

# Basic design of a double-pipe unit type internally heat integrated distillation column (HIDiC)

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## 1. Introduction

Distillation is not only the most energy consumer but also the most frequently-adopted separation operation in chemical industries since it separates a mixture only by the difference among vapor pressures (boiling points) of components. So distillation is often called as the king of separation processes. Therefore, research and development of technologies on energy savings of distillation is an extremely important and eternal mission for chemical engineers.

In 1978, Secondary Reflux Vaporization (SRV) system, that is an ingenious technology of energy saving for the distillation, was proposed by Dr. Mar in USA. In the SRV system, the rectifying section is pressurized to elevate its temperature level to be higher than that for the stripping section, and these two sections are contacted with each other like a heat exchanger. This structure makes the rectifying section a heat source or a side heater for the stripping section. If the temperature difference and the contact between these two sections are appropriate, a great energy saving can be expected by the SRV system. However, this system has not been put into practical use at that time and R&D had not been continued.

In the nearly time in Japan, Heat Integrated Distillation Column (HIDiC), that is almost equivalent to the SRV system, has been investigated by numerical simulations. A lot of papers for the HIDiC have been reported by Prof. Takamatsu and Dr. Nakaiwa et al. until now. In these papers, some possibilities of operation of HIDiC without a reboiler and a condenser, that is called an ideal HIDiC operation, are shown to obtain the best energy saving from thermodynamic point of view. After long R&D period, a pilot plant of the HIDiC was built and operated at last in 2005<sup>2)</sup>. Since the feed flow rate of the HIDiC pilot plant is about 2000 kg/h, it is rather a commercial scale column. The consecutive operation of the pilot HIDiC for 1000 hours has already been achieved. The energy consumption of the pilot HIDiC has been saved at less than 40% of a conventional distillation column with the same scale.

In this paper, the structure and the detail of the pilot HIDiC are shown, and its basic design strategy is explained.

## 2. Principle of HIDiC

A distillation column separates a mixture by the difference of boiling points. Vapor and liquid phases appear in distillation columns, so it is a gas-liquid contacting unit. In conventional distillation columns, liquid is usually produced by condensation at external coolers (condensers), and vapor is produced by vaporization at external heaters (reboilers). It is a great waste of energy since cooling and heating are concurrent at different external heat exchangers. The Vapor Recompression (VRC) system, that is a well-known heat pump technology, can recover

the energy from the top vapor by reusing it as a heat medium in the heater at the bottom of the column (Figure 1). Figure 2 shows a concept of the HIDiC. In the HIDiC system, a heat pump is used not to the top and the bottom of the column but to the whole column, that is, the cooling of the rectifying section is directly carried out by contacting the rectifying section with the stripping section. In an ideal situation, both cooling and heating outside the column are no longer required since both vapor and liquid are produced inside the column.

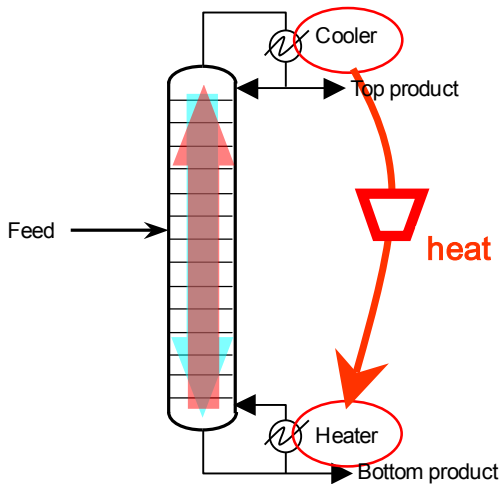


Figure 1 Concept of VRC

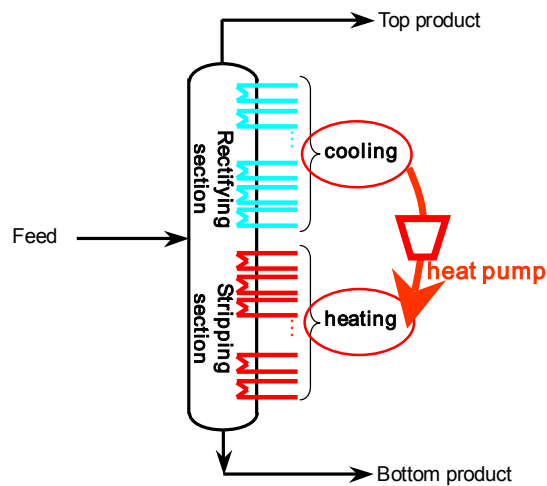


Figure 2 Concept of HIDiC

According to the concept of the HIDiC, the structure must allow the heat transfer from the rectifying section at high temperature to the stripping section at low temperature (Figure 3). Therefore, a compressor should be arranged between the rectifying section and the stripping section to pressurize the rectifying section and make its temperature higher than that in the stripping section.

