Results with pinch based scan method for heat pumps and vapour recompression

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Abstract

The possibilities for the use of heat pumps and vapour recompression can quite easily be determined by pinch technology. In nine companies in the Netherlands scans were carried out. From these scans, multiple possibilities have been found that are already viable. The potential of a hybrid energy supply for industrial partners in the long term is even greater. A heat pump scan using supporting software can identify the opportunities in just one day.

Pinch; heat pump; vapour recompression; heat transformer; industry; scan method;

1. Introduction

Waste heat is getting more attention by industrial companies because of their ambition to go sustainable (Grift, 2017). Studies show that approximately 30% of the industrial primary energy consumption is at a level below 200 °C (Davidse, 2012). This is in the temperature range where heat pumps and vapour recompression are attractive solutions (60-200 °C). Direct heat exchange between waste heat streams (hot streams) and streams to

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be heated (cold streams) can be determined by pinch methodology as developed in the 70ties by Linnhoff and Flower (Linnhoff & Flower, 1978). A accessible explanation is published in 1998 by Linhoff March (March L. , 1998).

The so called grand composite curve gives insight in the theoretical minimum heat and cold demand, but also in the utilities needed. So the potential of heat pumps and cogeneration can be determined from one graph, i.e. the grand composite curve (Figure 1). The grand composite curve is essential for heat pump evaluation because ad hoc measures can block future developments towards a sustainable situation.

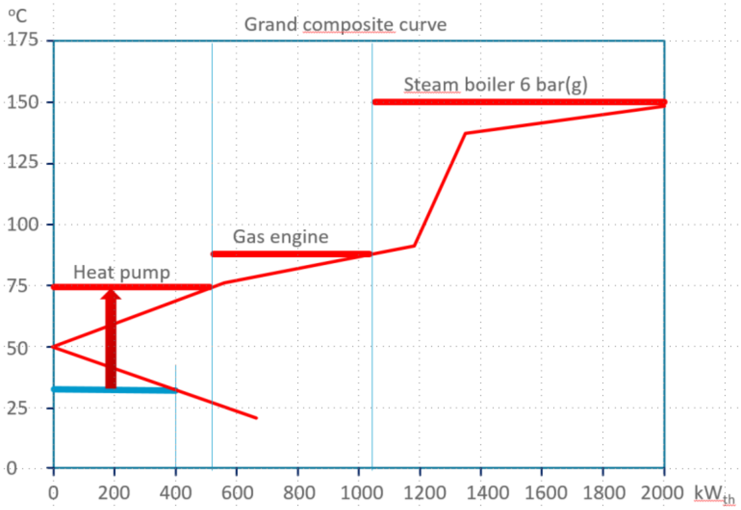

Figure 1. Design of utilities based on grand composite curve. The heat pump is chosen with an external temperature lift of 40 K (COP about 4,2).

After the potential for heat pumps and cogeneration is determined, the challenge is to define feasible solutions, mostly in an existing situation. The feasibility depends on aspects such as:

- Temperature levels
- Mean thermal capacity available and needed
- Fluctuation in capacity
- Load profile
- Physical condition of streams (Gas, liquid, evapourating, condensing)
- Physical properties of streams (specific heat, enthalpy)
- Contaminations
- Distance between streams (coordinates)
- Crossings needed (piping bridge, underground, indoor)
- (Marginal) energy tariffs

In order to determine the feasibility of connecting waste heat streams with cold streams, (directly or with heat pumps or vapour compression), Energy Matters developed a simple method which is explained in the next section.

2. Approach

In most situations there is some distance between hot and cold streams. A common way for transporting heat from one process to another is by using pipes in which a liquid is circulated (mostly water). For every point the potential energy of the process streams (primary streams) are directly exchanged with the transport fluid in the transport system (secondary streams). The advantage is that the pinch can be calculated more accurate because in the pinch method, you always have to choose the minimum temperature difference in the heat exchangers, although the dominating streams are not known yet. So in this approach the temperature difference at the pinch equals zero provided that the transport liquid temperatures are brought in instead of the process temperatures. The temperature difference between process and transport liquid depends on the phase (change) of the process stream. If the process stream is directly utilizable in the transport system the difference is zero.

