Insight in heat exchanger network synthesis

The ten streams literature case from Ahmad (1985) - Case 18

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This ten streams example was first presented by Ahmad in 1985. It was also studied by Ravagnani et al, Yerramsetty & Murty, Khorasany & Fesanghary, Gorji-Bandpy et al., Huo et al., He & Cui, Peng & Cui, Myankooh & Shafiei, Huang & Karimi and Wang et al. It comprises six hot streams and four cold streams, one hot utility and one cold utility. In many studies different data have been used; most of them, however, used the data as reported by Khorasany et al. which are given in Table 18.1. These data will be used for further analysis.

Table 18.1

Tsupply °C	Ttarget °C	Heat kW	U*f kW/K,m^2	mcp kW/K	Descript. -
85	45	6252	0.05	156.3	H1
120	40	4000	0.05	50.0	H2
125	35	2151	0.05	23.9	H3
56	46	12500	0.05	1250.0	H4
90	86	6000	0.05	1500.0	H5
225	75	7500	0.05	50.0	H6
40	55	7000.5	0.05	466.7	C1
55	65	6000	0.05	600.0	C2
65	165	18000	0.05	180.0	C3
10	170	13008	0.05	81.3	C4
200	198		0.05		Heating
15	20		0.05		Cooling

Hot utility : 100 /kW,y
Cold utility : 15 /kW,y
HEX cost : 60 x Area (m^2)/y

It is appropriate to mention the important differences between the original data used by Ahmad and those in the other studies: in the latter, hot stream H5 can be combined with cold stream C2, creating an independent system; in the former hot stream H5 has a load of 7500 kW which excludes such independent system; in the former, cold stream C3 has a load of 19500 kW, in the latter that load is only 18000 kW; in the former, utility temperatures have to be estimated and best estimates differ from the data used in the latter. Consequently, no valid comparison can be made between the results of the two data sets.

Cost will be expressed in k (thousand units).

Composite curves are shown in Figure 18.1.

The heating load has been chosen on the basis of the trade-off curve (Fig.18.2) which shows an overall cost minimum of 5578.317 k for a heating load of 20255.5 kW (cooling 14650 kW).

All heat transfer coefficients are the same; consequently, minimum area is achieved with vertical heat exchange in the Composite Curves diagram. With the given heat exchanger cost function, minimum cost also corresponds with minimum area. Said minimum area is 55550.28 m².

Targeting procedures indicate that, with the given cost function, the match H5-C2 forming an independent system does not lead to lower total cost and, consequently, said match will not be imposed a priori.

Further, with the given cost function, the number of units is irrelevant. The targets of heating and area for minimum cost can be achieved with a network of 64 heat exchanger units, spread over 19 vertical bands. There are a huge number of initial networks satisfying the criterion of minimum cost.

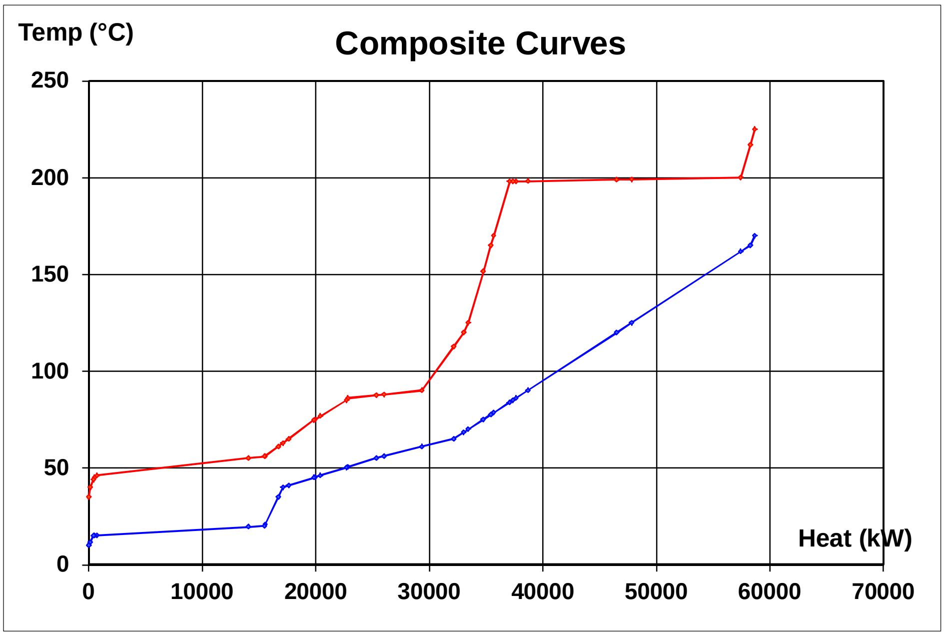

Figure 18.1

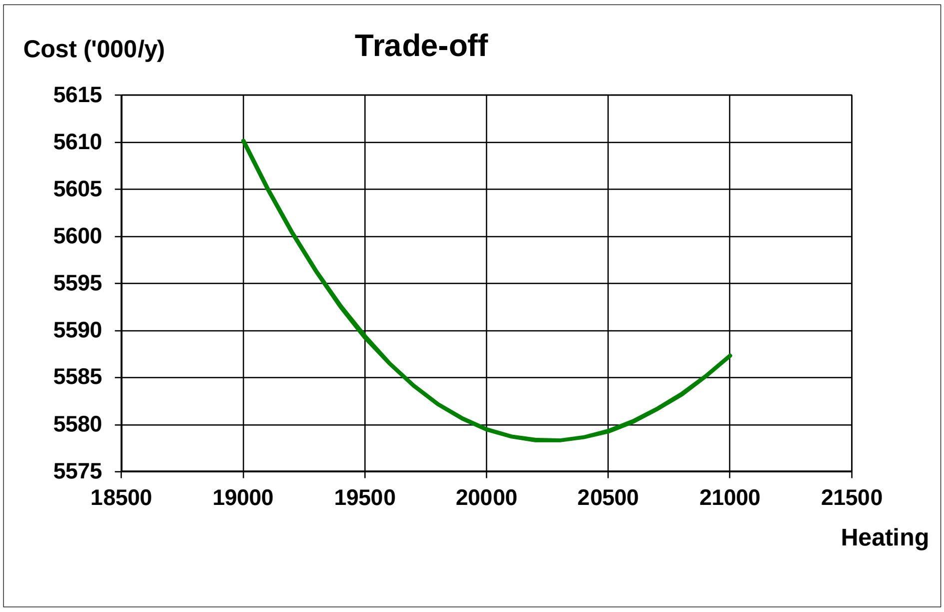

Figure 18.2

The number of bands can be reduced from 19 to 13 without fundamentally changing the character of the grid by merging bands 1 & 2, 10 & 11, 14 through 17 and 18 & 19; with this grid, still a huge number of initial designs (roughly estimated at between 10 and 40 million!) can be developed with 47 units for a cost of 5578.520 k. These networks have a large number of stream splits which because of the complexity is undesirable and, therefore, the objective of this study will be to develop networks without stream splits.

On the basis of the reduced grid, a limited number of initial networks were set up using a synthesising LP program. The number of heat exchanger units was then further reduced by applying specific procedures to eliminate the smallest heat exchangers. This process was continued until the number of units was reduced to about 23. At that stage, the few remaining splits were unwound in order to obtain networks without stream splits and these networks were then further developed.

A network was also developed based on pinch design rules and applying the tick-off procedure. The pinch caused by cold stream C1 was considered as well as the utility pinch caused by the hot utility. This network was fine-tuned resulting into the network shown in Figure 18.4; it was further developed into the best network with 13 units as shown in Figure 18.15.

The best results are summarized in Table 18.2 and compared with those of published studies. The results are further illustrated in Figure 18.3.

Several published networks were revised either to correct some errors, for fine-tuning or for further evolution in order to get a better result. The networks without stream split mentioned in Table 18.2 are shown in Figure 18.5 through Figure 18.19.

The Composite Curves diagram and the grid resulting from the pinch analysis suggest an intermediate heater on both cold streams C3 and C4. All networks with 23 through 20 units show such heater on C3; all networks with 23 through 12 units show such heater on C4.

Similarly, the Composite Curves diagram and the grid also suggest an intermediate cooler on both hot streams H2 and H3. For the initial networks studied, said cooler on H2 is eliminated during the evolution process when going down from 64 units to 47; the intermediate cooler on H3 is maintained in the networks with 23 through 21 units. There might be other initial networks that keep the cooler on H2 also intermediate after evolution.

All networks have cost very close to the theoretical minimum - the network with 23 units is within 0.1%; the network with 12 units is still within 1%. The match H5ï C2 creating an independent system appears in the networks with 13 units and less. The networks with 10 and 9 units are composed of 3 independent systems.

As an alternative calculation, a fix cost of 8000/year was added to the cost function for all networks shown below; the results are included in Figure 18.3. All networks with a number of units from 20 down to 11 have a cost that is within 0.5% of the minimum. The result for the best network is also reported in Table 18.2; it is better than that of published networks with stream splits.

Only a very limited number of initial networks have been analysed and many more networks may exist with cost very close to that of reported networks or even marginally better. Specifically, networks with a better trade-off between area and heating would be expected for networks with 13, 16 and 19 units.

Using the grid from pinch analysis in combination with simple but appropriate tools enables the development of networks which in terms of simplicity and cost can be seen as benchmarks.

Table 18.2

		QHot(MW)	Area (m^2)	Cost ('000)	# HEX
Published Optimum Heat Exchanger Networks					
1	Wang et al. (2015)	20387.0	55416	5585.39	22
2	He & Cui (2013)	20267.4	56043	5609.27	18
3	Peng & Cui (2015)	20339.0	55686	5596.08	18
4	Gorji-Bandpy et al. (2011) revised	19549.1	58196	5655.82	15
5	Myankooh & Shafiei (2015 - based on 4)	19992.3	57118	5642.11	15
6	Peng & Cui (2015)	20038.0	56655	5619.59	15
7	Ravagnani et al. (2005) revised	20529.1	56260	5652.38	13
8	Yerramsetty & Murty (2008)	20745.4	56085	5666.76	13
9	Huo et al. (2013)	20007.5	57094	5642.44	13
10	Myankooh & Shafiei (2015 - based on 7)	19991.9	57096	5640.72	13
11	Khorasany & Fesanghany (2009) revised	19605.5	57953	5647.77	12
12	Huang et al. (fix cost 8000/y; 1 split - revised)	20207.0	56778	5734.43	11
13	Huang et al. (fix cost 8000/y; 3 splits - revised)	20359.0	56187	5724.40	12
This research					
	Initial networks with stream splits	20255.5	55550	5578.32	64
		20257.0	55551	5578.52	47
	Networks without stream splits	20370.0	55419	5583.62	23
		20380.0	55411	5584.25	22
		20369.0	55436	5584.54	21
		20389.0	55406	5585.01	20
		20271.0	55656	5586.47	19
		20422.0	55380	5587.23	18
		20426.0	55425	5590.40	17
		20356.0	55712	5599.55	16
		20498.0	55469	5601.30	15
		20480.0	55725	5614.65	14
		19815.0	57161	5624.28	13
		20294.0	56421	5635.00	12
		20289.0	56742	5653.66	11
		20256.5	61075	5909.91	10
		20256.5	65844	6196.05	9
	Best network inclusive fix cost	20498.0	55469	5721.30	15

