Distillation Absorption 2010
A.B. de Haan, H. Kooijman and A. Górak (Editors)
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AN INTRODUCTION TO NEW HIGEE DEVICE AND ITS INDUSTRIAL APPLICATIONS

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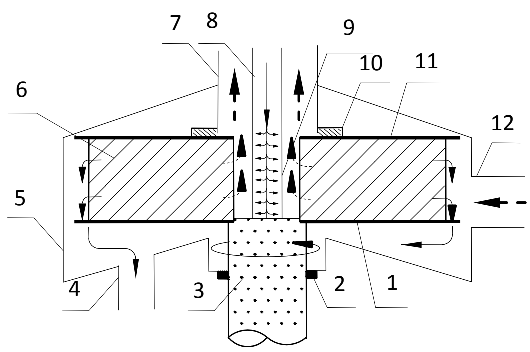
Abstract
A new HIGEE device-rotating zigzag bed (RZB) was developed in the context of process intensification. The RZB is structurally featured by a combinatorial rotor of one series of baffles attached to a rotating disk with another series to a stationary disk. The novel structure of the RZB determines its many advantages over the other HIGEE devices. The RZB is free of dynamic seal, capable of intermediate feed and simple coaxial multi-rotor configuration. These advantages qualify the RZB for utilization in continuous distillation. Three cases in different common processes were presented here to illustrate its industrial application. So the RZB is a kind of high efficiency gas-liquid contactor and opens up broad prospects for HIGEE technology commercialized in industrial continuous distillation processes.

Key words: HIGEE, rotor, zigzag, stationary, application

1. Introduction

In the last two decades, more and more attention from academia and industries was paid to process intensification (PI). However, the PI concept may date back to the late 1970s when Ramshaw, as the innovator, and his team[1] at Imperial Chemical Industries (ICI) started thinking about the way to substantially reduce the size of equipment and production system. They extended "artificial gravity"—centrifugal field into mass and heat transfer operations and thus pioneered rotating packed bed (RPB)[2,3]. This novel technology is often referred to as Higee (an acronym for high gravity). RPB, recognized as the first example of PI concept, can decrease equipment volume by 1~2 orders of magnitude compared with its conventional counterpart. A typical RPB is schematically shown in Figure 1. As the centrifugal force can be several hundred times the gravity, some benefits can be attained such as very high mass transfer efficiency, reduced tendency to flooding, resistance to moderate disturbance and inclination. These benefits make RPB an attractive alternative in mass transfer services. Of course, the rotor of rotating bed can be made of various kinds of media. So far, to the best of our knowledge, several types of rotor exist as reported in literatures[4]. It should be noticed that the common to these rotors is that both upper and lower plate are rotational, which results in their same disadvantages presented below.

From the standpoint of industrial application, rotating bed now available has inherent disadvantages. Firstly, inside the rotating bed there exists one dynamic seal (see Fig. 1), which prevents the gas from bypassing the rotor, but compromises the reliability and longevity due to its contact with working fluid. Secondly, ONE unit can not be competent for continuous distillation owing to incapability of feeding the rotor at radial position, equivalent to middle plate of traditional distillation column. Thus two units of rotating bed are required for continuous distillation; one as rectifying and the other stripping (see Fig.2). Finally, it is structurally difficult for these rotating beds to coaxially install multiple rotors in one casing. Todd[5] has filed a patent for a coaxial multi-rotor centrifugal contactor, which is very complicated due to dynamic seals and liquid collection/drainage devices between adjacent rotors. The complicated structures are adverse to fabrication and hamper their practicability.



1-lower plate 2-shaft seal 3-shaft 4-liquid outlet 5-casing 6-rotor 7-gas outlet 8-liquid inlet 9-liquid distributor 10-dynamic seal 11-upper plate 12-gas inlet

Fig.1 A simplified schematic of typical RPB

To resolve the problems above, a new kind of rotor was invented, which based on a new idea that the upper plate is stationary and the lower rotational. The HIGEE device including this kind of rotor was called rotating zigzag bed (RZB), which was patented in China[6,7] and United States[8] and has been successfully applied in continuous distillation processes. The aim of this paper is to present the structures, characteristics and several application cases of RZB.