Another challenge is to deal with fluctuations in both the heat source and the heat sink. One solution is to split heat exchangers so you can gather waste heat at several temperature levels (Anastasovski, 2014). A more practical solution is to place hot water buffers, at both sides of the system if necessary (Chaturvedi & Bandyopadhyay, 2012). To prevent exergy losses from mixing liquids at different temperatures, these vessels are stratified. As shown in Figure 2 the liquid is brought in very slowly by using screens on top and at the bottom of the vessels.

If a hot or cold stream has a constant flow, buffering vessels and or pumps can be eliminated. If the hot or cold stream can be transported easily one heat exchanger can be eliminated.

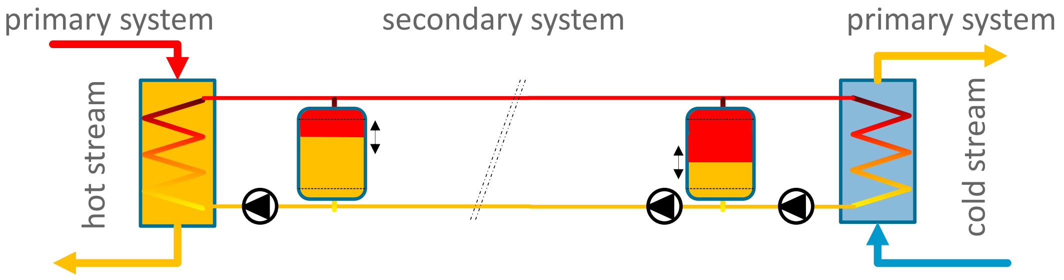

Figure 2. General approach to waste heat recovery.

3. Integrating heat pumps

If the hot stream is not able to deliver heat to the cold stream directly due to a temperature difference, the temperature can be increased using a heat pump, as shown in Figure 3. Another technique is using recompression, which is only possible when the hot stream is in the gaseous phase (see Figure 4). From an economical perspective the maximum increase in temperature of both systems is about 50 K (Coefficient of Performance (COP) > 4)[1]. In addition, buffers and heat exchangers can be needed with fluctuating heat or cool streams.

