Energétique avancée

Process integration and exergy analysis

Dr Francois Marechal

5. Improve the MER of a process

Goals

Different ways of modifying the minimum energy requirement of a process

Short summary

5. Improve the MER of a process

Before searching for defining a heat exchangers network that satisfies the MER, we will study the possibilities of improving the MER.

A hierarchical approach can be used. The energy analysis method considers the industrial system as an onion. The hearth of the process is the reaction. For improving the MER we will first concentrate on the reactions and the operating conditions of the reactor

Once these are fixed, we are able to try to optimize the separation units (distillations, stripping, absorptions, membranes,...).

The next layer is the utility system that aims in satisfying the MER at minimum cost.

Once all the previous layers are fixed, the complete list of streams for the heat exchangers is fixed and the synthesis of the heat exchangers network can be executed.

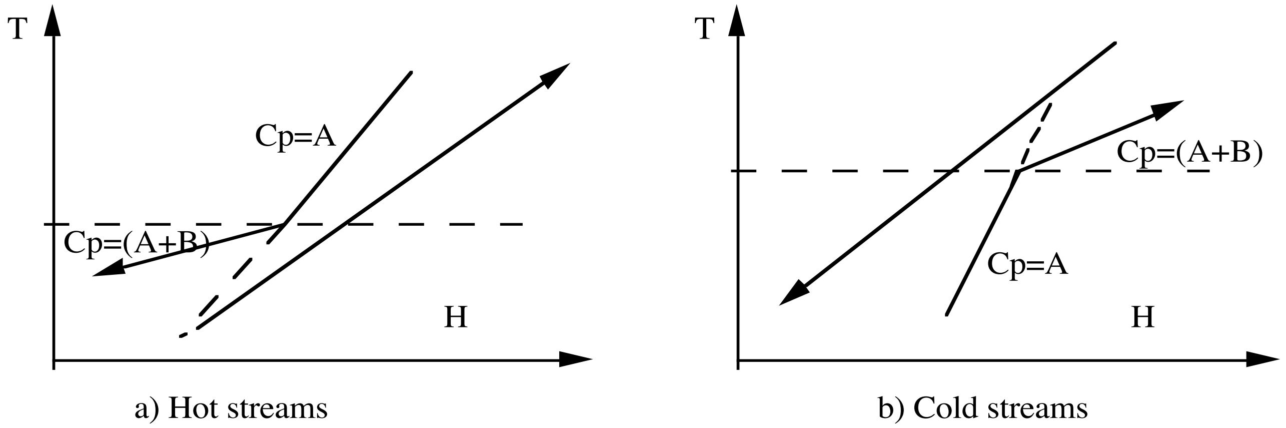
Improving the MER can be made by analysing the shape of the composite curves.

The analysis of the composite curve shape allows to propose process modifications and to choose the utilities.

The pinch point identifies the bottleneck of the process where energy has the most difficulties to flow. The stream involved in the pinch point determination and the one in its neighbourhood requires more attention.

Which streams defines the pinch point?

The pinch point is always created by the inlet temperature of a stream. It can be the inlet of a stream or one of the streams created if fluid phase changes occur.



a) Hot streams b) Cold streams

Figure 44. The pinch is introduced by the inlet temperature.

The figure 44 illustrates this affirmation. For the hot composite curve figure 44 (a), the pinch point can occur if the curve features an angular corner pointing to the cold composite curve. It is only possible if the slope of the curve decreases when the temperature decreases. It is obtained when a new Cp is taken into account in the lower temperature interval corresponding to a new hot stream involved. The pinch point will then appear at the upper temperature of the interval. It corresponds to the inlet temperature of the new hot stream entering the composite curve.

The same reasoning can be done for the cold composite curve figure 44 (b), where the angular corner must point to the hot composite curve to have a chance to produce a pinch point.

The important streams are such that they introduce strong angular corner in the neighbourhood of the pinch point.

The figure 45 shows how to analyse the composite curves to identify the important streams.

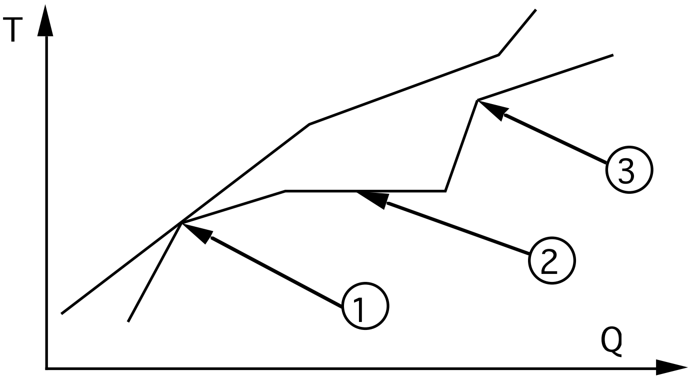


Figure 45. The composite curves analysis

1 - The stream which defines the pinch point.

This is the most important because it defines the minimum energy requirement.

2 - The stream with big Cp and specially the condensing or evaporating streams. They produce steps in the composite curve which prevent the fitting of the two curves. These streams often define the pinch point. And when their heat load is high, they define most of the energy requirement.

3 - The stream involved in pseudo pinch point: where the hot and cold composite curves are close but do not intersect. A slight modification of the process operation can lead this pinch point to be active.

The same points can be found on the grand composite curve as shown figure 46.