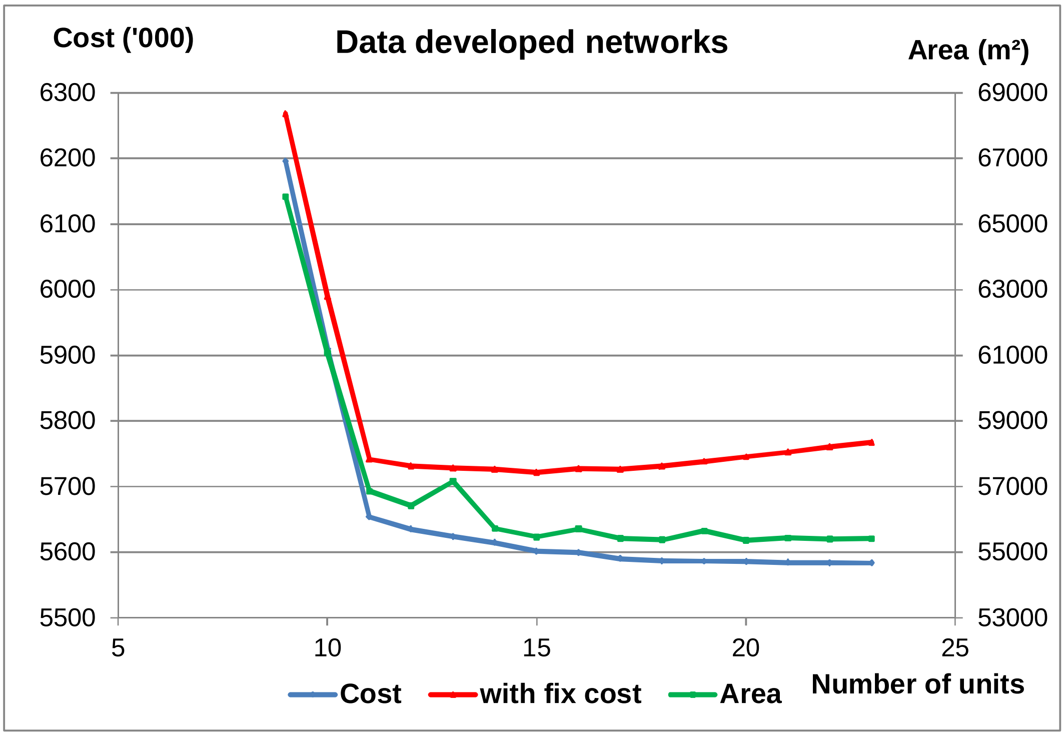
Cost ('000)
Data developed networks
Area (m²)
6300
6200
6100
6000
5900
5800
5700
5600
5500
69000
67000
65000
63000
61000
59000
57000
55000
53000
5
10
15
20
25
Cost
with fix cost
Area
Number of units

Figure 18.3

6H+4C										
U*f H =	0.05	H	20006.0	Area	56756.6	Cost	Energy	2216.61	U*f C =	0.05
Th in	200.0	C	14400.5	# HEX	14		Capital	3405.39	Tc in	15.0
Th out	198.0						Total	5622.00	Tc out	20.0

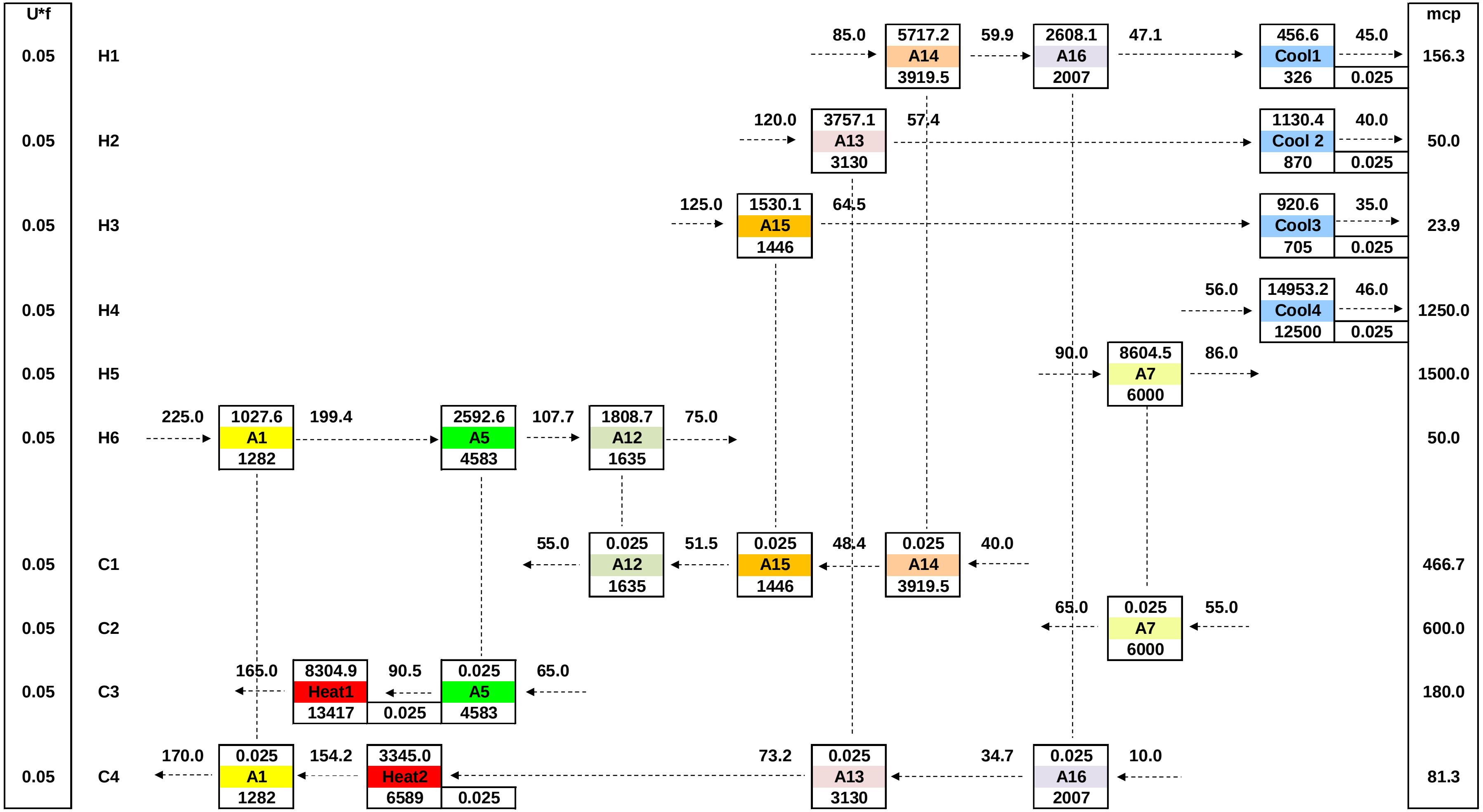

Figure 18.4

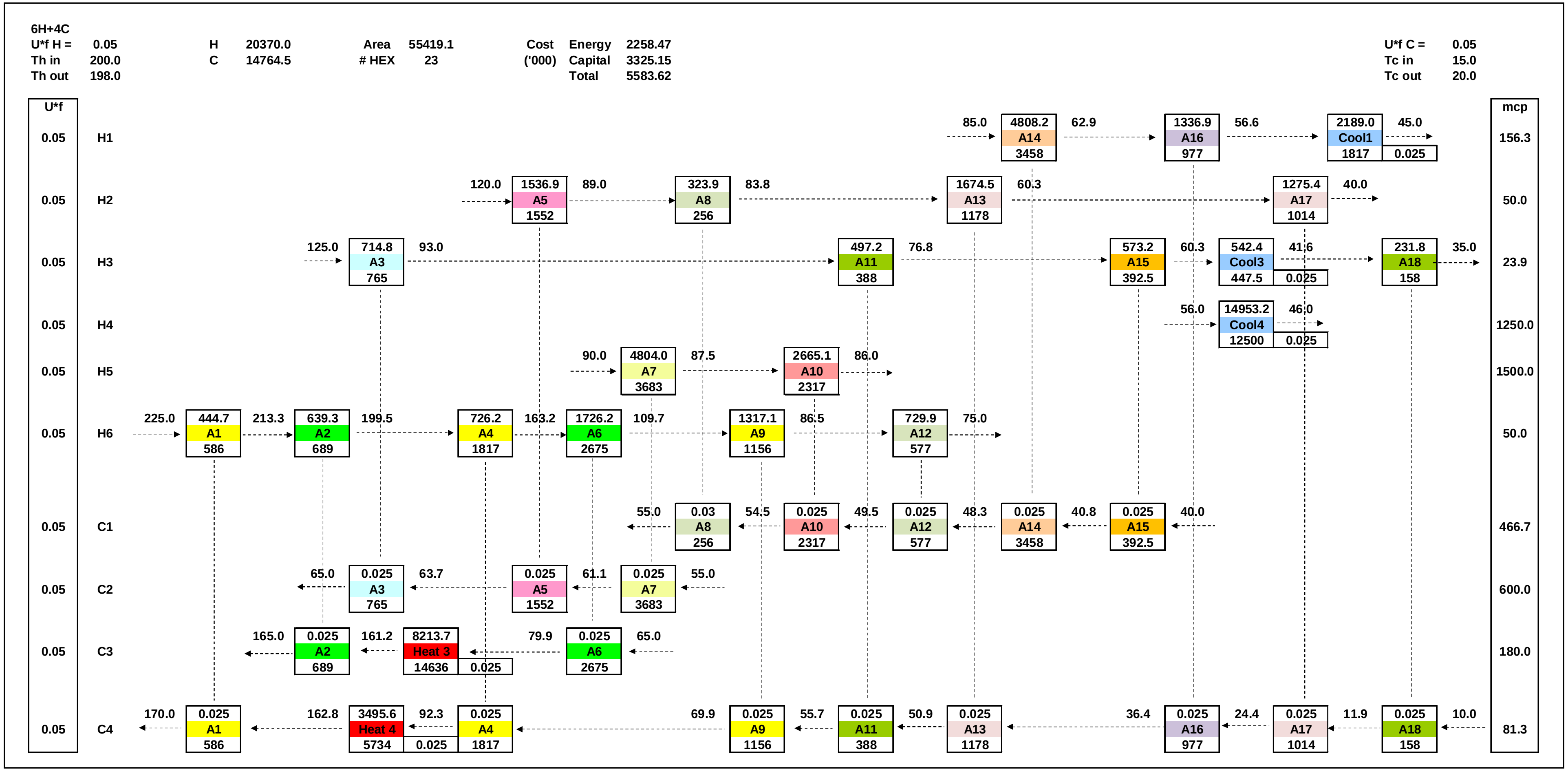
6H+4C
U*f H = 0.05
Th in 200.0
Th out 198.0
H 20370.0
C 14764.5
Area 55419.1
HEX 23
Cost ('000)
Energy 2258.47
Capital 3325.15
Total 5583.62
U*f C = 0.05
Tc in 15.0
Tc out 20.0
U*f
mcp
0.05 H1 156.3
85.0 4808.2 A14 3458 62.9 1336.9 A16 977 56.6 2189.0 Cool1 1817 0.025 45.0
0.05 H2 50.0
120.0 1536.9 A5 1552 89.0 323.9 A8 256 83.8 1674.5 A13 1178 60.3 1275.4 A17 1014 40.0
0.05 H3 23.9
125.0 714.8 A3 765 93.0 497.2 A11 388 76.8 573.2 A15 392.5 60.3 542.4 Cool3 447.5 0.025 41.6 231.8 A18 158 35.0
0.05 H4 1250.0
56.0 14953.2 Cool4 12500 0.025 46.0
0.05 H5 1500.0
90.0 4804.0 A7 3683 87.5 2665.1 A10 2317 86.0
0.05 H6 50.0
225.0 444.7 A1 586 213.3 639.3 A2 689 199.5 726.2 A4 1817 163.2 1726.2 A6 2675 109.7 1317.1 A9 1156 86.5 729.9 A12 577 75.0
0.05 C1 466.7
55.0 0.03 A8 256 54.5 0.025 A10 2317 49.5 0.025 A12 577 48.3 0.025 A14 3458 40.8 0.025 A15 392.5 40.0
0.05 C2 600.0
65.0 0.025 A3 765 63.7 0.025 A5 1552 61.1 0.025 A7 3683 55.0
0.05 C3 180.0
165.0 0.025 A2 689 161.2 8213.7 Heat 3 14636 0.025 79.9 0.025 A6 2675 65.0
0.05 C4 81.3
170.0 0.025 A1 586 162.8 3495.6 Heat 4 5734 0.025 92.3 0.025 A4 1817 69.9 0.025 A9 1156 55.7 0.025 A11 388 50.9 0.025 A13 1178 36.4 0.025 A16 977 24.4 0.025 A17 1014 11.9 0.025 A18 158 10.0