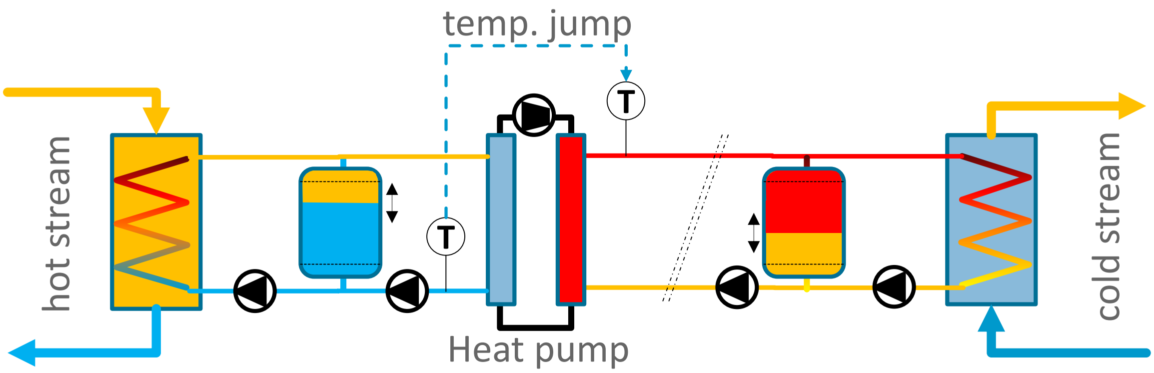

Figure 3. General approach with an integrated heat pump

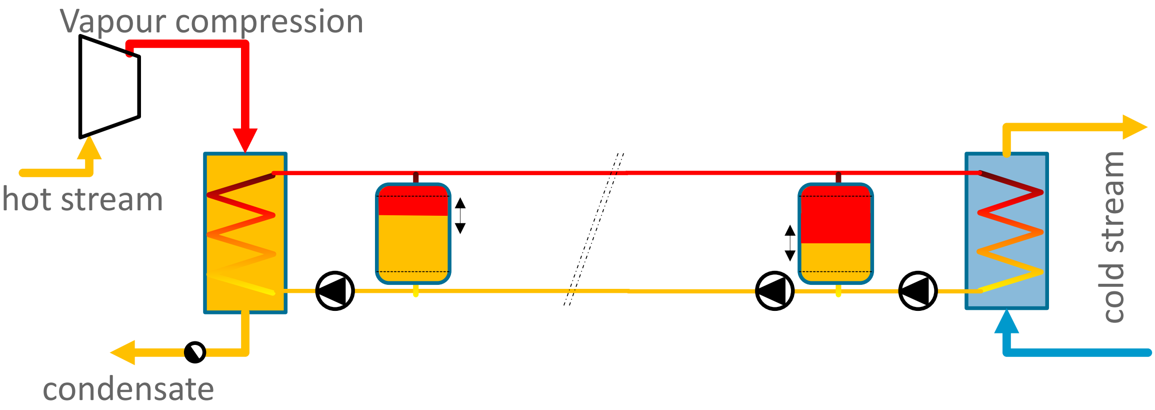

Figure 4. General approach with an integrated vapour compression.

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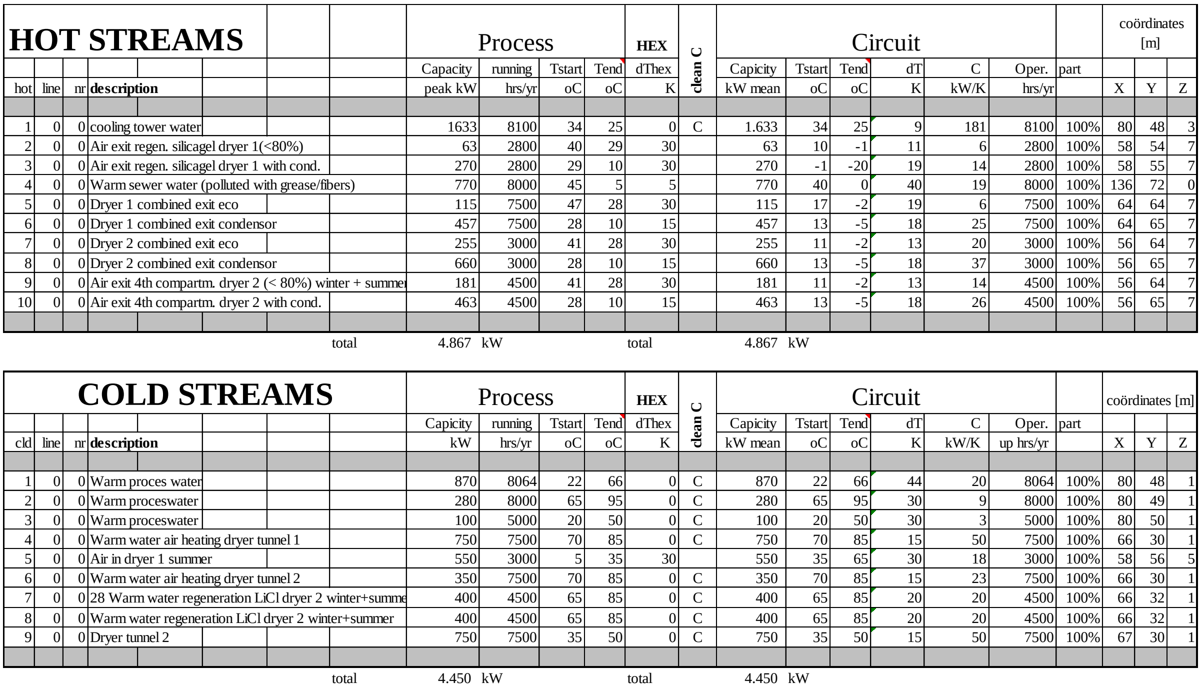
[1] Heat pumps working with “temperature glide” could have a higher COP (Borgås, 2014).