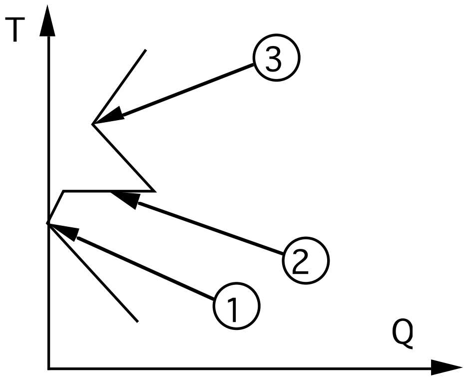


Figure 46. Grand composite curve analysis

The process modifications will be suggested by the type of the identified important streams. The leitmotiv will be "try to fit the hot and cold composite curves together" or " try to squash the grand composite curve on the temperature axis".

The process modifications depend on the process context, we can not give an exhaustive list of the possibilities. They mainly concern operating condition modifications to change the temperature levels or the flow rates and the structure modifications.

The intrinsic energy efficiency of each unit of the process is important for defining the global demand of the process.

But, according to their relative position with respect to the pinch point, improving the energy efficiency of some units might not be useful in the global context.

The units consuming energy above the pinch point have to be minimized.

The same for the units producing energy above the pinch point: their production has to be maximized.

Caution might be paid for units between the pinch point and a pseudo pinch point, because the effect of the optimization might be limited by the activation f a new pinch point.

5.1. Distillation columns

In the following, we will analyse two of the more important modifications that can be proposed from the composite curve analysis in chemical plants. The same philosophy will be applied for other modifications.

The first modification is the columns pressure modifications.

The second will be the mechanical vapour recompression in distillation column train.

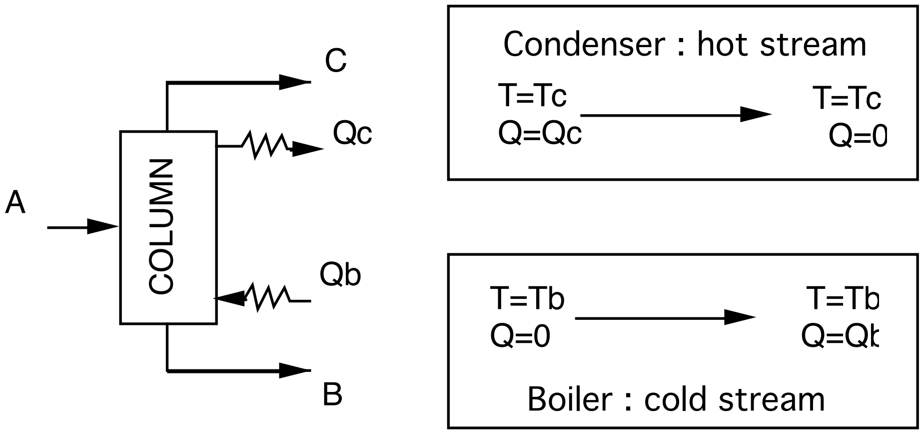
When starting from simulation or validation results, data collection is an important step of the energy integration. The boiler and condenser case requires a few comments.

A boiler is a cold stream to be heated up.

A condenser is a hot stream to be cooled down. Its flow rate includes the distillate and the reflux.

In a "short-cut" distillation column simulation, the condenser and boiler temperatures are considered as constant, equal respectively to the boiling or the dew point. As no more precise information is available, this choice is a conservative case.

Figure 47 gives the detail about the streams entering the integration.



Qc: Condenser heat load (simulation results).
Tc: Condenser temperature (Boiling point of the distillate C).
Qb: Boiler heat load.
Tb: Boiler temperature (Dew point of the residue B).

Figure 47. Distillation column: the streams entering the integration.

A single distillation column includes one boiler and one condenser. For reason of simplicity, the fluid phase changes will be considered isothermal. The corresponding grand composite curve is given figure 48. The boiler will exchange with the hot utility (steam for example) and the condenser will be cooled down by cold utility (cooling water, for example).

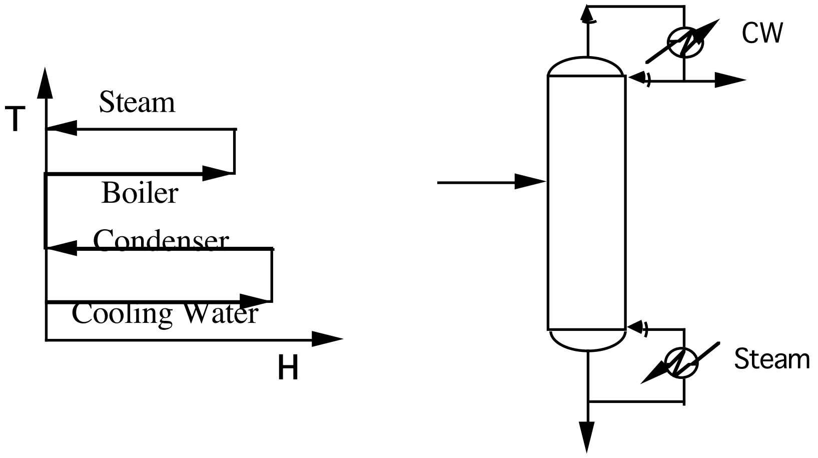
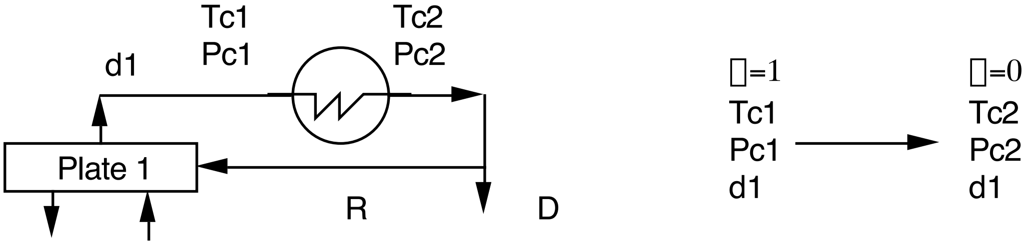


Figure 48. Single distillation column: grand composite curve.

