

Module-04: Targeting

Lecture-12: Grand Composite Curve

While composite curves provide overall energy targets, these do not indicate the amount of energy that should be supplied at different temperature levels through utilities.

A graph of net heat flow against shifted temperature can be plotted from the data of the Problem Table (heat cascade) or it can be plotted from shifted temperature level composite curves. This graph is known as the **Grand Composite Curve (GCC)**. It highlights process/utility interface. It indicates the difference between the heat available from the process hot streams and the heat required by the process cold streams, relative to the pinch, at a given shifted temperature. Thus, the GCC is a plot of the net heat flow against the shifted (interval) temperature. It is also called residual heat curve. This is also a tool used for setting multiple utility targets and placement of equipment such as heat engines, heat pumps, distillation column, drier, evaporator, furnaces, CHP and to any other unit operation, be it process or utility, which could be represented in terms of source and sink.

Construction of GCC using PTA data

A four stream problem as discussed in Lecture-11 problem Table Algorithm as given in Table 4.2 considered for generation of GCC.

Table 4.2 Four stream problem for PTA for $\Delta T_{\min}$ equal to 10°C .

Stream Serial No.	Stream Type	CP (KW / K)	Actual Temperatures		Shifted Temperatures	
			$T_s (^{\circ}\text{C})$	$T_t (^{\circ}\text{C})$	$T_s (^{\circ}\text{C})$	$T_t (^{\circ}\text{C})$
1	Cold	2.25	20	135	25	140
2	Hot	3	170	60	165	55
3	Cold	4.25	80	140	85	145
4	Hot	2	150	30	145	25

The PTA for the above problem is reproduced in Fig.4.8 below:

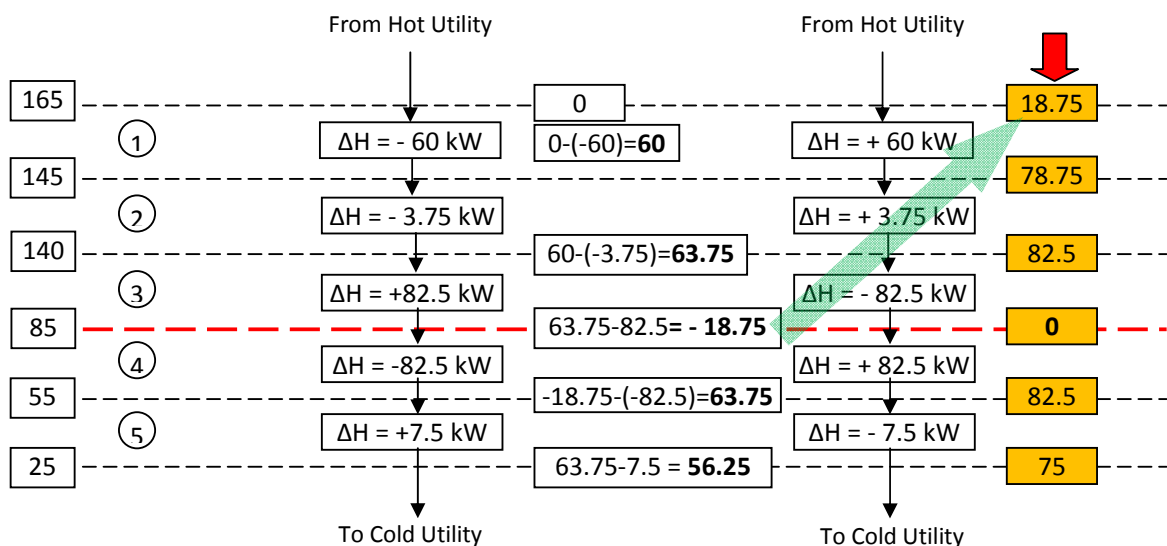


Fig.4.8 Problem table cascade

Fig 4.9 shows the GCC for the problem shown in Table 4.2. It is constructed using the data given in Fig.4.8.

