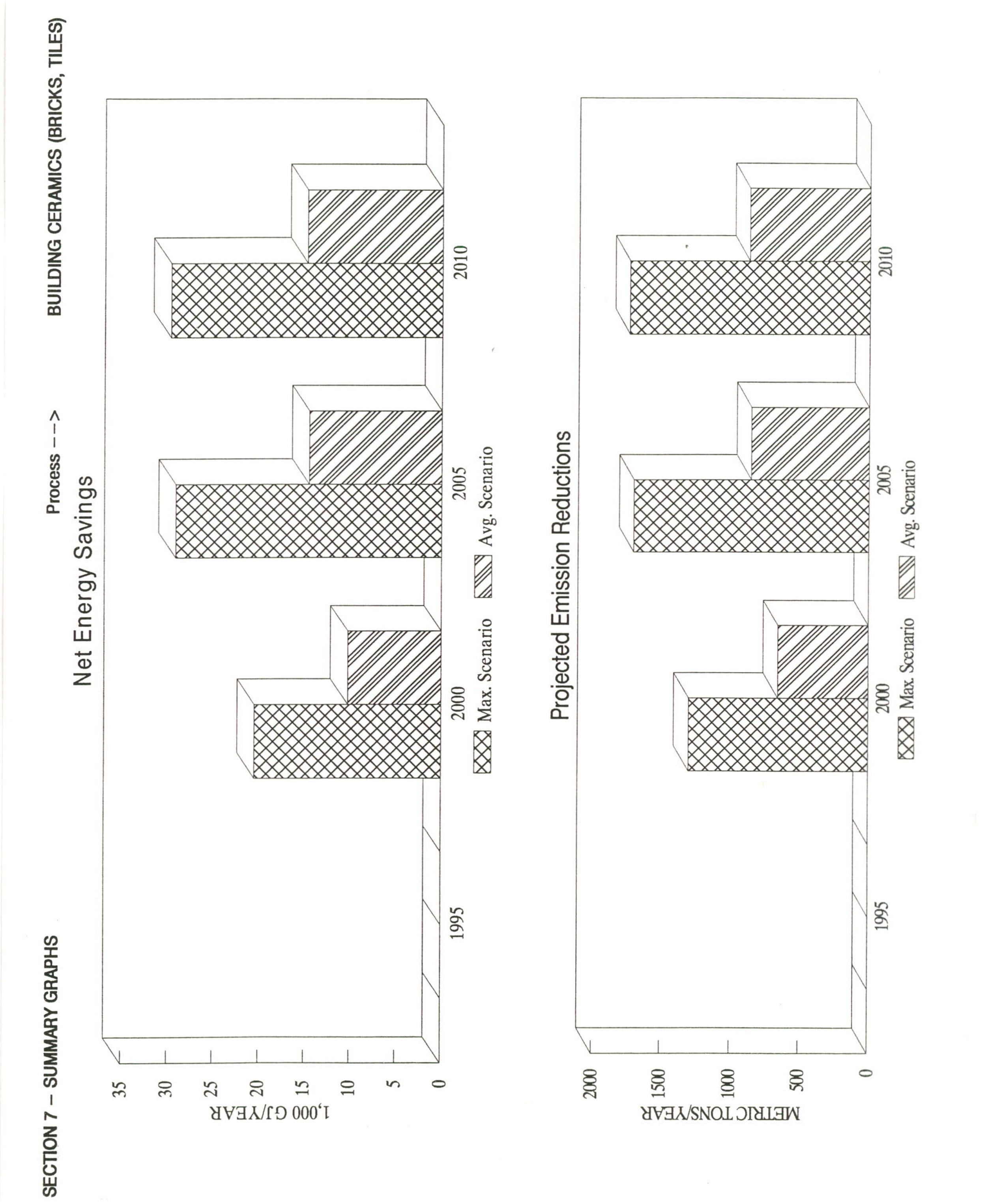


Figure 11.1 Net energy savings and projected emission reduction in the Dutch building ceramics industry

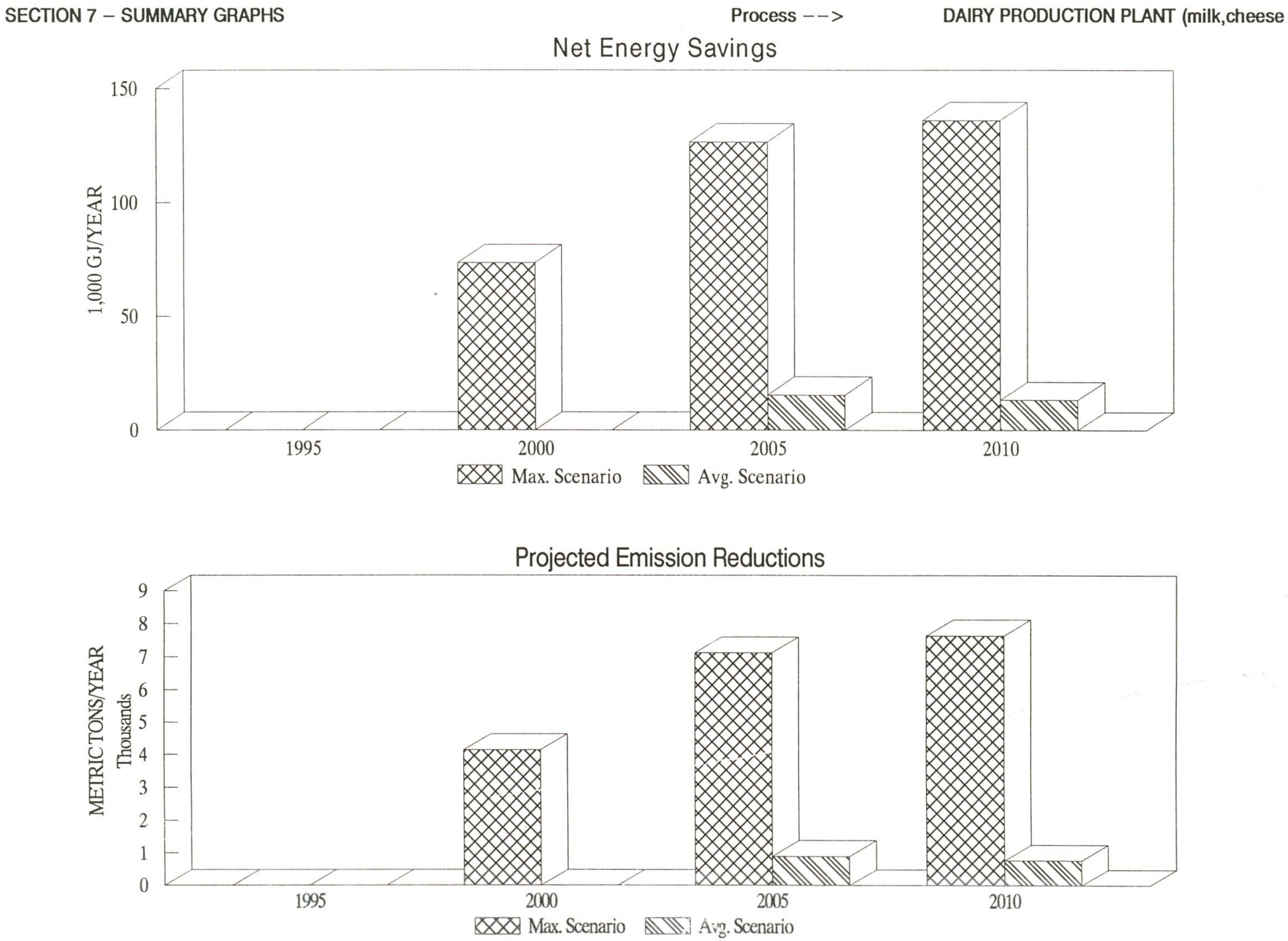


Figure 11.2 Net energy savings and projected emission reduction in the Dutch dairy industry.

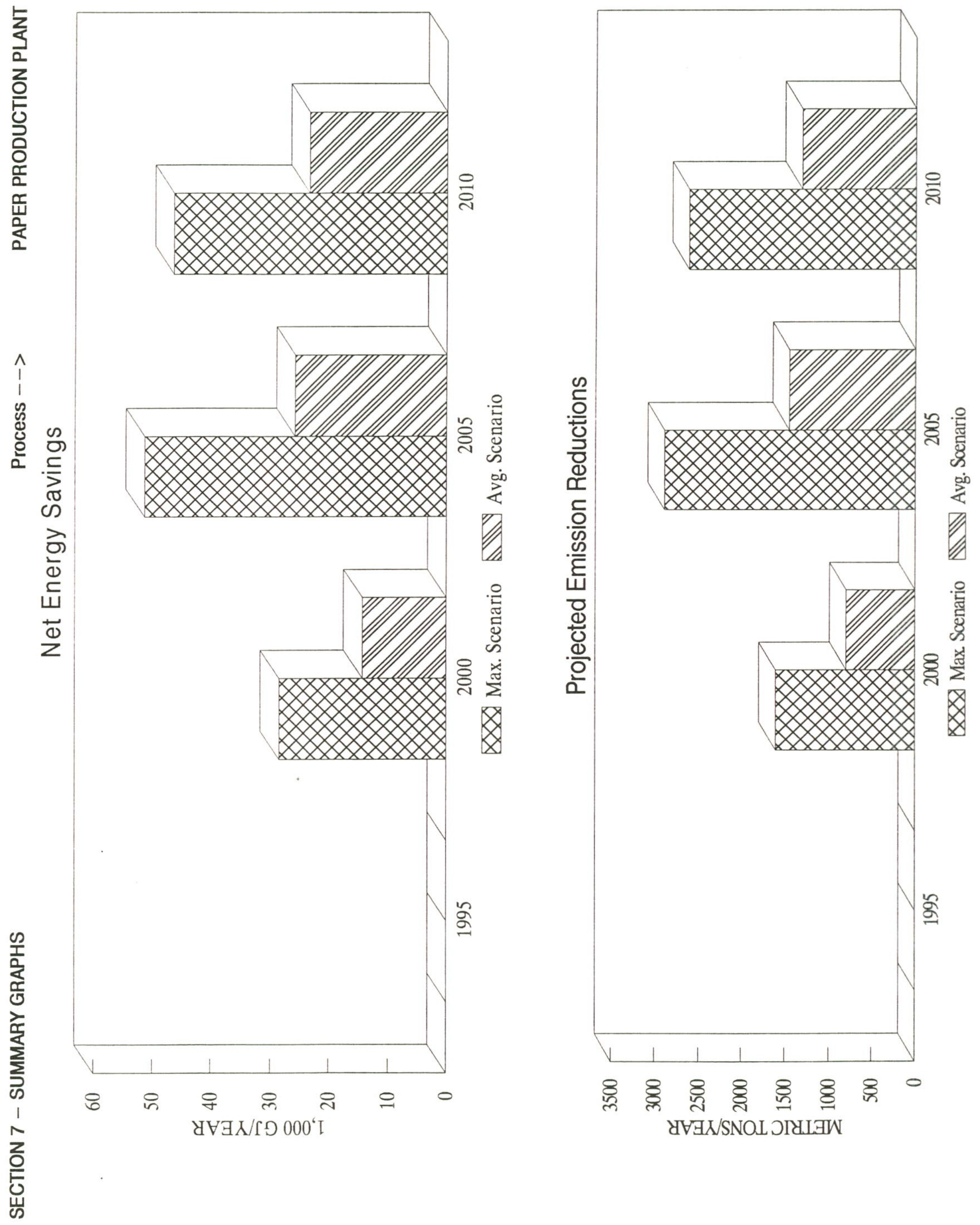


Figure 11.3 Net energy savings and projected emission reductions in the Dutch paper industry