When simulating a distillation column with a more precise model (plates simulation), the composition and flow rates of the condenser and boiler stream on the distillation column side are calculated. In this case, the streams entering the integration can be rigorously taken into account: the H-T diagram can be considered.

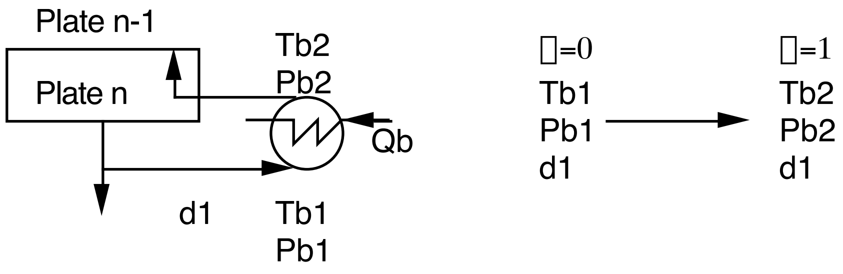
Figure 49a gives the case of the hot stream in a total condenser.



d1: condenser flow rate = distillate + reflux (R+D).
Tc1: Saturation temperature at Pc1 of the vapour leaving the first plate of the column.
Pc1: Condenser inlet pressure.
Tc2: Saturation temperature of the liquid leaving the condenser at Pc2. In certain cases, the stream will be undercooled.
Pc2: Condenser outlet pressure.

Figure 49a. Condenser

The same analysis can be done for the cold stream in a boiler of the figure 49b.



d: Flow rate in the boiler. It is calculated from the inlet and outlet temperatures and the heat load of the boiler.
Tb1: Saturated liquid temperature at Pb1.
Tb2: Saturated vapour temperature at Pb2.
The composition is the residue composition.

Figure 49b. The boiler.

Other configurations can be studied according to the specific technology used in the boilers and condensers.

5.1.2. Pressure of the distillation columns

When integrating columns together, pressure column changes are also possible.

The analysis of the composite curves can be done in the same way. In figure 50, the objective of the process improvement is to put the stage CA (condenser of column A) above the stage BB (boiler of column B). The MVR is a way to realize this objective, an other way is to change the columns pressure in order to change the temperature levels of both the boiler and the condenser.

For example figure 50, if the column B pressure can be decreased in order to have a boiler BB temperature below the condenser CA temperature, the resulting curves will be the case (b). The hot and cold composite curves fit better and the grand composite curve is closer of the temperature axis. In this case, the energy recovery is the boiler BB heat load for both hot and cold utilities.