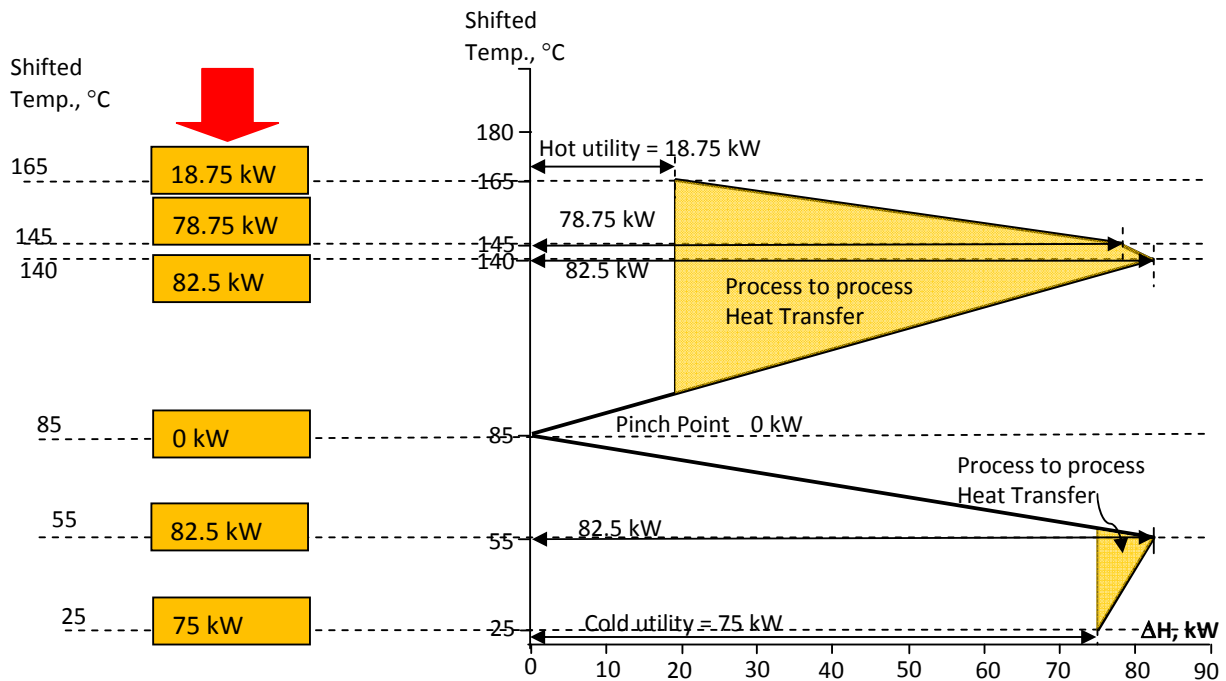


Fig 4.9 Construction of Grand Composite Curve from PTA data for problem in Table 4.2

The values of net heat flow to the top and from the bottom end of the PTA are the heat supplied to and removed from the cascade, and thus indicates the hot and cold utility targets. GCC not only informs about how much net heating and cooling is required, but also provides an opportunity to find at what temperature levels it is needed? Thus, there is no need to supply all the utility heating at the highest temperature interval. Instead, a considerable amount of it can be supplied at lower temperatures bringing down the utility cost. In GCC the pinch is also easily identified as the point where net heat flow is 0. At this point the GCC touches the temperature axis.

By watching GCC one can easily identify the nature of problem. For example if pinch point occurs at one end of the temperature range then it is a "threshold" problem. Similarly single, double and multiple pinch problems can be identified with ease.

Construction of GCC using composite curves

An alternate procedure for construction of GCC is through composite curves. The construction of GCC using composite curves is illustrated in Fig 4.10. Fig.4.10(a) shows the hot and cold composite curve where as Fig.4.10(b) shows the hot and cold composite curves using shifted temperatures. Fig.4.10(c) shows how Grand Composite curve can be constructed using composite curve with shifted temperatures.

