Pinch Analysis with crisscross optimization prior to design

Case 8 ï Example from Shenoy, modified by Frausto-Hernandez and Ravagnani

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Case 8 is a well-known example from Shenoy with 2 hot steams, 2 cold streams and a hot and a cold utility and has been studied by many authors. The data set is given in Table 8.1. Energy consumption in the table corresponds with an overall DTMin of 20 K.

Table 8.1

Tsupply °C	Ttarget °C	Heat kW	DT-Shift K	U*f kW/K,m²	Descript °C
175	45	1300		0.2	H1
125	65	2400		0.2	H2
20	155	2700		0.2	C1
40	112	1080		0.2	C2
180	179	605		0.2	Heating
15	25	525		0.2	Cooling

Cost data

Heating : 120 /kW,year Cooling : 10/kW,year

Area Cost : 30000 + 750 x Area $^{0.81}$ annuity : 0.3221

Trade-off, as shown in Figure 8.1 shows a total cost minimum around a Heating load of 350 kW, requiring an approach temperature of 12.5 K.

With said load, the analysis generates a Grid Diagram with 8 integration bands, leading to 15 HEX units with a total surface area of 1660.53 m³. Since heat transfer coefficients are all the same, crisscross is no issue and this area is the same as calculated in the analysis with vertical heat exchange. The number of integration bands can easily be reduced to 4.

The grid diagram and the calculated HEX loads suggest to concentrating the cooling in one heat exchanger on hot stream H1. On the basis of this, the network generated is shown in Figure 8.2, showing a configuration that is identical with that suggested by Shenoy, using GAMS.

However, inspection of the data set before design indicates that it is possible to satisfy the heat loads on streams H1 and C2 with one single heat exchanger each provided the cooling load is put on hot steam H2 instead of on hot stream H1. If, in the Grid Diagram, the cooling load is shifted to hot stream H2, then automatically only one HEX is assigned to cold stream C2. Final optimization and

fine tuning lead to the network of Figure 8.3 with only 5 units and a cost which is 3.2% lower than the reference of Shenoy.

