B. Joseph **ChE 477** **PS # ENERGY** **Energy Integration**

Required Reading :

Handout. Heat Exchanger Networks . Excerpted from Douglas' book.

Chapter 19, Section 3.5. Improvements in Heat Integration.

This chapter discusses the concept of minimum utility calculation using the temperature intervals diagram. This is an important target for you to know when designing heat exchanger networks. It tells you how far you are away from the optimum.

Problems.

Problem 19.7
Problem 19.8

19.7 From Figure P19.7 we have

a. Performing an energy balance on interval C we have

$(1+ mC_{p,2} + 3)(400 - 300) - (4)(380 - 280) = 600$

$mC_{p,2} = 600/100 = 6.0$

$mC_{p,2} = 6.0$ MBtu/h°F

Performing an energy balance on interval D we have

$(6 + 3)(300 - 200) - (mC_{p,5} + 4)(280 - 180) = -300$

$mC_{p,5} = -(-300 - 500)/100 = 8.0$

$mC_{p,5} = 8.0$ MBtu/h°F

Performing an energy balance on interval B we have

$Q_B = (1)(500 - 400) - (5)(480 - 380) = -400$ MBtu/h

$Q_B = -400$ MBtu/h

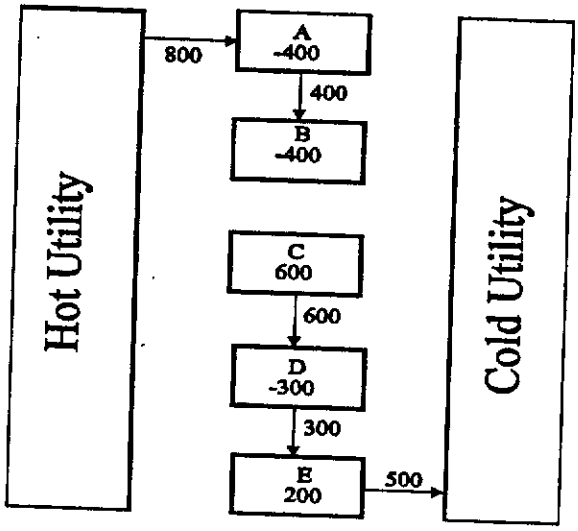
Performing an energy balance on interval E we have

$Q_E = (6)(200 - 100) - (4)(180 - 80) = 200$ MBtu/h

$Q_E = 200$ MBtu/h

b. Construct the cascade diagram - shown on next page

Stream	Mc_p (MBtu/h/°F)	T_{in} (°F)	T_{out} (°F)	Q(MBtu/h)
1	1.0	600	300	300
2	6.0	400	100	1800
3	3.0	400	200	600
4	5.0	380	580	-1000
5	8.0	180	280	- 800
6	4.0	80	380	-1200
				-300



