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Development on a Coaxial Heat Integrated Distillation Column (HIDiC)

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Abstract−Various configurations of a column for performing the principle of HIDiC can be proposed, but a coaxial column which is installed a packing in an inside tube and outer side may be one of the simplest columns for HIDiC. In order to examine whether or not the configuration of the packed column mentioned above is appropriate to HIDiC, an experimental apparatus has been set up and heat and mass transfer rates have been measured by using benzene-toluene system.

Key words: Distillation, Heat Transfer, Packing, Shell and Tube, Energy Saving

INTRODUCTION

A distillation column, a major energy-consuming device, is widely used in oil refineries and other chemical plants. More than 80% of the exhaust energy from oil refineries is warm water that is disposed in the earth. A distillation column is, in general, divided into two sections, the rectifying section and the stripping section. Thermal energy has to be supplied to the stripping section and removed from the rectifying section. The bottom reboiler and top condenser single-handedly undertake the input and output of thermal energy, respectively. If the energy removed from the rectifying section could be reused for the stripping section, or waste-heat were available, energy savings would be achieved in a distillation column.

For a binary distillation column it is even feasible to conduct heat integration between its rectifying and stripping sections. Recently Takamatsu et al. further claimed that by such a heat integration, reboilers and condensers are, in principle, not necessary for distillation processes. It means that separation of binary mixtures can be achieved even when the reflux ratio and/or re-boil ratio are zero. Hence, operating costs can be sharply reduced.

In a heat integrated distillation column (HIDiC) system the rectifying and stripping sections are separated by installing a compressor and a throttling valve between them as shown in Fig. 2. The manipulation is completed by heat exchange between two sections. To provide the necessary temperature driving forces for heat to be transferred from the rectifying section to the stripping section, the former must be operated at a higher pressure than the latter. In the rectifying section, the total vapor flow and liquid flow become smaller towards the bottom. In other words, reflux is changed from stage to stage by condensation or evaporation. An operable HIDiC system must have mutual heat transfer between rectifying and stripping sections and efficient distillation at each section. An HIDiC system will improve energy saving in distillation plants. The theoretical quantity of energy saving and a method of design were shown in the previous reports. A simulator for the design of the HIDiC system has been developed by using a modified relaxation method and also a modified McCabe-Thiele method. However, it is difficult to find research on actual equipment. A fundamental and experimental research was done by Lueprasitsakul et al. by using a wetted-wall system. Their results suggested that the HIDiC system could be feasible even on the wetted-wall system. An HIDiC system for industrial use, however, requires much more internal heat transfer and higher efficiency of distillation at each section. Little research for actual use has been done because of the difficulty of simultaneous mass and heat transfer. Industrial use of the HIDiC system has been attempted by using a shell and tube type column with packing by Noda et al.

Looking closely at this system, it can be seen that the whole column acts like a heat pump. The heat-transfer medium is the liquid flowing down the stripping section. The stage with the lower temperature in the rectifying section is linked to the stage with the lower temperature in the stripping section. A large amount of energy consumed for those distillation columns could be saved by HIDiC. In order to reduce the output of carbon dioxide from chemical plants, the HIDiC system could be one of the most promising systems and should be completed as soon as possible. In previous papers the shell and tube type column shown in Fig. 1a was proposed for HIDiC and experimental work was done by using the benzene and toluene system. In the column, reasonably good heat transfer and distillation could be going on simultaneously. An industrial benzene-toluene distillation column is about 20,000 mm height and ϕ3,000 mm diameter. A bench plant is planned to be established in the Maruzen Petrochemical ethylene complex to prove the possibility of operation and reality of the idea of HIDiC.

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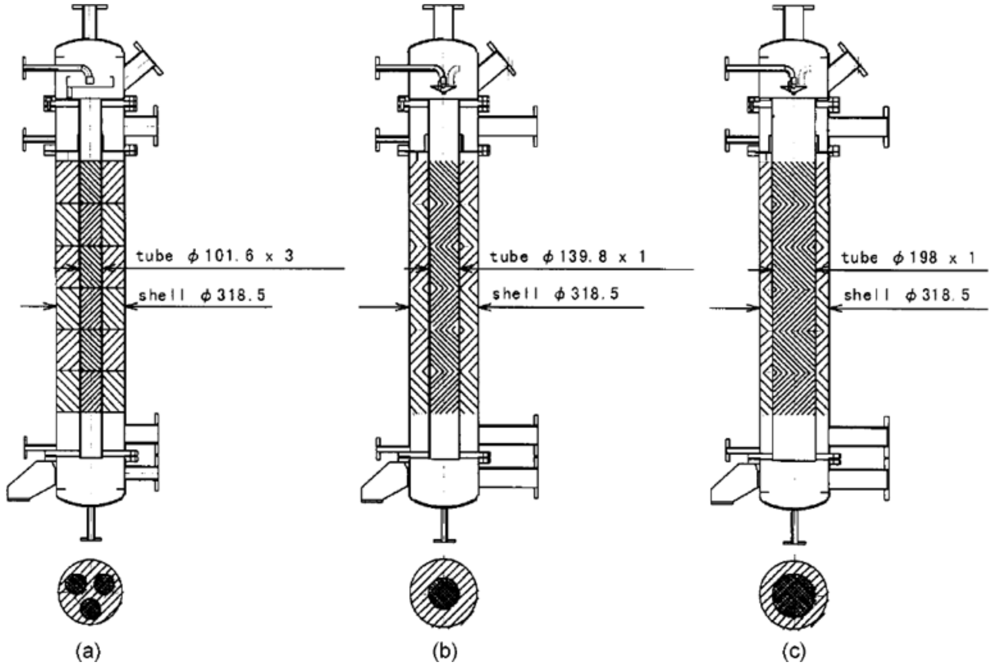

Fig. 1. a Multi-tube column, b Coaxial column, c Coaxial column.