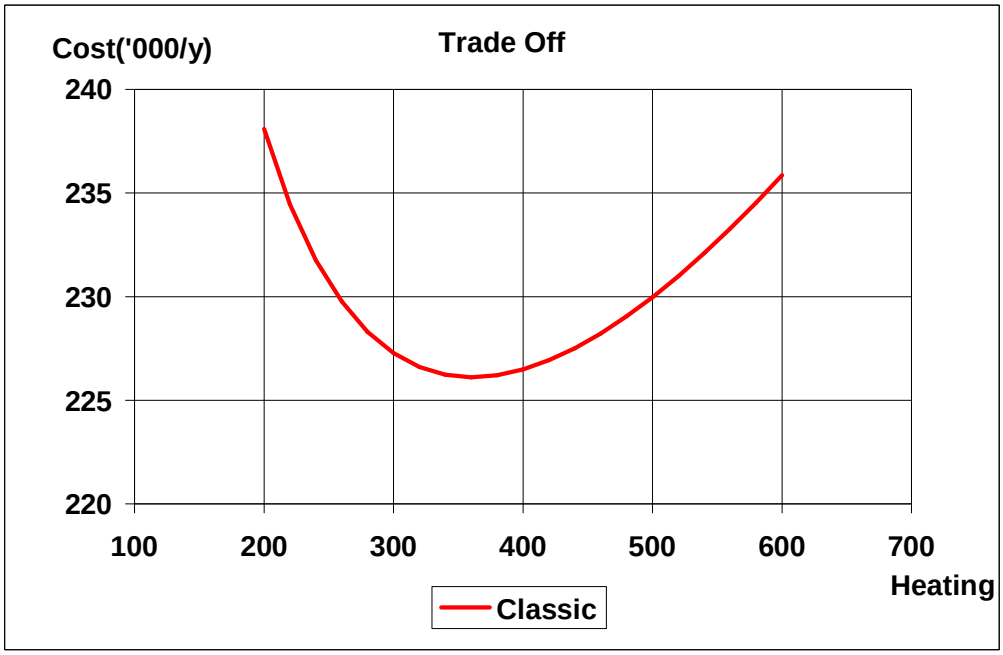

Figure 8.1

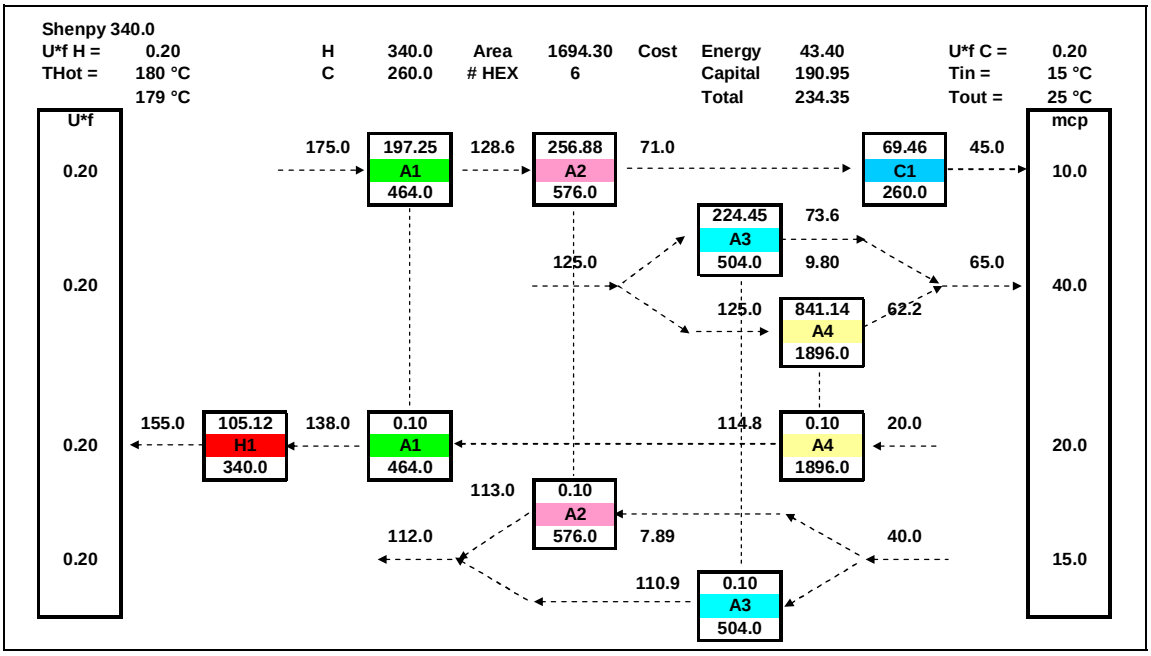

Figure 8.2

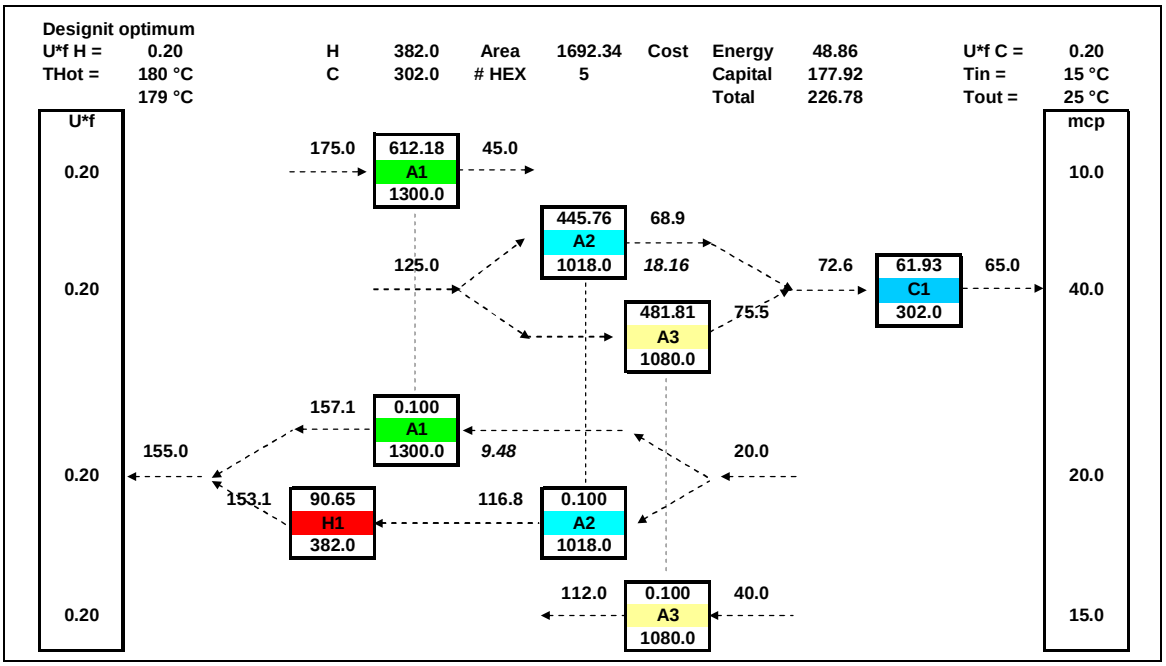

Figure 8.3

A similar stream data set has been used by Frausto-Hernandez (2003) and also by Ravagnani et al. and others albeit with stream specific heat transfer values and modified cost data as shown in Table 8.2. It was treated by Ravagnani in 2005 using Particle Swarm Optimization and by Fieg in 2009 using a hybrid genetic algorithm in combination with several other search and optimization strategies.

Table 8.2

Tsupply	Ttarget	Heat	DT-Shift	U*f	Descript
°C	°C	kW	K	kW/K,m²	°C
175	45	1300	2.5	2.615	H1
125	65	2400	2.5	1.333	H2
20	155	2700	2.5	0.917	C1
40	112	1080	2.5	0.166	C2
180	179	200		5.000	Heating
15	25	120		2.500	Cooling

Cost data Heating : 110 /kW,year Cooling : 10/kW,year

HEX $1200 \times \text{Area}^{0.57}$

