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A Hydraulic and Feasibility Study of New Tower Internal in Gas Processing Plants

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Abstract : A new tower internal, which is called CSE, is presented. The CSE is composed of a nozzle perforated in its bottom along the entire periphery and equipped with a multi vane axial swirler at the inlet and hollow cylindrical separator at the outlet of the nozzle. According to the experimental work for obtaining the necessary hydraulic information of the CSE, which is used for preliminary design of a separation column, the CSE showed a stable operation over the wide rage of gas/liquid ratio. However, it caused large pressure drop due to the high gas velocity which should carry liquid droplets through the element. The high pressure drop may cause problems in energy recovery and the application of the CSE can be limited to the high pressure columns. Assuming that the tray efficiency of the CSE is the same with the existing separation columns, the results of the column design showed the size reduction of the column diameters by 30 to 40% and investment cost saving, depending on operating conditions. The application of the CSE to separation column may also contribute to the de-bottlenecking the existing column.

Key words: tower internal, cost saving, capacity increase, gas processing plant

1. Introduction

Chemical process industries have been large attention on the de-bottlenecking of their existing plants for production increase and reduction of unit consumption. For some equipment, such as pump, blower, and heat exchanger, de-bottlenecking can be relatively easy and straightforward. However, de-bottlenecking a tower column is a major problem. A capacity increase of tower may cause reduction of separation efficiency and further increase makes tower operation impossible. Also replacing existing tower or installing a second tower in parallel is unacceptable in most cases.

Fair and Seibert (Fair and Seibert, 1996) suggested many possible ways of increasing tower capacity. They also pointed out advantages and disadvantages of each de-bottlenecking method.

One of the widely used methods to increase tower capacity is by replacing tower internals with new ones, such as packing or high performance trays. Most of the research on this field has concentrated on improving mass transfer efficiency and increasing tower capacity (Alpbaz *et al.*, 2002).

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In this paper, a new tower internal called CSE (contact and separation element), which may be employed on de-bottlenecking tower column, will be introduced and its capacity limitation and hydraulic results will be shown. Also based on the hydraulic information of the CSE obtained from the experiment, the size and cost of the separation column with the CSE will be compared with those of the existing column.

2. Theoretical Study

2.1 Operation Principle of the CSE

The vortex jet designed to solve the problem of continuous ignition of liquid fuel with the development of rocket technology in Russia was applied to the field of chemical process in early 1960's. One of application area of vortex jet was gas-liquid separator. Recently, a new tower (Kiselev, 1989, 1990) internal which utilizes the phenomena of vortex jet in mass transfer column was introduced and its possible application has been studied (Choi and Choo 1997).

A schematic diagram of the CSE is shown in Fig. 1. As shown in Fig. 1, the element is composed of a nozzle perforated on its bottom along the entire periphery. A multi vane axial swirler is located at the

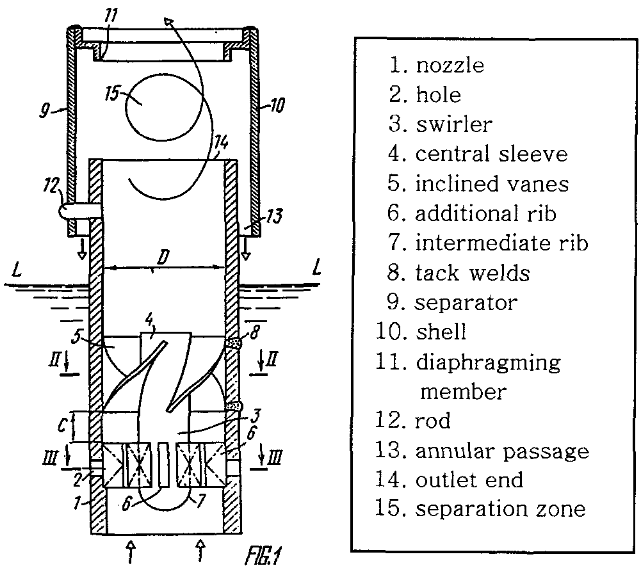

Fig. 1. A schematic diagram of the CSE.