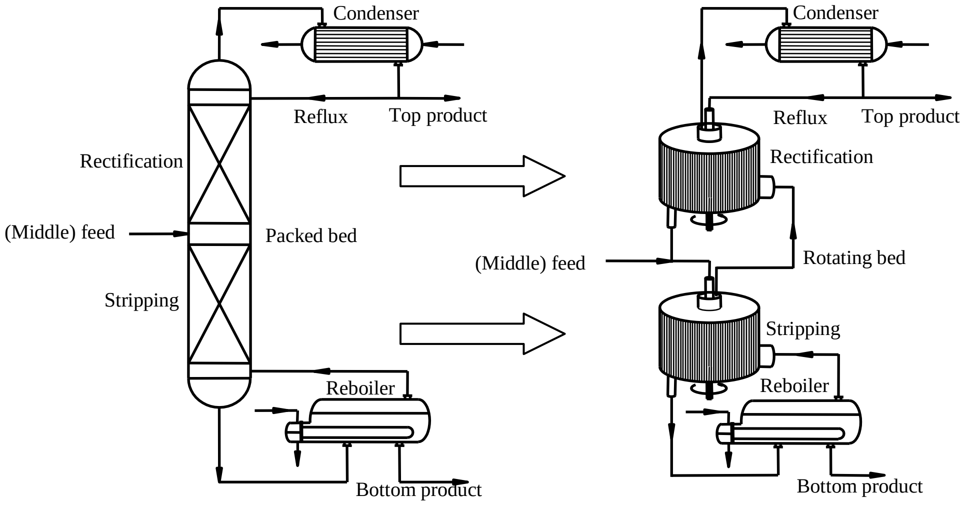
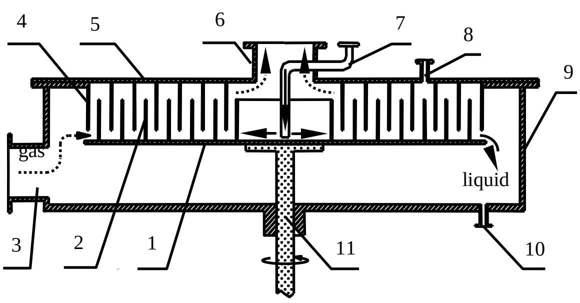


Figure 2 Continuous distillation process using packed bed and rotating

2. Rotating Zigzag Bed

The RZB is featured by a combinatorial rotor of a rotating disk with a stationary one, on which two series of concentric circular sheets are fixed respectively as shown in Figure 3: one series as rotational baffles, the upper part of which is perforated, and the other as stationary baffles. The perforated rotational baffles allow gas to traverse and prevent liquid from back-mixing to some extent. These baffles are arranged together with alternate sheets staggered in a vertical direction by certain distance with respect to adjacent sheets. Thus the clearance between the rotational baffles and the upper disk as well as between stationary baffles and the lower disk offers zigzag flow channels for gas and liquid. In the interior of RZB the continuous gas phase flowing in a staggered way contacts with the liquid phase that was repeatedly dispersed and coalesced, as shown in Figure 4. Contact process in mass transfer zone can be divided into three steps. The first step, zone I, is crosscurrent contact of gas with liquid droplets. The second, zone II, is gas countercurrently contacting with liquid falling down along the stationary baffles. And the last, zone III, is crosscurrent contact of two phases when the liquid travels through the space between the stationary baffle and rotational disk. This analysis was partially confirmed by experiments. Here, the second step presumedly makes a major contribution because the turbulent surfaces of falling liquid renew rapidly due to friction imposed by rotational gas flow and continual impact by liquid droplets. This is equivalent to a small wetted-wall column in centrifugal field and the rotor of RZB can be considered as a cluster of such wetted-wall columns. It should be noted that the detailed gas-liquid contact mechanism in RZB still needs further investigation.