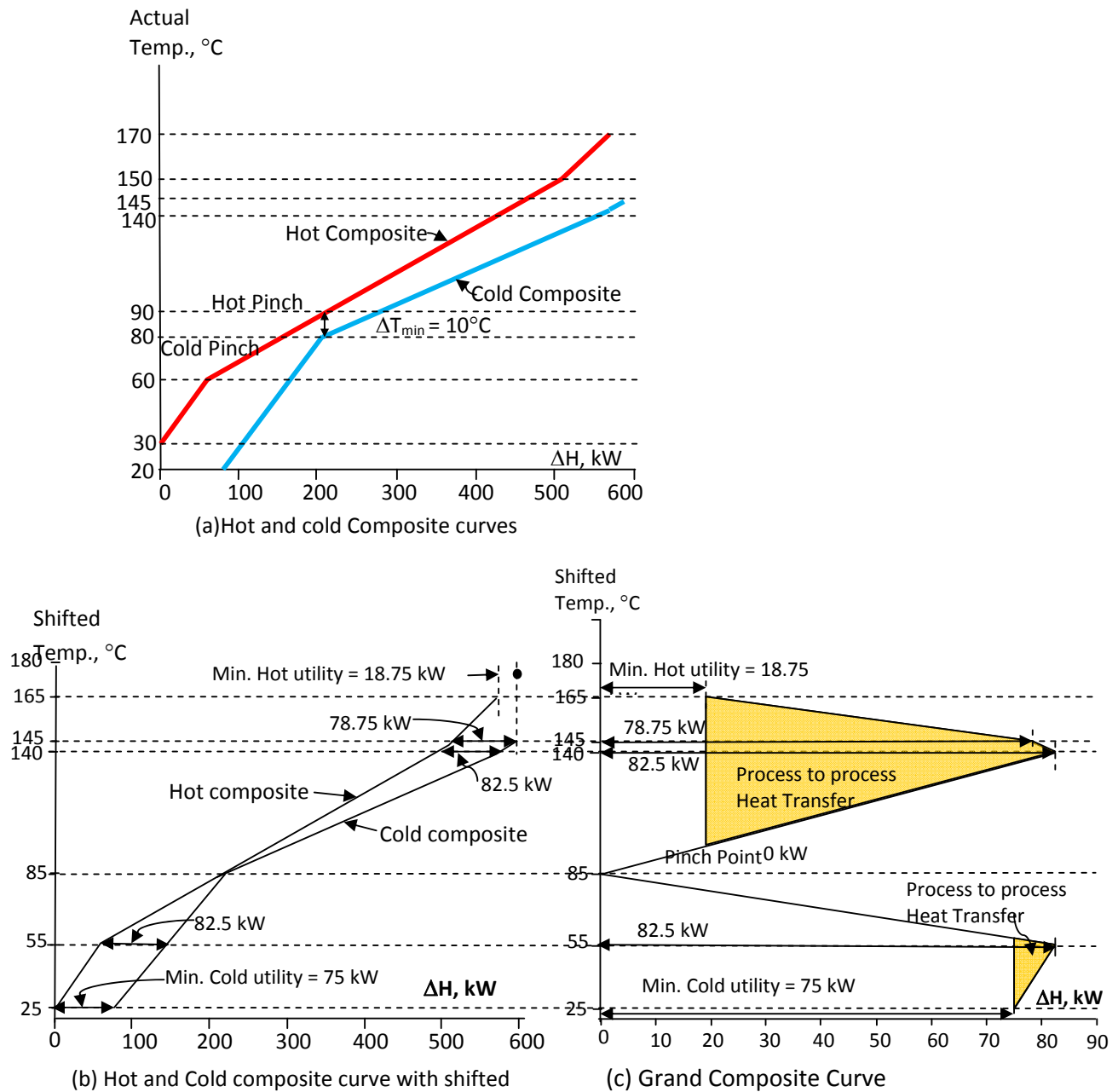


Fig.4.10 Construction of Grand Composite Curve using composite

Properties of Grand Composite Curve

The GCC provides a graphical representation of the heat flow through the process- from hot utility to those parts of the process above the pinch point, and from the process below the pinch point to the cold utility. Because the GCC represents heat flow in an ideal process there is no heat flow through the pinch point. However in a non-ideal case heat may pass through the pinch point as shown in Fig 4.11 (b). In Fig.4.11(a) the hot utility transfers heat vertically to the segment "a-b" in the above pinch region. Hence, it is a heat sink. Whereas, in below pinch region, the segment "a-c" rejects its heat to the cold utility making it a heat source. For a non-ideal case (Fig 4.11(b)) where 10 kW heat is transferred through pinch, the hot and cold utility amount increases by 10 kW each.

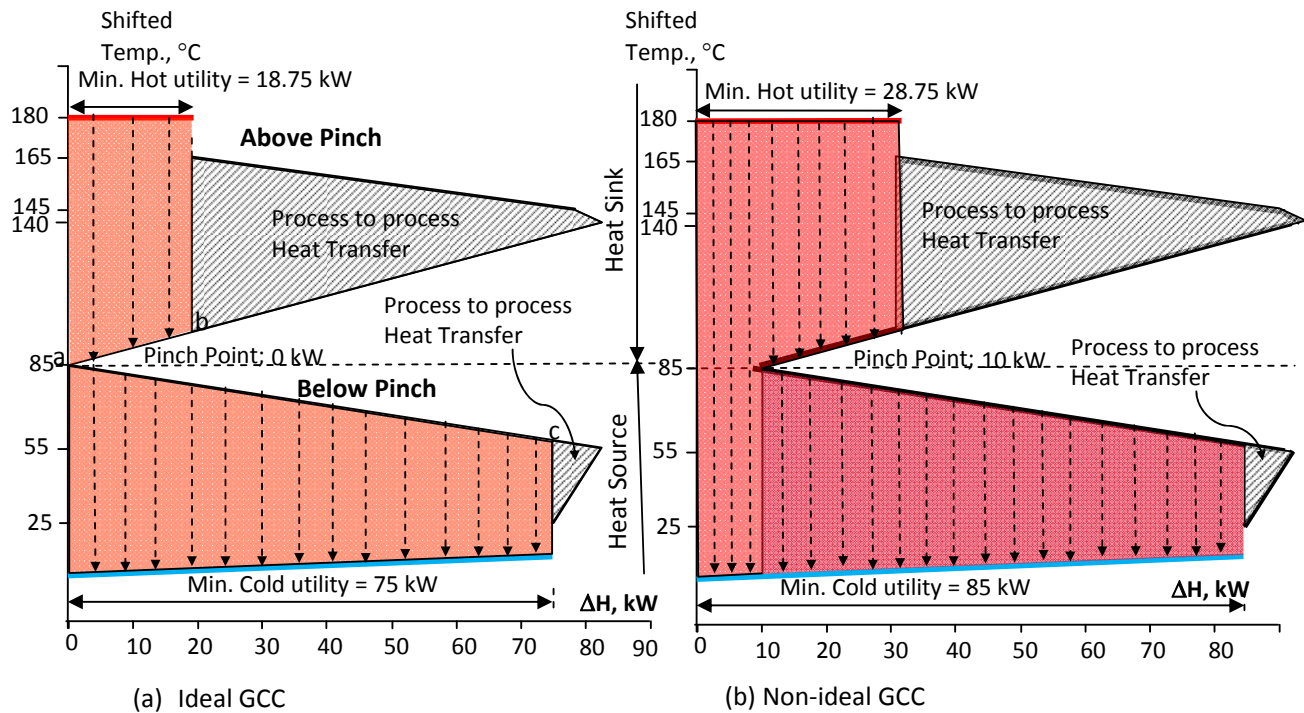


Fig. 4.11 Grand Composite Curve

The Grand Composite curve is not only a useful tool for energy targeting and selection of multi temperature level utilities, but also helps in understanding the interface between the process and the utility system. It is also an useful tool to study the interaction between heat-integrated reactors, evaporators and separators and rest of the process. The regions where the GCC bends back on itself and net heat can be exchanged between different temperature intervals are known as pockets or re-entrants (The area covered by pattern). Note that they do not represent all the heat exchange taking place between hot and cold streams, which is only revealed by the composite curves. For the four-stream Example of Table 4.2, the total heat exchange in the process is 485 kW but only 73 kW occurs in the pockets (65 above and 8 below the pinch). The profile of the GCC represents residual heating and cooling demands after recovering heat within the process.

GCC for Threshold problems

To demonstrate GGC of threshold problems two four stream problems one given in Table 4.4 requiring only hot utility and the other in Table 3.9 requiring only cold utility is considered. These tables are reproduced from Module 4 and 3.