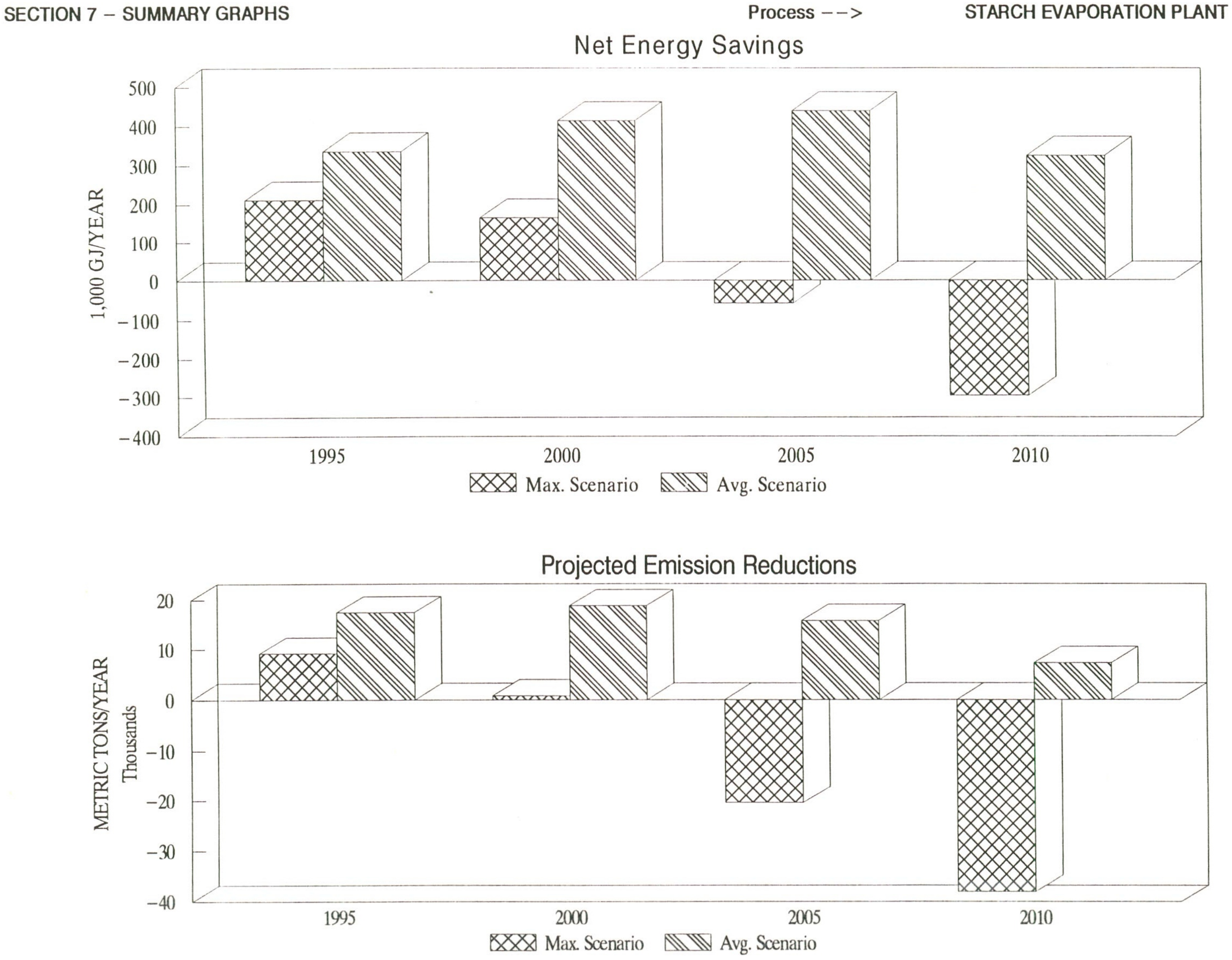


Figure 11.4 Net energy savings and projected emission reductions in the Dutch starch industry

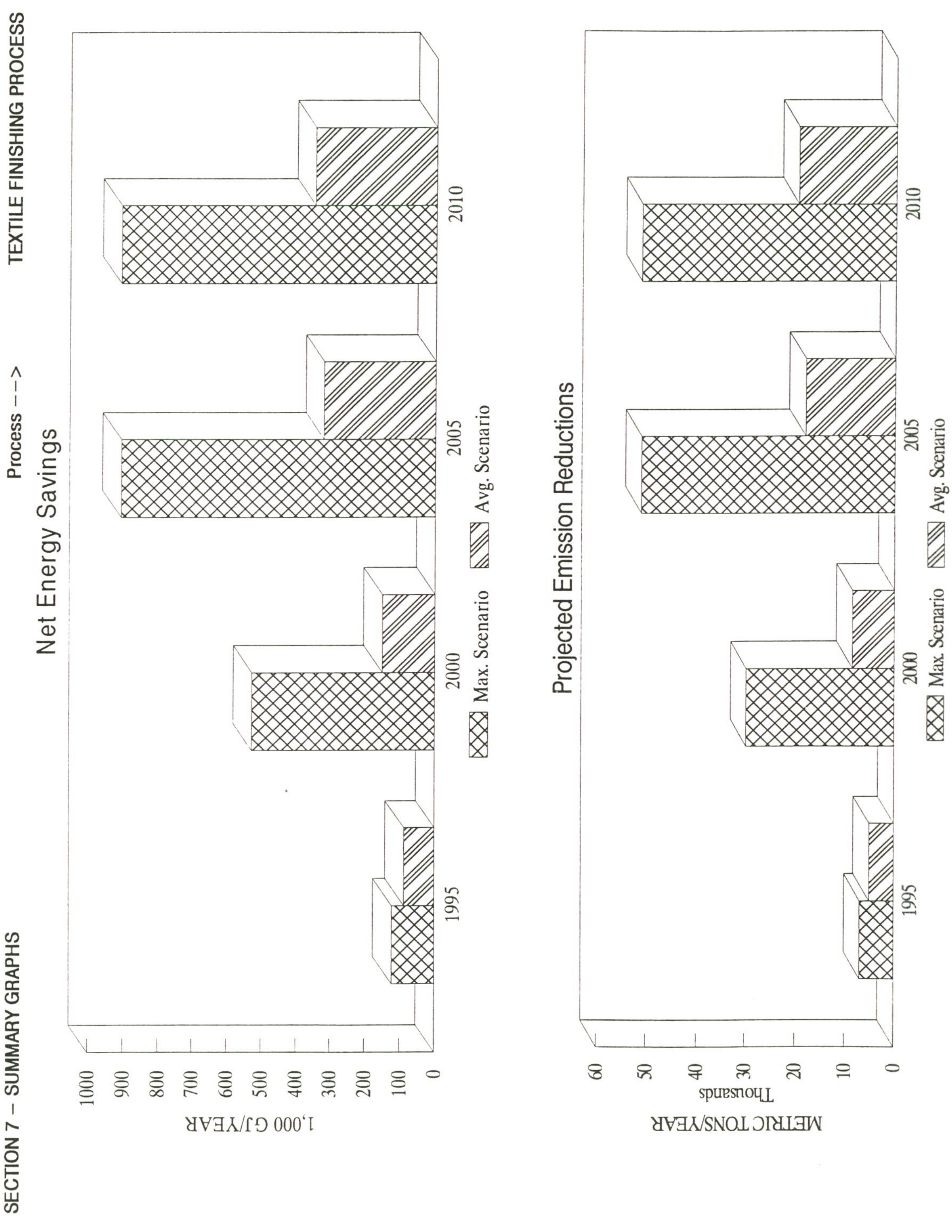


Figure 11.5 *Net energy savings and projected emission reductions in the Dutch textile finishing industry.*

12 Conclusions and recommendations

- The estimate of potential for industrial heat pumps in the present study was made on the basis of a number of selected reference processes a) for which a usable process description and preferably a pinch study were available and b) which account for a considerable proportion of the primary energy consumption in the sector concerned.
- The potential for industrial heat pumps in The Netherlands is indicated by the following tables:

Table 12.1 Potential for Heat Pumps in the Food and Drink industry

Sector	Type HP	$P_{condensor}$ [MW]	P_{drive} [MW]	Number	E-savings TJ	Emission Reduction CO_2 [ton.10^3/jr]
Dairy	MVR	450	30	60	10,686	545
	closed cycle	60	20	40	212	11
Sugar	MVR	500	40	8	3,069	157
	close cycle	-	-		-	-
Starch	MVR	200	8	4	2,899	148
	closed cycle	-	-		-	-
Beers	MVR	6	0.3	6	150	7.6
Malt	closed cycle	4	1	6	39	1.9
Oils & Fats	MVR	200	10	pm	4,752	242
	closed cycle	pm	pm	pm	pm	-
Total		1420	108.3	124	21,807	1112.5

Table 12.2 Potential for Heat Pumps in the rest of industry

Sector	Type HP	$P_{condensor}$ [MW]	P_{drive} [MW]	Number	E-savings TJ	Emission Reduction CO_2 [ton.10^3/jr]
Paper	closed cycle	80	15	20	1,167	59.5
Textile	MVR	-	-	-	-	-
Finishing	closed cycle	4	0.8-1	10 - 15	30	1.5
Ceramics	MVR	-	-	-	-	-
and glass	closed cycle	12[1]	0.5 [2]	3	308	15.7
Chemicals	MVR	1,000	80	pm	22,737	1,159
	closed cycle [3]	36.8	1	6	94.4	48.1
Base	MVR	-	-	-	-	-
materials	closed cycle	pm	pm	pm	pm	pm
Total		1,132.8	96.5	44	25,186	1,283.8

[1] Some of these are heat transformers in the ceramics industry
[2] Drive power of heat transformers not taken into account
[3] Ethylene and ureum production

- The limited availability of thermal process data for the chemical industry is the main reason why estimates of potential for industrial heat pumps in this sector could not really be properly carried out. On the basis of foreign pinch studies of processes which are also commonly found in The Netherlands chemical industry, it can however be concluded that this potential is considerable, particularly in the case of mechanical vapour recompression.
- In some (sub)sectors of Netherlands industry, the application of heat pumps will be necessary in the future in order to bring about a marked reduction in primary energy consumption. Because energy prices are relatively low it is in many case not particularly attractive from the economic point of view to achieve this reduction.
- Industrial heat pumps are relatively uncommon in The Netherlands. Almost all the heat pumps which have been installed are vapour recompression systems. In small to medium units steam ejectors are often used, particularly in the dairy industry. Larger units are based on mechanical vapour recompression.
- Of the existing potential for heat pumps at the present time (far) less than 5% is used.
- It has been demonstrated that both the total investment and the primary energy consumption of mechanical vapour recompression for evaporation in the dairy industry are lower than those of the traditional six-stage evaporation using a steam ejector.
- The primary energy consumption of the traditional sugar refinery and the traditional dairy plant can be halved by using combined heat and power systems with gas turbines, making use of the exhaust gases from the turbine for drying, and applying vapour recompression for the evaporation and crystallisation of sugar. Because of the high investment costs, schemes of this kind are only of interest for new plants.
- Industrial heat pumps are mostly used for evaporation. In some cases top products from distillation columns or strippers are also compressed and subsequently condensed. Apart from heat recovery, the recovery of solvent can also be an important (environmental) target.
- Wet flue gas purification can in the future offer considerable possibilities for the application of heat pumps. This applies in situations in which there is also a demand for relatively low-temperature heat.
- In-unit applications are far more common than inter-unit applications.
- Sectors in which heat pumps have already been applied are the food and drink industry, the textile industry, the (petro)chemical industry and the paper and card board industry. The chemical industry in particular offers a vast potential which has hitherto not been exploited. The most important reason for this is the low cost of fuel in relation to the investment costs.
- Pinch technology can provide a relatively simple and rapid insight into the elements of a process where there is a potential for heat pumps. The application of heat pumps does however introduce ‘utility pinches’, which have to be taken into account in the design of the heat exchanger network.

- Pinch technology has hitherto been principally applied in large-scale processes, in which the process conditions are assumed to be constant, which is in fact essential if the complexity of the system is not to get out of hand. Smaller-scale processes offer practical possibilities of studying the effect of changes in the process conditions on the location and shape of the pinch. This can lead to better heat recovery possibilities not only above or below the pinch, but also 'over the pinch', with the aid of heat pumps.
- It is not likely that there will be large-scale penetration by absorption and closed compression heat pumps for industrial use so long as the price of primary energy remains low.
- It is recommended that further studies should be carried out into the use of water as a cooling agent.
- In situations in which the combined heat and power plant is too large and consequently gives rise to heat surpluses at process temperature level, the application of heat pumps pointless. High prices for the electricity produced and subsidies for combined heat and power installations are important factors here. This applies in particular to situations in which the plant's own demand for power is relatively high as compared with its demand for heat.
- The selection and implementation of technical and economic attainable heat pumps in these processes is carried out with the IEA/Annex 21 computer programmes (Chalmers/ETA programme and the RCG market assessment speadsheet). The selection of these processes has taken place in cooperation with the National Teams during the 3rd Annex 21 expert meeting, September 1993. The following processes in The Netherlands are selected:
  - Dairy production plant (cheese, milk, whey)
  - Textile plant
  - Paper production plant
  - Building ceramics (bricks, tiles) plant
  - Methanol plant
  - Ethylene plant (naphta feed)
  - Ureum plant
  - Starch evaporation plant
- For all these processes, one or two heat pumps were found to have an acceptable pay back period. Criterion for feasibility is: with an annuity factor of 0.1, there must be an annual profit. The results are:

Table 12.3

Process	**Pinch [°C]**	**Heat pump type**	**Condenser capacity [kW]**	**Pay back period [yr]**
Textile	35	GM, CC,[1)] Screw R22	6400	3.8
Dairy	71	Absorp, LiBr-H2O, nat. gas	3420	8.6
Dairy	71	TVR	2480	4.8
Paper	86	GM, CC, ECO, TURBO, R114	3830	5.3
Paper	86	Heat Transf LiBr-H2O	1843	9.9
Building Ceramics	52	GM, CC, Screw, R22	470	8.1
Ureum	133	GM, CC, Turbo, H2O	3800	5.1
Ethylene	95	Heat Transf LiBr-H2O	6676	7.4
Ethylene	95	GM, CC, Turbo, R114	3036	8.1
Methanol	505	No Heat Pump av.		
Starch evaporation	100	MVR	156737	0.5

[1)] GM = gasmotor driven
CC = closed cycle
Screw/Turbo = compressor type
ECO = economiser
MVR = mechanical vapour recompression
TVR = thermal vapour recompression

- The meaning of the Market Assessment spreadsheet is limited, since the results are very sensitive for the industrial growth, the future energy prices and the market penetration incentives.
- The market assessment spreadsheet gives no heat pump potential for scarce (mostly large!) plants with sometimes good perspectives for heat pumps.
  This effect is illustrated at the tree ethylene and the two urea plants in The Netherlands.