By this contact between these two sections, the liquid and vapor flow rate profile of the HIDiC is very different from those for the conventional column. It is considered that liquid and vapor flow rate are nearly constant in the conventional distillation column. However, the flow rate profile changes in the HIDiC since the internal heat transfer causes condensation in the rectifying section and evaporation in the stripping section. As shown in Figure 3, both the liquid and vapor flow rates increase downward in the rectifying section, and upward in the stripping section. The condenser and the reboiler duty are significantly reduced since the vapor and liquid flows needed for separation are produced not in the external heat exchangers but inside the column.

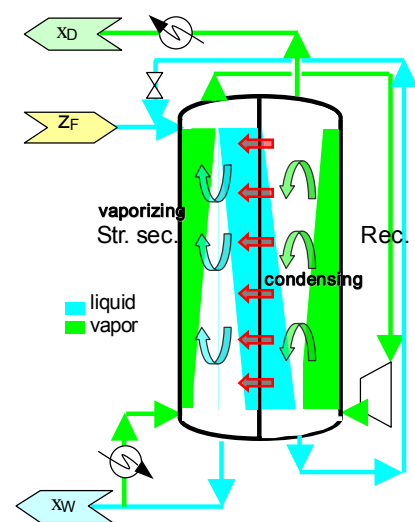


Figure 3 Liquid and vapor flow rate in HIDiC

### 3. Structure and Design of HIDiC

Figure 4-(a) shows a structure for HIDiC named as Double Pipe Unit. The inside and

the outside of the inner pipe function as the rectifying section and the stripping section respectively, and the wall surface of the inner pipe is the heat transfer area. Structured packings are filled both in the rectifying and stripping sections. The heat transfers from the inner pipe to the outer pipe. As mentioned above, the liquid and vapor flow rates change in the HiDiC, so the diameter of the inner pipe must be altered in the axial direction. Broken lines in Figure 4-(b) show liquid loads when the diameter of inner pipe is constant and solid lines show liquid loads when the diameter of the inner pipe is changed.

To realize the structure, four items must be designed; diameters of the inner and outer pipes, the height at which the diameter of the inner tube is changed, the number of double pipe units for a HiDiC pilot plant, and the packing height. To design these items, performance of distillation and heat transfer such as shown in Figure 4-(c) were required. It is important to see a range of design, that is, minimum and maximum loads.

The performance data was obtained by a test equipment in Kimura Chemical Plants, in which packing heights of both inner and outer pipe sides are 1 m each. The test equipment was operated at flow rates and temperatures that correspond to those in the actual pipe unit of the HiDiC pilot plant.