Table 4.4 A four stream problem for modified Problem Table Algorithm for $\Delta T_{\min} = 10^\circ\text{C}$

Stream Number	Stream Type	Heat Capacity Flow Rate (kW / $^\circ\text{C}$)	Source Temperature ($^\circ\text{C}$)	Target Temperature ($^\circ\text{C}$)
1	HOT	2.5	150	60
2	HOT	8.0	90	60
3	COLD	3.0	20	125
4	COLD	3.0	25	100

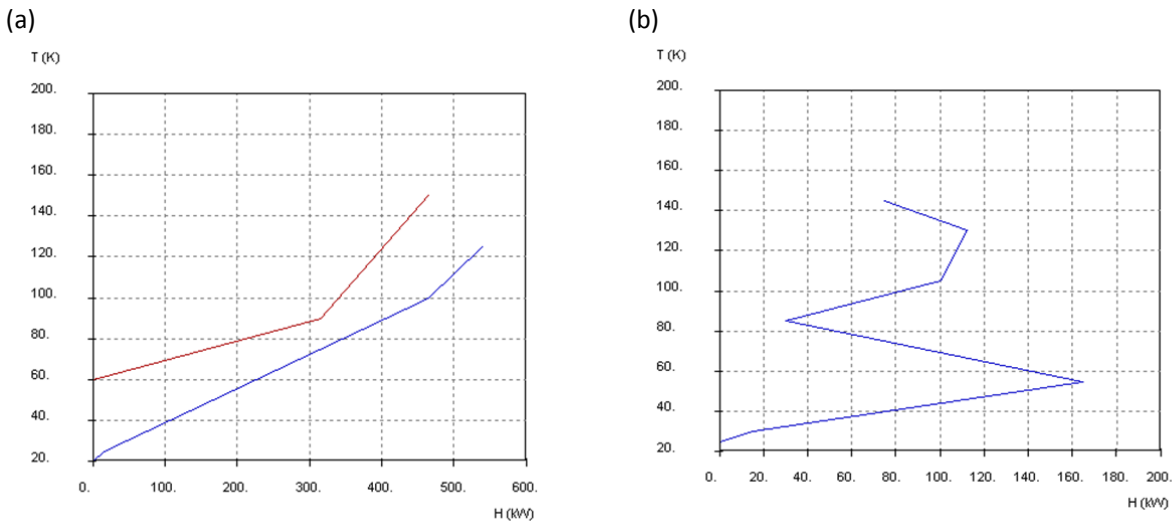


Fig. 4.12 (a) Composite curves and (b) GCC for threshold problem of Table 4.4

Table 3.9: Four stream problem utility prediction for $\Delta T_{\min}$ equal to 10°C .

Name of the stream	Supply Temperature $T_s, ^{\circ}\text{C}$	Target Temperature $T_t, ^{\circ}\text{C}$	CP $\text{kW}/^{\circ}\text{C}$	ΔH kW
Hot-1	190	55	3.5	-472.5
Hot-2	155	40	1.8	-207
Cold-1	20	140	2	240
Cold-2	70	150	2.5	200

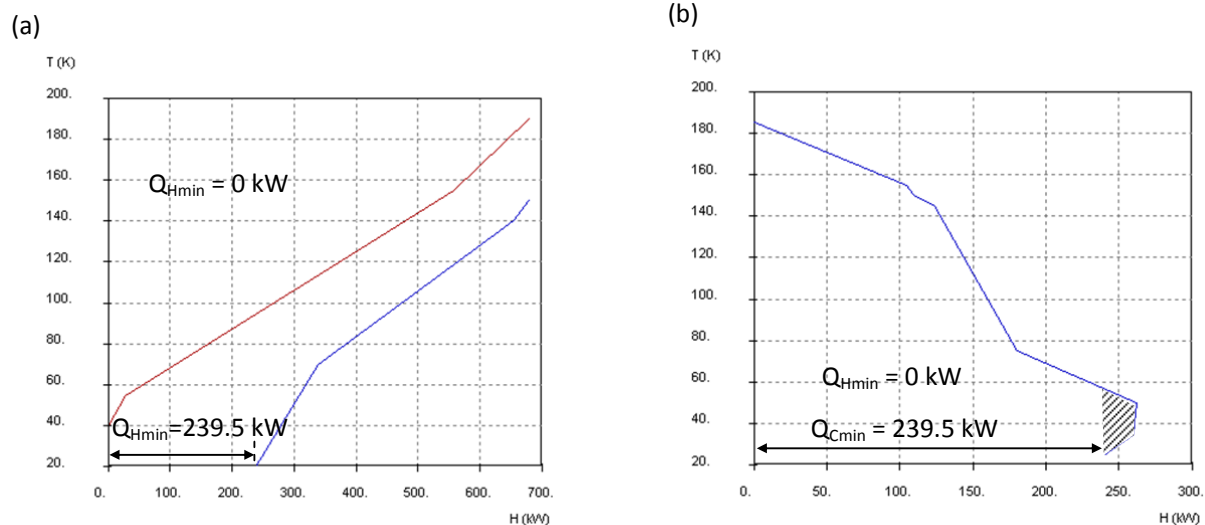


Fig.4.13 Composite curves and GCC for threshold problem of Table 3.9

Multiple Utility Targeting with the Grand Composite Curve

Several utilities having different temperature levels are used in processes to cool or heat process streams. Common hot utilities used for process heating are steam at different pressures, thermal fluid or hot oil, flue gas, heat rejected from heat engines, exhaust heat from refrigeration system and heat pump condensers and electrical heating. Similarly cold utilities used are cooling water, air, steam raising and boiler feed water heating, refrigerated fluid, chilled water, heat pump evaporator, reboilers of distillation column and heat engines below the pinch.

The utilities can be divided as constant and variable temperature utilities. For example a condensing steam, provides latent heat of condensation at a single temperature. Thus it is a constant-temperature utility. Whereas, the hot flue gas provides sensible heat over a temperature range and thus can be called a variable temperature utility. Some utilities are a mix of both types. The common example of such a utility is heating using a furnace as well as hot gases released from the furnace. Whereas, heating inside a furnace can be termed as constant temperature, heating by flue gases released from furnace is of variable temperature.

To minimize energy cost the designer should maximize the use of cheaper utility levels and at the same time minimize the use of expensive utility levels. For example a designer should maximize the use of Low pressure (LP) steam than medium pressure(MP) and high pressure(HP) steam. Similarly, one should maximize the use of cooling water rather than refrigeration.