1-rotational disc 2-rotational baffle 3-gas inlet 4-stationary baffle 5-stationary disc 6-gas outlet 7-liquid inlet 8-middle feed 9-liquid outlet 10- casing 11-shaft

Fig 3 A simplified sketch of the RZB and its rotor

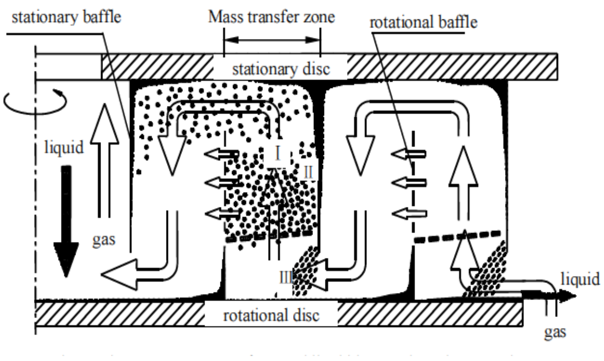
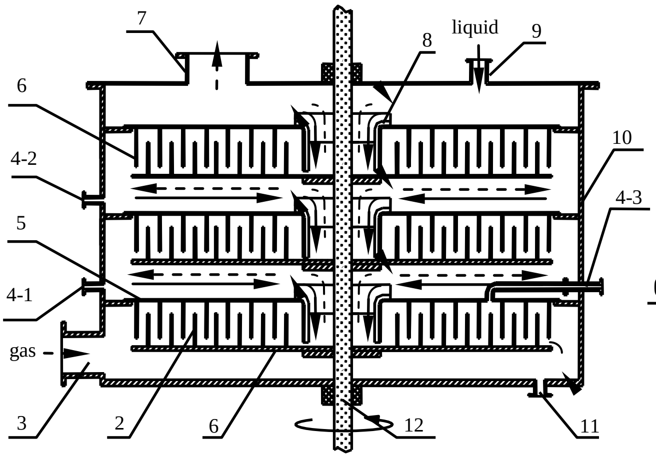


Fig 4 Local contact mechanism of gas-liquid in RZB

The unique rotor brings the RZB several advantages over the other rotating beds. Firstly, the RZB doesn't need the dynamic seal in Figure 1, which simplifies the construction, installation and improves the reliability of equipments. Secondly, middle feeds for distillation processes can be easily realized by installing an inlet at the stationary upper disk. Thus it is viable for only one unit of RZB to perform a continuous distillation task. Thirdly, for the RZB it is simple and convenient to install multiple rotors in one casing as illustrated in Figure 5. In this configuration, without liquid collection apparatus between rotors, the liquid still can pass sequentially through each of the rotor. While without dynamic seals between rotors, the gas also can flow sequentially through each of the rotor. Additionally, the RZB doesn't require initial liquid distributor because the baffles themselves can play the role of distributor and collector respectively, repeatedly dispersing and collecting the liquid. These outstanding advantages greatly simplify the interior structure of multi-rotor rotating bed and make continuous distillation systems more compact as shown in Figure 6.



1-rotational disk 2-rotational baffle 3-gas inlet 4-1, 2, 3-liquid inlet 5-stationary disk 6-stationary baffle 7-gas outlet 8-guide pipe 9-reflux pipe 10-rotor housing 11-liquid outlet 12-rotating shaft