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14 Authentication

Name and address of the principals
Novem B.V.
PWP

Names and functions of the cooperators
J.B. de Wit - research coordinator
J.P. van der Stoel -
Dr. P.J.T. Bussmann -
A.A.L. Traversari -

Names of establishments to which part of the research was put out to contract
–

Date upon which, or period in which, the research took place

Signature	Approved by
J.B. de Wit research coordinator	P.A. Oostendorp section leader

Appendix 1 Annex infosheet

Project - Annex XXI

Knowledge sharing in heat pump technology

Global Environmental Benefits of Industrial Heat Pumps

Question:

What can industrial heat pumps do for

The environment?

Productivity?

Energy efficiency?

Answer:

Curb the Greenhouse Effect by reducing pollutants

Conserve primary energy

Improve plant productivity

Maximize cost-effectiveness

How can you support the growth of Industrial Heat Pumping to achieve these benefits?

If your company/organization is....

In a **Process Industry**, whose manufacturing requires a large amount of energy, particularly steam or process heat

A **Manufacturer** of industrial process and/or heat pump equipment, compressors, heat exchangers, etc.

An **Architectural/Engineering** firm that designs industrial processes

A **Utility** selling gas or electricity, with an active industrial customer technical assistance program

An **R & D Funding Organization**, supporting energy-related industrial process efficiency

Then....

Participate in this exciting and ambitious effort to promote the application of Industrial Heat Pumps (IHPs).

Products

- Comprehensive report on global environmental benefits of Industrial Heat Pumps
- Guidelines for IHP Application
- Detailed IHP design manual
- Expert computer program to assist IHP implementation
- International Expert Meetings

Your Input

Describing existing IHP installations and waste heat quality, quantity, and temperature level in industrial processes (where IHPs may be suitable)

Our Output

Illustrating the emission reductions, cost reductions and energy savings of IHPs, with products that benefit you.

IEA
OECD
heat pump
centre

IEA Implementing Agreement on Advanced Heat Pump Systems
Information Sheet - Annex XXI

Annex Objectives

- Heighten industry's awareness of large energy cost savings associated with industrial heat pumping
- Broaden the information base to further develop IHPs
- Estimate the market potential for various types of IHPs to the year 2010 and illustrate the opportunities for their use.
- Estimate the potential environmental benefits of emissions reduction (including greenhouse gases).

First steps ⟶ Results

This Annex began with an Expert Meeting in June 1991, and is scheduled to conclude in April 1994 with an international workshop.

Analytical Tool

A key product is the development of a computer program designed to evaluate IHP technical feasibility and IHP cost and performance for specified process conditions. This valuable tool will be available to organizations and individuals from participating countries*.

Worldwide Networking

The basis for formulating a full, integrated, and up-to-date information base, this activity consists of 3 Expert Meetings, drawing from industry, utilities, and research institutes to foster development in IHPs.

The Workplan

Includes: IHP technical evaluation (state-of-the-art); process characterizations; determining IHP technical fit with processes; estimating potential number of IHPs, potential energy savings and emissions reduction (SO_x, NO_x, and greenhouse gases CO_2, CH_4, N_20, and CFCs).

Participating countries* will be asked to contribute information from their respective industrial, equipment manufacturing and utility sectors to assist in executing the study. The results will be compiled and calculated to generate worldwide estimates.

Confidentiality of data provided is assured.

For further information contact the IEA Heat Pump Centre or your Country Contact.

What is the IEA?

Founded in 1974, the International Energy Agency is the forum for 23 countries active in efforts to promote and develop alternative energy sources, increase energy efficiency, maintain information systems and centres, and approach energy developments in a global context through cooperative relations with non-member countries and international organizations.

What is the Implementing Agreement on Advanced Heat Pumps (IAAHP)?

A programme of cooperative research, development, demonstrations, and exchanges of information regarding advanced heat pump systems, organized under the auspices of the IEA and carried out by member countries. All activities are coordinated or supported by the Heat Pump Centre.

What is an IAAHP Annex?

A task identified as significant by the IAAHP membership in the field of heat pumping technology. Conducted by participating countries, one of which acts as the Operating Agent (manager of the task).

What is the IEA Heat Pump Centre?

The international focal point for heat pump information. Contact the Centre with inquiries on heat pump issues, publications and other Heat Pump Centre activities.

IEA Heat Pump Centre
P.O. Box 17
6130 AA SITTARD
The Netherlands
Tel.: +31-46-595-236
Fax: +31-46-510-389.

Your Country Contact:
IMET-TNO
Ir. J.B. de Wit
P.O. Box 342
7300 AH APELDOORN
The Netherlands
Tel.: +31-55-493-771

**Signatories: USA (Operating Agent), Canada, Japan, The Netherlands, United Kingdom and Sweden. Other countries considering joining are France, Germany, Malaysia and Norway.*

Appendix 2 Chalmers/ETA Annex 21 IHP Programme Description

NIET IN KLEUR AFDRUKKEN / WEL DUBBELZIJDIG

APPENDIX 5

CIT
Energiteknisk Analys
Chalmers Industriteknik

Comments to IEA/OECD Annex XXI computer program.

Introduction

The computer program is fully integrated in the Microsoft Windows environment and requires Windows Version 3.1 or later. Access to the various items (which correspond to the tasks in the working plan and other auxiliary subjects) is made through menu choices.

Most items consist of a number of steps. Short messages inform of the action to take. In each step selections should be made and/or values should be specified. To continue the 'OK' bottom should be pressed. To cancel or to go back a step the 'Cancel' bottom should be pressed.

New menu options can appear in an item.

Definitions and information

IHP = Industrial Heat Pump

PBP = Simple Pay Back period (=Investment/(annual saving)

The available IHP:s are numbered from 1.

Available predefined processes are numbered from 501. It is not possible to change any information in these processes.

User-defined processes are numbered from 1.

Process information can either be 'Full' or 'Simple':

> 'Full' means that the data consist of complete process stream data, suitable for pinch analysis.
>
> 'Simple' means that the data are simplified, e.g. the total heat demand is given as one load at a temperature.

The global temperature difference value in the process data either reflects the current heating demand (when this is available) or is set to a value used in the source literature from the National Teams.

The interval pinch temperatures indicated in the process list refers to the global temperature difference in the process data. Thus, it can change considerably when the global temperature difference is changed.

Great attention should be taken to the selection of global temperature difference when technical and economic opportunities are to be determined.

Attention to the absolute size of the processes must also be taken. Either may the absolute size not be suitable for the actual situation or the absolute size may not be given at all in the process data. The absolute size can be set by the 'Resize process data' submenu under the 'Edit' and 'Edit processes' menus.

If the absolute size is not given in the source literature this is marked in the process list. The size in the process data has in these cases been set in a way that the current heat demand is equal to 1000 kW.

Sink, source, delivering, extraction and internal temperatures:

- Temperature difference between heat sink and condenser refers to the difference between IHP working fluid and the sink stream(s).
- Temperature difference between heat source and evaporator refers to the difference between IHP working fluid and the source stream(s).
- These two differences can be set when compression type IHP:s are dealt with. Concerning the absorption type the difference is included in the performance data and cannot be changed.
- Thus, IHP delivering/extraction temperatures refer to the IHP working fluid (internal) in the compression IHP type case but to external sink/source temperatures in the absorption type case.

Menu choices

File

Print
Prints the current screen

Printer setup
Selection and setup of printers

Exit
Stops executing of the program

Performance of IHP:s

List types
Lists the IHP types for which information is available.

List compression types
List information on compression driven IHP:s.

List absorption types

List information on absorption IHP:s.

Selection of IHP

From specified operating conditions, the program determines which types of IHP:s that can operate at these conditions.

Plot performance

The y-axis, x-axis and parameter to be plotted should be selected, and there are also possibilities to specify detailed IHP data. Depending on available information and IHP type various parameters can be plotted. The scales of the graph are set by specifying the interval to be plotted.

Calculations

For given conditions the program calculates the performance of the selected IHP. The size of the sink and source should be specified as well as the temperature of these. On the sink side it is the entrance and target temperatures that must be specified. On the source side it is the entrance temperature and the lowest acceptable exit temperature that should be specified. The source size must reflect the specified entrance and minimum exit temperatures. It is also possible to specify detailed data for the various IHP:s.

If 'Economics' is selected, economic data must be specified. The program estimates the installation cost. This cost can be altered by specifying a factor. The estimated cost is multiplied with this factor before the PBP and annual profit is calculated.

Processes data and calculations of processes

List processes

List the available processes, both user-defined and predefined. A specification of the process as well as information on source literature can be shown.

Composite curves

Calculates and plots the Grand composite curve (GCC) and the Composite Curves (CC) for the selected process. Either a global minimum temperature difference is used or individual minimum temperature difference contributions from each process stream. Be sure to check that individual minimum temperature differences are included in the process data before this option is used (use the '**Edit process**' menu). If not any temperature differences are specified in the process data, 0 K will be used.
Zooming and output of the graphs are possible by selecting the '**Zoom GCC + CC**' menu.
By selecting the '**Heat demand**' menu the minimum hot utility is calculated and plotted for various global temperature differences from 0 K to 50 K.

Edit processes

Editing, saving and replacing of processes.

Predefined processes cannot be edited.

User-defined processes can be edited by selecting a information cell and changing the text in it. Adding and deleting streams are also possible, see the 'Edit' menu. The edited process can either replace the old version (**'Replace existing user process'** in the 'Edit' menu) or saved as a new process (**'Save as new user process'** in the 'Edit' menu).
A user-defined process can be deleted by choosing **'Delete user process'** in the 'Edit' menu.
The absolute size of a user-defined process can be changed by **'Resize process data'** in the 'Edit' menu. All size dependent data are then multiplied by the factor specified.

Predefined processes can be saved as a user created process (use **'Save as new user process'** in the 'Edit' menu. In this way a user-defined process is created which can be edited.

Create process data

Creates a new set of user-defined process data. This data must be saved with **'Save as new user process'**.
Other alternatives, often more rapid ones, exist to create new data. Totally three possibilities exist:

- Save a predefined process and edit it in the next step.
- Create by the 'Create process data' menu.
- Create in MS Excel in text format (the exact format must be known).

Update process list

Updates the process list to include the new user-defined processes created.

Integration Technical and economic integration of IHP:s in processes

Technical opportunities

A process, an IHP and detailed conditions for the IHP should be specified. Most important is the minimum temperature difference between the internal working fluid and the sink and source streams. These temperature differences should include any distribution system. The global temperature difference in the process should also be specified. This parameter is very important for the opportunities and great concern should be paid to the setting of it.
By selecting the **'Heat demand'** menu the minimum hot utility is calculated for various global temperature differences from 0 K to 50 K and plotted.

By selecting the **'Composite curve'** menu the GCC and CC can be plotted.

The IHP delivering temperatures to be tested can be changed or excluded.

The opportunities are presented as the theoretical largest possible IHP versus the IHP heat extraction temperature with the delivering temperature as parameter.

By selecting **'Zoom IHP'** menu the graph is zoomed and modifications to it can be made.

Economic opportunities

The first steps correspond to the ones in 'Technical opportunities'. However, the delivering temperatures to be tested cannot be changed.

In the economic data, which must be specified, an optional factor can be set. The estimated IHP cost is multiplied with this factor before the PBP and annual profit is calculated.
Additional heat exchangers needed in the process due to the IHP integration are estimated from the number of process streams and the difference between pinch temperature and the sink and source temperatures. The cost of the heat exchangers are calculated by the equation shown. The constant in the equation can be altered.

Based on the technical opportunities the largest IHP at each temperature lift can be identified. The size and PBP of this installation are shown in graphs versus the temperature lift. Since this represents the largest possible IHP a more realistic value ought to be found at a smaller size. Thus the results are also presented for half of the maximum size.
The graphs can be zoomed and modified by selecting the menu **'Zoom graphs'**.

Based on the graphs a suitable temperature lift should be selected. The economic results for this temperature lift are then shown. Annual results are shown by selecting the menu **'Result report'**. These are the result which should go into the market study.

Options

Units

Specification of the units to be used.

Energy costs

Specification of default energy costs. These can be changed in the items where they are used.

CE cost index

All costs included in the program are valid for 1992. To calculate to the present situation the present Chemical Engineering Plant Cost Index must be set.