The tool that is used for targeting multiple utilities is the Grand Composite Curve, which plots process energy deficit (above pinch) and energy surplus (below pinch) as a function of shifted temperature.

Multiple constant temperature utility Targeting

The same GCC shown in Fig.4.11 is reproduced below. In the base case shown below it can be seen that the deficit heat in the above pinch area is supplied by High Pressure (HP) steam at the highest temperature level which is higher than $\Delta T_{\min}$ from the next lower temperature level. With this heat from HP steam the above pinch section is in heat balance. However, if one looks into the cost aspects, then he will realize that a low pressure(LP) steam would have been a right choice to supply heat which costs far less than the HP steam as shown in Fig 4.14(b).

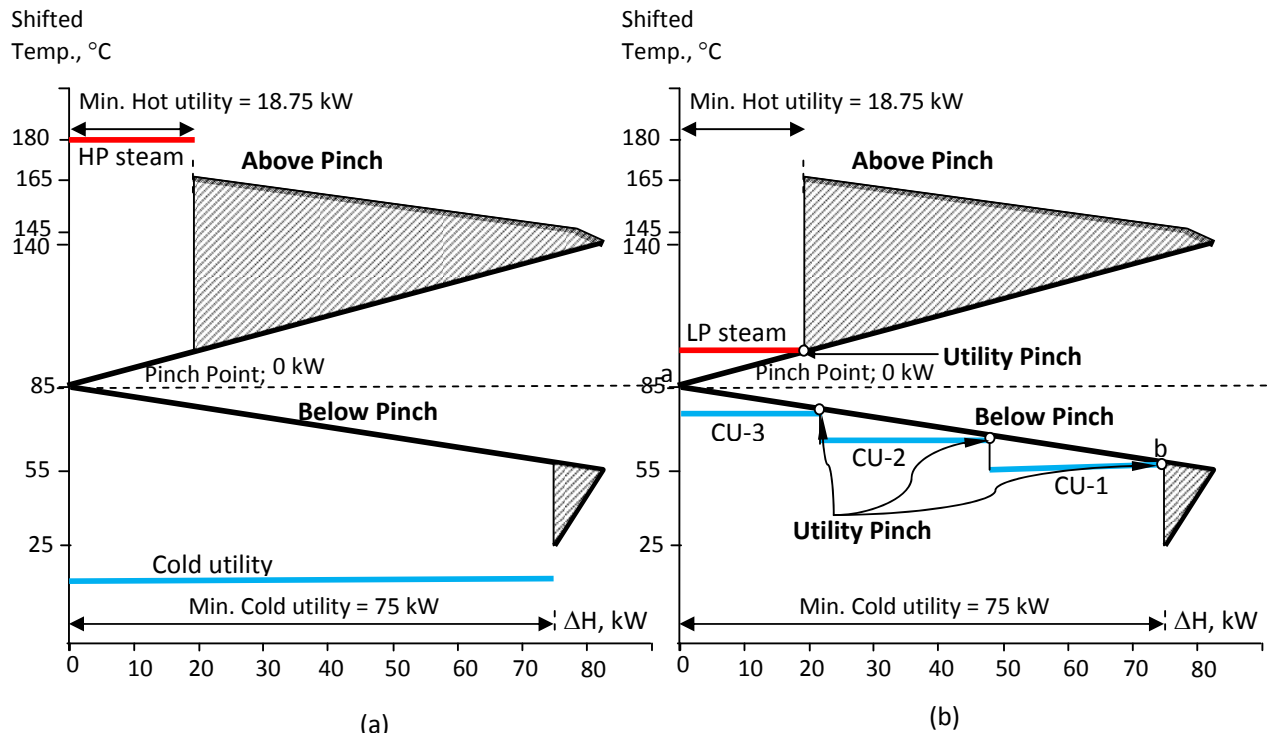


Fig.4.14 Multiple utility targeting using Grand Composite

Similarly, in Fig.4.14(a) the cold utility is provided at the lowest temperature level to cold "a-b" segment of GCC. This can be substituted with three cold utilities (CU-1, CU-2 and CU-3) at far higher temperatures to satisfy the cooling requirements (Fig.4.14(b)). By doing so, one can decrease the cost of cold utility. However, when multiple utilities are used, it creates multiple utility pinch and the design becomes somewhat complex. Though use of multiple utility decreases the operating cost of utility it increases the fixed cost of heat exchange. Thus, the designer should strike a balance between fixed and operating costs while suggesting multiple utilities. The opportunity to use multiple utilities largely depends on the nature of the GCC curve.

To give a feel how multiple utilities are employed Fig.4.15 is drawn. Fig.4.16 shows how multiple utility can be targeted through composite curve and how utility pinches are created in multiple utility targeting.