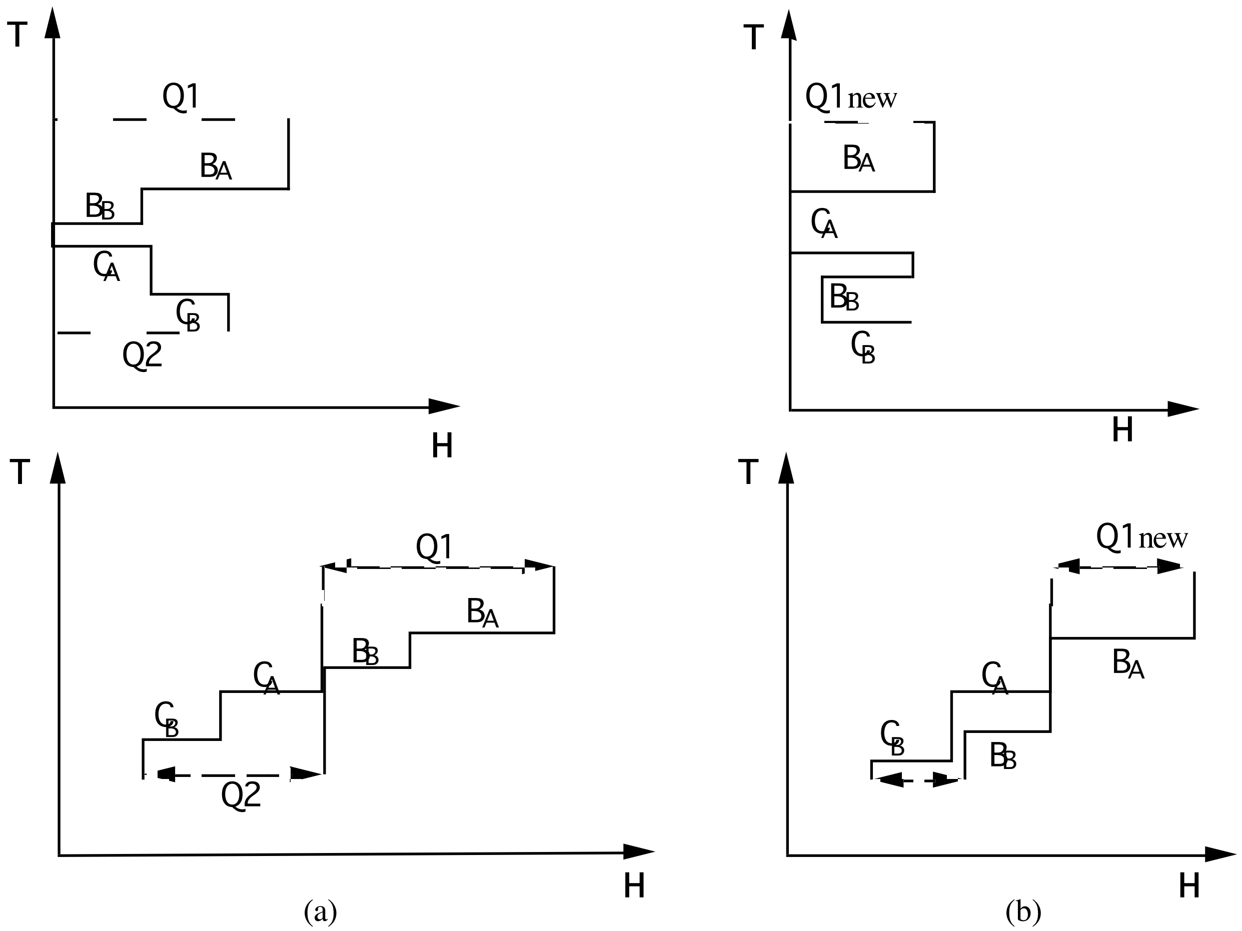


Figure 50. Pressure changes in integrated distillation columns.

If pressure decrease was not possible in column B, the pressure of column A can be increased. The mechanical power will be smaller than in the case of the MVR as the feed of column A is a liquid.

An important remark is that the operation of the column is modified. The new operating conditions have to be calculated by simulation. In case of retrofit or revamping study, the results will be carefully analysed to verify the technological feasibility of the new running conditions.

The reasoning is already valid for the integration of more than two columns.

The problem has to be analysed globally as it can be seen in figure 51. Pressure increase of the column A has no effect on the energy recovery as well as the pressure decrease of column B. But if the pressure of column C is decreased, the pinch point BB CA can become active, and in this case pressure modifications of A or B pressure can become attractive.

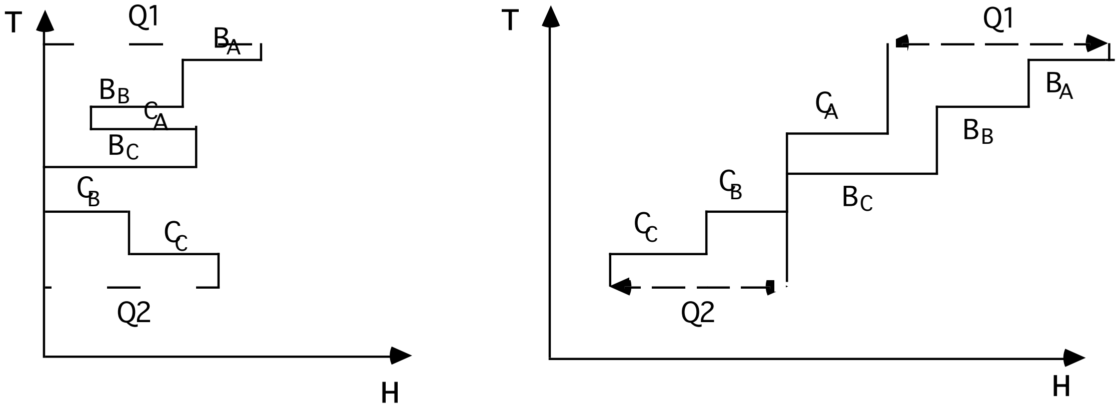


Figure 51. Integration of three distillation columns.

The rules for pressure modifications in integrated distillation columns are:

Decrease the pressure of the column which boiler is above and the closest of the pinch point.
Increase the pressure of the column which condenser is below and the closest of the pinch point

5.1.2.2. Mechanical Vapour Recompression (MVR)

The mechanical vapour recompression (MVR) consists in compressing the vapour entering the condenser before the exchange (figure 53), so as the condensation temperature is increased and the heat can be used to heat up the boiler. The figure 52 gives the evolution of the temperature and the heat load of the condenser when the compression ratio increases.

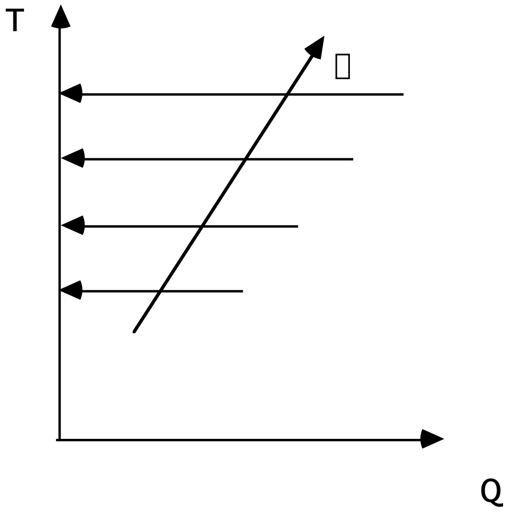


Figure 52. Temperature and heat load of the condenser as a function of compression ratio.

The heat load of the condenser increases since the mechanical power is added in the process and must be evacuated to not perturb the column operation. Additional cooling will be required to perform the sub cooling necessary to obtain the saturated liquid after the expansion valve.

The expected energy saving is related to the use of the energy of the condenser in the boiler. This is obtained by changing the temperature level of the condenser using the mechanical power. Since mechanical power is more expensive than thermal energy, this mechanical vapour recompression is not always interesting. Cost study has to be performed.

The MVR structure and the composite curves after mechanical vapour recompression in a single column is described figure 53.

