Pinch technology improves olefin heat recovery

Pinch technology applied to an existing olefins unit shows heat utilization can be improved

J. Bartoň, Chemopetrol, Research Institute of Inorganic Chemistry, Ústí nad Labem, Czechoslovakia

Introduction. Pyrolysis of naphthas or gas oils to provide ethylene and propylene for polymers is gaining in popularity in many countries. Pyrolysis takes place at the comparatively high temperatures of 800 to 850°C. The very common solution of pyrolysis gas heat recovery in an ethylene unit is shown in Fig. 1.

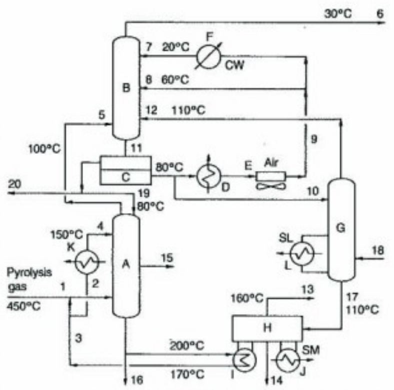
Pinch technology. Linnhoff is one of the pioneers of better understanding of heat utilization in an exchanger network.[1]

Pinch technology allows finding the temperature point (the pinch) that divides the temperature scale in a process into two parts. If there is a pinch in a process (not every process has a pinch), heat from external sources must be supplied to the process at temperatures above the pinch, and must be taken from the system by cooling media at temperatures below the pinch only. If we want minimum consumption of energy for heating and cooling from external sources, matching process streams across the pinch and adding heat to the system from external sources below the pinch temperature is not allowed.

Pinch in pyrolysis gas heat recovery technology. In Table 1 the values of products of mean heat capacity and mass flow according to Fig. 1 are given following Linnhoff's concept of "hot" and "cold" process streams. The main source of heat in the given technology is the heat content of pyrolysis gas. This hot stream is divided into four hot streams, H1 through H4 (Table 1). The main cold stream is C1, which represents the consumption of heat for generation of process steam. The results of enthalpy balances following Linnhoff's method for calculation of the pinch temperature are shown in Table 2. For example, enthalpy balance at the temperature interval 450°C down to 170°C is calculated as follows:

$$(m\, c_p\, (450 - 170))_{H1} + (m\, c_p\, (190 - 170))_{H4} - (m\, \Delta H)_{C1} =$$
$$404 + 68{,}040 - 104{,}144 = -35{,}700 \text{ kW}$$

Condensation or evaporation of water proceeds at constant temperature, which is stated in Table 1 (see streams H3, H5 and C1). The temperature difference, ΔT, between hot and cold streams is generally optional and considered as 10°C. This means that the heat contained in hot streams down to 170°C may be used for generation of process steam, which is generated at 160°C. In Table 2 in the column called "Input," the needed inputs of heat flux in kW are shown at given temperature levels. Because of the lack of heat in hot streams at the level 450 to 170°C, the performance 35,700 kW must be added at this temperature level from external sources (medium pressure steam) to establish the equilibrium between the source of heat and its consumption. The output from this level (see column "Output" in Table 2) to the temperature level 170 to 120°C is then zero. There is no heat flux across 170°C and this temperature is the pinch. It is necessary to point out that the value of the pinch is expressed on the hot streams temperature scale and depends on the temperature difference between hot and cold streams, ΔT. From inspection of Fig. 1, we can find two violations of rules derived from pinch technology. Low pressure steam is used for preheating process water in the stripper. This means



1. Inlet of pyrolysis gas
2. Oil and gas mixture
3. Quench oil
4. Quench oil
5. Gas phase from quench oil tower to quench water tower
6. Noncondensed gases (C_1 to C_5 hydrocarbons)
7. Quench water
8. Quench water
9. Quench water
10. Process water to stripper
11. Mixture of quench water and pyrolysis gasoline
12. Vapor mixture of water and hydrocarbons
13. Process steam
14. Blow down
15. Light pyrolysis oil
16. Heavy pyrolysis oil
17. Feed water for process steam
18. Stripping steam
19. Reflux to quench oil tower
20. Pyrolysis gasoline

A. Quench oil tower
B. Quench water tower
C. Separator
D. Preheaters
E. Air coolers
F. Water coolers
G. Stripper
H. Generator of process steam
I. Quench oil boilers
J. Medium pressure steam boilers
K. Preheater of hydrocarbons
L. Stripper boiler
SM. Medium pressure steam
SL. Low pressure steam
CW. Cooling water

Fig. 1—Typical pyrolysis gas heat recovery scheme.

