

Development status and future research direction of molecular distillation technology

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Abstract: Molecular distillation is a new separation technology. Compared with the traditional separation technology, the operating temperature is far lower than the boiling point of liquid, the distillation pressure is under extremely high vacuum, the heating time is short, the system is basically oxygen-free, and the effective components in the system can be guaranteed to the maximum extent. The basic principle, technical characteristics and equipment of molecular distillation technology are reviewed, and its advantages and disadvantages are analyzed and evaluated. The application of molecular distillation technology in industrial production, existing problems and solutions are introduced, which shows a broad application prospect. The advantages and disadvantages of the application of molecular distillation technology in various fields are discussed. In this paper, the molecular distillation technology is comprehensively reviewed from the aspects of its principle, structure type, industrial application and research status. Finally, on this basis, the key problems to be solved urgently in the future of molecular distillation technology are put forward, and the prospect of promoting the industrialization process of molecular distillation technology is put forward.

Keywords: Molecular distillation, Separation technology, molecular distillation technology

1. Introduction

Molecular distillation technology is a special liquid-liquid separation technology, which came into being in the 1920s. It is a new separation technology gradually emerging with the in-depth study of the theory of gas movement in vacuum and the continuous development of vacuum distillation technology [1]. It belongs to a special high vacuum distillation technology, and its most notable feature is that the distance between the evaporation surface and the condensation surface of distilled material molecules is not affected by the collision resistance between molecules, and the distance between the evaporation surface and the condensation surface is smaller than the average free path of molecular movement of distilled material molecules under this condition. It can solve the separation problem of substances with heat sensitivity and high boiling point. Molecular distillation, also called short-path distillation, is a continuous distillation process under high vacuum [2]. The molecular distillation process can be divided into five parts: liquid film formation on the evaporation surface, free evaporation of liquid film on the evaporation surface, transfer of gas-phase space molecules, condensation of gas molecules on the condensation surface and collection of distillation products [3].

As a mild distillation separation method, molecular distillation technology overcomes the disadvantages of high temperature and long heating time of conventional distillation, and can solve the problems that conventional distillation can't solve. It has a broad application prospect. As a mature separation technology, distillation is widely used in industrial production. Molecular distillation uses the difference of the average free path of molecular movement of different substances to achieve the purpose of separation, which can solve the problems that cannot be solved by conventional distillation technology. Molecular distillation is an unbalanced separation process under high vacuum [4]. The molecular distillation process is different from the traditional distillation process. In the traditional distillation, the separation is carried out at the boiling point temperature, the evaporation and condensation processes are reversible, and the liquid phase and the vapor phase will form an equilibrium state. Molecular distillation is an irreversible distillation process that is carried out at a temperature far from the boiling point of a substance at atmospheric pressure, more specifically, it is a process of molecular evaporation [5]. Molecular distillation has the advantages of short residence time of materials, low operating temperature, high separation degree and clean and environment-friendly process. It is especially suitable for enriching or purifying organic compounds with high boiling point, high viscosity or heat sensitivity, and is widely used in many fields.

2. Principle and characteristics of molecular distillation technology

2.1. Basic principle and process

According to the theory of molecular motion, the molecules of liquid mixture will move more violently when heated, and when they receive enough energy, they will become gas molecules and escape from the liquid surface [6]. Molecular distillation is a non-equilibrium distillation under high vacuum, which has a special mechanism of mass and heat transfer. Molecular distillation technology means that under high vacuum conditions, the distance between the evaporation surface and the condensation surface is less than or equal to the average free path of the vapor molecules of the separated materials, and the molecules escaping from the evaporation surface do not collide with the molecules of the residual air, nor do they collide with each other themselves, so that they rush and condense on the condensation surface without hindrance [7]. The average free path of light molecules is large, but that of heavy molecules is small. If a condensation surface is set at a position which is smaller than the average free path of light molecules but larger than the average free path of heavy molecules from the liquid surface, the light molecules will fall on the condensation surface and be condensed, while the heavy molecules will return to the original liquid surface because they can't reach the condensation surface, thus the mixture will be separated. The specific separation process is shown in Figure 1.