Appendix 3 Annex 21 Market Assessment

Spreadsheet summary output of selected Dutch Processes

- **Dairy Production Plant**
- **Ethylene Plant**
- **Paper Production Plant**
- **Starch Evaporation plant**
- **Urea Plant**
- **Textile Finishing Plant**
- **Builing Ceramics plant**

SECTION 6 – SUMMARY OUTPUT

PROCESS DAIRY PRODUCTION PLANT (milk,cheese,whey)

Current No. of Plants	91
Projected Industry Growth	1%
# Existing Plants w/IHPs	0
Total Process Heat Demand (1,000 GJ/year)	10,752

	1995	2000	2005	2010
Projected Process Heat Demand (1,000 GJ/year)	10,968	11,528	12,116	12,734
Supplied by Non–IHP Technologies	24%	35%	35%	35%

IHP Data		Maximum Profit Scenario				Average Profit Scenario			
		1995	2000	2005	2010	1995	2000	2005	2010
THERMAL VAPOUR REC									
Refrigerant Used	STEAM								
Payback		4.8	4.8	4.8	4.8	6.1	6.1	6.1	6.1
Market Share		43%	79%	79%	79%	85%	85%	85%	85%
Projected Penetration		0%	2%	4%	5%	0%	0%	1%	1%
Projected # of IHPs		0	2	4	5	0	0	1	1
ABSORPTION HEAT PUMP TYPE 1									
Refrigerant Used	LiBr–H2O								
Payback		8.6	8.6	8.6	8.6	9.3	9.3	9.3	9.3
Market Share		57%	21%	21%	21%	15%	15%	15%	15%
Projected Penetration		0%	0%	0%	0%	0%	0%	0%	0%
Projected # of IHPs		0	0	0	0	0	0	0	0
0									
Refrigerant Used		0							
Payback		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Market Share		0%	0%	0%	0%	0%	0%	0%	0%
Projected Penetration		0%	0%	0%	0%	0%	0%	0%	0%
Projected # of IHPs		0	0	0	0	0	0	0	0
0									
Refrigerant Used		0							
Payback		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Market Share		0%	0%	0%	0%	0%	0%	0%	0%
Projected Penetration		0%	0%	0%	0%	0%	0%	0%	0%
Projected # of IHPs		0	0	0	0	0	0	0	0
0									
Refrigerant Used		0							
Payback		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Market Share		0%	0%	0%	0%	0%	0%	0%	0%
Projected Penetration		0%	0%	0%	0%	0%	0%	0%	0%
Projected # of IHPs		0	0	0	0	0	0	0	0

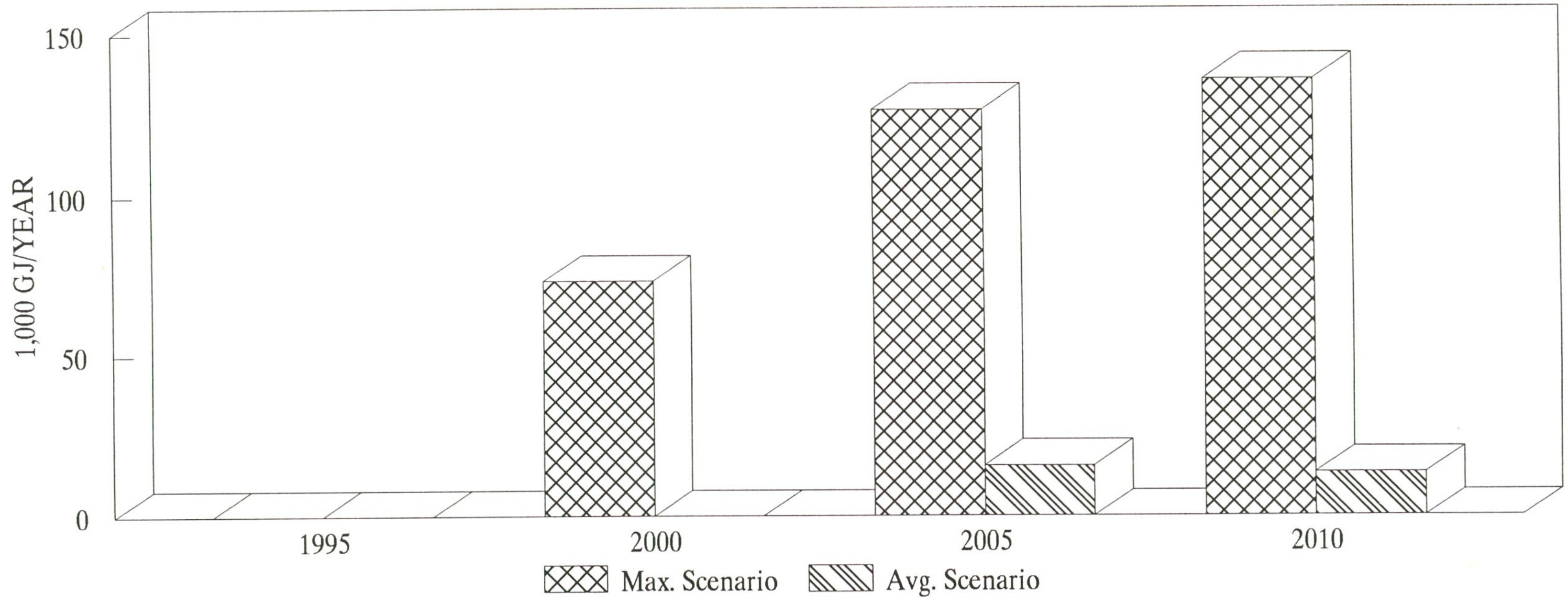
SECTION 6 – SUMMARY OUTPUT

PROCESS DAIRY PRODUCTION PLANT (milk,cheese,whey)

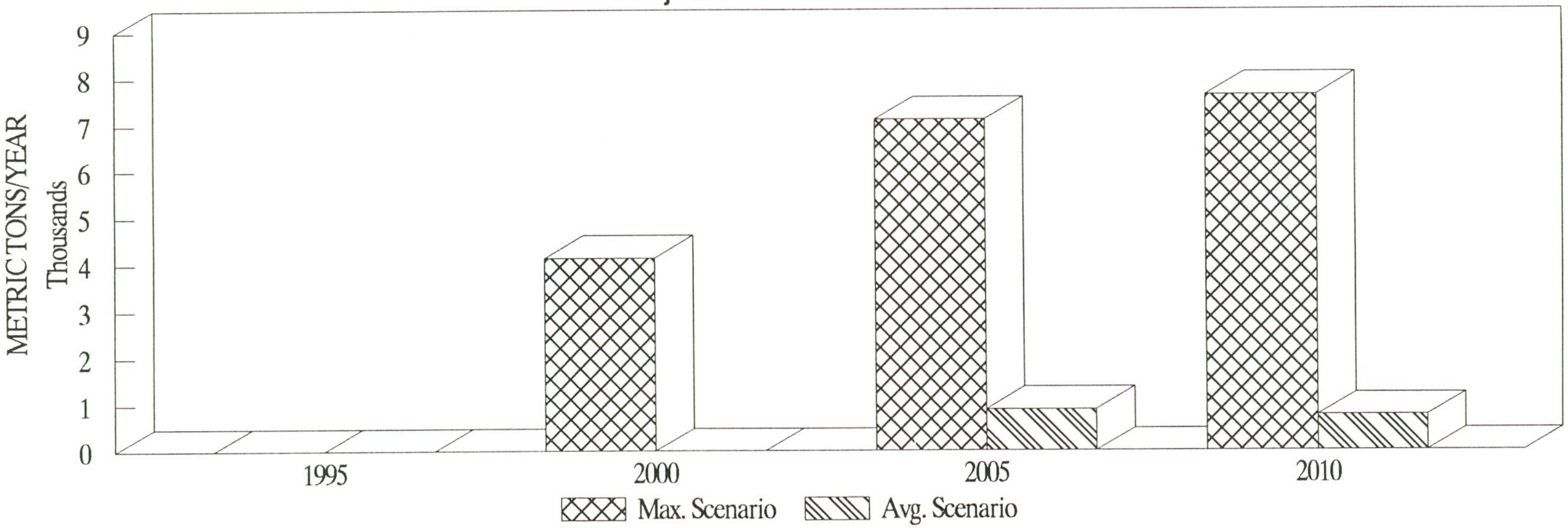
	Maximum Profit Scenario				Average Profit Scenario			
	1995	2000	2005	2010	1995	2000	2005	2010
Total Projected IHP Penetration	0%	2%	4%	5%	0%	1%	1%	1%
Total Projected # of IHPs	0	2	4	5	0	0	1	1

	Maximum Profit Scenario				Average Profit Scenario			
	1995	2000	2005	2010	1995	2000	2005	2010
Net Energy Savings/IHP Energy Delivered (1,000 GJ/year)								
Natural Gas	0	74	127	136	0	0	16	14
Coal	0	0	0	0	0	0	0	0
Oil	0	0	0	0	0	0	0	0
Electricity	0	0	0	0	0	0	0	0
Other	0	0	0	0	0	0	0	0
Total	0	74	127	136	0	0	16	14
Net Energy Savings (Million $/year)								
Natural Gas	0.0	0.5	0.8	0.9	0.0	0.0	0.1	0.1
Coal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oil	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Electricity	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total								
-- Million $/yr	0.0	0.5	0.8	0.9	0.0	0.0	0.1	0.1
-- Local Currency	0.0	0.9	1.5	1.6	0.0	0.0	0.2	0.2
(Million/yr)	1.85 fl per U.S.$							
Projected Emission Reductions (metric tons/year) [excluding IHP refrigerant use]								
SOx	0	0	0	0	0	0	0	0
NOx	0	5	8	9	0	0	1	1
CO2	0	4,133	7,104	7,630	0	0	888	763
CO	0	1	2	2	0	0	0	0
CH4	0	0	0	0	0	0	0	0
PM	0	0	0	0	0	0	0	0
Total	0	4,140	7,114	7,641	0	0	889	764
Projected Emission Reductions (tons/year) [excluding IHP refrigerant use]								
SOx	0	0	0	0	0	0	0	0
NOx	0	5	9	10	0	0	1	1
CO2	0	4,576	7,864	8,447	0	0	983	845
CO	0	1	2	2	0	0	0	0
CH4	0	0	0	0	0	0	0	0
PM	0	0	0	0	0	0	0	0
Total	0	4,582	7,875	8,459	0	0	984	846

Net Energy Savings



Projected Emission Reductions



SECTION 6 – SUMMARY OUTPUT

PROCESS ETHYLENE PLANT (500.000 MTA)

Current No. of Plants	3
Projected Industry Growth	1%
# Existing Plants w/IHPs	0
Total Process Heat Demand (1,000 GJ/year)	35,400

	1995	2000	2005	2010
Projected Process Heat Demand (1,000 GJ/year)	36,112	37,954	39,890	41,924
Supplied by Non–IHP Technologies	10%	20%	30%	30%

			Maximum Profit Scenario				**Average Profit Scenario**		
IHP Data		1995	2000	2005	2010	1995	2000	2005	2010
HEAT TRANSFORMER									
Refrigerant Used	LiBr–H_2O								
Payback		8.0	8.0	8.0	8.0	9.3	9.3	9.3	9.3
Market Share		52%	75%	75%	75%	95%	95%	95%	95%
Projected Penetration		0%	2%	4%	4%	1%	3%	5%	6%
Projected # of IHPs		0	0	0	0	0	0	0	0
GAS ENGINE CC TURBO R114									
Refrigerant Used	R114								
Payback		8.1	8.1	8.1	8.1	11.2	11.2	11.2	11.2
Market Share		48%	25%	25%	25%	5%	5%	5%	5%
Projected Penetration		0%	1%	1%	1%	0%	0%	0%	0%
Projected # of IHPs		0	0	0	0	0	0	0	0
0									
Refrigerant Used		0							
Payback		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Market Share		0%	0%	0%	0%	0%	0%	0%	0%
Projected Penetration		0%	0%	0%	0%	0%	0%	0%	0%
Projected # of IHPs		0	0	0	0	0	0	0	0
0									
Refrigerant Used		0							
Payback		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Market Share		0%	0%	0%	0%	0%	0%	0%	0%
Projected Penetration		0%	0%	0%	0%	0%	0%	0%	0%
Projected # of IHPs		0	0	0	0	0	0	0	0
0									
Refrigerant Used		0							
Payback		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Market Share		0%	0%	0%	0%	0%	0%	0%	0%
Projected Penetration		0%	0%	0%	0%	0%	0%	0%	0%
Projected # of IHPs		0	0	0	0	0	0	0	0