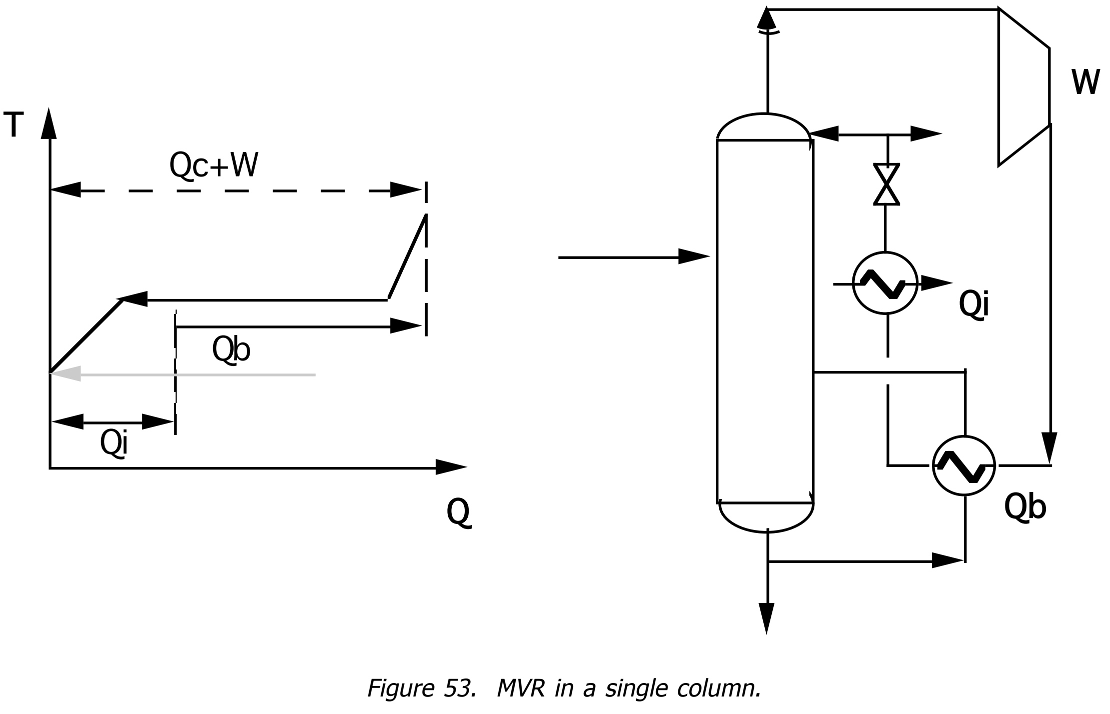


Figure 53. MVR in a single column.

The condenser line is now above the boiler and it can heat up the boiler. Additional cooling Qi = Qc + W - Qb is required.

The energy recovery is very interesting: W of mechanical power gives an energy recovery of Qb for the hot utility and Qc-Qi for the cold utility.

The economy depends on the different energy costs. A common value can be used as an idea: 1 mechanical kW by electricity = 3 kW of heat. The mechanical vapour recompression will be attractive if the energy recovery is three times greater than the mechanical power required for the recompression. Indeed, it depends on the availability of the energy on the plant: utility network, with excess or not of steam for the condensation or for expansion in steam engines; or the electricity cost.

When the column is integrated in a process, the recompression is not always interesting. The pinch point is once again the key for the energy recovery:

In figure 54, the column is above the pinch point, in the heat sink. In this case, the heat of the condenser can be used to heat up other cold streams than the boiler. The mechanical vapour recompression adds W of mechanical power which is directly converted into thermal power with no other significant effect: the economy of hot utility is the mechanical power introduced in the process.

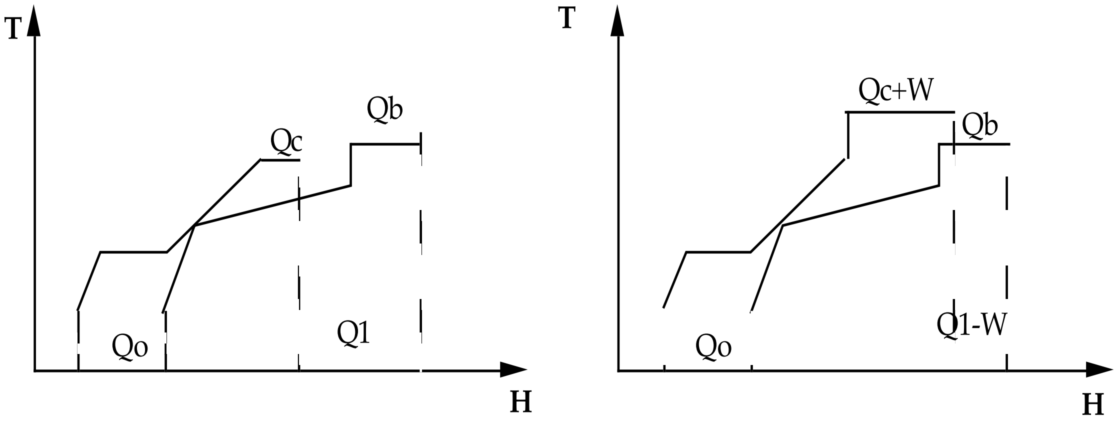


Figure 54. MVR above the pinch point

In figure 55, the column is below the pinch point in the heat source. The boiler takes its heat load on the hot process streams above him. The MVR produces an extra hot stream heat load of W which is evacuated by cooling water. This case is surely not interesting.