HOT STREAMS				Process				**HEX**	**clean C**	Circuit							coördinates [m]		
				Capacity	running	Tstart	Tend	dThex		Capicity	Tstart	Tend	dT	C	Oper.	part			
hot	line	nr	**description**	peak kW	hrs/yr	oC	oC	K		kW mean	oC	oC	K	kW/K	hrs/yr		X	Y	Z
1	0	0	cooling tower water	1633	8100	34	25	0	C	1.633	34	25	9	181	8100	100%	80	48	3
2	0	0	Air exit regen. silicagel dryer 1(<80%)	63	2800	40	29	30		63	10	-1	11	6	2800	100%	58	54	7
3	0	0	Air exit regen. silicagel dryer 1 with cond.	270	2800	29	10	30		270	-1	-20	19	14	2800	100%	58	55	7
4	0	0	Warm sewer water (polluted with grease/fibers)	770	8000	45	5	5		770	40	0	40	19	8000	100%	136	72	0
5	0	0	Dryer 1 combined exit eco	115	7500	47	28	30		115	17	-2	19	6	7500	100%	64	64	7
6	0	0	Dryer 1 combined exit condensor	457	7500	28	10	15		457	13	-5	18	25	7500	100%	64	65	7
7	0	0	Dryer 2 combined exit eco	255	3000	41	28	30		255	11	-2	13	20	3000	100%	56	64	7
8	0	0	Dryer 2 combined exit condensor	660	3000	28	10	15		660	13	-5	18	37	3000	100%	56	65	7
9	0	0	Air exit 4th compartm. dryer 2 (< 80%) winter + summer	181	4500	41	28	30		181	11	-2	13	14	4500	100%	56	64	7
10	0	0	Air exit 4th compartm. dryer 2 with cond.	463	4500	28	10	15		463	13	-5	18	26	4500	100%	56	65	7

total 4.867 kW total 4.867 kW

COLD STREAMS				Process				**HEX**	**clean C**	Circuit							coördinates [m]		
				Capicity	running	Tstart	Tend	dThex		Capicity	Tstart	Tend	dT	C	Oper.	part			
cld	line	nr	**description**	kW	hrs/yr	oC	oC	K		kW mean	oC	oC	K	kW/K	up hrs/yr		X	Y	Z
1	0	0	Warm proces water	870	8064	22	66	0	C	870	22	66	44	20	8064	100%	80	48	1
2	0	0	Warm proceswater	280	8000	65	95	0	C	280	65	95	30	9	8000	100%	80	49	1
3	0	0	Warm proceswater	100	5000	20	50	0	C	100	20	50	30	3	5000	100%	80	50	1
4	0	0	Warm water air heating dryer tunnel 1	750	7500	70	85	0	C	750	70	85	15	50	7500	100%	66	30	1
5	0	0	Air in dryer 1 summer	550	3000	5	35	30		550	35	65	30	18	3000	100%	58	56	5
6	0	0	Warm water air heating dryer tunnel 2	350	7500	70	85	0	C	350	70	85	15	23	7500	100%	66	30	1
7	0	0	28 Warm water regeneration LiCl dryer 2 winter+summe	400	4500	65	85	0	C	400	65	85	20	20	4500	100%	66	32	1
8	0	0	Warm water regeneration LiCl dryer 2 winter+summer	400	4500	65	85	0	C	400	65	85	20	20	4500	100%	66	32	1
9	0	0	Dryer tunnel 2	750	7500	35	50	0	C	750	35	50	15	50	7500	100%	67	30	1

total 4.450 kW total 4.450 kW

Table 1. Specifications of streams

4. Example food industry

A food industry producing gelatin has carried out a heat pump scan. This scan contains three steps; (1) identifying the main hot and cold as shown in Table 1, (2) visualizing of the available streams in a temperature-capacity table and (3) a composite curve (not shown), (4) composition of the grand composite curve as shown in Figure 4. Besides an overall report the results of the feasibility calculations of single combinations are presented in separate case-reports.