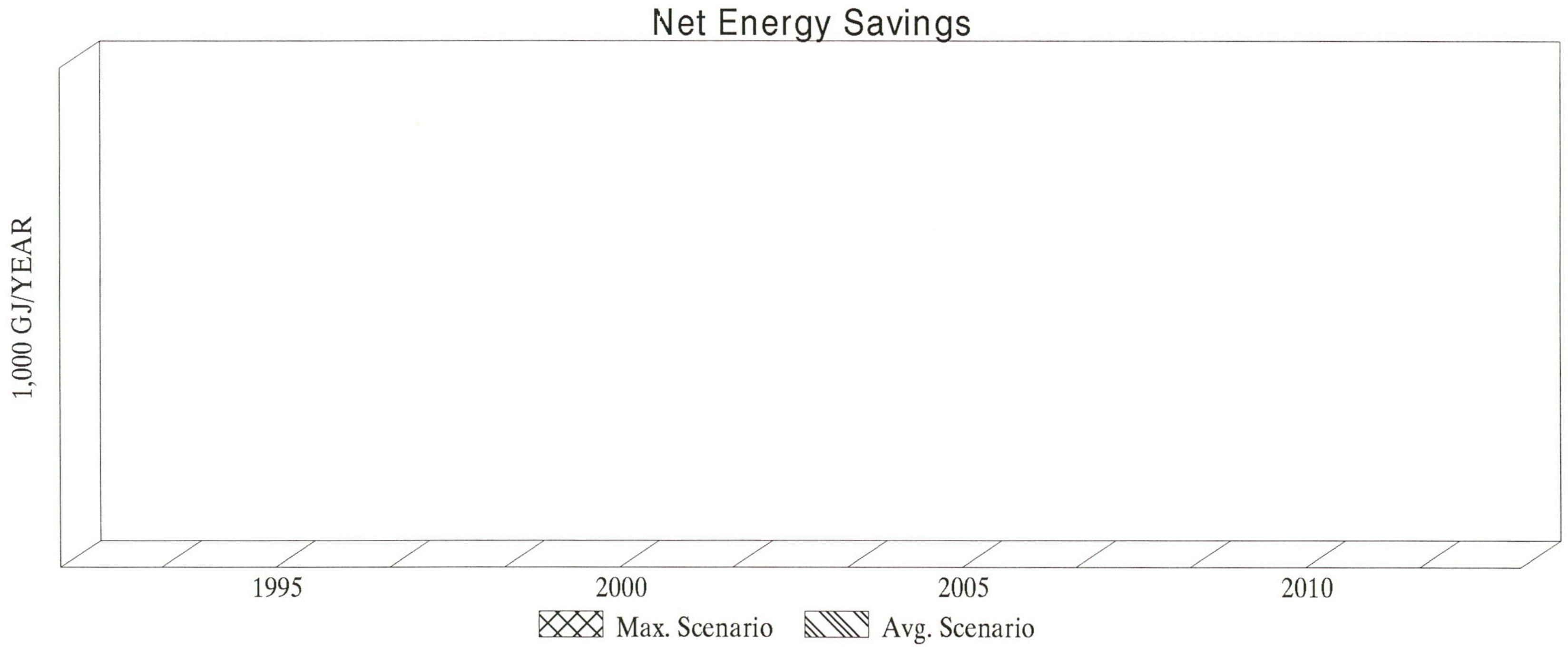
SECTION 6 – SUMMARY OUTPUT

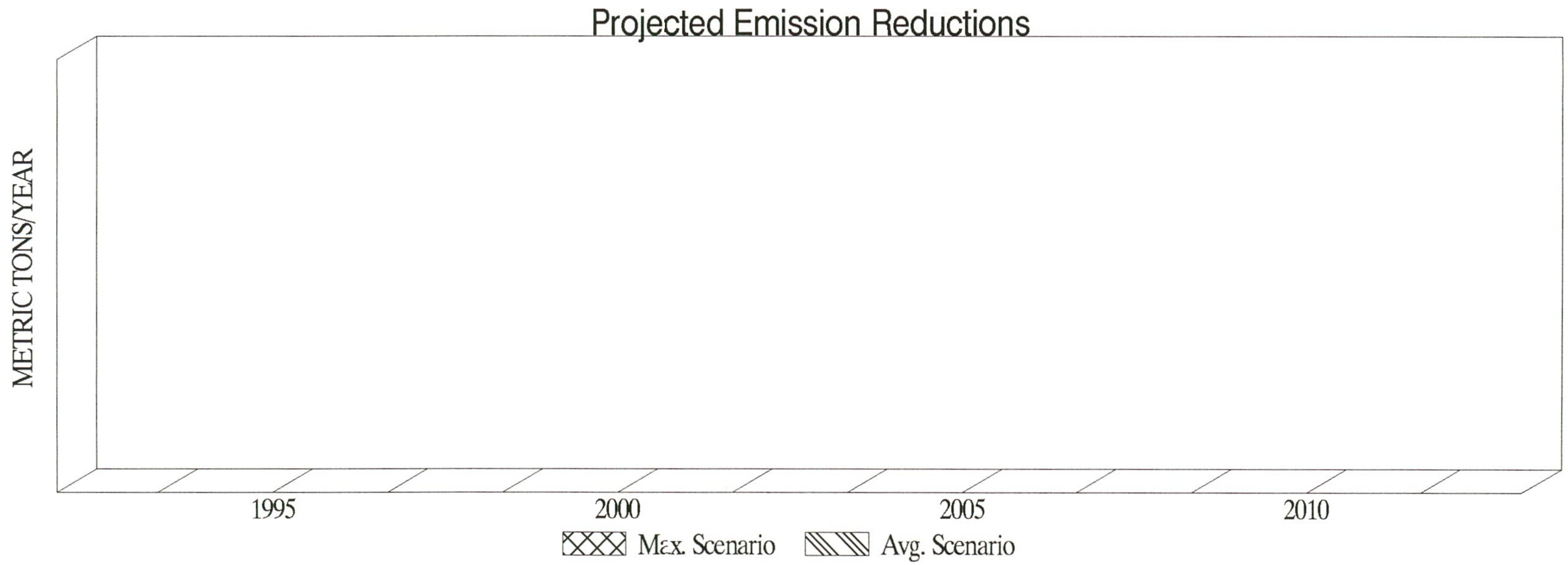
PROCESS ETHYLENE PLANT (500.000 MTA)

	Maximum Profit Scenario				Average Profit Scenario			
	1995	2000	2005	2010	1995	2000	2005	2010
Total Projected IHP Penetration	1%	3%	5%	6%	1%	3%	5%	6%
Total Projected # of IHPs	0	0	0	0	0	0	0	0

	Maximum Profit Scenario				Average Profit Scenario			
	1995	2000	2005	2010	1995	2000	2005	2010
Net Energy Savings/IHP Energy Delivered (1,000 GJ/year)								
Natural Gas	0	0	0	0	0	0	0	0
Coal	0	0	0	0	0	0	0	0
Oil	0	0	0	0	0	0	0	0
Electricity	0	0	0	0	0	0	0	0
Other	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	0	0
Net Energy Savings (Million $/year)								
Natural Gas	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Coal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oil	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Electricity	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total								
-- Million $/yr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-- Local Currency	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(Million/yr)	1.85 fl per U.S.$							
Projected Emission Reductions (metric tons/year) [excluding IHP refrigerant use]								
SOx	0	0	0	0	0	0	0	0
NOx	0	0	0	0	0	0	0	0
CO2	0	0	0	0	0	0	0	0
CO	0	0	0	0	0	0	0	0
CH4	0	0	0	0	0	0	0	0
PM	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	0	0
Projected Emission Reductions (tons/year) [excluding IHP refrigerant use]								
SOx	0	0	0	0	0	0	0	0
NOx	0	0	0	0	0	0	0	0
CO2	0	0	0	0	0	0	0	0
CO	0	0	0	0	0	0	0	0
CH4	0	0	0	0	0	0	0	0
PM	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	0	0

Process --> ETHYLENE PLANT (500.000 MTA)





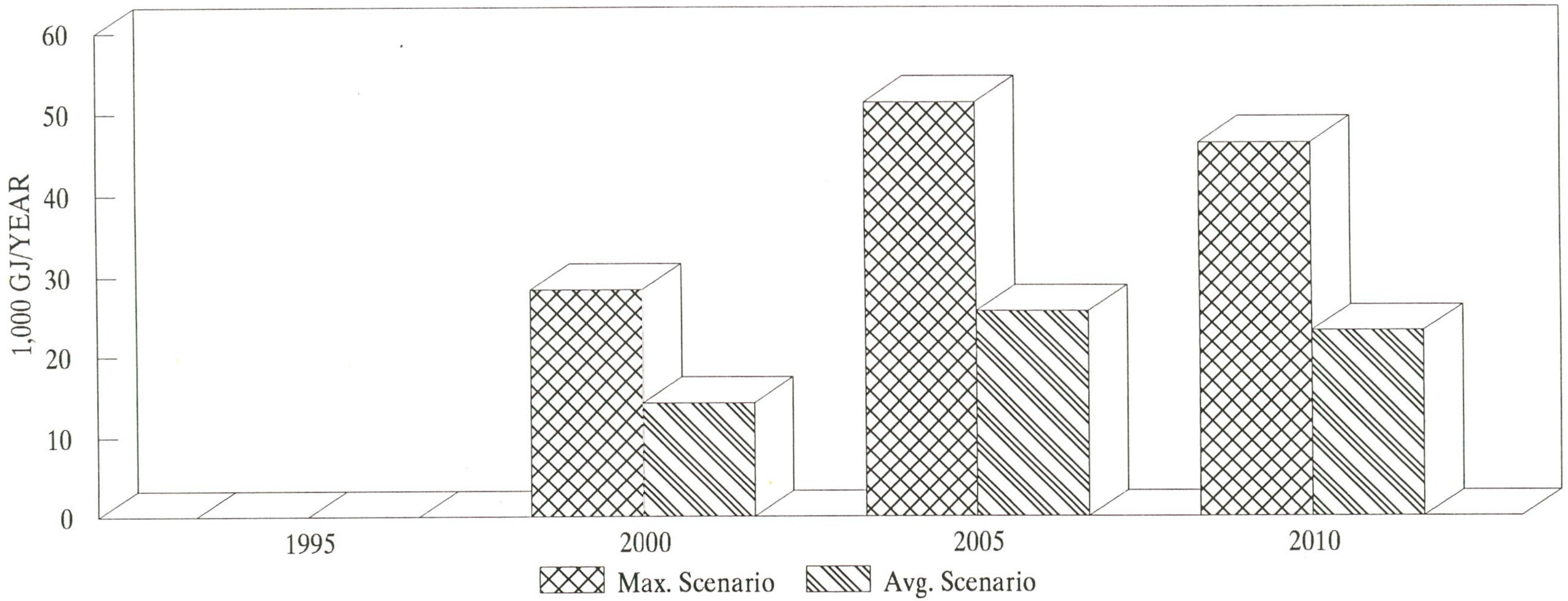
SECTION 6 – SUMMARY OUTPUT

PROCESS PAPER PRODUCTION PLANT

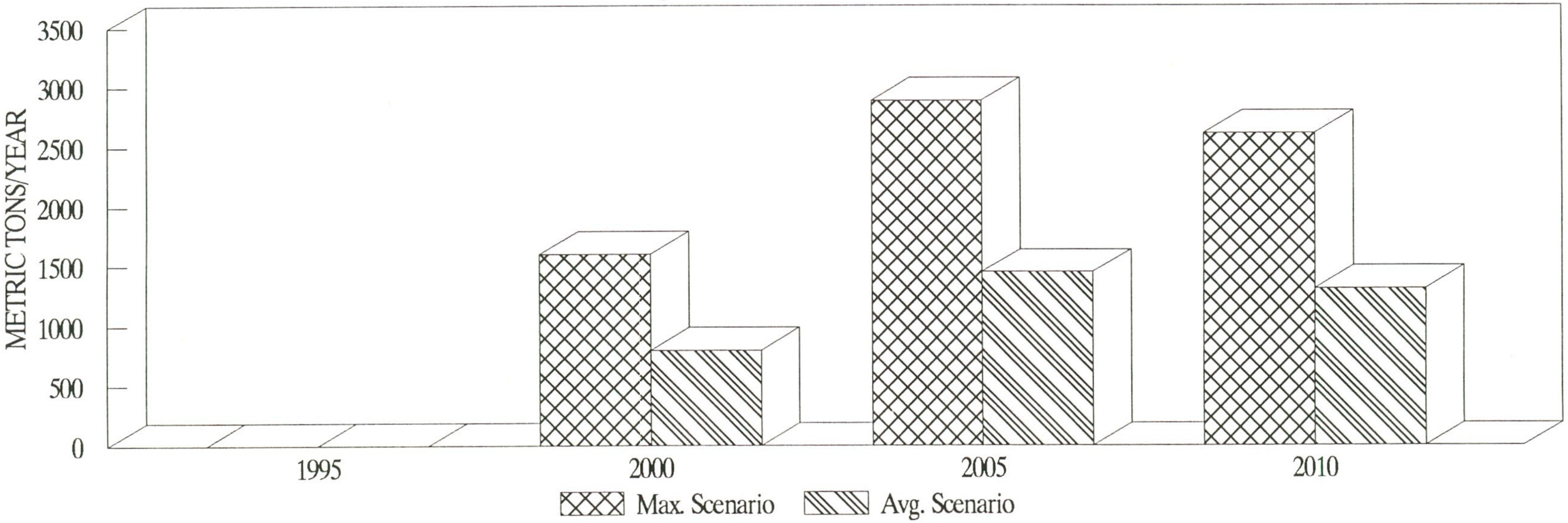
	Maximum Profit Scenario				Average Profit Scenario			
	1995	2000	2005	2010	1995	2000	2005	2010
Total Projected IHP Penetration	1%	3%	5%	6%	1%	3%	5%	6%
Total Projected # of IHPs	0	1	2	2	0	1	2	2