The overall DeltaT of 5K and the corresponding Heating and Cooling loads result from the trade-off calculations as shown in Figure 8.4 using classic pinch analysis; these results are identical with those obtained by Ravagnani.

Table 8.3 shows optimum DT-shift values obtained by crisscross optimization in order to achieve minimum surface area for a targeted Heating load of 185 kW.

Table 8.3

Tsupply	Ttarget	Heat	DT-Shift	U*f	Descript
°C	°C	kW	K	kW/K,m²	°C
175	45	1300	0.0	2.615	H1
125	65	2400	1.0	1.333	H2
20	155	2700	0.0	0.917	C1
40	112	1080	8.0	0.166	C2
180	179	185		5.000	Heating
15	25	105		2.500	Cooling

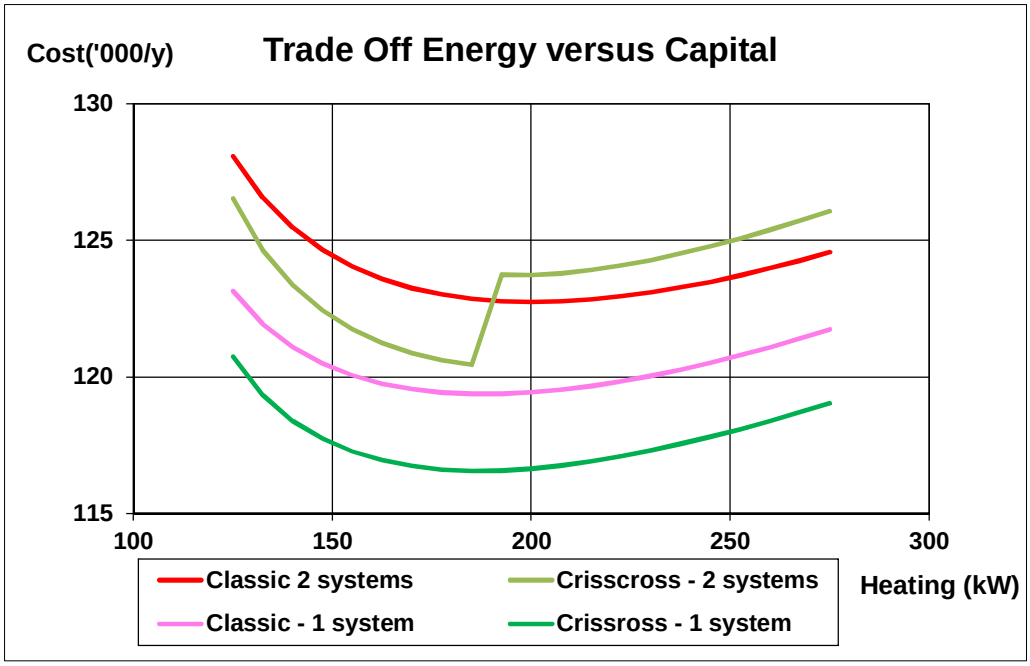

Figure 8.4

The optimum Heating load following classic pinch analysis is 200 kW; with crisscross optimization, the optimum Heating load is only 185 kW.

The targeted area is 669.94 m² without crisscross, dropping to 636.70 m² with crisscross; cost targets for a pinched design (2 systems) and one single system are given in Table 8.4.