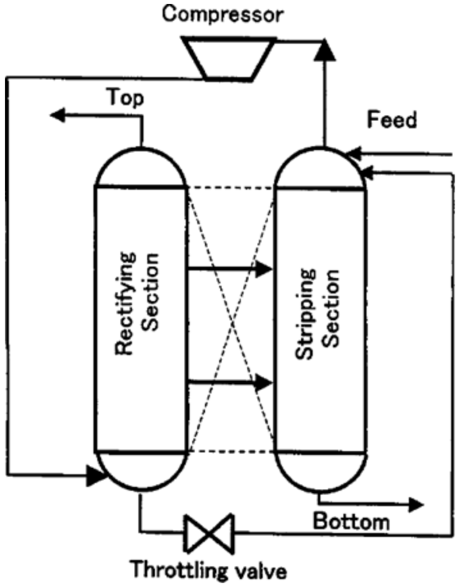

Fig. 2. Schematic flow diagram of HIDiC.

The dimensions of the bench plant are 20,000 mm height and ϕ254 mm diameter. To determine the possibility of the system, a coaxial column has been chosen for the bench plant, and by a numerical simulation the cross-sectional area of some sections should be changed along the height. It would be extremely difficult to manufacture a column having three 20,000 mm pipes, the diameter of which should be changed in the column, and in this paper two different sizes of an inner tube of coaxial columns were tested.

EXPERIMENTAL

1. Experimental Equipment

The flow schematic diagram of the system is shown in the previous papers. Three types of column were tested. The first one was a multi-tube type, the second and the third were a coaxial type with different diameter of inside tube. A sheet type packing was installed in an inner pipe in the column and a mesh type packing was inserted between column and the pipe at the length of 1,140 mm.

The cross-sectional and side view of the first column are shown in Fig. 1a. Diameter of the shell column is ϕ318.5, and in the shell column three pipes (of which outer diameter is ϕ101.6) are installed. Two distillation columns (A and B) are in the larger shell column-A. Column-A has an area between the inner of the shell column and outer side of the inner pipe, and column-B has an area of the inner pipe. Regular type packing is inserted by 1,140 mm height in both columns at the same level. The liquid of the reflux was returned to the top of the packing so as not to spread over other area than the heat exchange area. The dimensions and capacities of the main parts of the equipment are listed in Table 1. Secondly, two coaxial columns were tested on the same system and the cross-sectional views of the two columns are shown in Fig. 1b and 1c. The dimensions of the coaxial columns are also shown in Table 1.

2. Operation Procedure and Measurement of Experimental Data

To determine the over-all heat transfer coefficient and the ability of distillation of the column, which could be expressed by NTSM, we used the benzene and toluene system at total reflux under atmospheric pressure. The purity of the top and the bottom was

Table 1. Dimensions of the test columns

	Multi-tube	Coaxial-b	Coaxial-c
Column-A Diameter (mm)	318.5	318.5	318.5
Column-B Diameter (mm)	101.6×3	139.8×1	198×1

measured at total reflux and the amount of heat transfer between two sections was measured by a steam drain from the re-boiler. Although temperature difference between each section in a real HIDiC will be generated by pressure difference, in this research temperature difference between each section was created by the difference of the concentration of the benzene and toluene. First, a mixture of the same concentration was fed into both re-boilers. After stable state was reached, benzene or toluene was fed into one re-boiler and that produced a temperature difference between the two columns. The flow rates of distillate were measured by calibrated rotameters. The quantity of heat transfer was measured by the amount of the distillates. Temperatures were measured by thermocouples. Then, each condensed steam for heating of the re-boilers was measured by a beaker and a stopwatch. The heat duties of the two re-boilers were indirectly calculated by the measured steam drain. The amount of heat transfer through the wall of the tube was calculated by the difference between the measured steam drain A and B, and by this procedure the heat loss of the equipment could be eliminated. The mole fractions of distillate and bottom were analyzed by a gas chromatography (Shimadzu GC-14A).

3. Experimental Results

In Fig. 3 the relation between over-all heat transfer coefficient and vapor speed (F-factor) is shown. The relation between NTSM and vapor speed is shown in Fig. 4.

In the coaxial column the heat transfer coefficient and NTSM were almost the same as the results of the previous multi-pipe column. Efficiency of distillation is almost independent of the vapor speed in the pipe, but the over-all heat transfer coefficient is increasing with the vapor speed. The quantity of liquid in the column also increases with the amount of vapor and more liquid reaches the heat transfer area. The direction of heat transfer in this paper was from outer shell to the inner tube.