Figure 5 Schematic diagram of the RZB with multiple rotors

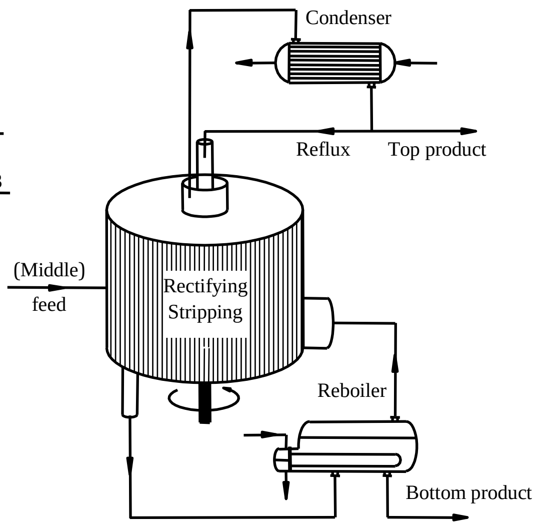


Figure.6 Continuous distillation process using RZB

3. Industrial Applications

Now HIGEE devices have been commercialized in absorption, desorption, desulfurization, dedusting, and nanomaterial synthesis, but few industrialization in distillation except for pilot plant tests was reported. The RZB just fills this gap and so far more than 100 units have been used in chemical, pharmaceutical, fine chemical, biochemical and environment protection applications. The RZB is a successful example of HIGEE in industrial continuous distillation. Three typical examples are given as follows.

3.1 Conventional distillation

In a chemical plant, a three-rotor RZB, with outer diameter 75cm, installed in one casing with diameter 83cm and height 80cm, has been employed to recover methanol from water in continuous distillation. Figure 7 shows the industrial scene of the RZB in plant. With rotating speed of 1000 rpm and reflux ratio of 1.5 and methanol mass composition in feed of 0.7, the concentration of the top product is 99.8% and the concentration of the bottom residual is 0.2%, with product output 12ton/day. It is equivalent to a packed column with diameter of 0.6m and height about 10m. In a pharmaceutical plant, an RZB with two rotors with the outer diameter of 75cm is used to separate ethanol from water in continuous distillation. The photograph of scenes is also given in Figure 7.The casing is 80cm in diameter and 55cm in height. With rotating speed of 1000 rpm and reflux ratio of 2.5, if the mass fraction and flowrate of feed is 45% (ethanol) and 470 kg/h respectively, the concentration of the top product is larger than 95% and the concentration of the bottom residual liquid is less than 0.5%. It corresponds to a packed column with 0.4cm diameter and 9m height.

The dimension comparison between the RZB and packed column is given in Table 1, which suggests that 1~2 order of magnitude of reduction in height and volume respectively could be attained in RZB.

Therefore, the RZB is a kind of miniaturized gas-liquid contactors embodying the concept of process intensification. The RZB opens a possibility for HIGEE to commercially apply in continuous distillation processes.

Figure 7 Onsite pictures of recovery of methanol (left) and ethanol (right) by RZB in the industrial continuous distillations

Table 1 Dimension comparison between RZB and PB under the same conditions

	Methanol-water		Ethanol-water	
	RZB	Packed column	RZB	Packed column
Diameter/m	0.83	0.6	0.80	0.4
Total height/m	0.80	11.0	0.55	9.0
Volume/m^3	0.433	3.11	0.276	1.13
Height ratio/-	~0.07		~0.06	
Volume ratio/-	~0.14		~0.24	

3.2 Special distillation

Anhydrous ethanol (AEA) is not only used as chemical reagent and organic solvent (e.g. in etherification), but also used, pure or mixed with gasoline, as a promising automotive fuel. In a pharmaceutical plant, two units of RZB were utilized to produce anhydrous ethanol using extractive distillation, with flowsheet shown in Figure 8. The feed (about 90% ethanol) and extractive agent enter into the first RZB that separates the feed into anhydrous ethanol and extrantant-water mixture, which then goes to the second RZB operating at vacuum. The second RZB separates the feed into pure water and extractive agent, which is, after cooling, recycled to the inlet feed of the first RZB. The relevant size and operating parameters were listed in Table 2.

Table 2 Dimension and operation parameters of RZB in production of anhydrous ethanol

	Rotor		Casing		Power (kW)	Reflux ratio	Capacity (ton/day)	Product H_2O%
	Diameter(m)	Number	Diameter(m)	height(m)				
1-1	0.75	3	0.83	0.8	11	1	9.6	<0.7%
1-2	0.75	2	0.83	0.6	5.5	1	-	<0.3%

3.3 Stripping

RZB, as a kind of general gas-liquid contactor, can also be adopted in stripping processes. Due to unique features, application RZB in stripping shows some incomparable advantages over traditional contactors. In a biochemical plant, methanol was used as solvent in production of a product, which is high-viscous and thermal-sensitive. To remove the solvent residue in final product, originally batch distillation in a packed column was used, as illustrated by Figure 9a. On the one hand, the column was operated under reduced pressure in order to avoid thermal decomposition of the product in reboiler. However, reduced pressure causes another problem that the distillate—methanol only can be condensed by brine other than water. On the other hand, the feed is directly introduced in reboiler because the purer product is highly viscous and likely to clog the packing. To reduce batch time, a reboiler with a large volume is required. Obviously, reduced pressure, cooling brine and larger reboiler will increase energy consumption. Even so, there still exists 0.3% residue of methanol in product.