Figure 18.5

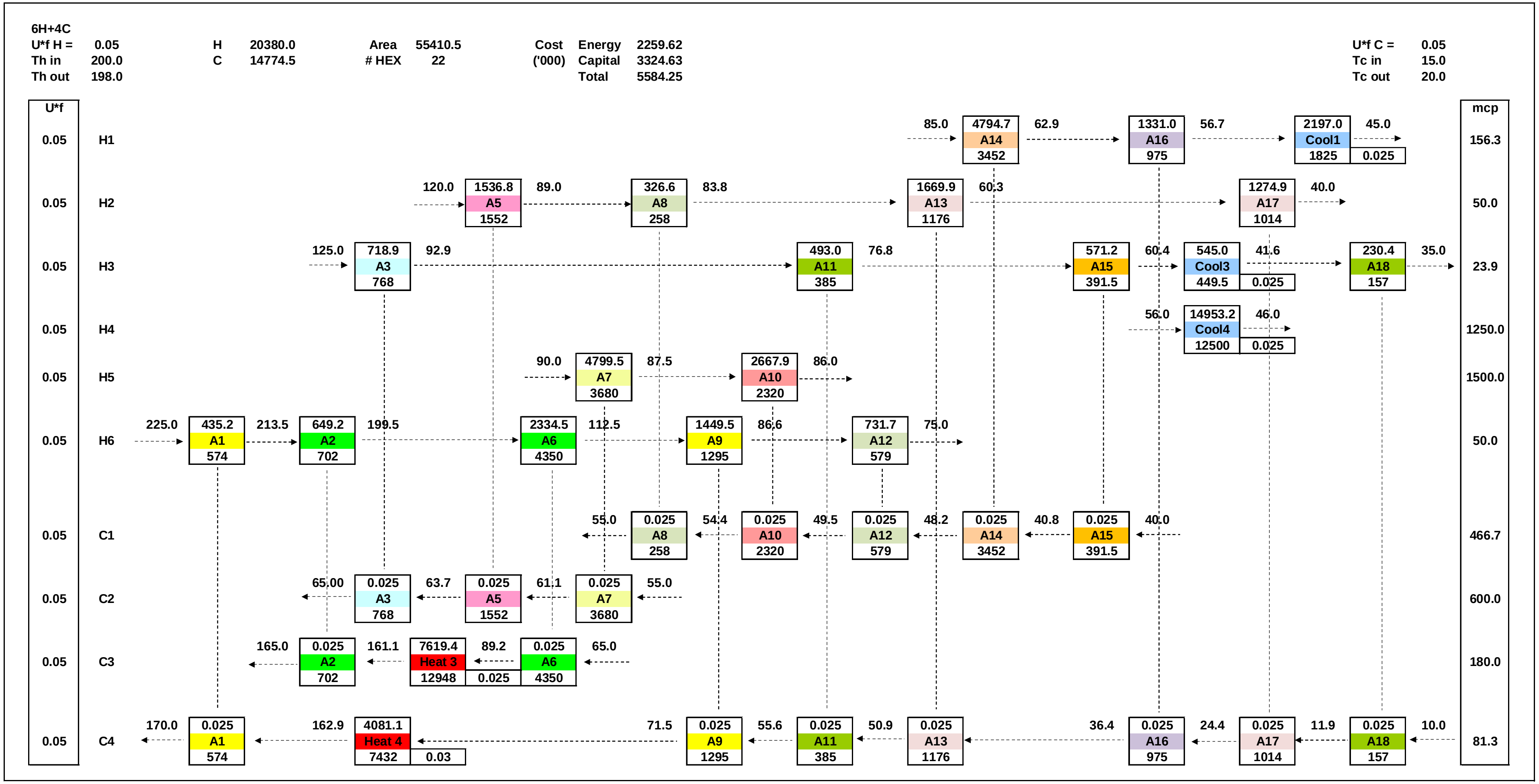
6H+4C
U*f H = 0.05
Th in 200.0
Th out 198.0
H 20380.0
C 14774.5
Area 55410.5
HEX 22
Cost ('000)
Energy 2259.62
Capital 3324.63
Total 5584.25
U*f C = 0.05
Tc in 15.0
Tc out 20.0
U*f
mcp
0.05
H1
85.0
4794.7
A14
3452
62.9
1331.0
A16
975
56.7
2197.0
Cool1
1825
45.0
0.025
156.3
0.05
H2
120.0
1536.8
A5
1552
89.0
326.6
A8
258
83.8
1669.9
A13
1176
60.3
1274.9
A17
1014
40.0
50.0
0.05
H3
125.0
718.9
A3
768
92.9
493.0
A11
385
76.8
571.2
A15
391.5
60.4
545.0
Cool3
449.5
41.6
0.025
230.4
A18
157
35.0
23.9
0.05
H4
56.0
14953.2
Cool4
12500
46.0
0.025
1250.0
0.05
H5
90.0
4799.5
A7
3680
87.5
2667.9
A10
2320
86.0
1500.0
0.05
H6
225.0
435.2
A1
574
213.5
649.2
A2
702
199.5
2334.5
A6
4350
112.5
1449.5
A9
1295
86.6
731.7
A12
579
75.0
50.0
0.05
C1
55.0
0.025
A8
258
54.4
0.025
A10
2320
49.5
0.025
A12
579
48.2
0.025
A14
3452
40.8
0.025
A15
391.5
40.0
466.7
0.05
C2
65.00
0.025
A3
768
63.7
0.025
A5
1552
61.1
0.025
A7
3680
55.0
600.0
0.05
C3
165.0
0.025
A2
702
161.1
7619.4
Heat 3
12948
0.025
89.2
0.025
A6
4350
65.0
180.0
0.05
C4
170.0
0.025
A1
574
162.9
4081.1
Heat 4
7432
0.03
71.5
0.025
A9
1295
55.6
0.025
A11
385
50.9
0.025
A13
1176
36.4
0.025
A16
975
24.4
0.025
A17
1014
11.9
0.025
A18
157
10.0
81.3

Figure 18.6

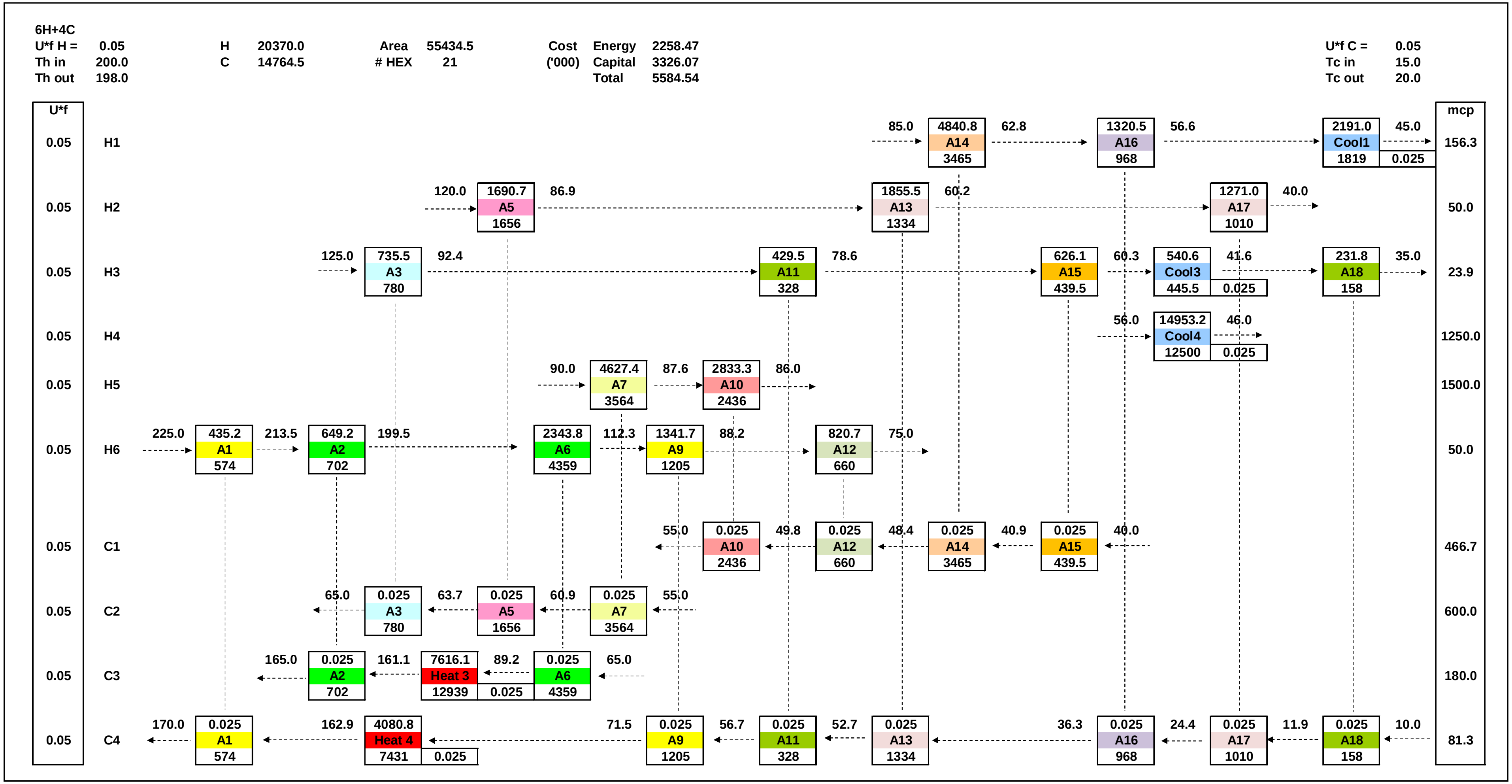
6H+4C
U*f H = 0.05
Th in 200.0
Th out 198.0
H 20370.0
C 14764.5
Area 55434.5
HEX 21
Cost ('000)
Energy 2258.47
Capital 3326.07
Total 5584.54
U*f C = 0.05
Tc in 15.0
Tc out 20.0
U*f
mcp
0.05 H1 156.3
0.05 H2 50.0
0.05 H3 23.9
0.05 H4 1250.0
0.05 H5 1500.0
0.05 H6 50.0
0.05 C1 466.7
0.05 C2 600.0
0.05 C3 180.0
0.05 C4 81.3
85.0
4840.8 A14 3465
62.8
1320.5 A16 968
56.6
2191.0 Cool1 1819 0.025
45.0
120.0
1690.7 A5 1656
86.9
1855.5 A13 1334
60.2
1271.0 A17 1010
40.0
125.0
735.5 A3 780
92.4
429.5 A11 328
78.6
626.1 A15 439.5
60.3
540.6 Cool3 445.5 0.025
41.6
231.8 A18 158
35.0
56.0
14953.2 Cool4 12500 0.025
46.0
90.0
4627.4 A7 3564
87.6
2833.3 A10 2436
86.0
225.0
435.2 A1 574
213.5
649.2 A2 702
199.5
2343.8 A6 4359
112.3
1341.7 A9 1205
88.2
820.7 A12 660
75.0
55.0
0.025 A10 2436
49.8
0.025 A12 660
48.4
0.025 A14 3465
40.9
0.025 A15 439.5
40.0
65.0
0.025 A3 780
63.7
0.025 A5 1656
60.9
0.025 A7 3564
55.0
165.0
0.025 A2 702
161.1
7616.1 Heat 3 12939 0.025
89.2
0.025 A6 4359
65.0
170.0
0.025 A1 574
162.9
4080.8 Heat 4 7431 0.025
71.5
0.025 A9 1205
56.7
0.025 A11 328
52.7
0.025 A13 1334
36.3
0.025 A16 968
24.4
0.025 A17 1010
11.9
0.025 A18 158
10.0

