Reduction of hydraulic resistance in vacuum columns as an effective tool in the formation of energetic rectification units

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Abstract. Using an example of ethylbenzene and diethylbenzene separation, we demonstrate that structured packing with a low specific flow resistance is an effective tool for setting up hardware and energy rectification packages. By replacing conventional plates with structured packing, the flow resistance and vertical temperature gradient are significantly lowered, providing favorable conditions for thermal coupling of the columns. Thermal coupling of the columns in a two-column setup for extraction of rectified ethylbenzene and diethylbenzene provides heating steam savings of 0.13 Gcal per tonne of diethylbenzene.

One of the important stages of the energy optimization of distillation systems is the integration of technological components into hardware and energy packages, which utilize the internal energy of process flows as fully as possible [3]. To address this, one must perform thermophysical analysis of the process flows for the new or upgraded technology to identify the most energy-intensive stages of the process, draft the conditions to utilize the internal energy of the flows and develop technical solutions to implement them.

To combine distillation columns into a hardware and energy package, top temperature of one of the columns must be higher than bottom temperature of the other one by a certain margin. This provides the temperature difference for effective operation of the selected evaporator type.

This condition can be achieved by varying the pressure in the columns or reducing the flow resistance by means of selecting specific contact devices.

Low flow resistance contact devices reduce the vertical temperature gradient of the columns and provide favorable conditions for their thermal coupling [3].

Replacing plate-type contact devices with structured packing [1, 2, 4, 5] can significantly reduce the flow resistance of columns and is an effective tool to set up hardware and energy packages.

Consider the application of the aforesaid to setting up hardware and energy package in the production of ethylbenzene.

The diagram of a two-column system for extraction of rectified ethylbenzene and diethylbenzene fraction is shown in figure 1. Key technological parameters of the process and the characteristics of the columns are shown in table 1.

Top temperature of the C-1 column is almost equal to the bottom temperature of C-2 column. In order to achieve thermal coupling of the columns, either the pressure of the column C-1 must be increased, or the flow resistance of the column C-2 lowered.

Figure 2 shows the top and bottom temperatures of the column C-1 depending on the pressure.
Figure 1. Technological configuration before modernization C-1 - ethylbenzene column; C-2 - ethylbenzene fraction column; HS – heating steam SS - secondary steam pressure of 0.15 MPa; CW - water circulating. HW – hot water; W – water condensate.

The evaporator of the column C-1 is heated with saturated steam at a pressure of 3 MPa and temperature of 230 °C. Temperature difference in the evaporator is about 30 °C.

Increasing the pressure in the column C-1 to 0.35 MPa will provide the necessary temperature difference for the evaporator in the column C-2 when he columns are thermally coupled. However, the bottom temperature of the column C-1 will rise to 228 °C, lowering the temperature difference in the evaporator to almost zero. Therefore, rising the pressure in the column C-1 to form a hardware and energy package is impractical.

Table 1. Characteristics of the columns C-1 and C-2 before modernization.

| Parameter name                  | C-1                  | C-2                  |
|---------------------------------|----------------------|----------------------|
| Type of contact devices         | Louvre-valve plate   | Lattice plate        |
| Contact device amount, pcs      | 90                   | 35                   |
| Top column pressure, mm Hg (kPa)| 1350 (180)           | 30 (4)               |
| Bottom column pressure, mm Hg (kPa)| 1600 (213)       | 150 (20)             |
| Flow resistance of the column, mm Hg (kPa)| 250 (33)  | 120 (16)             |
| Top column temperature, °C      | 160                  | 64                   |
| Bottom column temperature, °C   | 200                  | 160                  |
| Reflux ratio                    | 2                    | 1                    |
| Thermal load on evaporator , Gcal/h (Gcal/t EBR)*| 4.888 (0.22)  | 1.136 (0.13)         |

In a practical application, ethylbenzene vapors from the top of column C-1 are diverted to a condenser-evaporator. The heat from ethylbenzene vapor condensation is used to produce secondary steam with a pressure of 1.5 kgf/cm² at a temperature of 110 °C. This low-pressure steam is insufficient to evaporate the bottom product in the column C-2. Operation of the column C-2 and the evaporator requires supply of heating water steam at a pressure of about 1.4 MPa.

Figure 3 shows the boiling point of the bottom liquid in the column C-2 versus the column’s flow resistance. Analysis of this data shows that lowering the flow resistance of the column C-2 from 120 mm Hg to 20 mm Hg provides the necessary conditions for thermal coupling of the columns C-1 and C-2 without changing the basic process parameters (top pressure of the columns, reflux ratio, production ratio).

Necessary flow resistance at the required efficiency can only be achieved with structured packing [1, 2, 4, 5].
Chevron-brand packing is preferred [1] due to its highest flow rate (table 2). Using of domestic manufacturers devices allows to reduce import substitution [6].

Figure 4 shows the ethylbenzene extraction diagram after replacing the lattice plates with structured packing and combining the columns C-1 and C-2 into a hardware and energy package.

Uncondensed steam flow from the condenser-evaporator of the column C-1 is directed into evaporator of the column C-2 instead of the condenser (figure 2) and the evaporator columns. The temperature difference on the evaporator of the column C-2 will be about 30 °C, sufficient for effective operation of most vaporizers, particularly shell and tube. The evaporator of the column C-2 doubles as the condenser of the column C-1, saving additional water on vapor condensation.

Using the structured packing "Chevron 14-4" with packing height of 3.5 m, the C-2 column efficiency is 20 theoretical plates (TP), and the flow resistance (including 2 flow distributors) is ~20 mm Hg (2.7 kPa). If the pressure at the top of the column is maintained at 30 mm Hg (4 kPa), the flow resistance (including 2 flow distributors) is ~20 mm Hg (2.7 kPa). If the pressure at the top of the column is maintained at 30 mm Hg (4 kPa), the bottom pressure is lowered down to 50 mm Hg (6 kPa), and the temperature goes down to 126-127 °C.

Column C-2 upgrade requires minimal capital investment. Existing plates must be replaced with structured packing, and two liquid and steam distributors must be installed in the existing column body. Combining columns C-1 and C-2 into a hardware and energy package reduces the annual consumption of heating steam by ~ 8100 Gcal for an installation with a capacity of 17.5 kt/year of rectified ethylbenzene + 8000 kt/year of diethylbenzene fraction.

Reducing the flow resistance of distillation columns is an effective tool for setup of hardware and energy packages.

There are cases when the problem of thermal coupling of columns can be solved with structured packing.
Ethylbenzene production can benefit from structured packing that allows combining rectified ethylbenzene column and diethylbenzene fraction column into a hardware and energy package. Thermal coupling of such columns can lead to heating steam economy of 0.13 Gcal per tonne of diethylbenzene fraction.

References
[1] Leontiev V S 2015 Chemistry and Business 191 52–4
[2] Leontiev V S 2012 Electronic scientific journal "Oil and Gas Business" 1 178–86
[3] Leontiev V S 2012 Electronic scientific journal "Oil and Gas Business" 2 245–54
[4] Sokol B A, Chernyshov A K, Baranov D A et al. 2009 Packings of mass transfer columns (Moscow: Halley-print) 358
[5] Gualito J J, Cerino F J, Cardenas J C and Rocha J A 1997 Industrial & Engineering Chemistry Research 36 1747–57
[6] Khatkov V Y and Boyarko G Y 2018 Journal of Mining Institute 234 683–92