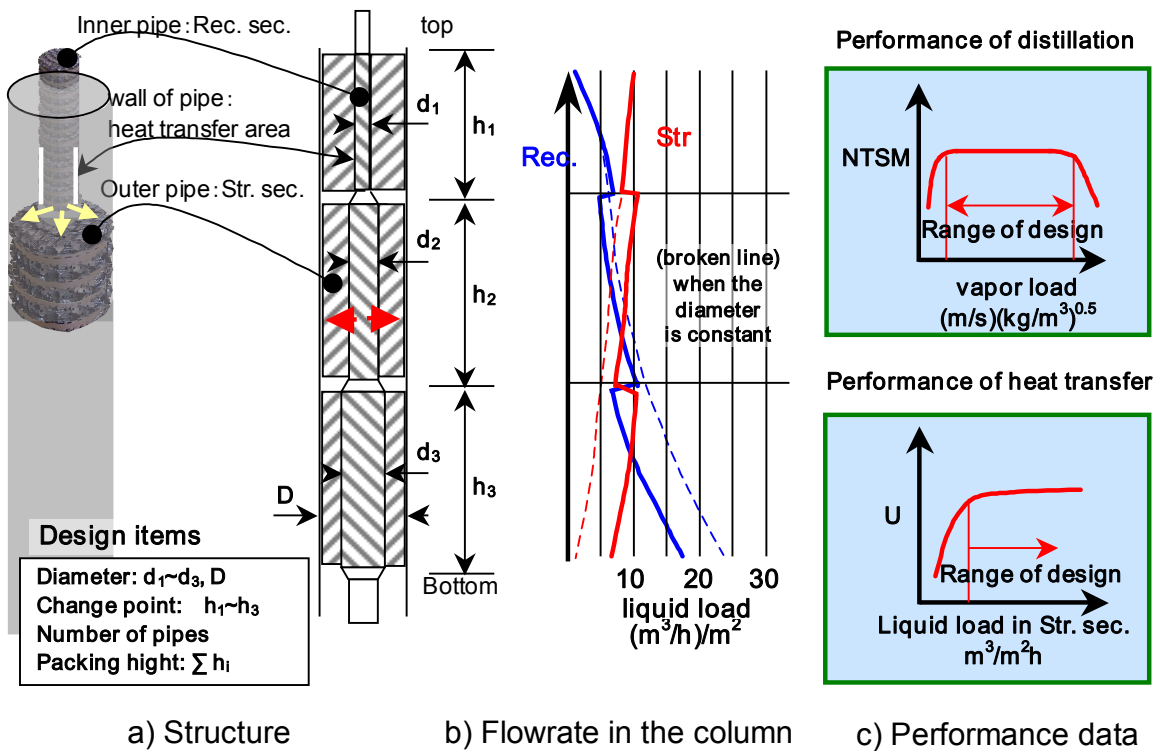


Figure 4 Design of double pipe-unit

#### 4. Detail of Pipe-unit

The performance of the heat exchange between the rectifying and stripping sections is very important since that indeed is the way of energy saving in the HiDiC. To obtain a good performance, the following three requirements must be satisfied.

- 1) Liquid condensed on the heat transfer surface in the rectifying section should be steadily removed to packings in order to make the heat transfer efficiency of condensation higher.

- 2) No dry spots should be generated on the heat transfer surface in the stripping section in order to keep the heat transfer area.
- 3) Vapor and liquid must flow uniformly both in the rectifying and the stripping section.

As one of structures that satisfies above three requirements, the Double Pipe-Unit was proposed. Its cut model is shown in Figure 5. In the figure, "wire spiral" is a device that is coiled on the wall of the outside surface of the inner pipe (heat transfer surface of the stripping section side). It allows the liquid flow to stick around the surface to ensure the heat transfer, and at the same time, to spread appropriate amount of liquid to the packing section. It also makes the heat transfer area larger, and good contact between the wall of pipe and packing.

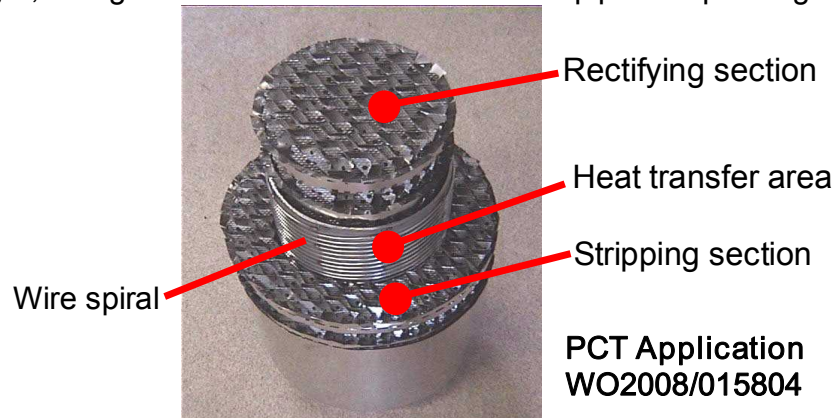


Figure 5 Cut model of double pipe-unit

## 5. Results of experiments

Figure 6 shows the result of distillation performance, and Figure 7 shows the result of heat transfer performance. In Figure 6, the circle and the square plots show Number of Theoretical Stage per Meter (NTSM) in the inner side and the outer side, respectively. It was found that NTSM in the outer side decreases sharply over about 2.5 of F-factor, which is the product of vapor velocity and square root of the vapor density. It is thought as the flooding point. In Figure 7, it was found that the overall heat transfer coefficient (U) is about 1100 W/(m<sup>2</sup>·K) if the liquid load in the outer side is more than 5.