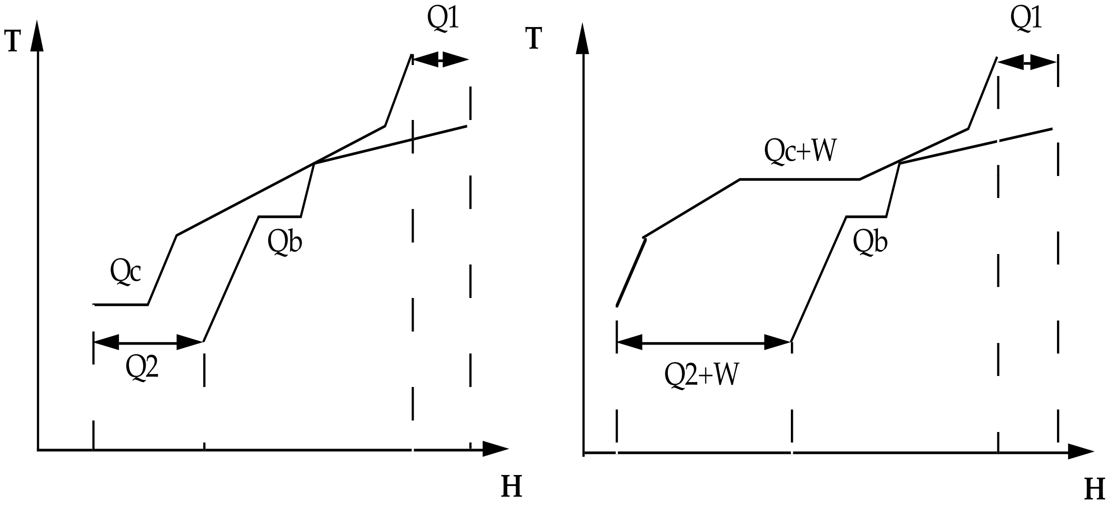


Figure55. MVR below the pinch point.

In figure 56, the boiler of the column is above the pinch point and the condenser below. When recompressing the condenser vapour, a hot stream is added in the heat sink decreasing the total hot utility demand. Moreover, a hot stream is taken out of the heat source decreasing the cold utility requirement. In this case, the MVR has similar effect as when the column is not integrated. This effect can be better because the condenser can leave the heat load to the boiler but also to other cold streams above the pinch point. The hot and cold composite curves fit one to the other.

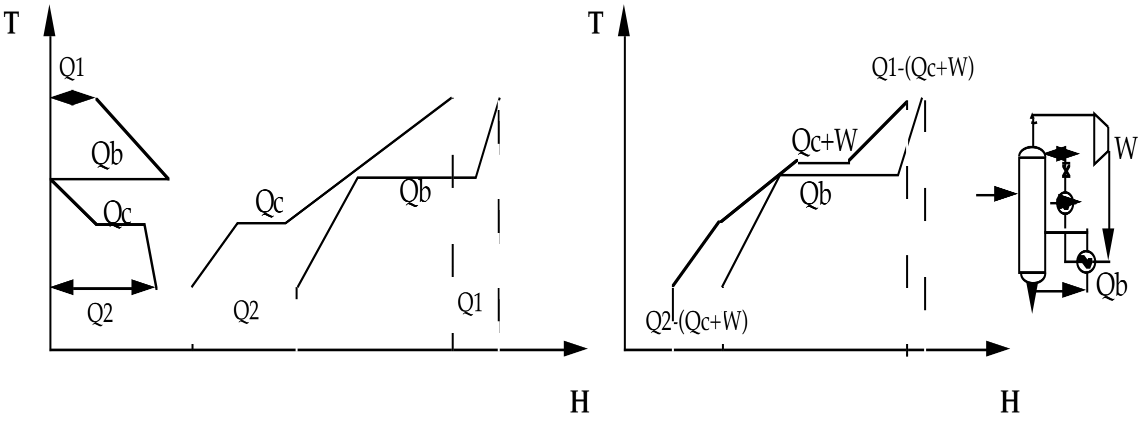
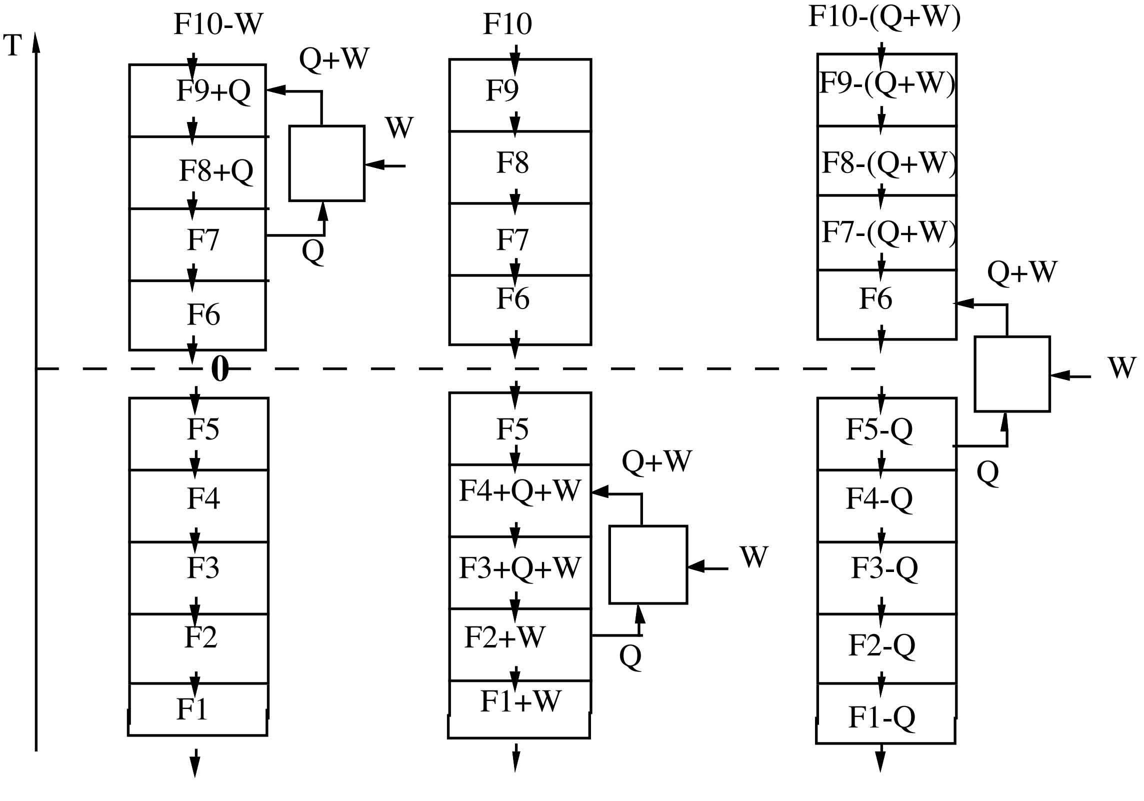


Figure 56. MVR around the pinch point.