Figure 18.7

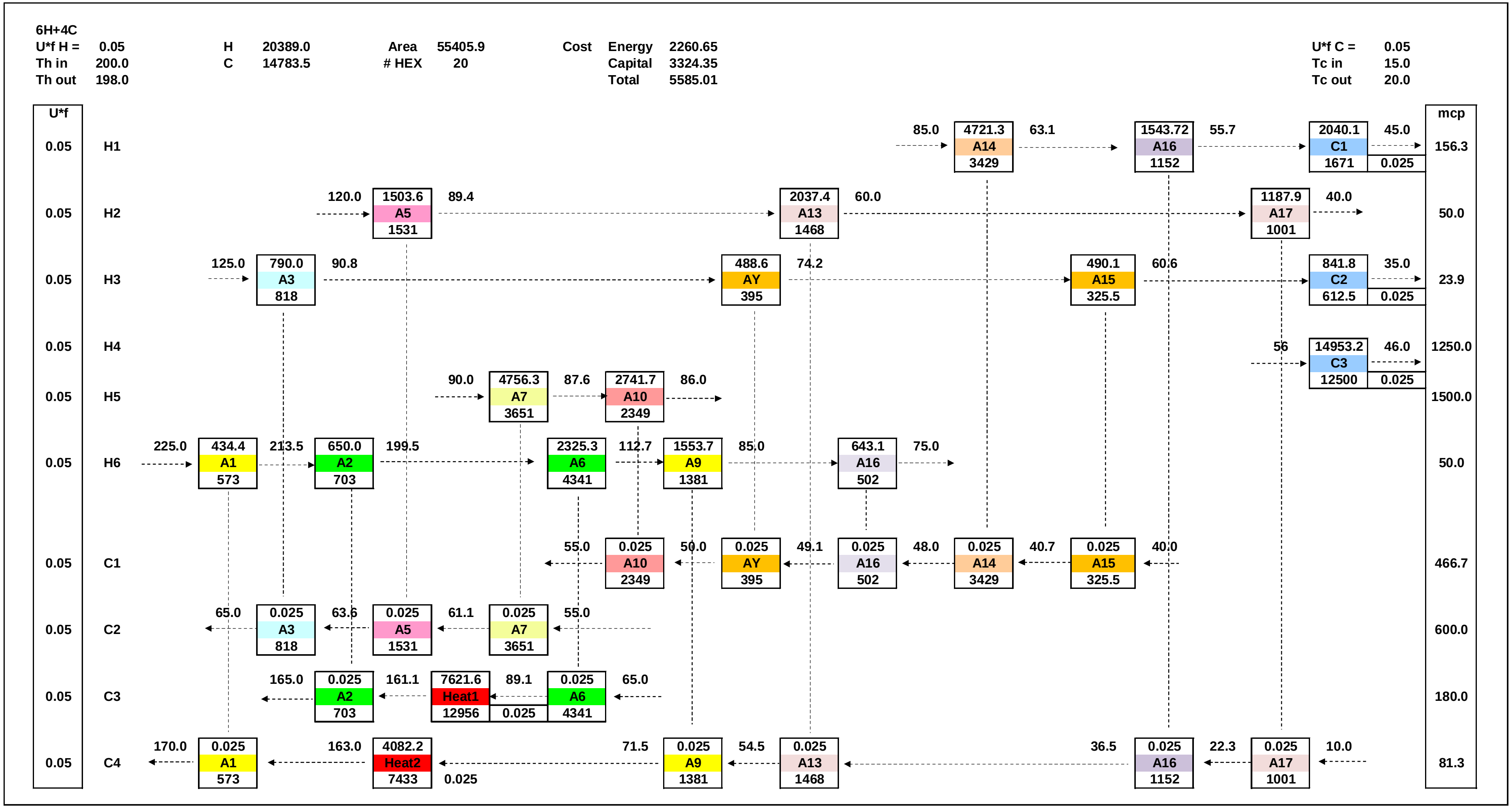
6H+4C
U*f H = 0.05
Th in 200.0
Th out 198.0
H 20389.0
C 14783.5
Area 55405.9
HEX 20
Cost
Energy 2260.65
Capital 3324.35
Total 5585.01
U*f C = 0.05
Tc in 15.0
Tc out 20.0
U*f
mcp
0.05 H1
0.05 H2
0.05 H3
0.05 H4
0.05 H5
0.05 H6
0.05 C1
0.05 C2
0.05 C3
0.05 C4
156.3
50.0
23.9
1250.0
1500.0
50.0
466.7
600.0
180.0
81.3
85.0
4721.3
A14
3429
63.1
1543.72
A16
1152
55.7
2040.1
C1
1671
0.025
45.0
120.0
1503.6
A5
1531
89.4
2037.4
A13
1468
60.0
1187.9
A17
1001
40.0
125.0
790.0
A3
818
90.8
488.6
AY
395
74.2
490.1
A15
325.5
60.6
841.8
C2
612.5
0.025
35.0
56
14953.2
C3
12500
0.025
46.0
90.0
4756.3
A7
3651
87.6
2741.7
A10
2349
86.0
225.0
434.4
A1
573
213.5
650.0
A2
703
199.5
2325.3
A6
4341
112.7
1553.7
A9
1381
85.0
643.1
A16
502
75.0
55.0
0.025
A10
2349
50.0
0.025
AY
395
49.1
0.025
A16
502
48.0
0.025
A14
3429
40.7
0.025
A15
325.5
40.0
65.0
0.025
A3
818
63.6
0.025
A5
1531
61.1
0.025
A7
3651
55.0
165.0
0.025
A2
703
161.1
7621.6
Heat1
12956
0.025
89.1
0.025
A6
4341
65.0
170.0
0.025
A1
573
163.0
4082.2
Heat2
7433
0.025
71.5
0.025
A9
1381
54.5
0.025
A13
1468
36.5
0.025
A16
1152
22.3
0.025
A17
1001
10.0

Figure 18.8

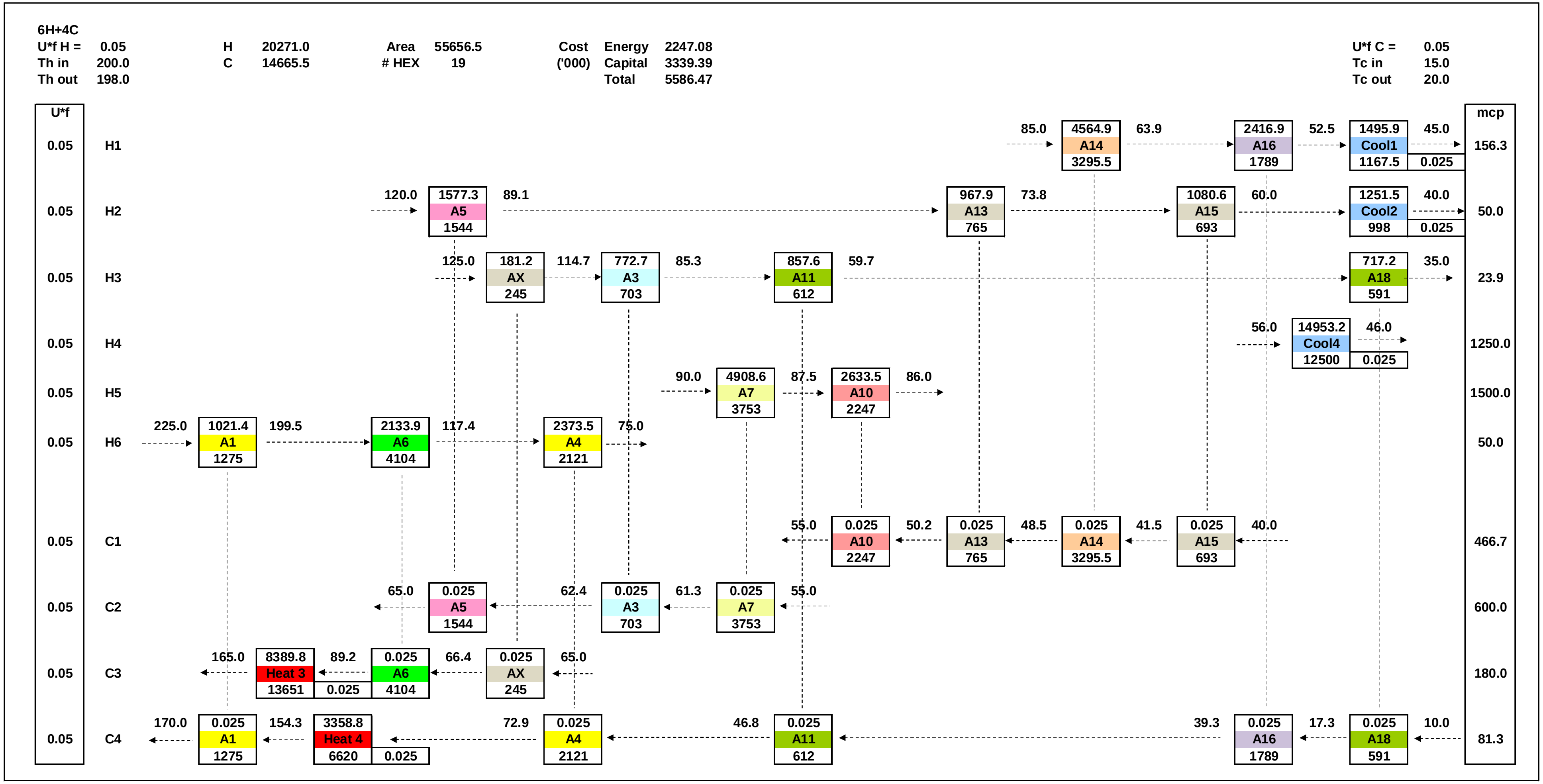
6H+4C
U*f H = 0.05
Th in 200.0
Th out 198.0
H 20271.0
C 14665.5
Area 55656.5
HEX 19
Cost ('000)
Energy 2247.08
Capital 3339.39
Total 5586.47
U*f C = 0.05
Tc in 15.0
Tc out 20.0
U*f
mcp
H1 0.05 156.3
H2 0.05 50.0
H3 0.05 23.9
H4 0.05 1250.0
H5 0.05 1500.0
H6 0.05 50.0
C1 0.05 466.7
C2 0.05 600.0
C3 0.05 180.0
C4 0.05 81.3
85.0 4564.9 A14 3295.5 63.9 2416.9 A16 1789 52.5 1495.9 Cool1 1167.5 0.025 45.0
120.0 1577.3 A5 1544 89.1 967.9 A13 765 73.8 1080.6 A15 693 60.0 1251.5 Cool2 998 0.025 40.0
125.0 181.2 AX 245 114.7 772.7 A3 703 85.3 857.6 A11 612 59.7 717.2 A18 591 35.0
56.0 14953.2 Cool4 12500 0.025 46.0
90.0 4908.6 A7 3753 87.5 2633.5 A10 2247 86.0
225.0 1021.4 A1 1275 199.5 2133.9 A6 4104 117.4 2373.5 A4 2121 75.0
55.0 0.025 A10 2247 50.2 0.025 A13 765 48.5 0.025 A14 3295.5 41.5 0.025 A15 693 40.0
65.0 0.025 A5 1544 62.4 0.025 A3 703 61.3 0.025 A7 3753 55.0
165.0 8389.8 Heat 3 13651 0.025 89.2 0.025 A6 4104 66.4 0.025 AX 245 65.0
170.0 0.025 A1 1275 154.3 3358.8 Heat 4 6620 0.025 72.9 0.025 A4 2121 46.8 0.025 A11 612 39.3 0.025 A16 1789 17.3 0.025 A18 591 10.0