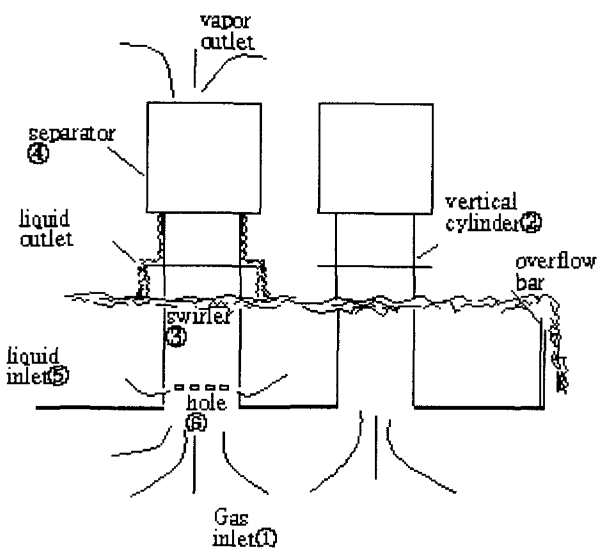

Fig. 2. Principle of the CSE operation.

inlet and hollow cylindrical separator at the outlet of the nozzle.

Fig. 2 represents the operating principle of the CSE when it is applied to the distillation column. As the vapor enters at the inlet nozzle ①, it carries small liquid drops flowing from the perforated holes ⑥ and passes through the axial swirler ③. Injective turbulence within the swirler may enhance heat and mass transfer between vapor and liquid. The swirling motion of vapor enables liquid droplets ⑤ to form thin liquid film on the inside wall of the element and liquid film moves upward through the vertical cylinder ② due to the resistance at the interface with vapor. The liquid film becomes a heavy sheet at the cylindrical separator ④ and returns to the liquid phase of tray. Vapor from the separator leaves the element and goes to the next tray.

2.2 Hydraulic Study

The total pressure drop, ΔP, across the CSE unit can be defined as

$$\Delta P = \Delta P_{dry} + \Delta P_{g-l} \tag{1}$$

where ΔP_{dry} represents the pressure drop with no liquid flow and $\Delta P_{g\text{-}l}$ means the pressure drop due to liquid flow.

The dry pressure drop of Equation (1) can be expressed as

$$\Delta P_{dry} = \rho W_0^2\left(\frac{1}{\mu^2} + \zeta\frac{F_0^2}{F_{bx}^2}\right) \tag{2}$$

where ρ and W_0 represent the gas density and the gas velocity across the unit, respectively. μ is the flow factor and ζ the inlet resistance factor. F_0 and F_{bx} mean areas of the unit and the inlet nozzle, respectively.

The pressure drop due to liquid flow is represented as

$$\Delta P_{g-l} = \frac{L}{G}\rho\left(\frac{CW_k^2}{2} + g\Delta z\right)\left(\frac{\nu_l}{\nu_w}\right)^{0.45} \tag{3}$$

where

L: mass flow of liquid
G: mass flow of gas
C: factor of specific spray
W_k: gas velocity within swirler channel
g: gravitational acceleration constant
Δz: height of the CSE unit
ν_l, ν_w: dynamic viscosities of liquid and water, respectively.

The flow factor of swirling pipe, μ, considers the swirling motion and geometric effect while the factor of specific spray, C, is a function of liquid flux and can be obtained from experiment.

3. Experimental Study

The experimental apparatus used in the hydraulic measurement is shown in Fig. 3. By using the air-water system, the pressure drop of the CSE according to various air and water flow rates can be measured. When the sieve tray is installed in the column, the pressure drop was measured in order to compare the hydraulic results between sieve tray and CSE. Also the concentration of dissolved oxygen was measured.

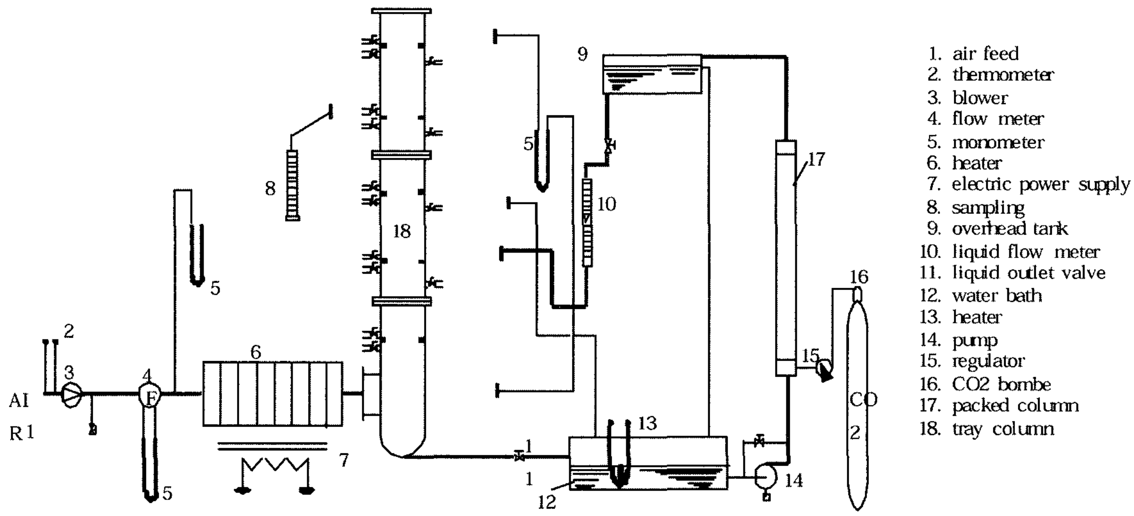

Fig. 3. A schematic representation of experimental apparatus.