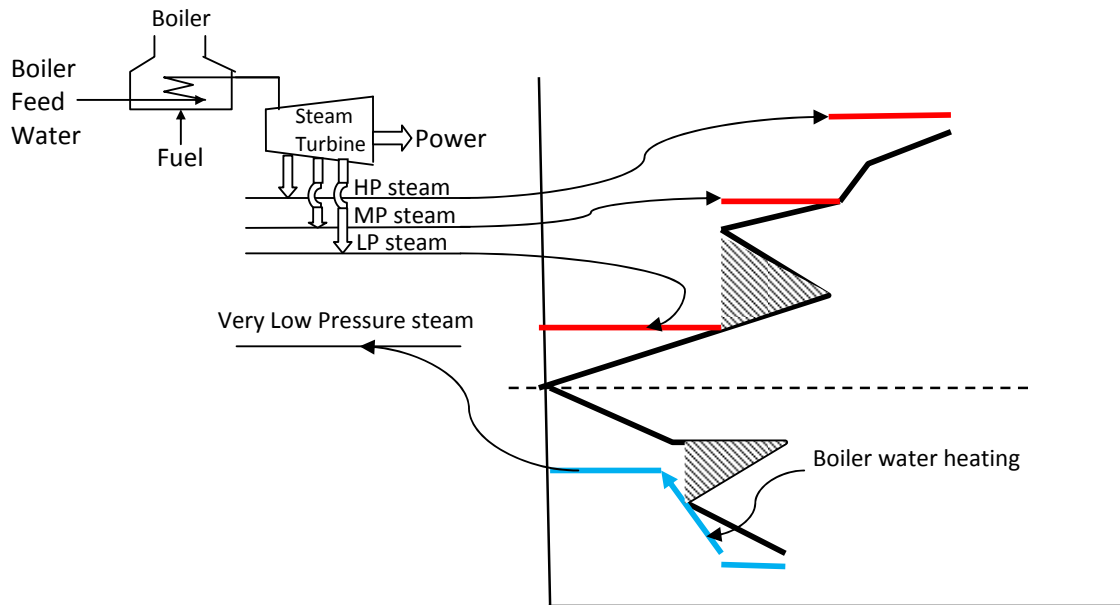


Fig.4.15 Shows how multiple utilities are placed in GCC

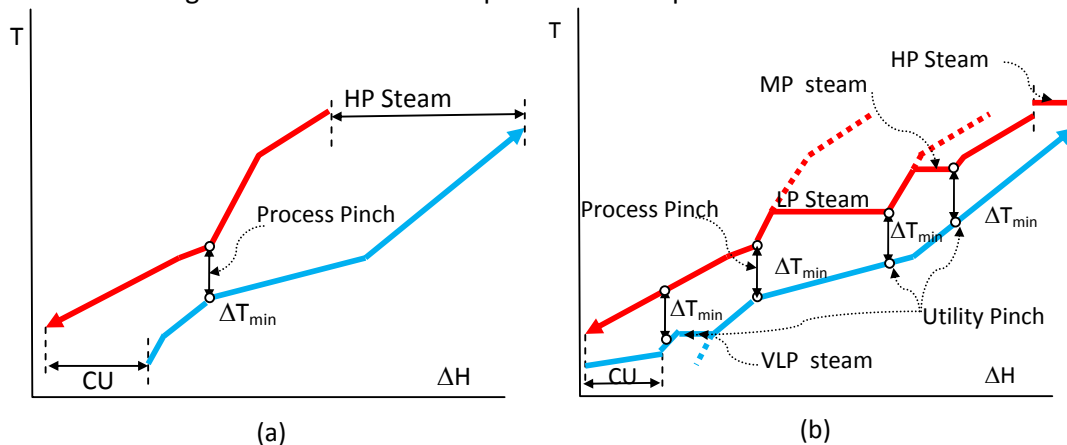


Fig.4.16 Multiple utility targeting using balanced composite curve and creation of utility pinch

Variable temperature utility Targeting

Variable-temperature utilities transfer sensible heat and therefore its temperature increases or decreases depending on whether it receives heat or gives heat. Common examples are hot oil circuits, exhaust gases from CHP systems, flue gases from boilers, boiler feed water being preheated and cooling water. but the utility itself plots as a sloping line instead of a horizontal one. The correct placement principles are: hot utilities should be used above the pinch of the GCC and cold utilities below. In this case, the utility plots are sloping lines instead of a horizontal one (as in the case of constant temperature utility).

For such utilities, there is a choice of maximum temperature, and one has to select it based on fixed and operating cost trade-offs. Further, it should be checked whether the utility stream is used once only (e.g. flue gas which is rejected to atmosphere after transfer of heat) or re-circulated (e.g. hot oil circuits where the hot oil after transferring heat is returned to a furnace).

for reheating or cooling water systems where after cooling a hot stream it is sent to cooling tower to reject its heat).

Fig.4.17 (a) shows re-circulated hot oil as hot utility and Fig.4.17(b) shows gas turbine exhaust as once through hot utility. It should be noted that in a once through hot utility all the heat is not transferred to the system and a part of it is rejected to atmosphere which is a function of its inlet temperature.