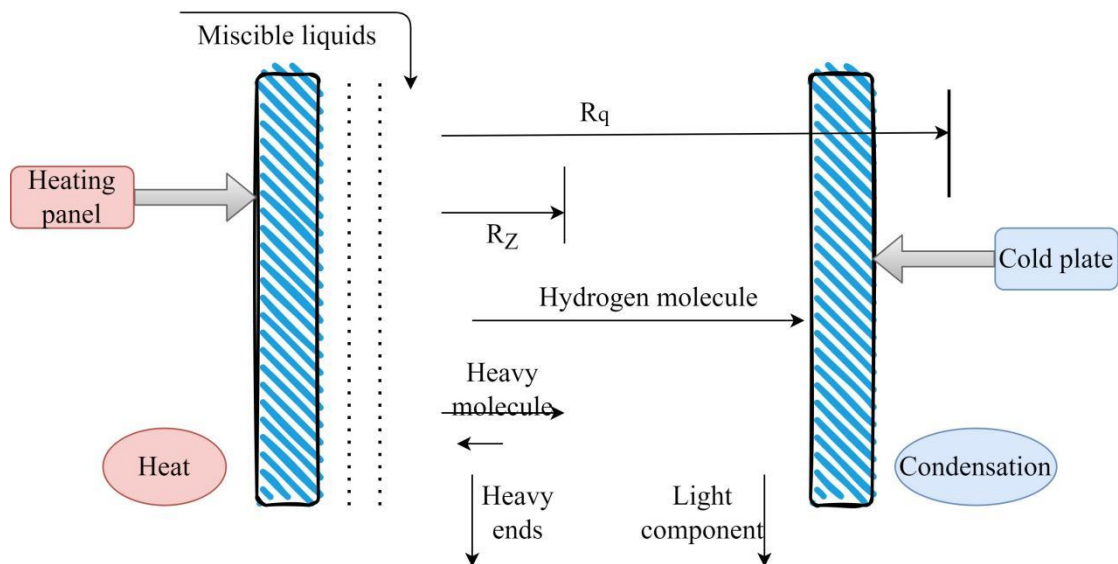


Figure 1: Schematic diagram of molecular distillation

The molecular mean free path is the core of the basic theory of molecular distillation [8]. When designing a molecular distiller, the distance between the evaporation surface and the condensation surface should not be greater than the average free path of molecules. The preheated feed liquid to be separated flows in from the inlet along the heating plate from top to bottom, and the heated liquid molecules escape from the heating plate and move to the condensing plate. Because of the large average free path, light molecules can reach the condensation plate and continuously aggregate in the condensation plate, and finally enter the light component receiving tank. Because the average free path of heavy molecules is small, they can't reach the condensation plate, so they flow into the heavy component receiving tank along the heating plate. The molecular distillation is different from the general conventional distillation, and it is a distillation that does not reach the gas-liquid equilibrium. The separation of molecular distillation is based on the different volatilities of different substances, and the separation operation is carried out below the boiling point of materials.

2.2. Characteristics of molecular distillation technology

Different from ordinary distillation, molecular distillation technology has many unique technical characteristics. Comparison between molecular distillation and ordinary distillation as shown in table 1.

Table 1: Comparison between molecular distillation and common distillation

Category	Ordinary distillation	Molecular distillation
Principle	Boiling point	Molecular mean free path
Reversibility	Reversible	Inreversible
Separating power	Weak	Strong
Temperature	Boiling point	Far below boiling point
Vacuum degree	Low	Tall
Heating-up period	Long	Short
Applicability	Applicability	Materials with high viscosity and boiling point

2.2.1. Advantages of molecular distillation technology

Firstly, molecular distillation has high vacuum and low operating temperature. Because of high vacuum, it has low operating temperature and low operating pressure. The important factor that molecular distillation apparatus can create a high vacuum system environment is its good sealing performance. Oxidation often occurs in the process of purification. Because substances are separated according to the difference of the average free path of molecular movement, they can be separated below the boiling point of the mixture. Secondly, the heating time of molecular distillation is short. There is a film scraper inside the evaporator of the molecular distillation apparatus. This design makes the materials form a uniform film on the surface of the evaporator, which increases the evaporation area and shortens the distillation time. The heating time in the molecular distiller is short. In the molecular distiller, the heated liquid is forcibly distributed into a thin film, the liquid holdup of the equipment is very small, and the residence time of the materials in the molecular distiller is very short. Third, the degree of separation is high. Because of its irreversibility, molecular distillation can separate the materials that can't be separated by ordinary distillation. Molecular distillation has higher relative volatility and higher separation efficiency than conventional distillation. Fourth, clean and environmentally friendly. Molecular distillation technology does not use any organic solvent and does not produce any pollution. It is considered as a mild green operation process. Fifth, there is no boiling and bubbling phenomenon. There are bubbling and boiling phenomena in ordinary distillation [9]. Molecular distillation is the free evaporation on the surface of the liquid layer. There is no dissolved air in the liquid and it is carried out under a high vacuum degree. Therefore, the whole liquid cannot be boiled and there is no bubbling phenomenon in the distillation process.