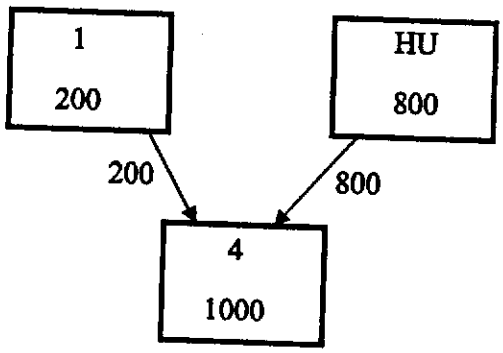
Q_H = 800 MBtu/h
Q_C = -500 MBtu/h

c. From cascade diagram

Pinch Temperatures
400°F and 380°F

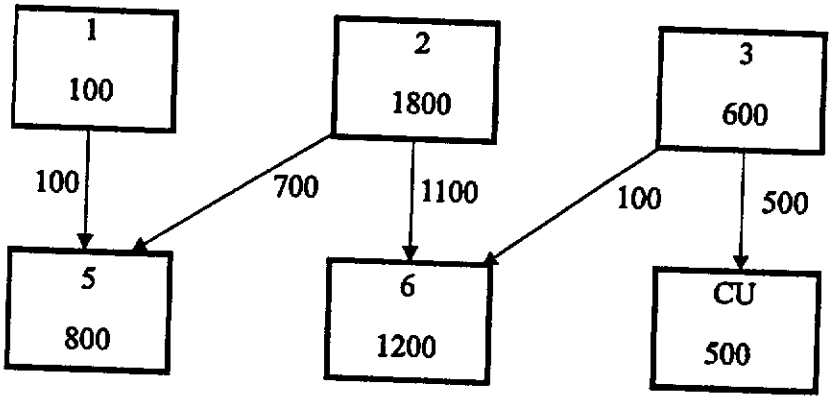
d. Minimum Number of Exchangers

Above Pinch



2 Exchangers

Below Pinch

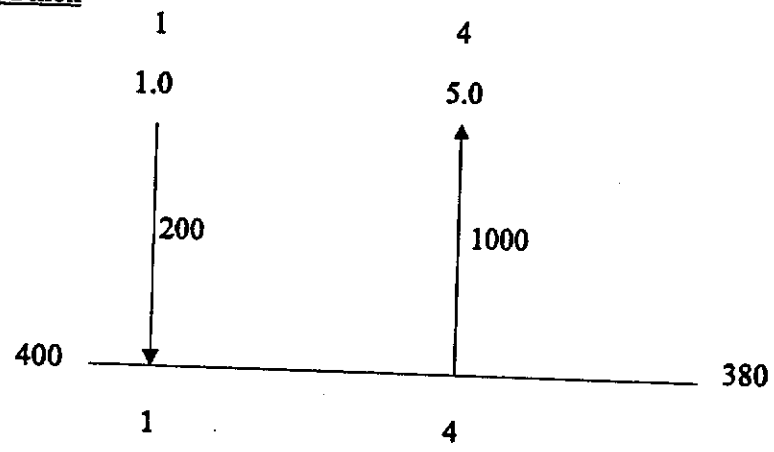


5 Exchangers

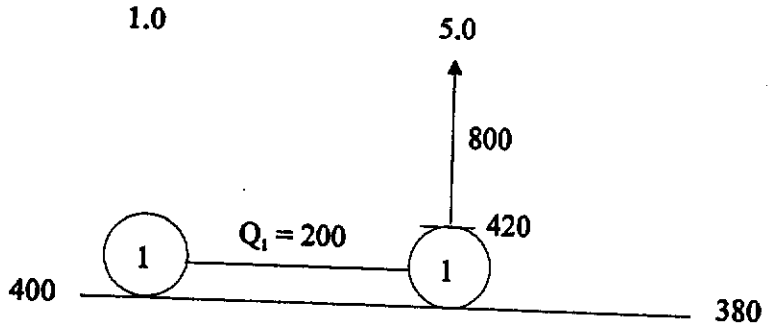
Total Number of Exchangers = 7

e. Design of Network

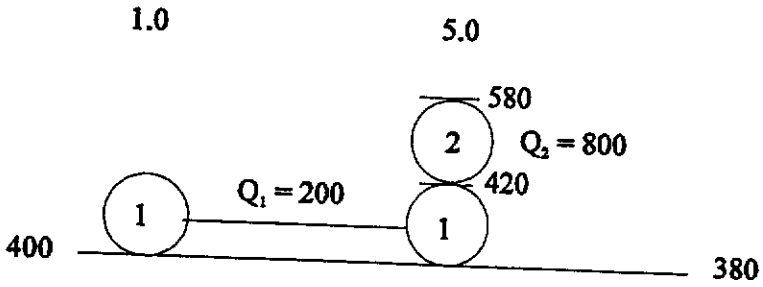
Above Pinch



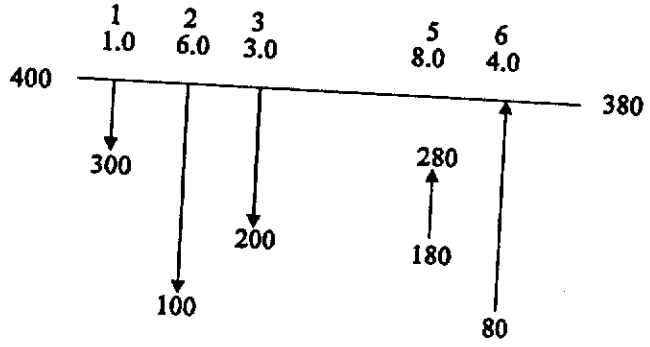
Match streams at pinch such that $MC_{pH} < MC_{pC}$ strm 1 ⟶ strm 4