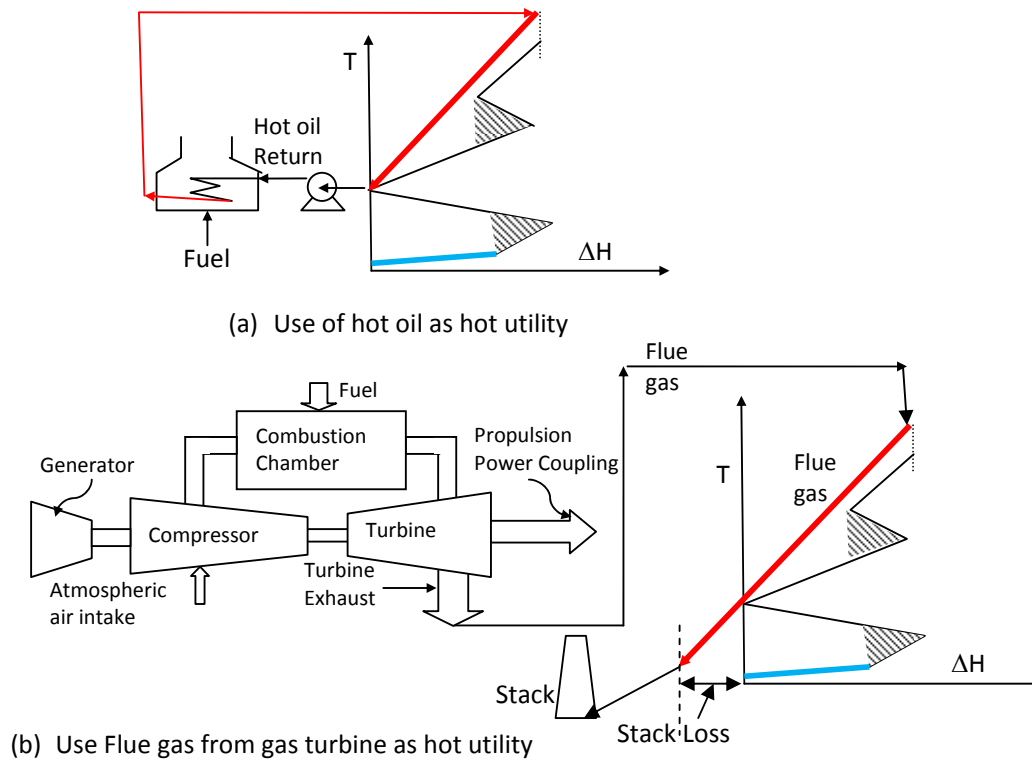


Fig.4.17 Variable temperature utility targeting

Mixed utility targeting

Both types of utilities such as constant temperature and variable temperature utilities can be applied a given GCC for targeting. Fig. 4.18 shows a such example where constant temperature hot utilities in terms of steam at different pressure is used in the above pinch region and a mixture of both types of utilities (Generation of steam, boiler water pre heating ,vapor superheating and cooling with cold water) is employed in the below pinch region of the GCC.

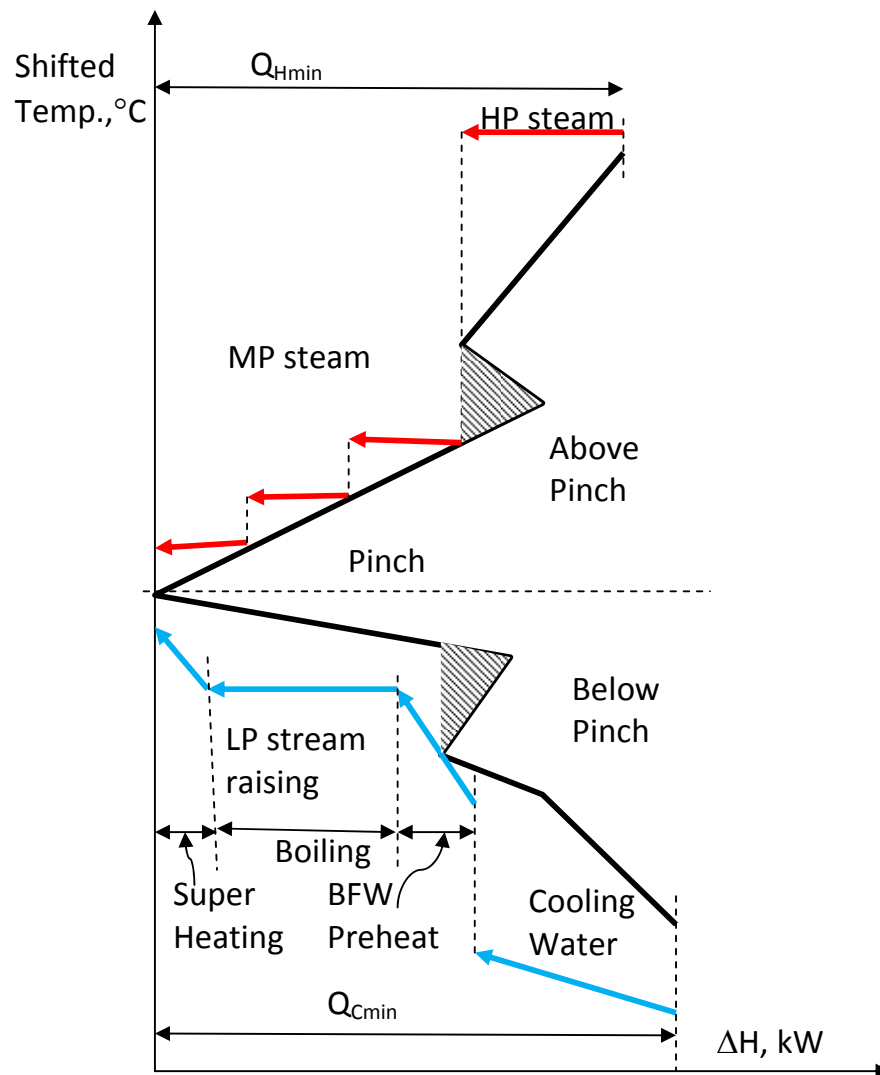


Fig4.18 Mixed utility targeting using GCC

Heat Recovery from the pockets of GCC

If there is enough potential in terms of ΔT or load in a pocket of GCC, it can be utilized to save utility. This is shown in Fig.4.19 (a) & (b). Fig.4.19(a) shows the “below pinch” region of a GCC. It shows that there is a substantial scope to save and generate utility using this pocket. Fig.4.19 (b) shows that MP steam can be raised using a part of this pocket. To maintain a heat balance inside this pocket LP steam is provided from the outside at a lower temperature.