Figure 18.9

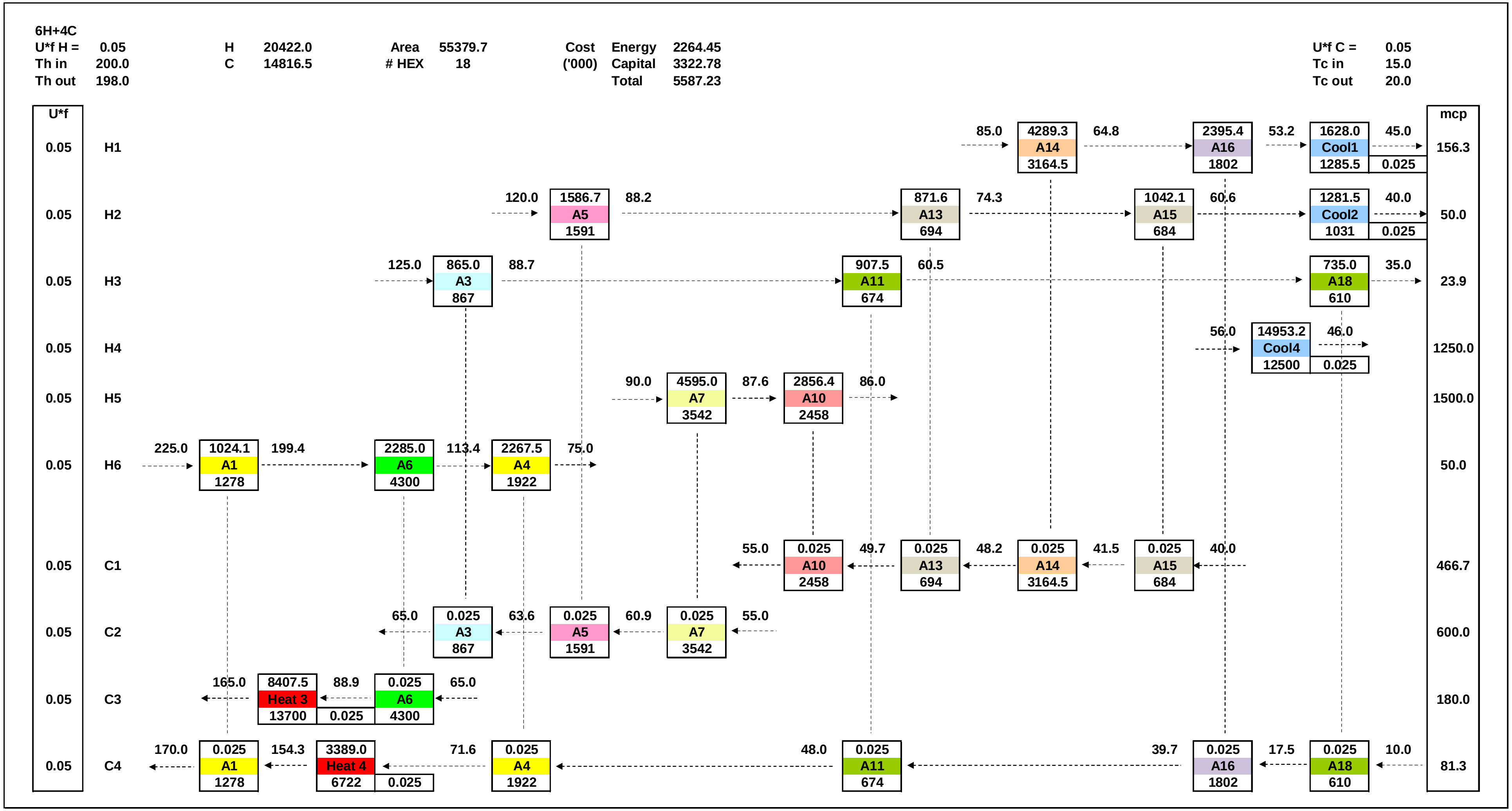
6H+4C
U*f H = 0.05
Th in 200.0
Th out 198.0
H 20422.0
C 14816.5
Area 55379.7
HEX 18
Cost ('000)
Energy 2264.45
Capital 3322.78
Total 5587.23
U*f C = 0.05
Tc in 15.0
Tc out 20.0
U*f
mcp
0.05 H1 156.3
85.0
4289.3 A14 3164.5
64.8
2395.4 A16 1802
53.2
1628.0 Cool1 1285.5 0.025
45.0
0.05 H2 50.0
120.0
1586.7 A5 1591
88.2
871.6 A13 694
74.3
1042.1 A15 684
60.6
1281.5 Cool2 1031 0.025
40.0
0.05 H3 23.9
125.0
865.0 A3 867
88.7
907.5 A11 674
60.5
735.0 A18 610
35.0
0.05 H4 1250.0
56.0
14953.2 Cool4 12500 0.025
46.0
0.05 H5 1500.0
90.0
4595.0 A7 3542
87.6
2856.4 A10 2458
86.0
0.05 H6 50.0
225.0
1024.1 A1 1278
199.4
2285.0 A6 4300
113.4
2267.5 A4 1922
75.0
0.05 C1 466.7
55.0
0.025 A10 2458
49.7
0.025 A13 694
48.2
0.025 A14 3164.5
41.5
0.025 A15 684
40.0
0.05 C2 600.0
65.0
0.025 A3 867
63.6
0.025 A5 1591
60.9
0.025 A7 3542
55.0
0.05 C3 180.0
165.0
8407.5 Heat 3 13700 0.025
88.9
0.025 A6 4300
65.0
0.05 C4 81.3
170.0
0.025 A1 1278
154.3
3389.0 Heat 4 6722 0.025
71.6
0.025 A4 1922
48.0
0.025 A11 674
39.7
0.025 A16 1802
17.5
0.025 A18 610
10.0

Figure 18.10

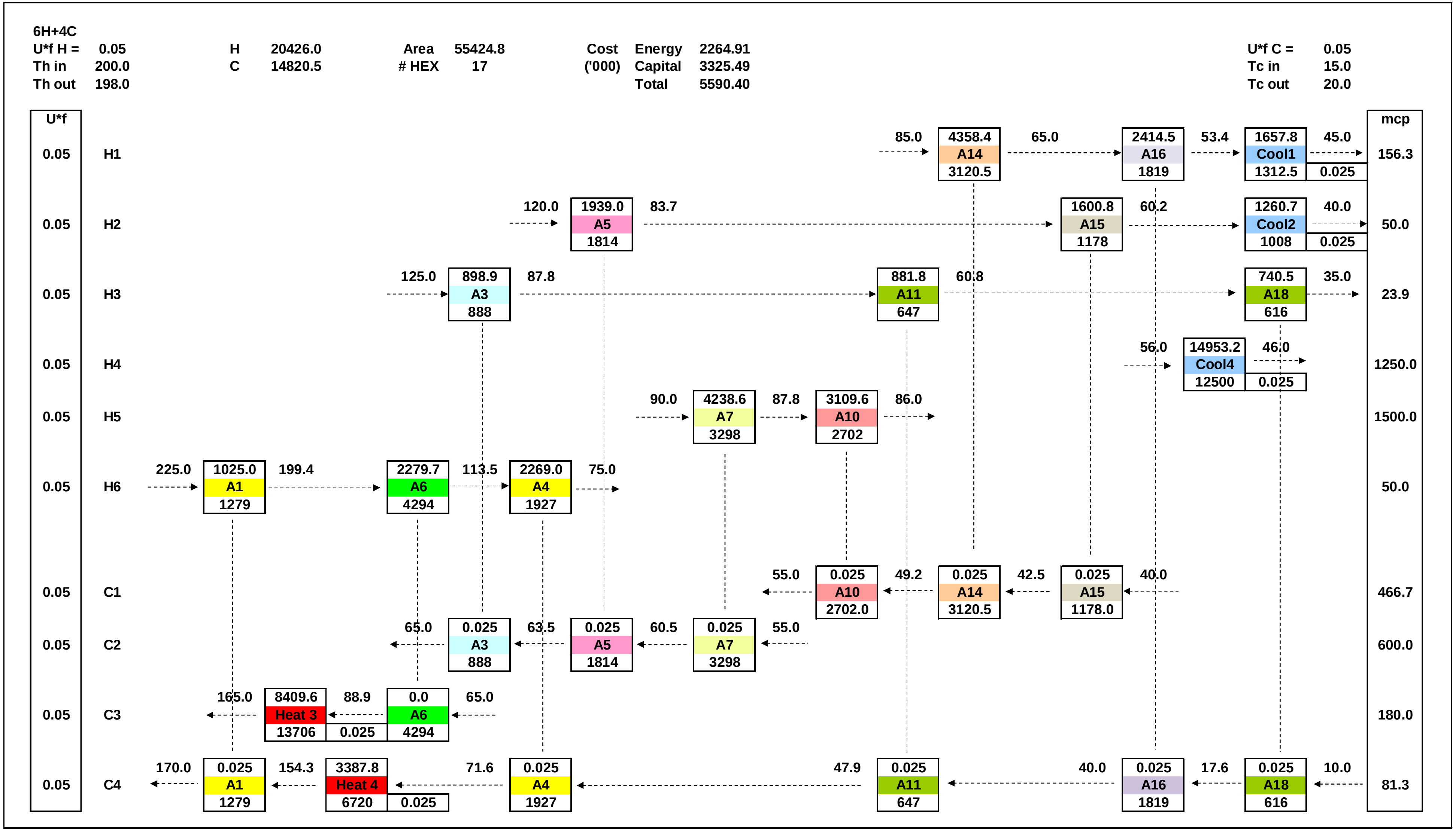
6H+4C
U*f H = 0.05
Th in 200.0
Th out 198.0
H 20426.0
C 14820.5
Area 55424.8
HEX 17
Cost ('000)
Energy 2264.91
Capital 3325.49
Total 5590.40
U*f C = 0.05
Tc in 15.0
Tc out 20.0
U*f
mcp
0.05 H1
85.0
4358.4 A14 3120.5
65.0
2414.5 A16 1819
53.4
1657.8 Cool1 1312.5 0.025
45.0
156.3
0.05 H2
120.0
1939.0 A5 1814
83.7
1600.8 A15 1178
60.2
1260.7 Cool2 1008 0.025
40.0
50.0
0.05 H3
125.0
898.9 A3 888
87.8
881.8 A11 647
60.8
740.5 A18 616
35.0
23.9
0.05 H4
56.0
14953.2 Cool4 12500 0.025
46.0
1250.0
0.05 H5
90.0
4238.6 A7 3298
87.8
3109.6 A10 2702
86.0
1500.0
0.05 H6
225.0
1025.0 A1 1279
199.4
2279.7 A6 4294
113.5
2269.0 A4 1927
75.0
50.0
0.05 C1
55.0
0.025 A10 2702.0
49.2
0.025 A14 3120.5
42.5
0.025 A15 1178.0
40.0
466.7
0.05 C2
65.0
0.025 A3 888
63.5
0.025 A5 1814
60.5
0.025 A7 3298
55.0
600.0
0.05 C3
165.0
8409.6 Heat 3 13706 0.025
88.9
0.0 A6 4294
65.0
180.0
0.05 C4
170.0
0.025 A1 1279
154.3
3387.8 Heat 4 6720 0.025
71.6
0.025 A4 1927
47.9
0.025 A11 647
40.0
0.025 A16 1819
17.6
0.025 A18 616
10.0
81.3

Figure 18.11

6H+4C
U*f H = 0.05 H 20356.0 Area 55711.6 Cost Energy 2256.86 U*f C = 0.05
Th in 200.0 C 14750.5 # HEX 16 ('000) Capital 3342.69 Tc in 15.0
Th out 198.0 Total 5599.55 Tc out 20.0