TABLE 1—Hot, H, and cold, C, streams in pyrolysis gas heat recovery

Stream	Temperature interval, °C	$m\,c_p$ kW K^{-1}	$m\,\Delta H$ kW	Comments
H1	450 → 100	243.0	–	Pyrolysis gas heat transferred in quench oil tower (condensation of oils included)
H2	100 → 30	77.9	–	Pyrolysis gas heat (heat of noncondensed gases) transferred in quench water tower
H3	100	–	91,666	Condensation of process steam
H4	190 → 80	20.2	–	Condensation of pyrolysis gasoline
H5	110	–	2,500	Condensation of low pressure steam for stripping
C1	160	–	104,144	Process steam generation
C2	60 → 70	4,433	–	Preheating of technological media by quench water
C3	80 → 110	111.1	–	Preheating of hydrocarbons going to pyrolysis heaters
C4	80 → 110	173.3	–	Preheating of quench water (process water) in stripper

TABLE 2—Heat balances at different temperature levels

Temperature interval (hot streams temperature scale), °C	Heat balance, kW	Input, kW	Output, kW
450 → 170	− 35,700	35,700*	0
170 → 120	+ 13,160	0	13,160
120 → 110	+ 2,271	13,160	15,431
110 → 100	+ 91,371	15,431	106,802
100 → 90	− 1,880	106,802	104,922
90 → 80	+ 981	104,922	105,903
80 → 70	− 43,551	105,903	62,352
70 → 30	+ 3,116	62,352	65,468**

* From steam
** To cooling media (water and air)

TABLE 3—Consumption of heating and cooling media in real system according to Fig. 1

Heating media	
Medium pressure steam	39,033 kW
Low pressure steam	5,200 kW
Total	44,233 kW
Cooling media	
Cooling water and air	74,001 kW

that the accessory heat flux is added to the system below the pinch. The condensation heat of low pressure steam must be taken from the system by cooling water. In Fig. 1 we can also find that the rule that no heat flux should be transferred across the pinch is broken. Quench oil should not be cooled below 170°C by hydrocarbons in exchanger K. Reflux of pyrolysis gasoline may also increase the consumption of medium pressure steam for generation of process steam in case the reflux ratio is higher than expected. A certain part of reflux to the quench oil tower is evaporated over the pinch temperature and it decreases the generation of process steam in boiler I (Fig. 1). From these reasons the real consumption of heating and cooling media highly exceeds minimal values from Table 2 (see Table 3).

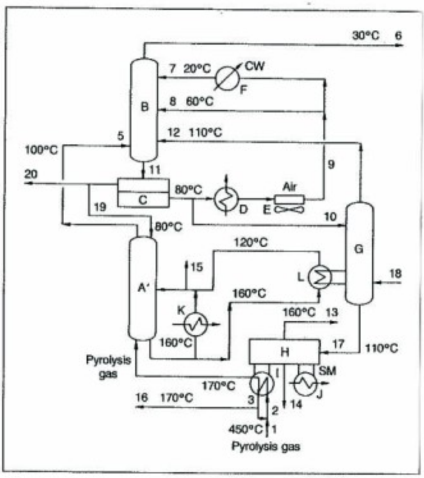


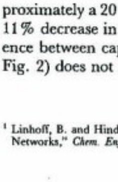
Fig. 2—Revised process diagram (see Fig. 1 for nomenclature).

Reconstruction of process diagram. Work on reconstructing the process diagram should follow pinch technology principles. First, a new stream should be introduced to the process diagram in Fig. 1 which would enable preheating hydrocarbons and process water by heat contained in the pyrolysis gas. It might be done, for example, according to Fig. 2. In boilers for generation of process steam, pyrolysis gas and quench oil would be mixed so that the temperature of pyrolysis gas and quench oil leaving the boilers was 170°C. Such a solution would remove also a negative influence of quench oil tower reflux on the generation of process steam. Instead of quench oil tower A (Fig. 1) a column A′ would be situated in the process (Fig. 2). The composition of oil circulating in this column would be similar to that in stream 15 in Fig. 1. The heat content of pyrolysis gas between 170 to 130°C would enable preheating hydrocarbons as well as process water to 110°C. The change of technology of pyrolysis gas heat recovery as indicated in Fig. 2 may decrease the consumption of heating and cooling media almost to the theoretical level stated in Table 2. It represents approximately a 20% decrease in consumption of steam and an 11% decrease in consumption of cooling media. The difference between capital cost of these two solutions (Fig. 1 vs. Fig. 2) does not seem to be significant.

LITERATURE CITED

[1] Linhoff, B. and Hindmarsh, E., "The Pinch Design Method for Heat Exchanger Networks," *Chem. Eng. Sci.*, *38*, 745, 1983.

The author



Jan Bartoň has been in the systems engineering group of the Research Institute of Inorganic Chemistry, Czechoslovakia, since 1980. He specializes in energy saving projects and naphtha pyrolysis modeling. Dr. Barton holds a PhD degree in organic technology from the Prague Institute of Chemical Technology and is the author of 30 papers in his field.