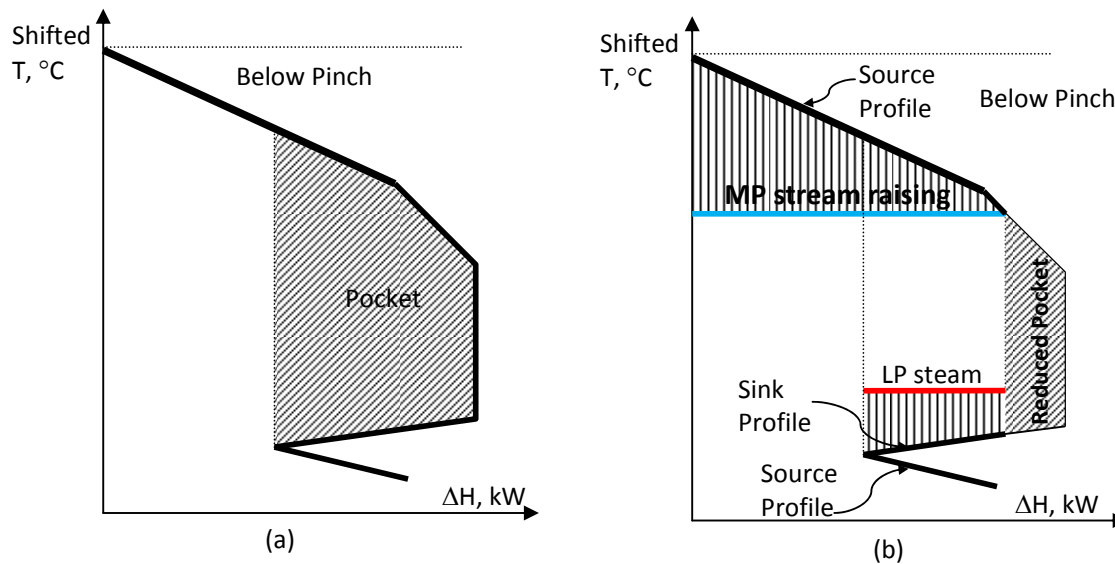


Fig.4.19 Utilization of Grand Composite Curve pocket

Integration of Equipment with Background GCC

To demonstrate the integration of Multiple Effect Evaporator(MEE) system with a background process given in Fig. 4.18, Fig.4.20 is drawn. Fig.4.20 shows that a part of HP steam can be replaced by LP steam to reduce the utility cost. However, there can be other alternative which HP steam for an amount of Q_{Hmin} but also integrates an equipment or a set of equipment with the GCC so that these equipment function without the need of any utility. In other words these ride on the GCC free of cost. Such an example is demonstrated in Fig.4.20 It can be seen that the "above pinch" region of the GCC offers large driving force(ΔT). This can be utilized to integrate a six effect MEE system into the upper part of the GCC as demonstrated in Fig.4.20 Though in this arrangement Q_{Hmin} amount of HP steam is supplied to the GCC which completely satisfy the requirement of the upper part of GCC, in addition it also satisfies the steam requirement for a six effect MEE system. Thus the MEE system runs almost free of cost on the background GCC.

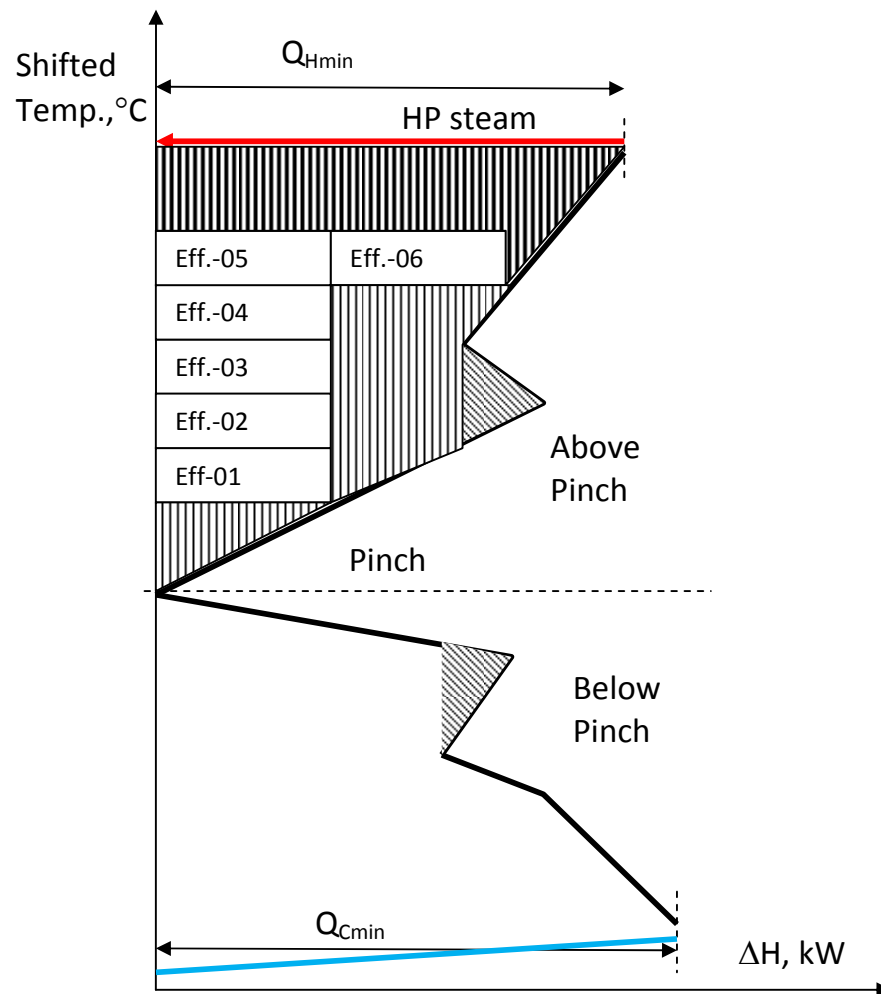


Fig.4.20 Integration of evaporator with background GCC

References

1. <http://ectc-varennnes.nrcan.gc.ca>
2. Linnhoff March, "Introduction to Pinch Technology" Targeting House, Gadbrook Park, Northwich, Cheshire, CW9 7UZ, England
3. Chemical Process Design and Integration, Robin Smith, John Wiley & Sons Ltd.
4. Ian C Kemp, Pinch Analysis and process integration, a user guide on process integration for effective use of energy, IChem^E, Elsevier Limited, 2007.