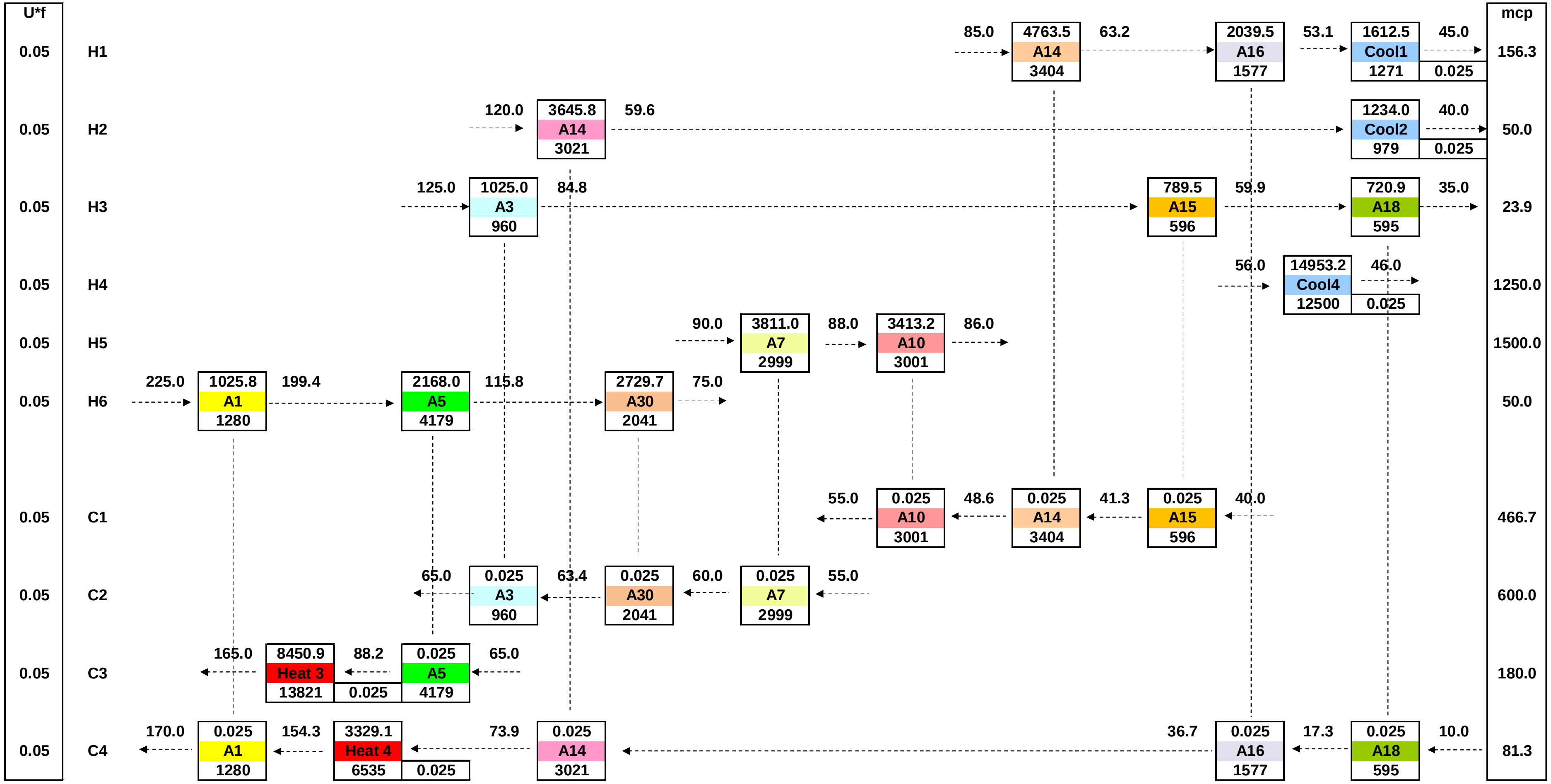

Figure 18.12

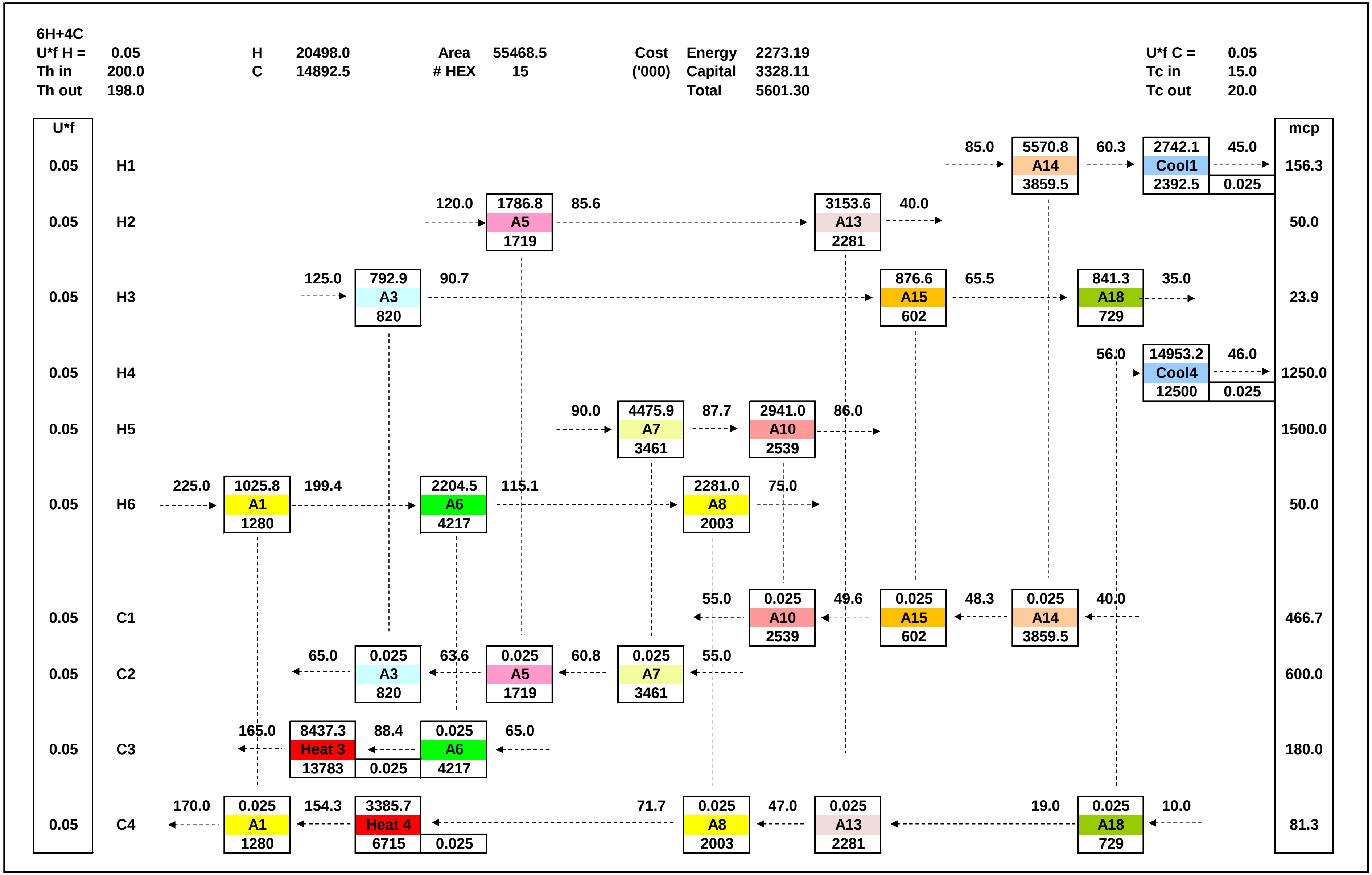
6H+4C
U*f H = 0.05
Th in 200.0
Th out 198.0
H 20498.0
C 14892.5
Area 55468.5
HEX 15
Cost ('000)
Energy 2273.19
Capital 3328.11
Total 5601.30
U*f C = 0.05
Tc in 15.0
Tc out 20.0
U*f
mcp
0.05 H1 156.3
0.05 H2 50.0
0.05 H3 23.9
0.05 H4 1250.0
0.05 H5 1500.0
0.05 H6 50.0
0.05 C1 466.7
0.05 C2 600.0
0.05 C3 180.0
0.05 C4 81.3
85.0
5570.8 A14 3859.5
60.3
2742.1 Cool1 2392.5 0.025
45.0
120.0
1786.8 A5 1719
85.6
3153.6 A13 2281
40.0
125.0
792.9 A3 820
90.7
876.6 A15 602
65.5
841.3 A18 729
35.0
56.0
14953.2 Cool4 12500 0.025
46.0
90.0
4475.9 A7 3461
87.7
2941.0 A10 2539
86.0
225.0
1025.8 A1 1280
199.4
2204.5 A6 4217
115.1
2281.0 A8 2003
75.0
55.0
0.025 A10 2539
49.6
0.025 A15 602
48.3
0.025 A14 3859.5
40.0
65.0
0.025 A3 820
63.6
0.025 A5 1719
60.8
0.025 A7 3461
55.0
165.0
8437.3 Heat 3 13783
88.4
0.025
0.025 A6 4217
65.0
170.0
0.025 A1 1280
154.3
3385.7 Heat 4 6715
0.025
71.7
0.025 A8 2003
47.0
0.025 A13 2281
19.0
0.025 A18 729
10.0

Figure 18.13

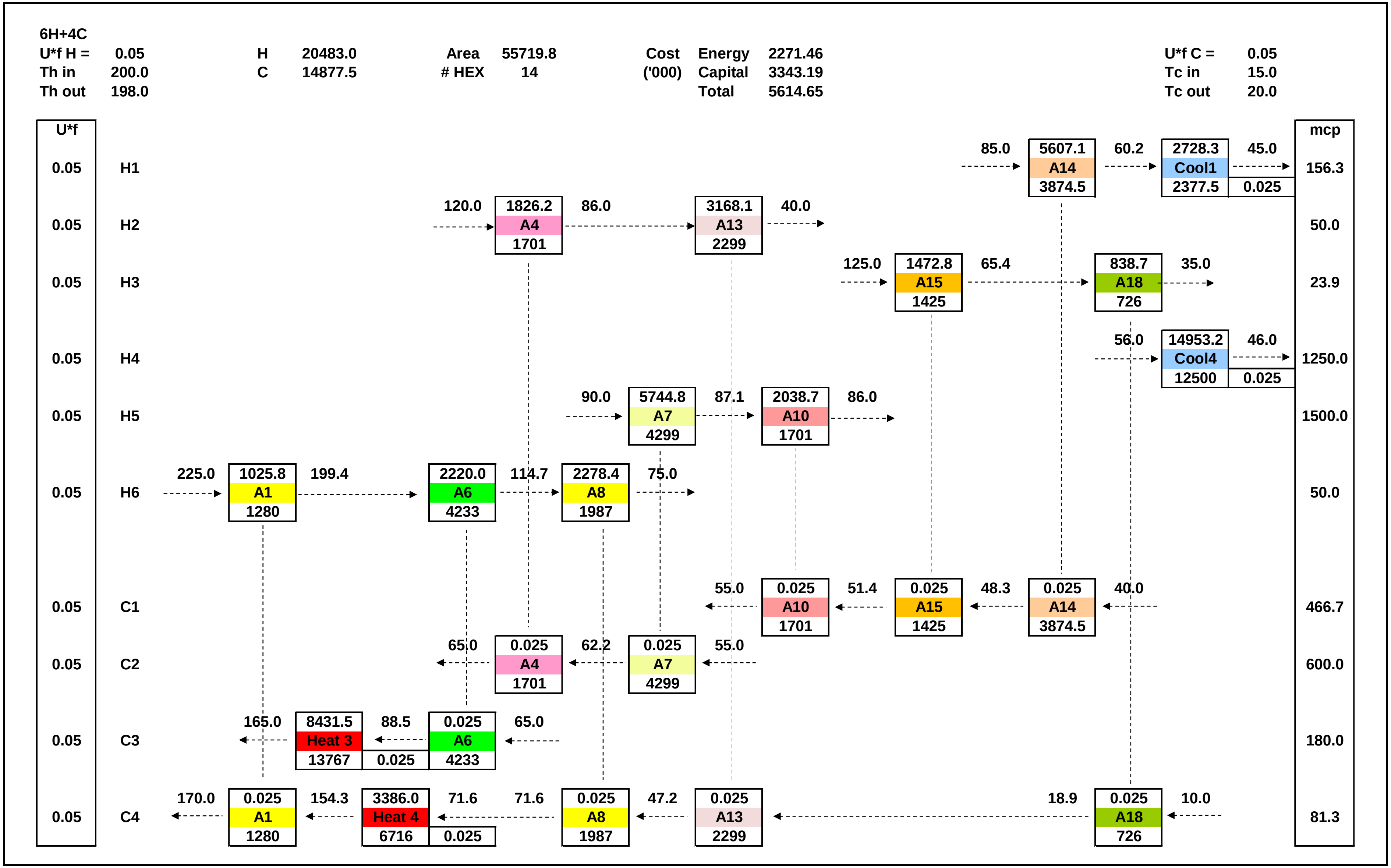
6H+4C
U*f H = 0.05
Th in 200.0
Th out 198.0
H 20483.0
C 14877.5
Area 55719.8
HEX 14
Cost ('000)
Energy 2271.46
Capital 3343.19
Total 5614.65
U*f C = 0.05
Tc in 15.0
Tc out 20.0
U*f
0.05 H1
0.05 H2
0.05 H3
0.05 H4
0.05 H5
0.05 H6
0.05 C1
0.05 C2
0.05 C3
0.05 C4
mcp
156.3
50.0
23.9
1250.0
1500.0
50.0
466.7
600.0
180.0
81.3
85.0
5607.1 A14 3874.5
60.2
2728.3 Cool1 2377.5 0.025
45.0
120.0
1826.2 A4 1701
86.0
3168.1 A13 2299
40.0
125.0
1472.8 A15 1425
65.4
838.7 A18 726
35.0
56.0
14953.2 Cool4 12500 0.025
46.0
90.0
5744.8 A7 4299
87.1
2038.7 A10 1701
86.0
225.0
1025.8 A1 1280
199.4
2220.0 A6 4233
114.7
2278.4 A8 1987
75.0
55.0
0.025 A10 1701
51.4
0.025 A15 1425
48.3
0.025 A14 3874.5
40.0
65.0
0.025 A4 1701
62.2
0.025 A7 4299
55.0
165.0
8431.5 Heat 3 13767 0.025
88.5
0.025 A6 4233
65.0
170.0
0.025 A1 1280
154.3
3386.0 Heat 4 6716 0.025
71.6
71.6
0.025 A8 1987
47.2
0.025 A13 2299
18.9
0.025 A18 726
10.0