Add hot utility exchanger

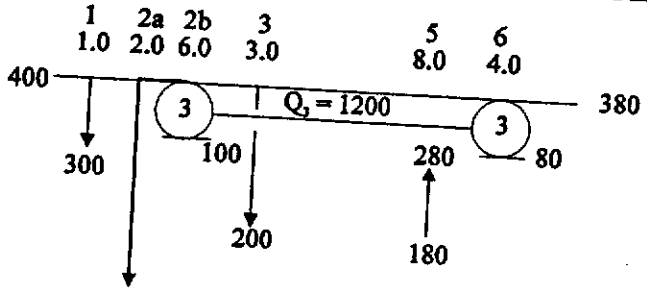


Design below Pinch

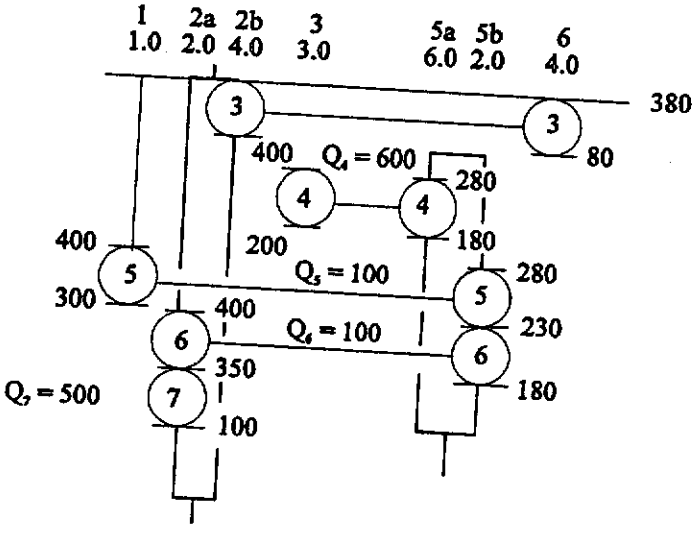


Match streams at the pinch so that $mC_{pH} > mC_{pc}$

split strm 2 into two streams with MC_p of 4.0 and 2.0 and match with strm 6



Split stream 5 into two streams with mC_p of 6.0 and 2.0 and match with strm 3 and strms 1 and 2