	Maximum Profit Scenario				Average Profit Scenario			
	1995	2000	2005	2010	1995	2000	2005	2010
Net Energy Savings/IHP Energy Delivered (1,000 GJ/year)								
Natural Gas	0	28	51	46	0	14	26	23
Coal	0	0	0	0	0	0	0	0
Oil	0	0	0	0	0	0	0	0
Electricity	0	0	0	0	0	0	0	0
Other	0	0	0	0	0	0	0	0
Total	0	28	51	46	0	14	26	23
Net Energy Savings (Million $/year)								
Natural Gas	0.0	0.2	0.3	0.3	0.0	0.1	0.2	0.2
Coal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oil	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Electricity	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total								
-- Million $/yr	0.0	0.2	0.3	0.3	0.0	0.1	0.2	0.2
-- Local Currency	0.0	0.3	0.6	0.6	0.0	0.2	0.3	0.3
(Million/yr)	1.85 fl per U.S.$							
Projected Emission Reductions (metric tons/year) [excluding IHP refrigerant use]								
SOx	0	0	0	0	0	0	0	0
NOx	0	2	3	3	0	1	2	2
CO2	0	1,596	2,885	2,609	0	798	1,443	1,304
CO	0	0	1	1	0	0	0	0
CH4	0	0	0	0	0	0	0	0
PM	0	0	0	0	0	0	0	0
Total	0	1,598	2,890	2,612	0	799	1,445	1,306
Projected Emission Reductions (tons/year) [excluding IHP refrigerant use]								
SOx	0	0	0	0	0	0	0	0
NOx	0	2	4	3	0	1	2	2
CO2	0	1,766	3,194	2,888	0	883	1,597	1,444
CO	0	0	1	1	0	0	0	0
CH4	0	0	0	0	0	0	0	0
PM	0	0	0	0	0	0	0	0
Total	0	1,769	3,199	2,892	0	885	1,599	1,446

Net Energy Savings



Projected Emission Reductions



SECTION 6 – SUMMARY OUTPUT

PROCESS STARCH EVAPORATION PLANT

Current No. of Plants	8
Projected Industry Growth	1%
# Existing Plants w/IHPs	0
Total Process Heat Demand (1,000 GJ/year)	4,700

Projected Process Heat Demand	1995	2000	2005	2010
(1,000 GJ/year)	4,794	5,039	5,296	5,566
Supplied by Non–IHP Technologies	10%	20%	30%	30%

		Maximum Profit Scenario				Average Profit Scenario			
IHP Data		1995	2000	2005	2010	1995	2000	2005	2010
MECH VAPOUR REC, TURBO									
Refrigerant Used	H2O								
Payback		0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6
Market Share		100%	100%	100%	100%	100%	100%	100%	100%
Projected Penetration		7%	27%	54%	59%	7%	27%	54%	59%
Projected # of IHPs		1	2	4	5	1	2	4	5
Refrigerant Used									
Payback									
Market Share		0%	0%	0%	0%	0%	0%	0%	0%
Projected Penetration		0%	0%	0%	0%	0%	0%	0%	0%
Projected # of IHPs		0	0	0	0	0	0	0	0
0									
Refrigerant Used		0							
Payback		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Market Share		0%	0%	0%	0%	0%	0%	0%	0%
Projected Penetration		0%	0%	0%	0%	0%	0%	0%	0%
Projected # of IHPs		0	0	0	0	0	0	0	0
0									
Refrigerant Used		0							
Payback		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Market Share		0%	0%	0%	0%	0%	0%	0%	0%
Projected Penetration		0%	0%	0%	0%	0%	0%	0%	0%
Projected # of IHPs		0	0	0	0	0	0	0	0
0									
Refrigerant Used		0							
Payback		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Market Share		0%	0%	0%	0%	0%	0%	0%	0%
Projected Penetration		0%	0%	0%	0%	0%	0%	0%	0%
Projected # of IHPs		0	0	0	0	0	0	0	0

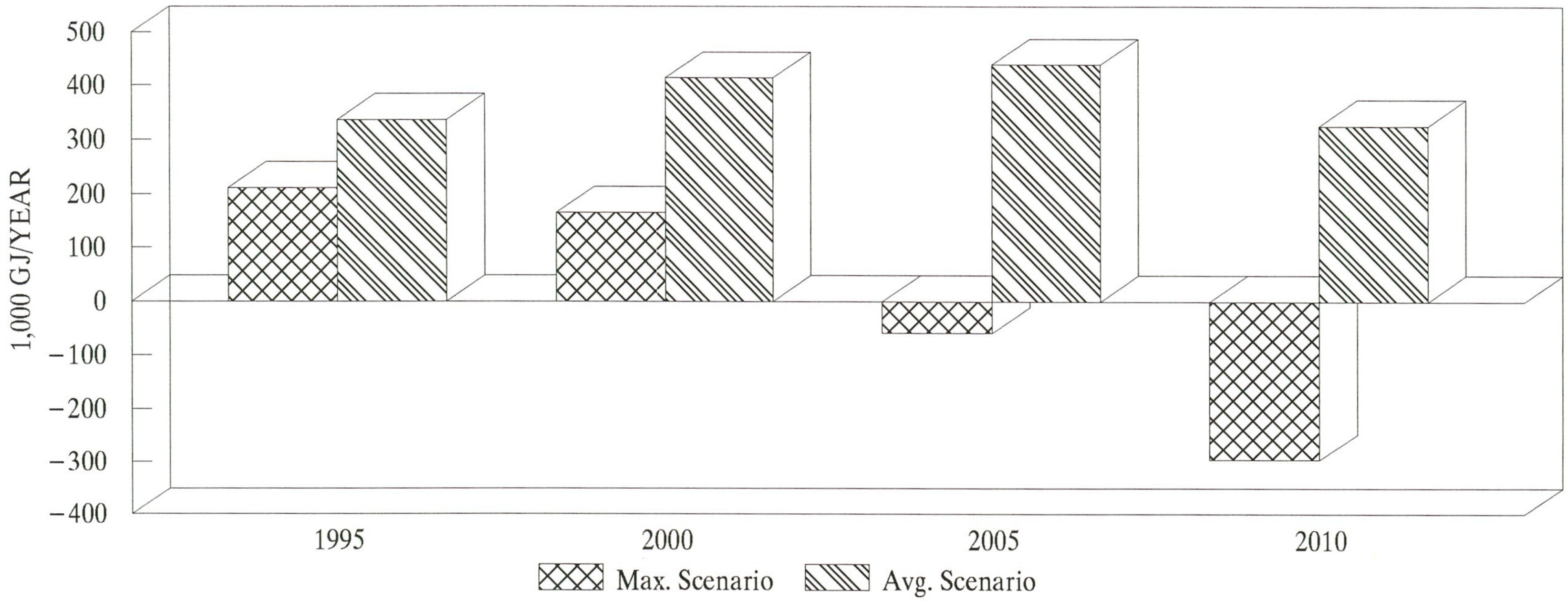
SECTION 6 – SUMMARY OUTPUT

PROCESS STARCH EVAPORATION PLANT

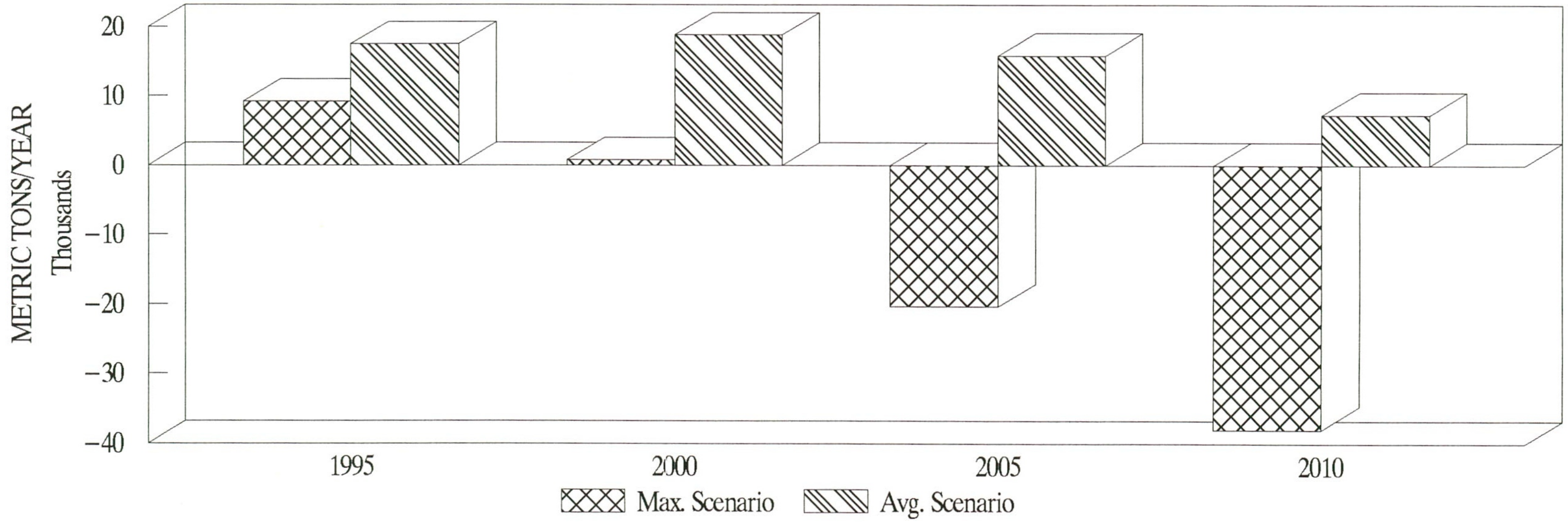
	Maximum Profit Scenario				Average Profit Scenario			
	1995	2000	2005	2010	1995	2000	2005	2010
Total Projected IHP Penetration	7%	27%	54%	59%	7%	27%	54%	59%
Total Projected # of IHPs	1	2	4	5	1	2	4	5

	Maximum Profit Scenario				Average Profit Scenario			
	1995	2000	2005	2010	1995	2000	2005	2010
Net Energy Savings/IHP Energy Delivered (1,000 GJ/year)								
Natural Gas	468	679	969	988	468	679	969	988
Coal	0	0	0	0	0	0	0	0
Oil	0	0	0	0	0	0	0	0
Electricity	(257)	(514)	(1,028)	(1,284)	(133)	(265)	(530)	(663)
Other	0	0	0	0	0	0	0	0
Total	211	165	(59)	(296)	335	414	439	325
Net Energy Savings (Million $/year)								
Natural Gas	1.8	4.4	6.3	6.4	1.8	4.4	6.3	6.4
Coal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oil	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Electricity	–4.6	–11.8	–23.6	–8.3	–2.4	–6.1	–12.2	–4.3
Total								
–– Million $/yr	–2.9	–7.4	–17.3	–1.9	–0.6	–1.7	–5.9	2.1
–– Local Currency	–5.3	–13.6	–31.9	–3.6	–1.1	–3.1	–10.9	3.9
(Million/yr)	1.85 fl per U.S.$							
Projected Emission Reductions (metric tons/year) [excluding IHP refrigerant use]								
SOx	(85)	(139)	(279)	(349)	(44)	(72)	(144)	(180)
NOx	(18)	(34)	(84)	(120)	6	4	(13)	(31)
CO2	9,296	902	(19,986)	(37,497)	17,504	18,896	16,000	7,486
CO	3	1	2	(1)	5	6	8	6
CH4	0	(0)	(1)	(1)	0	0	0	(0)
PM	(1)	(3)	(8)	(10)	(0)	(1)	(3)	(4)
Total	9,196	727	(20,356)	(37,978)	17,471	18,832	15,848	7,277
Projected Emission Reductions (tons/year) [excluding IHP refrigerant use]								
SOx	(94)	(154)	(309)	(386)	(48)	(80)	(159)	(199)
NOx	(20)	(38)	(93)	(132)	6	4	(14)	(34)
CO2	10,291	999	(22,125)	(41,510)	19,377	20,917	17,712	8,287
CO	3	2	2	(2)	5	6	9	7
CH4	0	(0)	(1)	(1)	0	0	0	(0)
PM	(1)	(4)	(8)	(11)	(0)	(2)	(4)	(5)
Total	10,180	805	(22,534)	(42,041)	19,340	20,847	17,544	8,056

Net Energy Savings



Projected Emission Reductions



SECTION 6 – SUMMARY OUTPUT

PROCESS UREA (200.000 MTA)

Current No. of Plants	3
Projected Industry Growth	1%
# Existing Plants w/IHPs	0
Total Process Heat Demand (1,000 GJ/year)	2,300