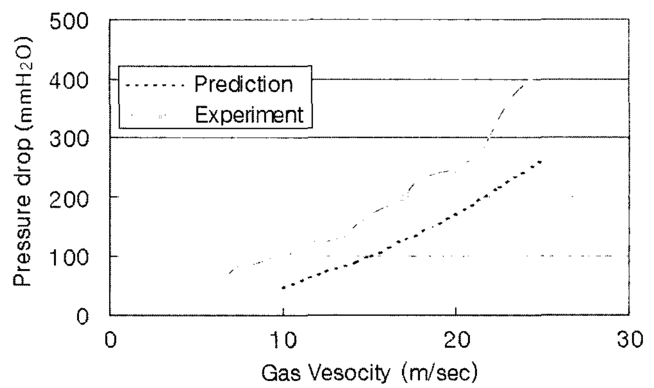

Fig. 4. Comparison between experiment and prediction (dry pressure drop).

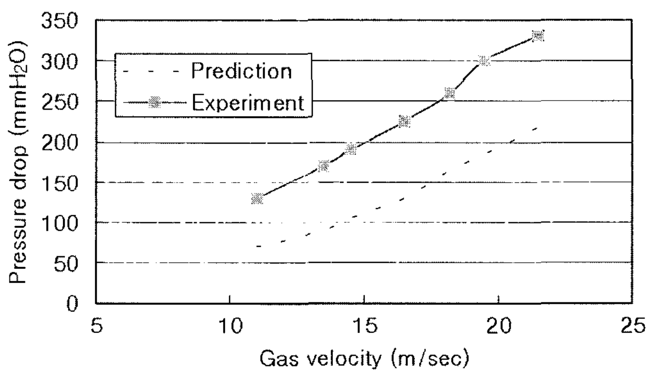

Fig. 5. Comparison between experiment and prediction (wet pressure drop).

4. Discussions

Comparisons between the experimental and predicted values based on Equation (2) and Equation (3) are shown in Fig. 4 and Fig. 5. Since the prediction is not based on the rigorous fluid dynamics, the comparison shows only a marginal agreement.

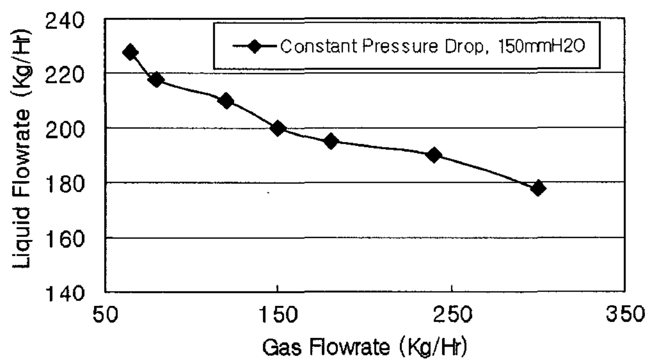

Fig. 6. Operating range of the CSE (constant pressure drop line).

Based on the hydraulic data, the constant pressure drop line of the CSE is obtained and shown in Fig. 6.

The operation flexibility in the CSE is much better than that of sieve tray. The high flow rate of air in sieve tray can cause excessive entrainment, while the low gas flow rate can show severe weeping. On the other hand, the CSE shows stable operation over the whole operation range shown in Fig. 6.

Using the results of the hydraulic experimental results, the basic specification of the single CSE is obtained and presented in Table 1. Also the expected performance comparison between CSE and bubble cap

Table 1. Basic specification for the CSE

Item	Value
Velocity factor, $(m/s)(kg/m^3)^{1/2}$	12~33
Max. liquid load on cross sectional area, (m^3/m^2h)	150
Pressure drop, (Pa)	390~3530
Applicable pressure, (MPa)	0.1~16

Table 2. Comparison between CSE and bubble cap tray

Item	Column Type	
	CSE	Bubble cap
Vapor velocity (m/s)	7.0	1.8
Reflux ratio	1.0	1.5
Capacity (%)	500	100
Production (Kg/h)	17,800	6800
Distillate	16,000	5000