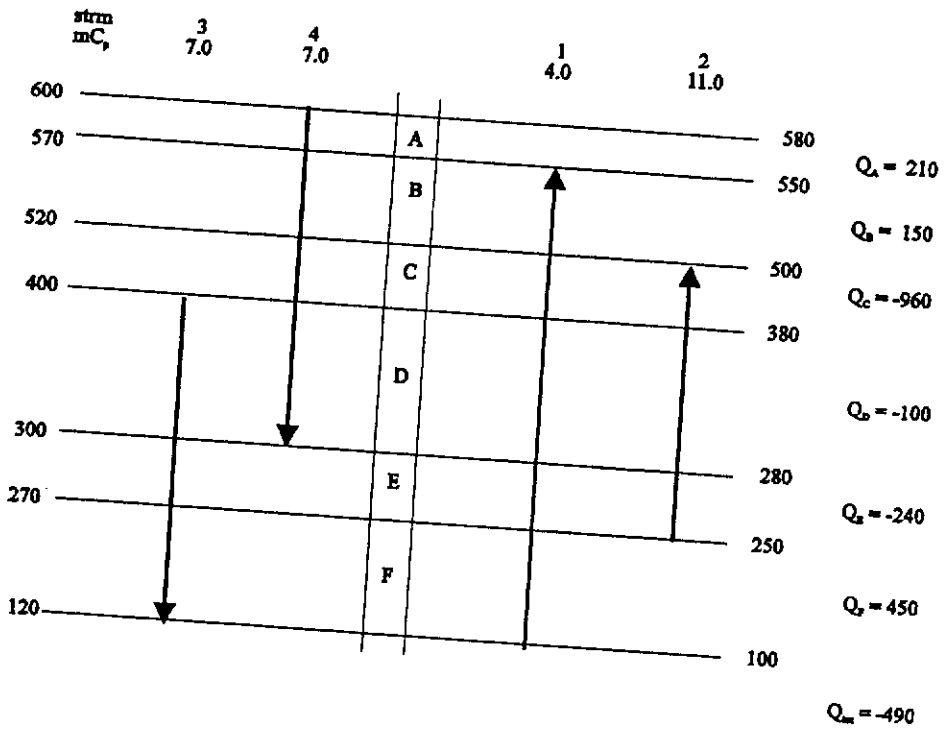


Exchanger Duties are as follows

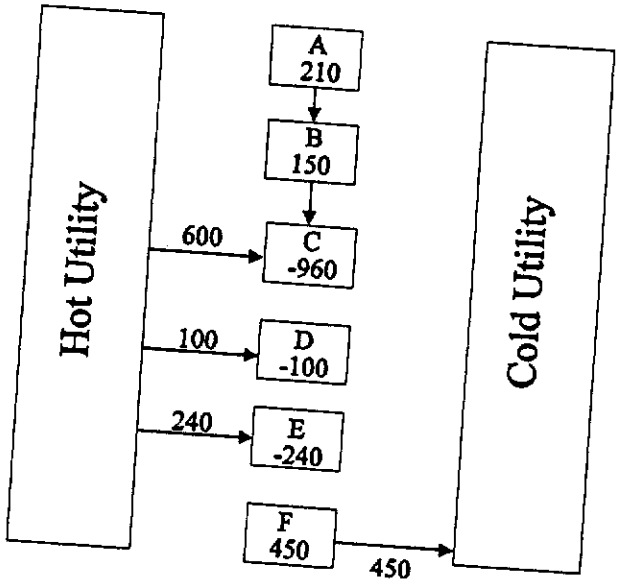
Q_1 = 200 MBtu/h
Q_2 = 800 MBtu/h
Q_3 = 1200 MBtu/h
Q_4 = 600 MBtu/h
Q_5 = 100 MBtu/h
Q_6 = 100 MBtu/h
Q_7 = 500 MBtu/h

19.8

Temperature Interval Diagram



Cascade Diagram



a. Pinch Temperatures are 280 and 300°F

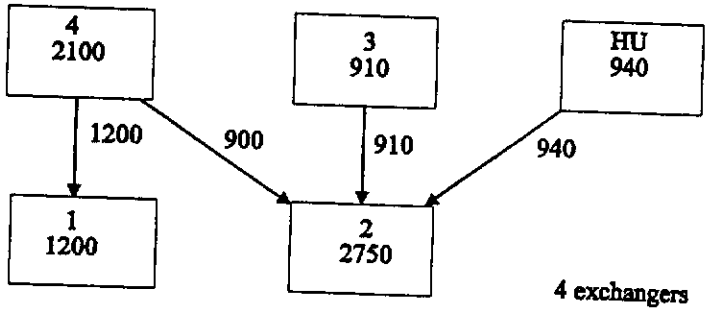
Pinch Temperatures are 250 and 270°F

b. Minimum Hot and Cold Utility Duties

Q_H = 940 MBtu/h
Q_C = 450 MBtu/h

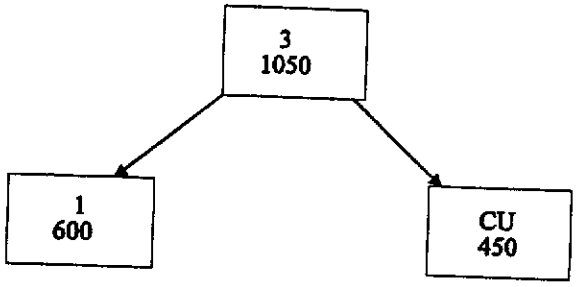
c. Minimum Number of Exchangers for a. and b. above