The waste heat in the outlet of the dryers are split into a cascade of two different streams: an economizer and a condenser (Table 1; *hot 2-3* and *9-10*) in to correct for the non-linear cooling trajectory. Most of the cold streams can be used directly in the water circuit. Only the drying air must have a heat exchanger with a temperature difference of 30 K (Table 1; cold 5). The total available waste heat is 4 867 kW and the heat consumption 4 450 kW.

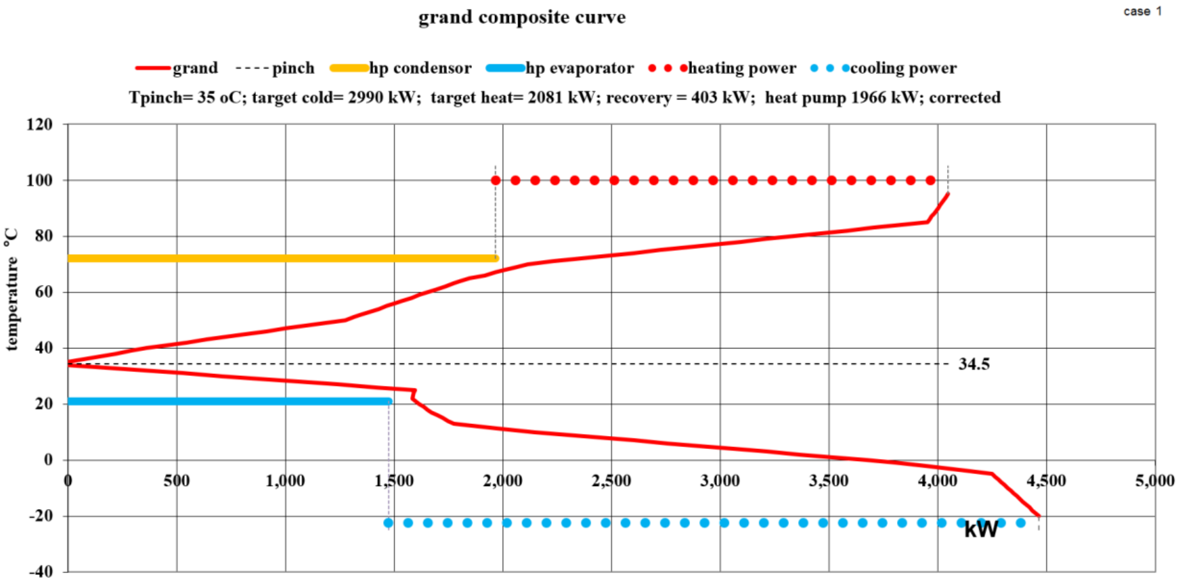


Figure 5. Grand composite curve

The grand composite curve in Figure 5 shows a pinch temperature of 34.5 °C, a direct heat recovery potential of 403 kW and a heat pump potential of 1 966 kW at a temperature level of about 70 °C.

TOP LIST OF OPPORTUNITIES																
HOT STREAM					**line**	**nr in list**	**stream nr**	**COLD STREAM**					**inv. k€**	**NPV k€**	**technique**	**Capicity kW**
🟥	🟥	🟥	🟥	🟥	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩
Warm sewer water (polluted with grease/fibers)					0	0	1	Warm proces water					110	311	hexo	347
cooling tower water					0	0	9	Dryer tunnel 2					237	184	hpo	750
🟥	🟥	🟥	🟥	🟥	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩
													347	**495**		**1097**

Table 2. Spreadsheet report with top list of opportunities with a positive NPV.