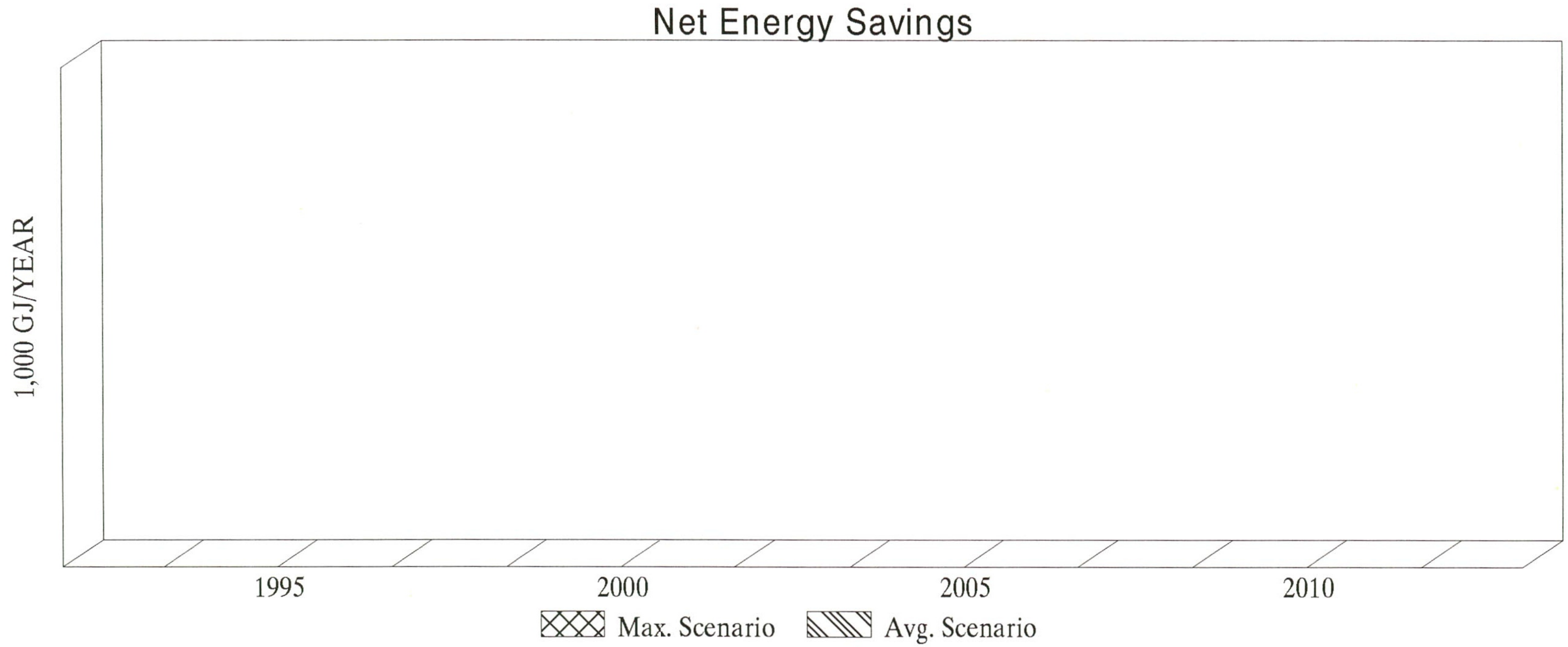
	1995	2000	2005	2010
Projected Process Heat Demand (1,000 GJ/year)	2,346	2,466	2,592	2,724
Supplied by Non–IHP Technologies	10%	20%	30%	30%

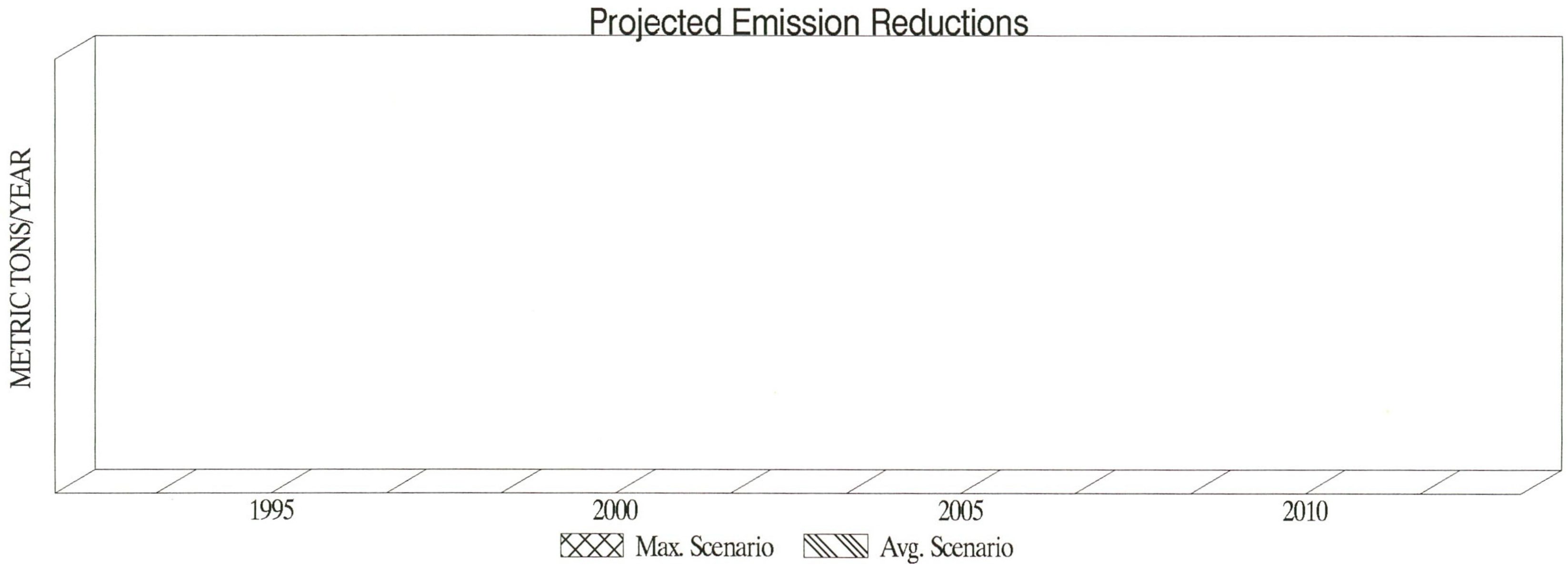
	Maximum Profit Scenario				Average Profit Scenario			
IHP Data	1995	2000	2005	2010	1995	2000	2005	2010
MVR CC SCREW H2O								
Refrigerant Used H2O								
Payback	5.1	5.1	5.1	5.1	10.6	10.6	10.6	10.6
Market Share	100%	100%	100%	100%	100%	100%	100%	100%
Projected Penetration	1%	3%	5%	6%	1%	3%	5%	6%
Projected # of IHPs	0	0	0	0	0	0	0	0
Refrigerant Used								
Payback								
Market Share	0%	0%	0%	0%	0%	0%	0%	0%
Projected Penetration	0%	0%	0%	0%	0%	0%	0%	0%
Projected # of IHPs	0	0	0	0	0	0	0	0
0								
Refrigerant Used	0							
Payback	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Market Share	0%	0%	0%	0%	0%	0%	0%	0%
Projected Penetration	0%	0%	0%	0%	0%	0%	0%	0%
Projected # of IHPs	0	0	0	0	0	0	0	0
0								
Refrigerant Used	0							
Payback	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Market Share	0%	0%	0%	0%	0%	0%	0%	0%
Projected Penetration	0%	0%	0%	0%	0%	0%	0%	0%
Projected # of IHPs	0	0	0	0	0	0	0	0
0								
Refrigerant Used	0							
Payback	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Market Share	0%	0%	0%	0%	0%	0%	0%	0%
Projected Penetration	0%	0%	0%	0%	0%	0%	0%	0%
Projected # of IHPs	0	0	0	0	0	0	0	0

SECTION 6 – SUMMARY OUTPUT

PROCESS UREA (200.000 MTA)

	Maximum Profit Scenario				Average Profit Scenario			
	1995	2000	2005	2010	1995	2000	2005	2010
Total Projected IHP Penetration	1%	3%	5%	6%	1%	3%	5%	6%
Total Projected # of IHPs	0	0	0	0	0	0	0	0
	Maximum Profit Scenario				Average Profit Scenario			
	1995	2000	2005	2010	1995	2000	2005	2010
Net Energy Savings/IHP Energy Delivered (1,000 GJ/year)								
Natural Gas	0	0	0	0	0	0	0	0
Coal	0	0	0	0	0	0	0	0
Oil	0	0	0	0	0	0	0	0
Electricity	0	0	0	0	0	0	0	0
Other	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	0	0
Net Energy Savings (Million $/year)								
Natural Gas	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Coal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oil	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Electricity	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total								
– – Million $/yr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
– – Local Currency	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(Million/yr)	1.85 fl per U.S.$							
Projected Emission Reductions (metric tons/year) [excluding IHP refrigerant use]								
SOx	0	0	0	0	0	0	0	0
NOx	0	0	0	0	0	0	0	0
CO2	0	0	0	0	0	0	0	0
CO	0	0	0	0	0	0	0	0
CH4	0	0	0	0	0	0	0	0
PM	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	0	0
Projected Emission Reductions (tons/year) [excluding IHP refrigerant use]								
SOx	0	0	0	0	0	0	0	0
NOx	0	0	0	0	0	0	0	0
CO2	0	0	0	0	0	0	0	0
CO	0	0	0	0	0	0	0	0
CH4	0	0	0	0	0	0	0	0
PM	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	0	0


Net Energy Savings
1,000 GJ/YEAR
1995
2000
2005
2010
Max. Scenario
Avg. Scenario


Projected Emission Reductions
METRIC TONS/YEAR
1995
2000
2005
2010
Max. Scenario
Avg. Scenario

SECTION 6 – SUMMARY OUTPUT

PROCESS: TEXTILE FINISHING PROCESS

Current No. of Plants	41
Projected Industry Growth	1%
# Existing Plants w/IHPs	0
Total Process Heat Demand (1,000 GJ/year)	5,285

	1995	2000	2005	2010
Projected Process Heat Demand (1,000 GJ/year)	5,391	5,666	5,955	6,259
Supplied by Non–IHP Technologies	0%	5%	10%	10%

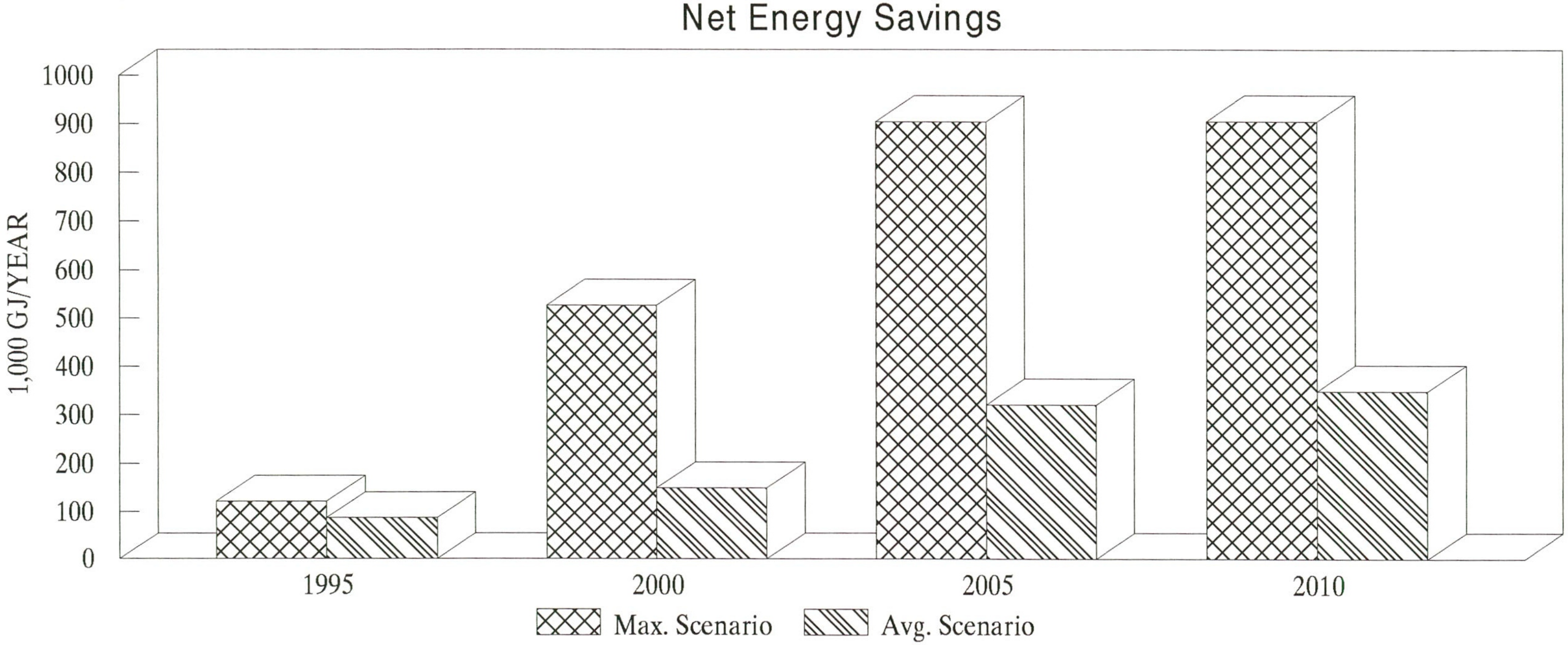
IHP Data		Maximum Profit Scenario				Average Profit Scenario			
		1995	2000	2005	2010	1995	2000	2005	2010
	GAS MOTOR CC SCREW R22								
	Refrigerant Used	R22							
	Payback	3.8	3.8	3.8	3.8	4.1	4.1	4.1	4.1
	Market Share	100%	100%	100%	100%	100%	100%	100%	100%
	Projected Penetration	3%	11%	21%	23%	1%	5%	11%	12%
	Projected # of IHPs	1	5	10	11	1	2	5	6
	Refrigerant Used								
	Payback								
	Market Share	0%	0%	0%	0%	0%	0%	0%	0%
	Projected Penetration	0%	0%	0%	0%	0%	0%	0%	0%
	Projected # of IHPs	0	0	0	0	0	0	0	0
	0								
	Refrigerant Used	0							
	Payback	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Market Share	0%	0%	0%	0%	0%	0%	0%	0%
	Projected Penetration	0%	0%	0%	0%	0%	0%	0%	0%
	Projected # of IHPs	0	0	0	0	0	0	0	0
	0								
	Refrigerant Used	0							
	Payback	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Market Share	0%	0%	0%	0%	0%	0%	0%	0%
	Projected Penetration	0%	0%	0%	0%	0%	0%	0%	0%
	Projected # of IHPs	0	0	0	0	0	0	0	0
	0								
	Refrigerant Used	0							
	Payback	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Market Share	0%	0%	0%	0%	0%	0%	0%	0%
	Projected Penetration	0%	0%	0%	0%	0%	0%	0%	0%
	Projected # of IHPs	0	0	0	0	0	0	0	0