Above the Pinch



4 exchangers

Below the Pinch

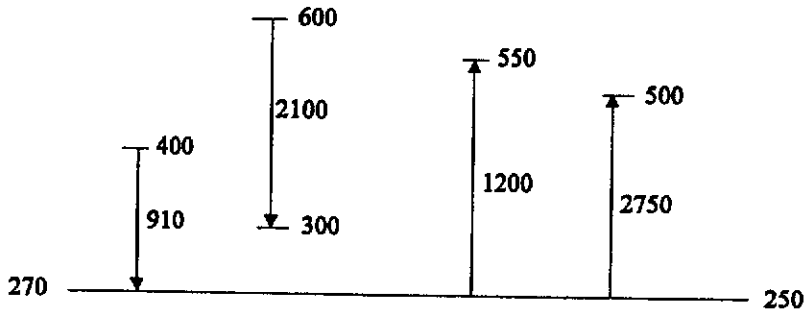


2 exchangers

Total Number of Exchangers = 6

d. Design Network - Above Pinch

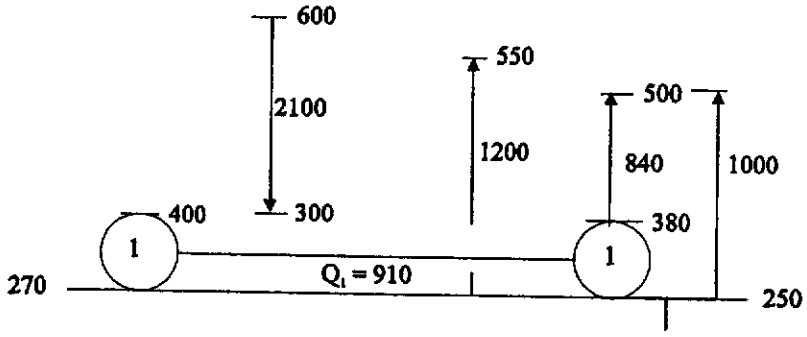
strm	3	4	1	2
mC_p	7.0	7.0	4.0	11.0



At pinch match streams for which $mC_{pH} \leq mC_{pC}$

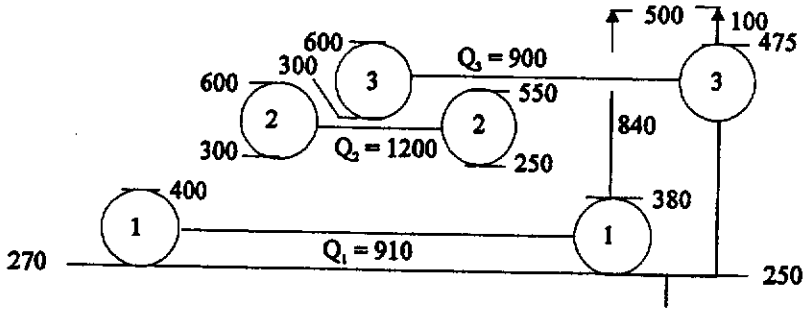
Match strm 3 with strm 2 - split strm 2 into two parts to avoid problems with ΔT_{lm}