The three cases here above can be represented in the thermal cascade (figure 57). The mechanical power is used to change the temperature level of the stream recompressed. The mechanical power raises the heat along the thermal cascade, it is a heat pump.



(a) (b) (c)

Figure 57. Mechanical power and thermal cascade.

In case a, the heat load Q is taken in the interval 7 and risen to interval 9. The problem table shows that the F10 (hot utility) is reduced of W, the thermal power to obtain zero flow at the pinch point. The mechanical power is used as hot utility.

In case b, the heat load Q is taken in the interval 2 and risen to interval 4. In this case, the zero flow at the pinch point imposes an increase of W for F1, the cold utility. The mechanical energy W is directly sent to the cold utility.

In case c, the heat load Q is taken in the interval 5 below the pinch point and is risen to interval 6 above the pinch point. This result to a net hot utility recovery of Q+W to find zero flow at the pinch point, and a cold utility recovery of Q.

The use of mechanical power to rise heat in the thermal cascade is energetically interesting when it rises heat from below to above the pinch point.

In process integration, mechanical vapour recompression does not necessary involve the matching of a condenser and the boiler of the same column. Distillation columns can be integrated together and the condenser of one column can heat up the boiler of another. This feature allows to reduce the compression ratio as shown figure 58. The compression ratio and the mechanical power required (W2) for the MVR in the integrated columns (condenser of A and boiler of B) is less than the one (W1) for the MVR of column A.

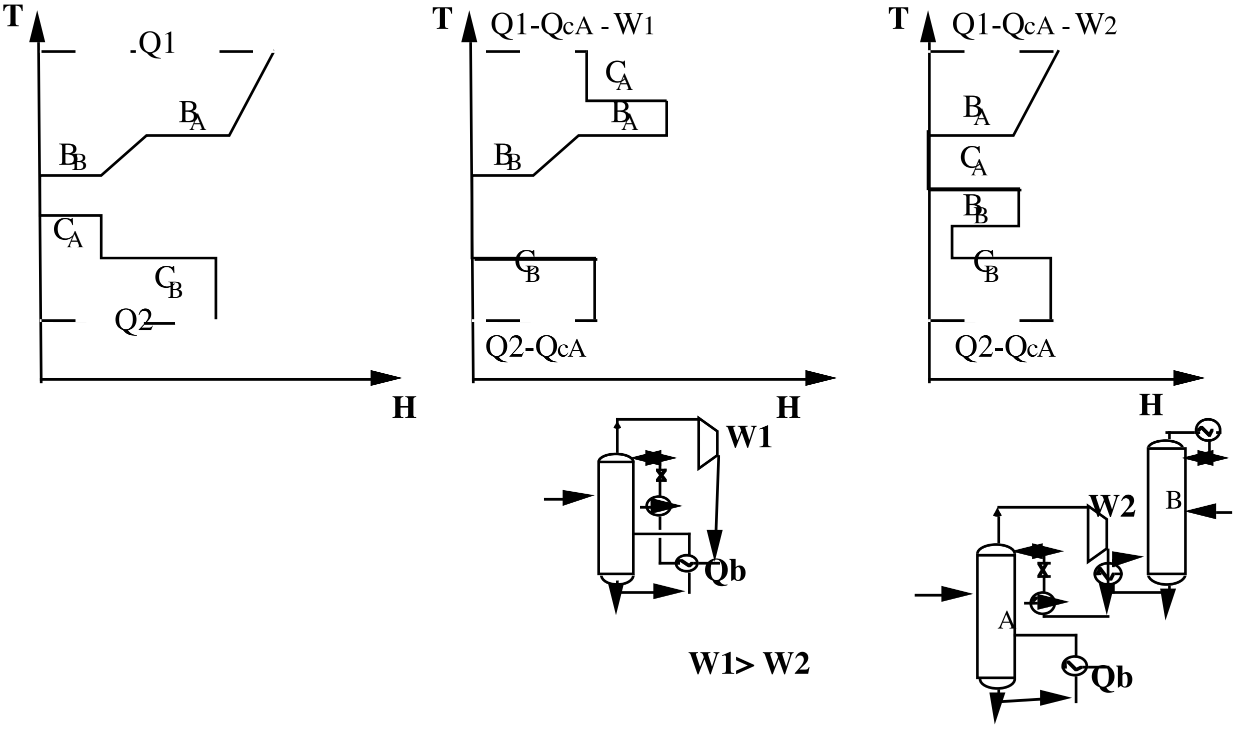


Figure 58. Integrated distillation column wit MVR.

The mechanical vapour recompression is economically effective when the compression ratio is small enough. The shape of the composite curves and specially the grand composite curve helps to detect the opportunity for vapour recompression.

A vapour recompression can be envisaged when grand composite features two stage (figure 59). One below the pinch point (A) which correspond to the recompressed stream and one above (B), where the recompressed stream will discharge its heat load. The choice of the compression ration will be done so as to be DTmin/2 above the stage B.