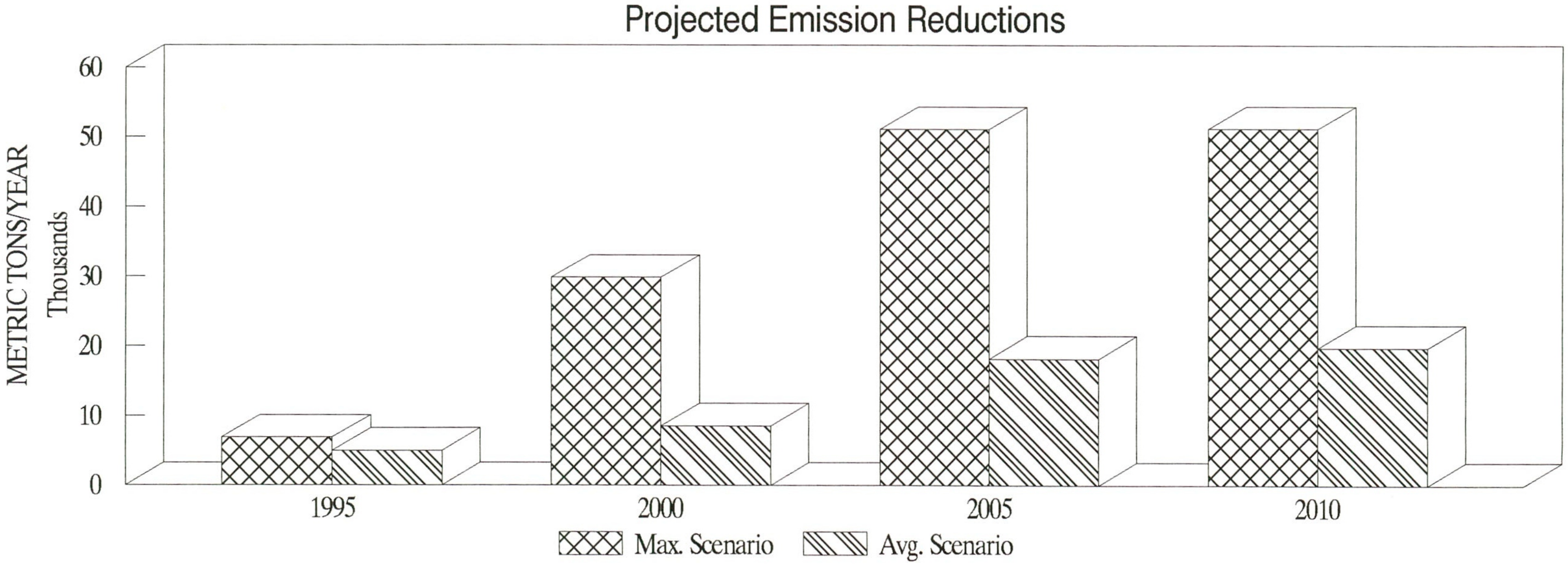
SECTION 6 – SUMMARY OUTPUT

PROCESS TEXTILE FINISHING PROCESS

	Maximum Profit Scenario				Average Profit Scenario			
	1995	2000	2005	2010	1995	2000	2005	2010
Total Projected IHP Penetration	3%	11%	21%	23%	1%	5%	11%	12%
Total Projected # of IHPs	1	5	10	11	1	2	5	6

	Maximum Profit Scenario				Average Profit Scenario			
	1995	2000	2005	2010	1995	2000	2005	2010
Net Energy Savings/IHP Energy Delivered (1,000 GJ/year)								
Natural Gas	119	515	896	898	86	147	319	346
Coal	0	0	0	0	0	0	0	0
Oil	2	11	9	9	2	3	3	3
Electricity	0	0	0	0	0	0	0	0
Other	0	0	0	0	0	0	0	0
Total	122	526	905	907	87	150	322	349
Net Energy Savings (Million $/year)								
Natural Gas	0.5	3.3	5.8	5.8	0.3	1.0	2.1	2.2
Coal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oil	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0
Electricity	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total								
– – Million $/yr	0.5	3.4	5.9	5.9	0.3	1.0	2.1	2.3
– – Local Currency	0.8	6.3	10.8	10.9	0.6	1.8	3.9	4.2
(Million/yr)	1.85 fl per U.S.$							
Projected Emission Reductions (metric tons/year) [excluding IHP refrigerant use]								
SOx	1	4	3	3	1	1	1	1
NOx	8	35	60	60	6	10	21	23
CO2	6,886	29,727	50,994	51,079	4,936	8,496	18,121	19,660
CO	2	8	14	14	1	2	5	5
CH4	0	1	1	1	0	0	0	0
PM	0	1	1	1	0	0	0	1
Total	6,897	29,775	51,072	51,157	4,944	8,510	18,149	19,690
Projected Emission Reductions (tons/year) [excluding IHP refrigerant use]								
SOx	1	4	3	3	1	1	1	1
NOx	9	39	66	66	6	11	23	25
CO2	7,623	32,908	56,450	56,544	5,464	9,405	20,060	21,764
CO	2	9	15	15	1	2	5	6
CH4	0	1	1	1	0	0	0	0
PM	0	1	1	1	0	0	1	1
Total	7,635	32,961	56,536	56,631	5,473	9,420	20,091	21,797


Net Energy Savings
1,000 GJ/YEAR
1000
900
800
700
600
500
400
300
200
100
0
1995
2000
2005
2010
Max. Scenario
Avg. Scenario


Projected Emission Reductions
METRIC TONS/YEAR
Thousands
60
50
40
30
20
10
0
1995
2000
2005
2010
Max. Scenario
Avg. Scenario

SECTION 6 – SUMMARY OUTPUT

PROCESS: BUILDING CERAMICS (BRICKS, TILES)

Current No. of Plants	72
Projected Industry Growth	1%
# Existing Plants w/IHPs	0
Total Process Heat Demand (1,000 GJ/year)	7,440

	1995	2000	2005	2010
Projected Process Heat Demand (1,000 GJ/year)	7,590	7,977	8,384	8,811
Supplied by Non–IHP Technologies	0%	5%	10%	10%

IHP Data		Maximum Profit Scenario				Average Profit Scenario			
		1995	2000	2005	2010	1995	2000	2005	2010
GAS MOTOR CC R22									
Refrigerant Used	R22								
Payback		8.1	8.1	8.1	8.1	11.2	11.2	11.2	11.2
Market Share		100%	100%	100%	100%	100%	100%	100%	100%
Projected Penetration		1%	3%	5%	6%	1%	3%	5%	6%
Projected # of IHPs		0	2	4	5	0	2	4	5
Refrigerant Used									
Payback									
Market Share		0%	0%	0%	0%	0%	0%	0%	0%
Projected Penetration		0%	0%	0%	0%	0%	0%	0%	0%
Projected # of IHPs		0	0	0	0	0	0	0	0
0									
Refrigerant Used		0							
Payback		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Market Share		0%	0%	0%	0%	0%	0%	0%	0%
Projected Penetration		0%	0%	0%	0%	0%	0%	0%	0%
Projected # of IHPs		0	0	0	0	0	0	0	0
0									
Refrigerant Used		0							
Payback		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Market Share		0%	0%	0%	0%	0%	0%	0%	0%
Projected Penetration		0%	0%	0%	0%	0%	0%	0%	0%
Projected # of IHPs		0	0	0	0	0	0	0	0
0									
Refrigerant Used		0							
Payback		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Market Share		0%	0%	0%	0%	0%	0%	0%	0%
Projected Penetration		0%	0%	0%	0%	0%	0%	0%	0%
Projected # of IHPs		0	0	0	0	0	0	0	0

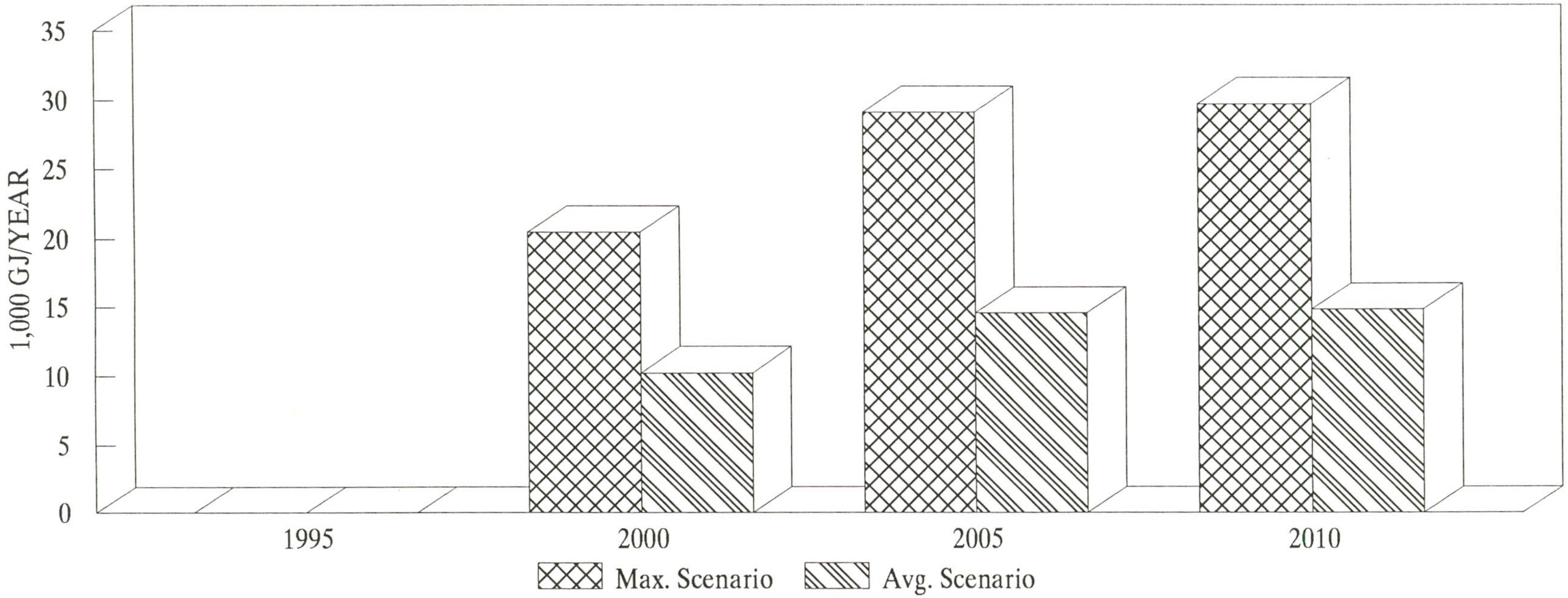
SECTION 6 – SUMMARY OUTPUT

PROCESS BUILDING CERAMICS (BRICKS, TILES)

	Maximum Profit Scenario				**Average Profit Scenario**			
	1995	2000	2005	2010	1995	2000	2005	2010
Total Projected IHP Penetration	1%	3%	5%	6%	1%	3%	5%	6%
Total Projected # of IHPs	0	2	4	5	0	2	4	5

	Maximum Profit Scenario				**Average Profit Scenario**			
	1995	2000	2005	2010	1995	2000	2005	2010
Net Energy Savings/IHP Energy Delivered (1,000 GJ/year)								
Natural Gas	0	15	26	27	0	8	13	13
Coal	0	2	0	0	0	1	0	0
Oil	0	4	3	3	0	2	1	1
Electricity	0	0	0	0	0	0	0	0
Other	0	0	0	0	0	0	0	0
Total	0	20	29	30	0	10	15	15
Net Energy Savings (Million $/year)								
Natural Gas	0.0	0.1	0.2	0.2	0.0	0.0	0.1	0.1
Coal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oil	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Electricity	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total								
–– Million $/yr	0.0	0.1	0.2	0.2	0.0	0.1	0.1	0.1
–– Local Currency	0.0	0.2	0.3	0.4	0.0	0.1	0.2	0.2
(Million/yr)	1.85 fl							
	per U.S.$							
Projected Emission Reductions (metric tons/year) [excluding IHP refrigerant use]								
SOx	0	2	1	1	0	1	0	0
NOx	0	2	2	2	0	1	1	1
CO2	0	1,297	1,696	1,731	0	648	848	866
CO	0	0	0	0	0	0	0	0
CH4	0	0	0	0	0	0	0	0
PM	0	0	0	0	0	0	0	0
Total	0	1,301	1,699	1,735	0	651	850	867
Projected Emission Reductions (tons/year) [excluding IHP refrigerant use]								
SOx	0	2	1	1	0	1	0	0
NOx	0	2	2	2	0	1	1	1
CO2	0	1,435	1,877	1,916	0	718	939	958
CO	0	0	0	0	0	0	0	0
CH4	0	0	0	0	0	0	0	0
PM	0	0	0	0	0	0	0	0
Total	0	1,441	1,881	1,920	0	720	941	960

Net Energy Savings



Projected Emission Reductions