strm	3	4	1	2a	2b
mC_p	7.0	7.0	4.0	7.0	4.0

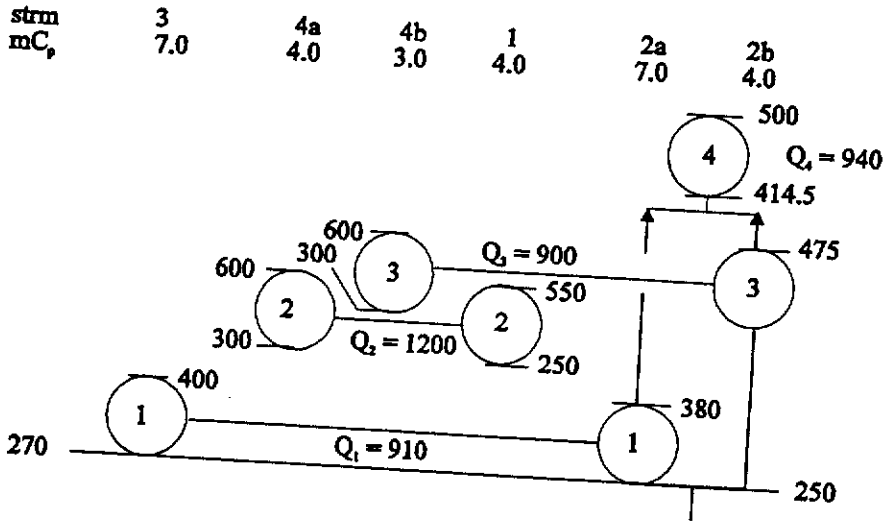


split stream 4 into two ($mC_p = 3.0$ and 4.0) and match with strms 1 and 2b

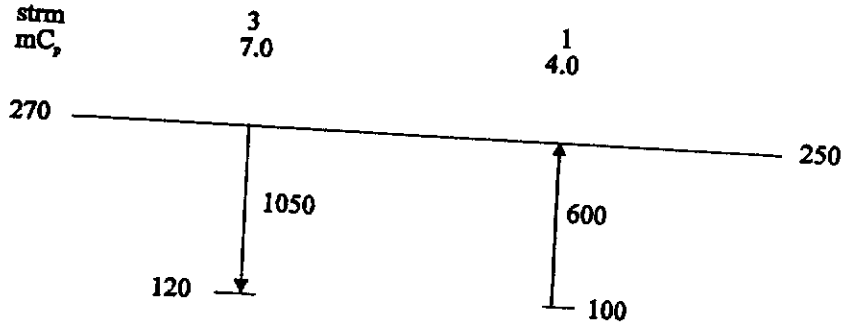
strm	3	4a	4b	1	2a	2b
mC_p	7.0	4.0	3.0	4.0	7.0	4.0



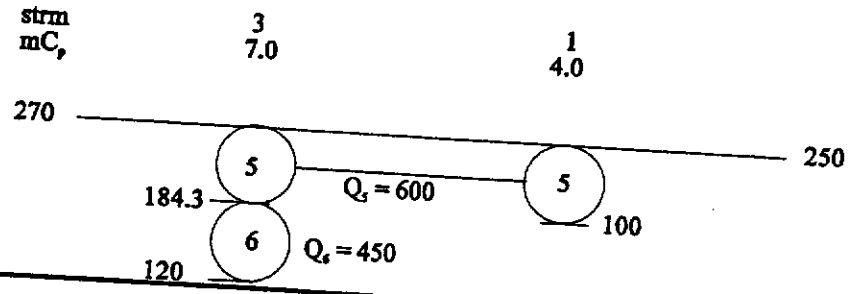
add hot utility exchanger to combined stream 2



Design Network - Below the Pinch



at pinch match streams for which $mC_{pH} > mC_{pC}$
match strm 3 with strm 1 and add a utility exchanger



Q_1 = 910 MBtu/h
Q_2 = 1200 MBtu/h
Q_3 = 900 MBtu/h
Q_4 = 940 MBtu/h
Q_5 = 600 MBtu/h
Q_6 = 450 MBtu/h

e. Regular utilities are available - how would above design change?

From the cascade diagram we can see that there exist multiple utility pinches. That is, we have pinch temperatures at 380 - 400°F, 280 - 300°F, and 250 - 270°F. We can design the network using these pinch temperatures and thus reduce the amount of high temperature utility (high pressure steam) from 940 to 600 MBtu/h. This would allow the use of medium and low pressure steam in temperature intervals D and E. However, the number of exchangers will go up. For each zone (A-C, D, E, F) we would need a total of 3 + 4 + 3 + 2 = 12 exchangers. This is 6 greater than before. Some of these extra exchangers may be combined. However, an economic analysis would have to be performed in order to evaluate whether the savings in high pressure steam would offset the increased capital investment for the greater number of heat exchangers. See Problem 19.9, below, for the heat exchanger network design.