Now this process was revamped using a unit of three-rotor RZB with flow diagram shown in Figure 9b. Compared with original process, the new one is atmospheric steam stripping, where the reboiler is not required. Steam and feed both are introduced in rotating bed. On the one hand, very short residence time of the product in RZB effectively prevents the product from decomposition even at a higher temperature. On the other hand, the concentrated methanol at the top could be easily condensed by cooling water and the vacuum pump and refrigerating unit does not need. In addition, the product quality is improved in that the residual mass concentration in product is lower than 0.1%. RZB steam stripping process was compared with packed column distillation process in Table 3, from which it can be seen that new technology greatly reduces capital and operating costs as well as area and space occupied. This is a good paradigm of intensifying chemical process by HIGEE technology.

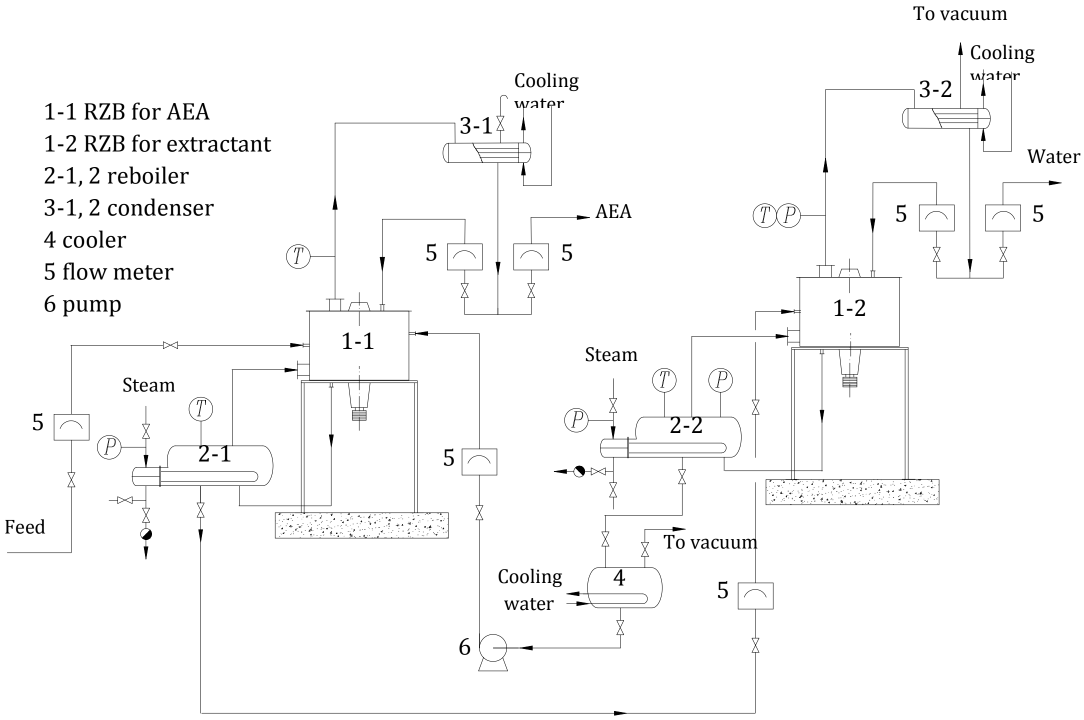


Figure 8 Flowsheet of AEA production using two RZBs by extractive distillation

Table 3 Comparison of RZB and packed column in solvent removal of heat-sensitive system

items		RZB	Packed column
Operation mode		Continuous	Batch
Process type		Stripping	Distillation
Capacity(kg/h)		2000	2000
Methanol fraction in product		0.1%	0.3%
Reboiler volume (m^3)		None	8
Cooling medium		water	Brine
Operating pressure		Atmospheric pressure	Reduced pressure
Power/kW	refrigerating set	-	20
	vacuum set	-	15
	RZB	18	-
	Total	18	35
Area occupied (m^2)		4	16
Space occupied (m^3)		12	80