Figure 18.14

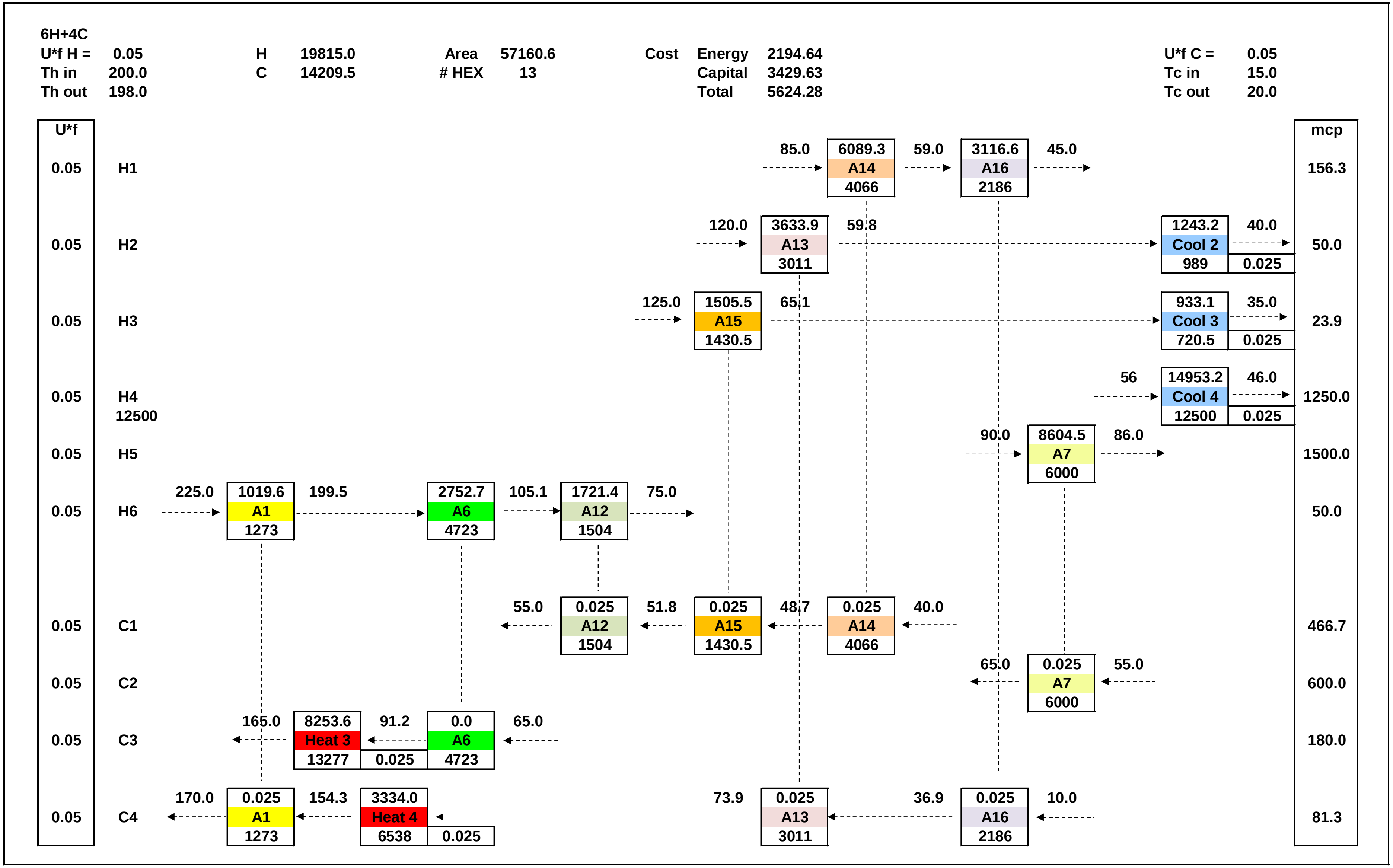
6H+4C
U*f H = 0.05
Th in 200.0
Th out 198.0
H 19815.0
C 14209.5
Area 57160.6
HEX 13
Cost
Energy 2194.64
Capital 3429.63
Total 5624.28
U*f C = 0.05
Tc in 15.0
Tc out 20.0
U*f
mcp
0.05 H1 156.3
85.0 6089.3 A14 4066 59.0 3116.6 A16 2186 45.0
0.05 H2 50.0
120.0 3633.9 A13 3011 59.8 1243.2 Cool 2 989 40.0 0.025
0.05 H3 23.9
125.0 1505.5 A15 1430.5 65.1 933.1 Cool 3 720.5 35.0 0.025
0.05 H4 12500 1250.0
56 14953.2 Cool 4 12500 46.0 0.025
0.05 H5 1500.0
90.0 8604.5 A7 6000 86.0
0.05 H6 50.0
225.0 1019.6 A1 1273 199.5 2752.7 A6 4723 105.1 1721.4 A12 1504 75.0
0.05 C1 466.7
55.0 0.025 A12 1504 51.8 0.025 A15 1430.5 48.7 0.025 A14 4066 40.0
0.05 C2 600.0
65.0 0.025 A7 6000 55.0
0.05 C3 180.0
165.0 8253.6 Heat 3 13277 91.2 0.025 0.0 A6 4723 65.0
0.05 C4 81.3
170.0 0.025 A1 1273 154.3 3334.0 Heat 4 6538 0.025 73.9 0.025 A13 3011 36.9 0.025 A16 2186 10.0

Figure 18.15

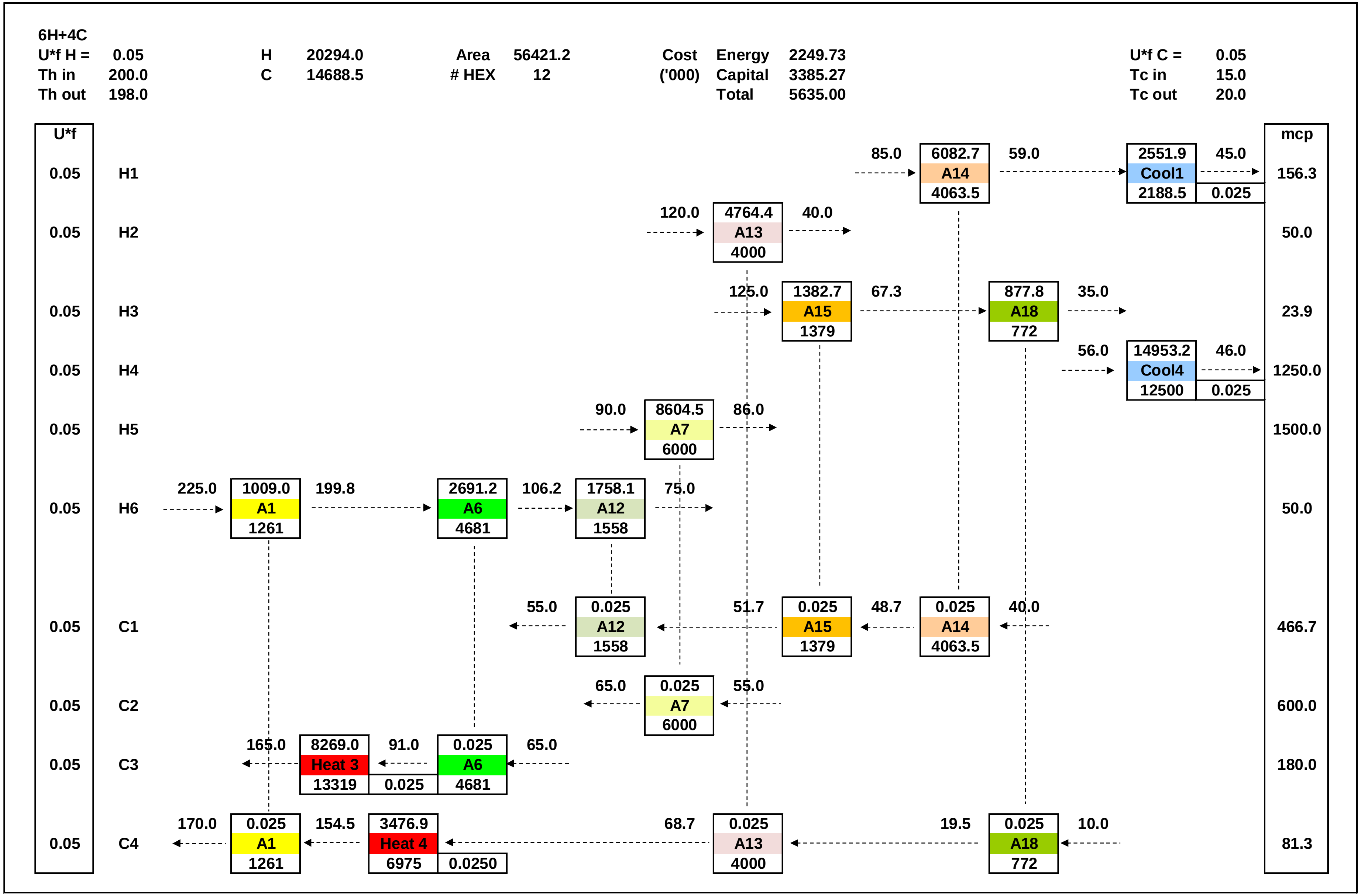
6H+4C
U*f H = 0.05
Th in 200.0
Th out 198.0
H 20294.0
C 14688.5
Area 56421.2
HEX 12
Cost ('000)
Energy 2249.73
Capital 3385.27
Total 5635.00
U*f C = 0.05
Tc in 15.0
Tc out 20.0
U*f
mcp
0.05 H1 156.3
0.05 H2 50.0
0.05 H3 23.9
0.05 H4 1250.0
0.05 H5 1500.0
0.05 H6 50.0
0.05 C1 466.7
0.05 C2 600.0
0.05 C3 180.0
0.05 C4 81.3
85.0
6082.7 A14 4063.5
59.0
2551.9 Cool1 2188.5
45.0
0.025
120.0
4764.4 A13 4000
40.0
125.0
1382.7 A15 1379
67.3
877.8 A18 772
35.0
56.0
14953.2 Cool4 12500
46.0
0.025
90.0
8604.5 A7 6000
86.0
225.0
1009.0 A1 1261
199.8
2691.2 A6 4681
106.2
1758.1 A12 1558
75.0
55.0
0.025 A12 1558
51.7
0.025 A15 1379
48.7
0.025 A14 4063.5
40.0
65.0
0.025 A7 6000
55.0
165.0
8269.0 Heat 3 13319
91.0
0.025
0.025 A6 4681
65.0
170.0
0.025 A1 1261
154.5
3476.9 Heat 4 6975
0.0250
68.7
0.025 A13 4000
19.5
0.025 A18 772
10.0

Figure 18.16

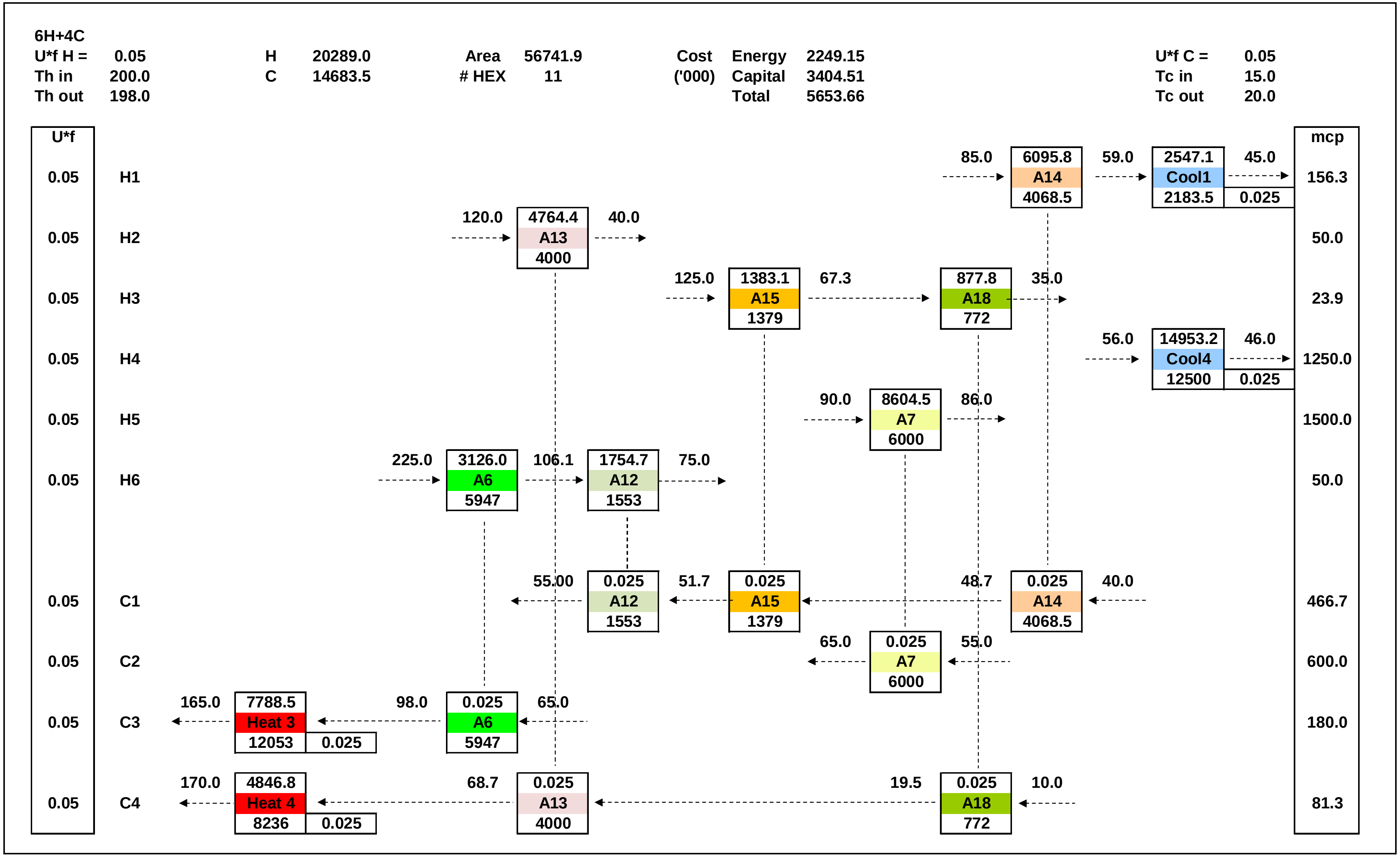
6H+4C
U*f H = 0.05
Th in 200.0
Th out 198.0
H 20289.0
C 14683.5
Area 56741.9
HEX 11
Cost ('000)
Energy 2249.15
Capital 3404.51
Total 5653.66
U*f C = 0.05
Tc in 15.0
Tc out 20.0
U*f
mcp
0.05 H1 156.3
0.05 H2 50.0
0.05 H3 23.9
0.05 H4 1250.0
0.05 H5 1500.0
0.05 H6 50.0
0.05 C1 466.7
0.05 C2 600.0
0.05 C3 180.0
0.05 C4 81.3
85.0
6095.8
A14
4068.5
59.0
2547.1
Cool1
2183.5
45.0
0.025
120.0
4764.4
A13
4000
40.0
125.0
1383.1
A15
1379
67.3
877.8
A18
772
35.0
56.0
14953.2
Cool4
12500
46.0
0.025
90.0
8604.5
A7
6000
86.0
225.0
3126.0
A6
5947
106.1
1754.7
A12
1553
75.0
55.00
0.025
A12
1553
51.7
0.025
A15
1379
48.7
0.025
A14
4068.5
40.0
65.0
0.025
A7
6000
55.0
165.0
7788.5
Heat 3
12053
0.025
98.0
0.025
A6
5947
65.0
170.0
4846.8
Heat 4
8236
0.025
68.7
0.025
A13
4000
19.5
0.025
A18
772
10.0