The feasibility calculations of individual connections between streams resulted in two combinations with a positive Net Present Value (NPV). Pre-heating warm process water (347 kW) gives a positive NPV of 311 k€. Lifting up the temperature of cooling tower water with a heat pump (750 kW) for use in the product dryers result in a NPV of k€ 184. All cases are documented automatically with detailed information about the piping dimensions, estimated costs, maintenance, energy savings, profits and payback period.

		theoretical savings		profitable savings		
industry	power demand	hex	hp	hex	hp	payback
	kW	kW	kW	kW	kW	year
patatoe	3367	1018	326	808	50	1.8
flavouring	635	266	55	211	0	1.7
dairy	4288	2922	946	2552	0	0.3
offset plates	3774	1138	1975	93	1717	3.3
gelatine	**4450**	**403**	**1966**	**347**	**750**	**2.6**
sugar	26236	743	17029	360	8850	1.0
fruit ingredients	3673	155	163	104	0	3.3
starch	16649	2414	3398	2412	0	1.6
chemicals	5000	0	2875	0	0	0.0

Table 3. Results of the scans (hex = heat exchangers only, hp = heat pump, payback = simple payback period of the package)

5. Other investigations

In total nine, companies were subject to an pinch analysis, with an analysis scope variating from one line or a compartment to the entire factory. An overview of the results gathered is given in Table 3.

The theoretical potential of waste heat utilization is up to 60% of the heating capacity demand. Due to the high investments needed and the high Internal Rate of Return Dutch companies evaluate projects (15% as forced by law) only a part of the potential is profitable. Almost half of the companies have profitable cases for heat pumps or vapour recompression. The package for the sugar factory consists of an additional heat exchanger and an additional vapour recompression system. The other heat pumps are regular heat pumps with a temperature level below 80 °C. All single measures have (simple) payback periods within 5 years. The total package of waste heat utilization combined (heat exchangers, heat pumps or vapour recompression combined) has payback periods up to 3.3 years.

6. Conclusions

The scan method developed gives insight in the possibilities of waste heat utilization. If the process parameters are known it takes only one day to bring in the data needed and to make a report. By using the pinch method for calculations and visual presentations, customers are better able to comprehend the used method. Other findings are:

1. Most companies have problems to acquire reliable data of waste heat streams;
2. Most companies are not aware of the technical possibilities of waste heat utilisation;
3. Almost all industries can find waste heat utilization projects with a positive NPV[1];
4. The investments of industrial heat pumps (especially high temperature > 80 ºC) are rather high in comparison to low temperature heat pumps and boilers;
5. Low electricity tariffs in combination with growing fuel tariffs makes industrial heat pumps more attractive;

7. Further development

Further development is initiated to:

- Adjust investment relations based on realized projects;
- Incorporate heat transformers;

Bibliography

Anastasovski, A. (2014). Design of common heat exchanger network for batch processes. *Applied Thermal Engineering*, 458–468.

Borgås, A. (2014). *Development of the Hybrid Absorption.* Trondheim: Norwegian University of Science and Technology - Mater Thesis.

Chaturvedi, N. D., & Bandyopadhyay, S. (2012). Minimization of a storage requitrement in a batch process using pinch analysis. *11th International Symposium on Process Systems Engineering* (pp. 670-679). Signapore: Elsevier.

Davidse, H. (2012). *Warmte-energie, de motor van de industrie.* Den Haag: VNCI.

Grift, J. M. (2017). Flexible heat supply and sustainability. *Proceedings Heat Pump COngres 2017.* Rotterdam: Stichting HPC 2017.

Klemeš, J. J. (2013). *Handbook of Process Intergration (PI).* . Cambridge: Woodhead Publishing ISBN 978-0-85709-593-0.

Linnhoff, B., & Flower, J. R. (1978). Synthesis of heat exchanger networks, I. Systematic generation of energy optimal networks. *AIChE Journal, American Institute of Chemical Engineers*, 633–642.

March, L. (1998). *Introduction to pinch technology*. Retrieved from www.ou.edu: http://www.ou.edu/class/che-design/a-design/Introduction%20to%20Pinch%20Technology-LinhoffMarch.pdf

March, L. (1998). *Introduction to Pinch Technology*. Retrieved from www.ou.edu: http://www.ou.edu/class/che-design/a-design/Introduction%20to%20Pinch%20Technology-LinhoffMarch.pdf

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[1] A positive NPV with an Internal Rate of Return of 15%