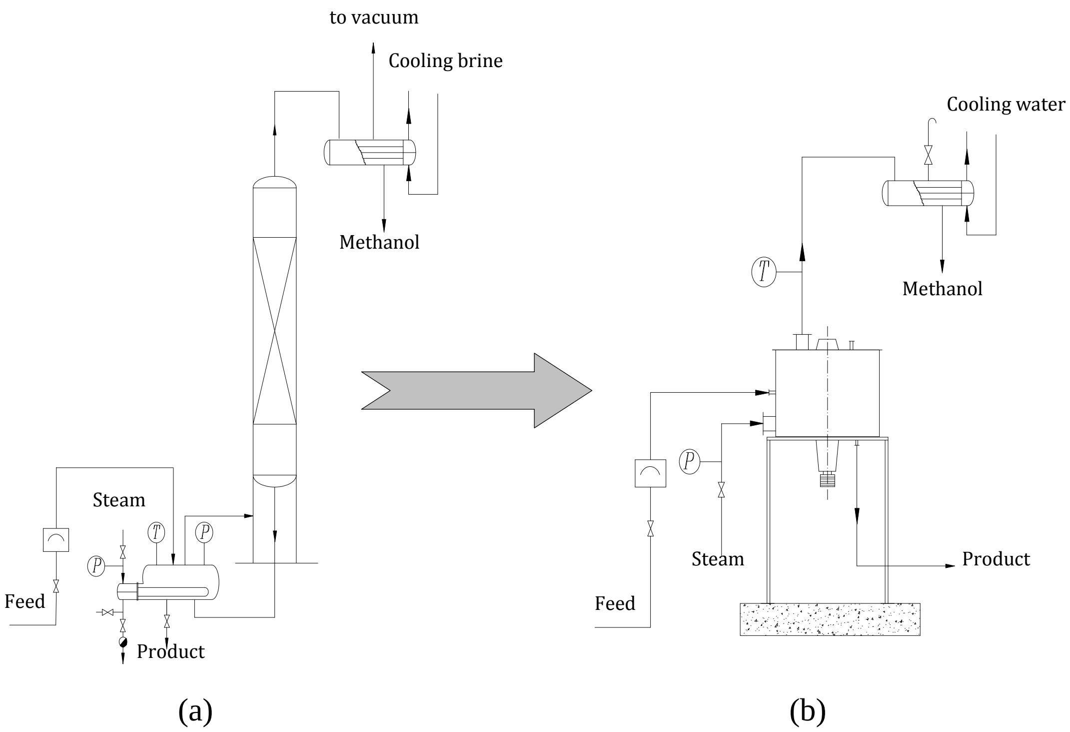


Figure 9 Flow diagram of methanol removal from heat-sensitive system using (a) packed bed by batch distillation (b) RZB by continuous steam stripping

4．Conclusions

A new type of Higee equipment-rotating zigzag bed (RZB) is developed. The RZB has many superior characteristics because of its unique rotor structure, which is distinguished by combination of a rotary element with a stationary one. The RZB can easily realize intermediate feed of continuous distillation processes in comparison with the RPB. Mass transfer capacity of the RZB can be greatly increased by multi-rotor configuration. These advantages qualify the RZB for utilization in continuous distillation. Now few HIGEE devices industrialized in distillation except for pilot plant tests was reported. The RZB just fills this gap and so far more than 100 units have been used in chemical, pharmaceutical, fine chemical, biochemical and environment protection applications. Commercially application cases show that the RZB is a promising alternative in chemical process industries, especially in continuous distillation operations.

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