Figure 18.17

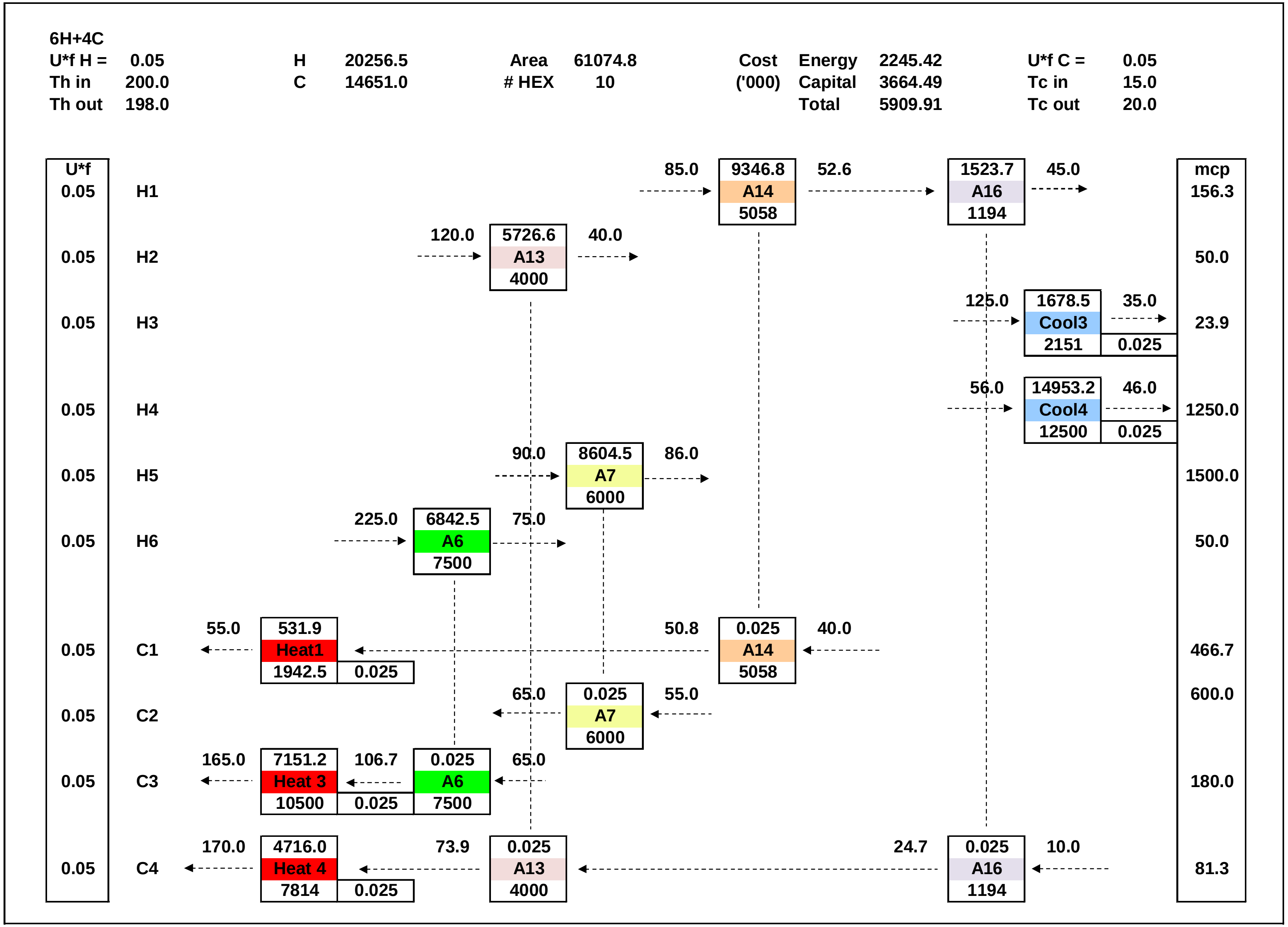
6H+4C
U*f H = 0.05
Th in 200.0
Th out 198.0
H 20256.5
C 14651.0
Area 61074.8
HEX 10
Cost ('000)
Energy 2245.42
Capital 3664.49
Total 5909.91
U*f C = 0.05
Tc in 15.0
Tc out 20.0
U*f
mcp
0.05 H1 156.3
85.0
9346.8 A14 5058
52.6
1523.7 A16 1194
45.0
0.05 H2 50.0
120.0
5726.6 A13 4000
40.0
0.05 H3 23.9
125.0
1678.5 Cool3 2151 0.025
35.0
0.05 H4 1250.0
56.0
14953.2 Cool4 12500 0.025
46.0
0.05 H5 1500.0
90.0
8604.5 A7 6000
86.0
0.05 H6 50.0
225.0
6842.5 A6 7500
75.0
0.05 C1 466.7
55.0
531.9 Heat1 1942.5 0.025
50.8
0.025 A14 5058
40.0
0.05 C2 600.0
65.0
0.025 A7 6000
55.0
0.05 C3 180.0
165.0
7151.2 Heat 3 10500 0.025
106.7
0.025 A6 7500
65.0
0.05 C4 81.3
170.0
4716.0 Heat 4 7814 0.025
73.9
0.025 A13 4000
24.7
0.025 A16 1194
10.0

Figure 18.18

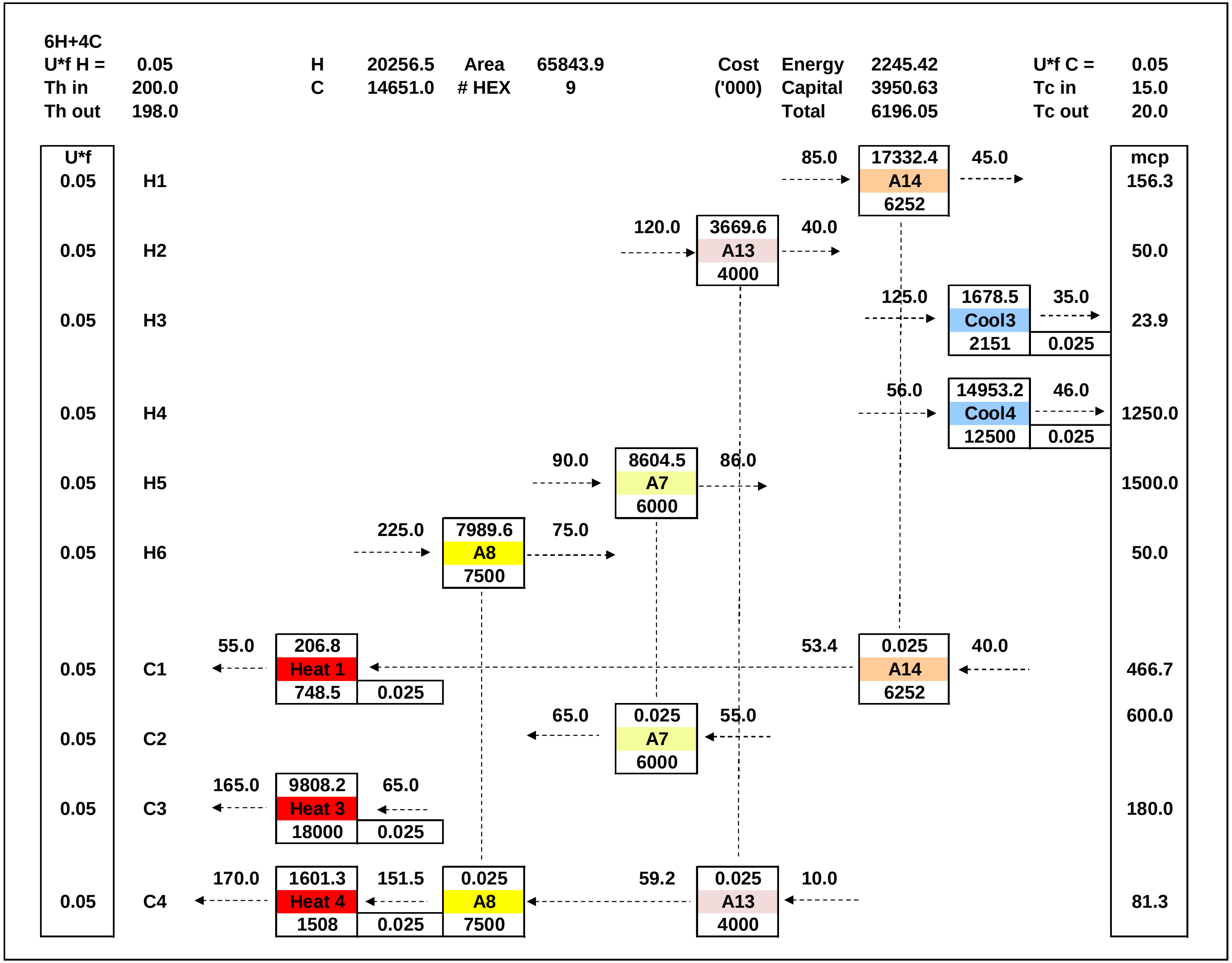
6H+4C
U*f H = 0.05
Th in 200.0
Th out 198.0
H 20256.5
C 14651.0
Area 65843.9
HEX 9
Cost ('000)
Energy 2245.42
Capital 3950.63
Total 6196.05
U*f C = 0.05
Tc in 15.0
Tc out 20.0
U*f
mcp
0.05 H1 156.3
0.05 H2 50.0
0.05 H3 23.9
0.05 H4 1250.0
0.05 H5 1500.0
0.05 H6 50.0
0.05 C1 466.7
0.05 C2 600.0
0.05 C3 180.0
0.05 C4 81.3
85.0
17332.4
A14
6252
45.0
120.0
3669.6
A13
4000
40.0
125.0
1678.5
Cool3
2151
35.0
0.025
56.0
14953.2
Cool4
12500
46.0
0.025
90.0
8604.5
A7
6000
86.0
225.0
7989.6
A8
7500
75.0
55.0
206.8
Heat 1
748.5
0.025
53.4
0.025
A14
6252
40.0
65.0
0.025
A7
6000
55.0
165.0
9808.2
Heat 3
18000
65.0
0.025
170.0
1601.3
Heat 4
1508
151.5
0.025
0.025
A8
7500
59.2
0.025
A13
4000
10.0

Figure 18.19