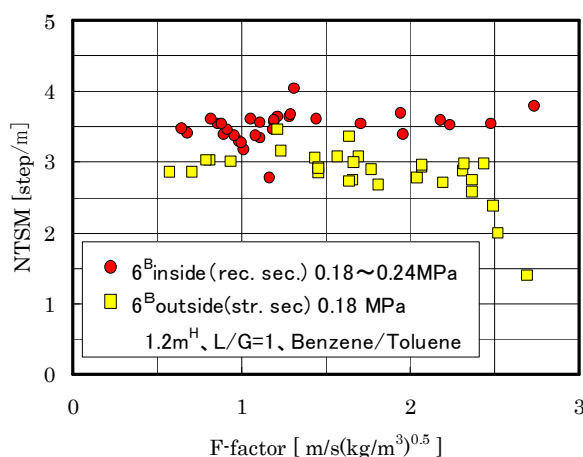


Figure 6 performance of distillation

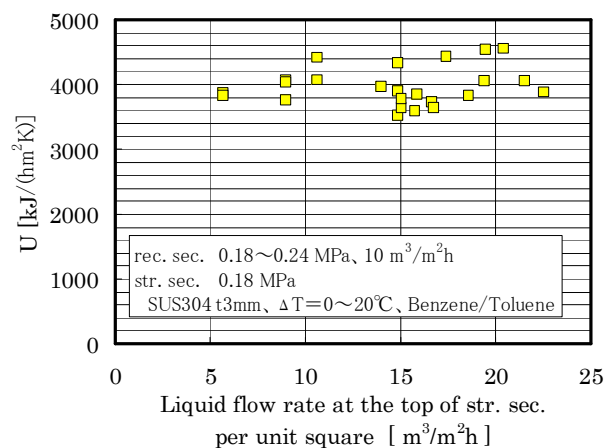


Figure 7 performance of heat transfer

## 6. Pilot HIDiC

The pilot HIDiC has been built and operated in 2005 at Chiba factory of Maruzen Petrochemical Co., Ltd. It is a cyclopentane stripper from the feed of 12-component gasoline distillate. The pilot HIDiC is 27 [m] of height and 1.4 [m] of diameter. It consists of seven Double Pipe Units (Figure 8). The diameter of the inner pipe of each Double Pipe Unit was altered three times (165 mm, 216 mm and 267 mm), and the diameter of the outer pipe is fixed at 406 mm. This change in the ratio of the cross sectional areas of the rectifying and the stripping section makes constant vapor velocity.

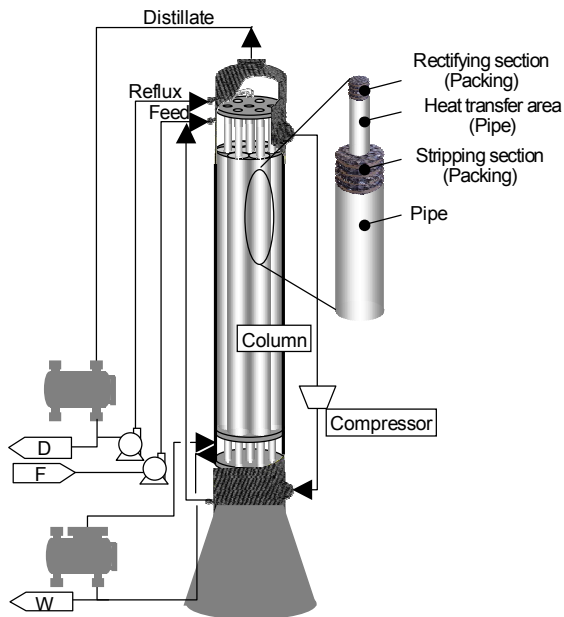


Figure 8 Structure of the pilot HIDiC



Figure 9 Photograph of the pilot HIDiC

## 7. Conclusions

In this paper, R&D for the first pilot HIDiC in Japan was explained. The principles of VRC and HIDiC systems were introduced and compared with each other. The structure and the design strategy of the HIDiC was explained. Double Pipe Unit for the HIDiC needs no redistribution device in the column since the wire spiral on the outer surface of the inner pipe also functions as a distributor.

The experimental results obtained in a test double pipe unit showed that NTSM decline abruptly at  $2.3 \text{ m/s}(\text{kg/m}^3)^{0.5}$  in the stripping section, suggesting the flooding occurred at the point. Since this flooding point in the rectifying section was not found, additional test would be required to brush up the design strategy of the HIDiC. It seems that the overall heat transfer coefficient  $U$  will drop if the liquid flow rate per unit cross sectional area in the stripping section decreases less than  $5 \text{ m}^3/(\text{m}^2\text{h})$  because of the increase in dry spots. Consequently the cross sectional areas of the rectifying and the stripping sections should be designed in the above mentioned  $F$ -factor ( $<2.3 \text{ m/s}(\text{kg/m}^3)^{0.5}$ ) and the liquid flow rate ( $>5 \text{ m}^3/(\text{m}^2\text{h})$ ) by changing the diameter of inner pipe. These results shown in Figure 6 and 7 might be dependent on the size of unit (the inner pipe = 6", the outer pipe = 12"). If the diameter of the outer pipe increases up to 20" for example, the liquid load might be less than about  $15 \text{ m}^3/(\text{m}^2\text{h})$ .

According to the results obtained, the pilot HiDiC has been built and operated very successfully. The authors wish that the HiDiC technology become common in chemical industries to realize our sustainable world.

### **Acknowledgements**

This work was supported by Ministry of Economy, Trade and Industry (METI), Japan, New Energy and Industrial Technology Development Organization (NEDO), Japan and National Institute of Advanced Industrial Science and Technology (AIST), Japan. Authors would like to express sincere appreciation to Prof. Shuzo Ohe of Science University of Tokyo for worthy advices on our HiDiC development project.

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