Table 8.4

Targets	Heating	Area	Cost 1 syst	Cost 2 syst
	kW	m²	'000/y	'000/y
Classic pinch analysis	200	649.19	119.31	122.63
	185	669.94	122.74	119.25
Crisscross	185	636.70	116.46	120.34

The Grid Diagram starts with 8 integration bands that easily can be reduced to 4 (Table 8.5), generating the network as shown in Figure 8.5 after final fine tuning. This network is identical with the network developed by Fieg et al. (2009) using a hybrid genetic algorithm in combination with several other search and optimization strategies.

Table 8.5

area	677.33	HEN Cost	88.38					
#HEX	6							
Description	Shift K	U*f kW/m²,K	mcp kW/K		Bands	T(°C)		
				1	2	3	4	
Heating	0.0	5.000	185.0	180.0	179.0			
H1	0.0	2.615	10.0		175.0	124.0	55.5	45.0
H2	1.0	1.333	40.0			125.0	65.0	
C1	0.0	0.917	20.0	155.0	145.8	120.3	20.0	
C2	8.0	0.166	15.0			112.0	40.0	
Cooling	0.0	2.500	10.5				25.0	15.0

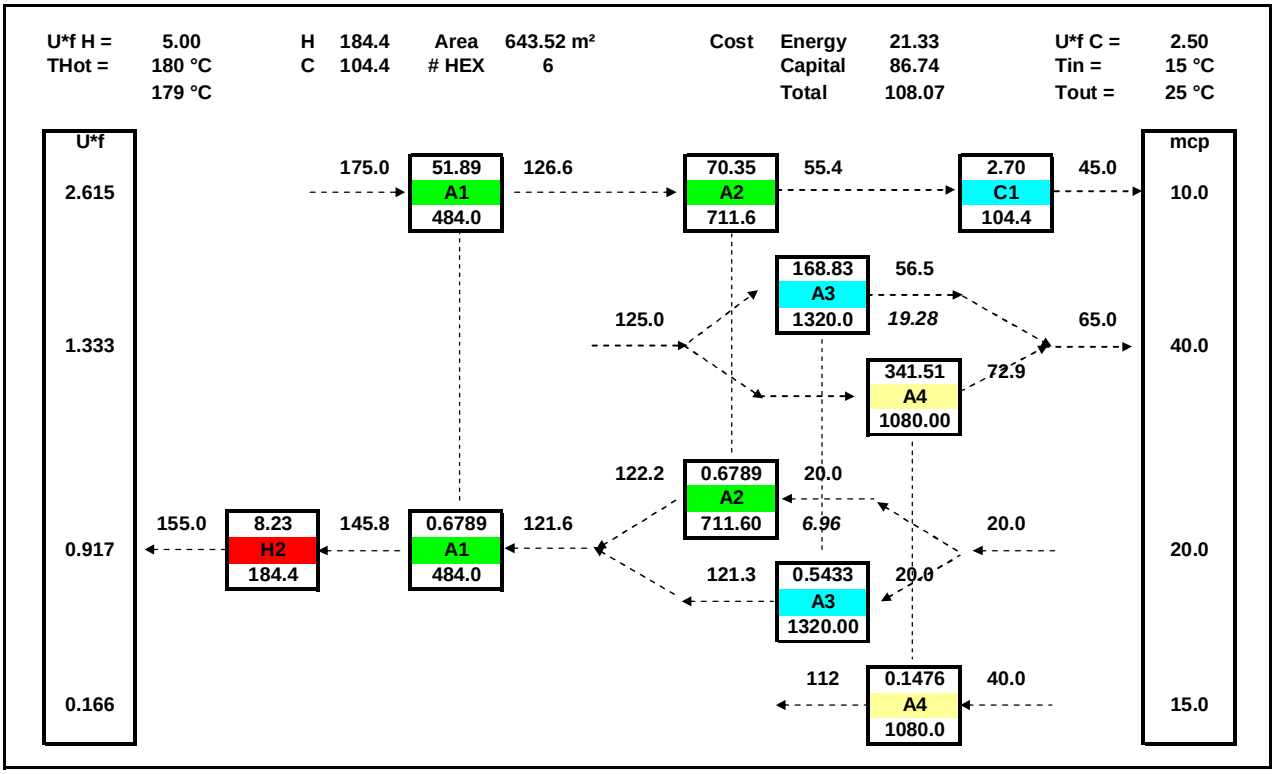

Figure 8.4