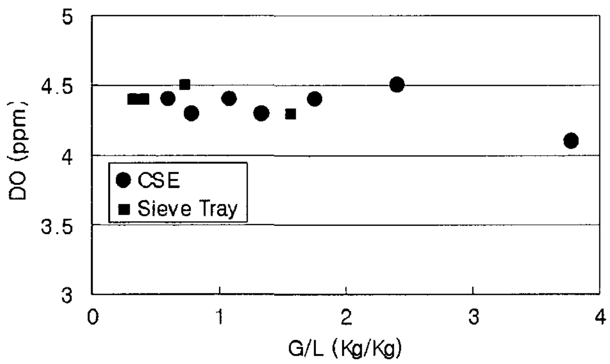

Fig. 7. Comparison of DO between CSE and sieve tray (raw water DO=0.4).

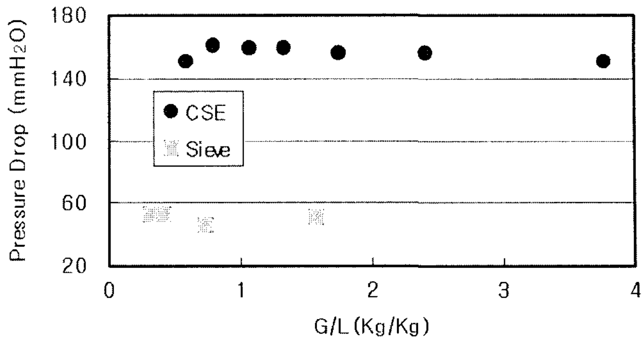

Fig. 8. Comparison of pressure drop between CSE and sieve tray.

Table 4. Comparison of equipment cost between existing column and CSE (1000 $)

Item	Existing column	CSE	Saving (%)
Re-contactor	363.1	204.0	44
De-ethanizer	378.6	338.6	11
LPG column	260.5	239.3	8

tray is shown in Table 2. Even though the mass transfer efficiency is not considered in this comparison, the CSE can be employed for the capacity increase in the existing columns due to the safe and stable operation flexibility.

The concentration of oxygen dissolved in the water treated with CSE is shown in Fig. 7 and the results are comparable to those of sieve tray. It is not possible to operate the column with sieve tray at high gas flow rate because of the entrainment. However, the CSE shows a stable and safe operation at high gas flow rate without loosing the tray efficiency. Also the pressure drop was measured and shown in Fig. 8. As expected, the pressure drop with CSE is much higher than that of sieve tray.

The results of the CSE application on the three towers in gas processing plant are compared with those of the existing columns, as shown in Table 3. The result of Table 3 is only based on hydraulic experimental results and the assumption that the tray efficiency of the CSE is the same with those of the existing columns. The CSE could not be applicable to the entire towers of de-ethanizer and LPG column because of the low gas flow rate within the lower section of the column. Therefore upper part of the column which shows large vapor flow rate can be replaced by the CSE. Even though mass transfer has not been considered in this tower design, the employment of CSE may be selected as one way de-bottlenecking the separation column. Also one can easily expect the cost reduction of new tower installation with the CSE and the results are shown in Table 4.

5. Conclusions

One of the major advantages of CSE is operating flexibility. Without excessive entrainment and severe weeping, it keeps stable and continuous contact between liquid and gas phase. It may increase the contact area and mass transfer efficiency between vapor and liquid phase caused by swirling motion. As a result, the CSE can reduce size in new tower design while at the same

Table 3. Comparison of tower size between existing column and CSE

Item	Existing column		CSE		Remark
	Diameter (mm)	Height (m)	Diameter (mm)	Height (m)	
Re-contactor	3350	16.8	2000	13.4	
De-ethanizer	1900/2400	31.9	1000/2400	31.9	Upper 18 trays
LPG column	1900	29.6	1000/1900	29.6	Upper 26 trays

time increasing the capacity of the tower in existing plants. Also the CSE can reduce tray spacing due to the prevention of entrainment. Therefore, the application of the CSE in separation column may reduce the investment cost and makes it possible to improve the tower performance.

One major problem in the CSE is a large pressure drop and another is that its application may be limited to the process at a high gas flow rate because gas should carry liquid droplets and pass through the axial swirler. One could easily expect that the CSE is suitable for the high pressure and high gas flow process. The other problem is the lack of theoretical analysis in the fluid dynamics for the swirling motion within the CSE due to the complicated phenomena and structural effects.

Even though much experiments and research will be required for application of the CSE on commercial plants, this kind of approach may provide a method for solving the problem of increasing the capacity of the tower.

Acknowledgement

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