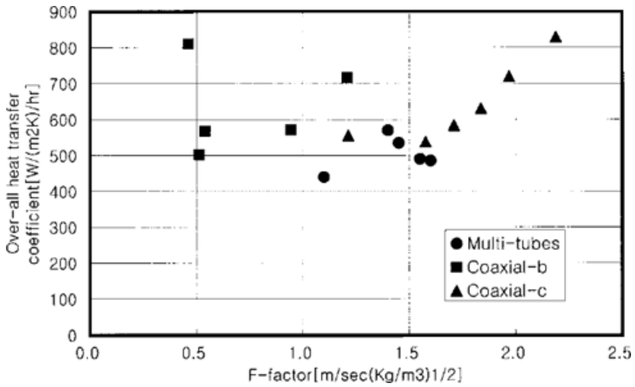

Fig. 3. Relation between F-factor and over-all heat coefficient.

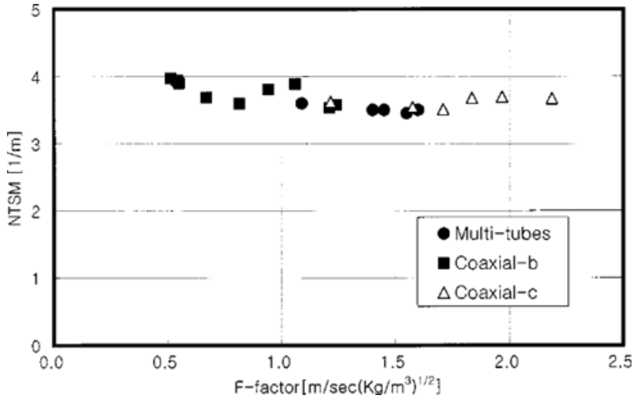

Fig. 4. Relation between F-factor and NTSM.

DISCUSSION

The experimental result shows that overall heat coefficients obtained were almost over a target figure of 500 [W/(m^2 K)/hr] and NTSM was over a target figure of 2.5 [1/m]. The overall heat coefficient of three different sizes of the inner tube was almost the same and dependent on the gas velocity. This fact suggests that the liquid inner tube flows towards surface of the tube, which means, as shown anywhere in a packed column, the liquid flow tends to shell side. Although the height of the test column was shorter than the planned bench plant, the results showed the promising future of HIDiC. In the planned bench plant, because of the vapor speed dependency of heat transfer coefficient, the diameter of the inner tube should be carefully designed. In the case of an actual plant it should be reasonable that the inner tube side works as a heater and shell side works as a condenser because the temperature of the shell side could be lower than that of the inner tube side. This system reduces heat loss from a column, and the thickness of the inner tube should be thinner than this experimental situation (The pressure of the shell side was higher than inside of the tube).

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NOMENCLATURE

F : F-factor [m/sec (kg/m^3)$^{1/2}$]
NTSM : number of theoretical stages per meter [1/m]
ΔH : quantity of heat transfer [W/hr]
U : overall heat transfer coefficient [W/(m^2 K)/hr]

REFERENCES

Japanese patent No.2694425.

Lueprasitsakul, V., Hasebe, S., Hasimoto, I. and Takamatsu, T., "Study of Energy Efficiency of a Wetted-wall Distillation Column with Internal Heat Integration," *J. Chem. Eng. Japan*, **23**(5), 580 (1990).

Mah, R. S. H., Nicholas, J. J. and Wodnik, R. B., "Distillation with Secondary Reflux and Vaporization," *AIChE J.*, **23**, 651 (1977).

Matsuo, H., Aso, K. and Yano, K., Preprint of the autumn meeting of the S.C.E.J. at Hokkaido (1995).

Mukaida, T., Noda, H., Kuratani, N., Takamatsu, T., Nakaiwa, M., Aso, K. and Nakanishi, T., Preprint of the autumn meeting of the S. C. E. J. at Yonezawa, 186 (1998).

Nakanishi, T., Aso, K., Takamatsu, T., Nakaiwa, M., Noda, H., Kuratani, N. and Yoshida, K., Preprint of the autumn meeting of the

S. C. E. J. at Yonezawa, 185 (1998).

Noda, H., Aso, K., Kobayashi, N., Nakaiwa, M. and Takamatsu, T., "On Development of New Distillation Column for Energy Saving: A Fundamental Experimental Research on Mass & Heat Transfer in HIDiC," Proceeding of the APCSEET (Singapore), 321 (1996).

Noda, H., Kuratani, N., Aso, K., Matsuo, H., Kobayashi, N. and Matsubara, G., Preprint of the autumn meeting of the S. C. E. J. at Hokkaido (1995).

Takamatsu, T., Nakaiwa, M., Huang, K., Noda, H., Nakanishi, T. and Aso, K., "Simulation-Oriented Development of a New Heat Integrated Distillation Column and its Characteristics for Energy Saving," *Comput. Chem. Eng.*, **S21**, 243 (1997).

US patent No. 5,783,047.