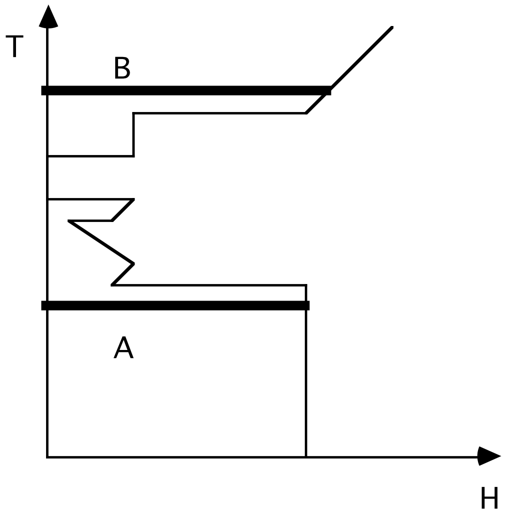


Figure 59. MVR and grand composite curve.

The condition necessary to detect the opportunity of mechanical recompression is thus the presence of two stages surrounding the pinch point. The rest of the grand composite curve must also be considered to analyse if no other pinch point will occur.

> The easy way to make this analysis is to consider the recompressed stream as a hot utility for the heat sink.

In the same way, to determine the amount of heat which can enter the mechanical recompression, the grand composite curve below the pinch is to be analysed.

> The easy way to make this analysis is to consider that the recompressed stream is fictively cooled down by a cold utility in the heat source.

The figure 60 illustrates these rules. Even if the condenser Qc is recompressed the heat recovery will be of Q2 and the pinch point changes.

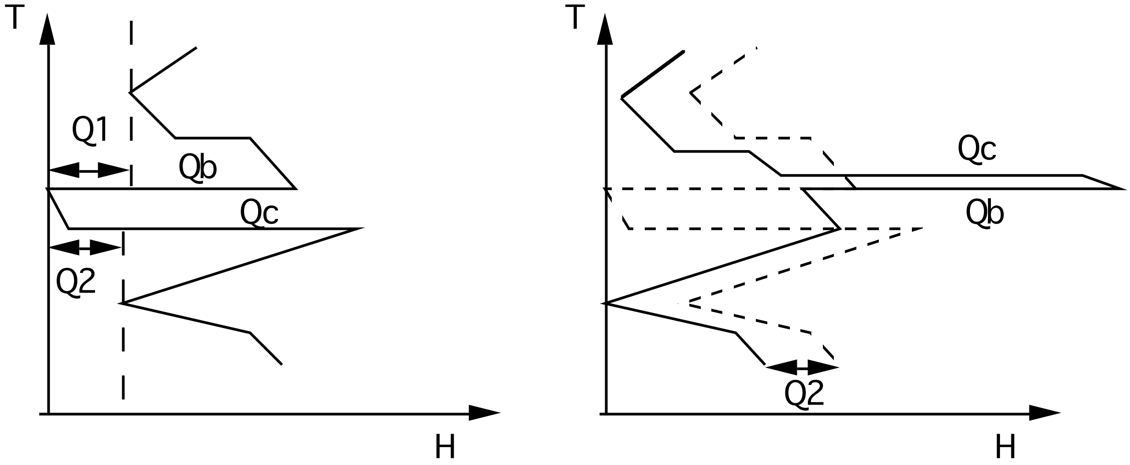
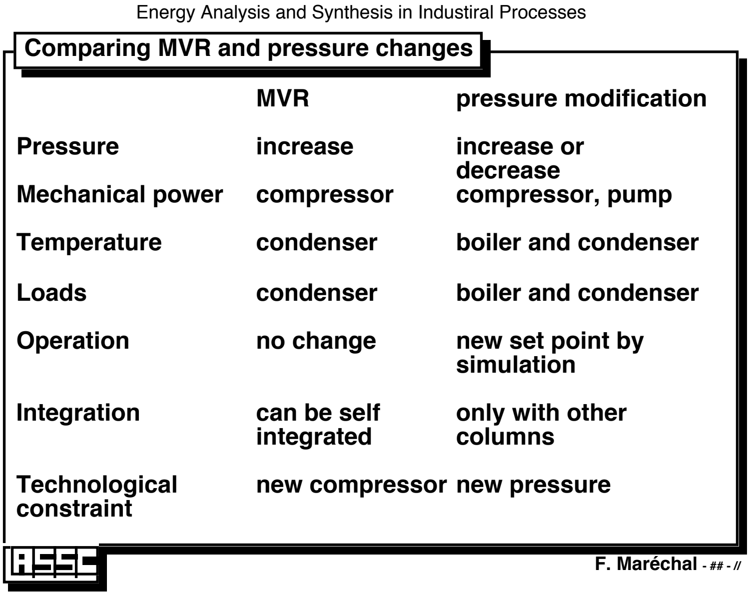


Figure 60. Detection of MVR opportunity.

5.1.3. Comparing MVR and pressure changes

The following table displays the differences between MVR and pressure changes.



Energy Analysis and Synthesis in Industiral Processes

Comparing MVR and pressure changes

	MVR	pressure modification
Pressure	increase	increase or decrease
Mechanical power	compressor	compressor, pump
Temperature	condenser	boiler and condenser
Loads	condenser	boiler and condenser
Operation	no change	new set point by simulation
Integration	can be self integrated	only with other columns
Technological constraint	new compressor	new pressure

F. Maréchal - ## - //

Form flexibility point of view, the pressure modification leads to more integrated process because it involves two columns or more. It has to be analysed by simulation to verify the operability of the modified process.