2.2.2. Limitations of molecular distillation technology

Every technology has its limitations, so does molecular distillation. First, there is little theoretical research. Molecular distillation technology is a new technology developed in recent decades. The basic theory of its related processes has not been fully revealed, and the real situation in the molecular still cannot be accurately summarized. The process design is blind, and it is difficult to determine the best design scheme, lacking some key data. So far, the mathematical model used to reveal the molecular distillation technology has not been fully established. Second, the production capacity is small. The evaporation surface area of molecular distillation is limited by the equipment structure, which is far smaller than the heating area of conventional distillation tower. Moreover, the material is thin film on the evaporation wall with a small area, and the heating area is almost equal to the evaporation wall, so the evaporation amount is very small and the production capacity is not large. Third, the equipment investment is high. Molecular distillation technology requires the system to reach a high degree of vacuum, so the vacuum tightness of the whole equipment is very high, which determines that it needs auxiliary systems such as high vacuum exhaust device and high vacuum dynamic and static sealing structure. Under the same production capacity, the volume of molecular distillation equipment is much larger than that of conventional distillation equipment. The technical difficulty of production, the relatively large investment in equipment and the high maintenance cost lead to the increase of production cost. Fourthly, the application scope is narrow. Molecular distillation technology is only suitable for the separation and purification of liquid or semi-solid substances that are flowable when properly heated. Molecular distillation requires high pretreatment of materials.

2.3. Application of molecular distillation technology

Molecular distillation technology is mainly used to extract, separate or refine vitamins and extract effective components of traditional Chinese medicine in the pharmaceutical industry. Vitamins are organic substances needed to maintain life, and they are the main elements to maintain the basic

functions of human body, so they play an extremely important role in human body. Natural vitamins have the characteristics of heat sensitivity, high boiling point, etc. They can be easily decomposed by ordinary distillation methods, and the problems caused by conventional distillation can be avoided by using molecular distillation to obtain high-concentration products [10]. Unsaturated fatty acids are easily decomposed and oxidized at high temperature. When molecular distillation technology is used to separate polyunsaturated fatty acids, saturated fatty acids and monounsaturated fatty acids are distilled out at first, while unsaturated fatty acids with more double bonds are distilled out at last when the distillation temperature is lower than the boiling point, thus enriching polyunsaturated fatty acids. (Escape Room: Tournament of Champions) Molecular distillation technology is used in the food industry, mainly for the separation and extraction of fatty acids and their derivatives, the extraction of natural pigments, antioxidants and food additives. Molecular distillation has the characteristics of low distillation temperature and no organic solvent residue, which can extract natural pigment [11]. (Jurassic World 3) Molecular distillation technology can be used in the fine chemical industry for deodorization and decoloration of wool derivatives, purification of plasticizers, separation of paraffin oil, crude oil residues and their analogues, purification of chemical intermediates or polymers, and refining and extraction of plant essential oils. (Avengers: Endgame) Molecular distillation can also treat natural essential oils, deodorize, decolorize and improve the purity, thus greatly improving the taste of natural spices. (Rambo: Last Blood) Molecular distillation technology is also widely used in agriculture, wax industry, petrochemical industry and other industries.

3. Research prospect of molecular distillation technology

3.1. Study on the principle of molecular distillation technology

The basic theory of each process of molecular distillation is studied, and the corresponding mathematical model is simulated. The theoretical research on molecular distillation process in China is very weak, with a serious lack of key data and blindness in process design, resulting in increased risk [12]. Study the transfer process of energy and mass in each step, analyze the influence of related factors in the process, and establish a mathematical model to describe the relationship between the temperature and composition of the main body and the surface. Combining model research with experimental verification provides theoretical basis for optimizing distillation operation and forecasting. Systematically study the molecular distillation unit, and strengthen the research and development of a new type of high-efficiency and energy-saving molecular distiller. It is also necessary to effectively solve the problem of vacuum sealing of the system and maximize the use of energy. It is necessary to combine the molecular distillation equipment with the technological requirements of the product, and actually set the structure and parameters of the molecular distiller according to the material properties of the product and the requirements for product quality and purity. In the process of molecular distillation, the liquid mixture is heated and evaporated, the liquid-liquid interface is cooled, the concentration of volatile phase decreases continuously, and the main phase has mass and heat transfer resistance. In the process of distillation, molecules escape from the gas-liquid interface at a certain speed, and there is interfacial resistance. At this time, the double effects of diffusion in the liquid film and molecular distillation and evaporation should be considered.

3.2. Research and development

Expand the research on the application scope of molecular distillation technology, and strengthen its application in the separation of heat-sensitive and high value-added materials, especially in the separation and purification of natural materials. Strengthen technical cooperation and exchange among universities and scientific research institutes, hold seminars on molecular distillation technology regularly, deepen basic theoretical research, take corresponding measures to solve the problems existing in each link, and actively absorb foreign advanced technical experience to continuously improve and develop molecular distillation technology from both technology and technology. We should establish special associations, hold thematic meetings on molecular distillation regularly, strengthen information exchange, and promote the process of industrial application.

4. Conclusion

The technical characteristics of molecular distillation technology are very prominent, and its application prospect is very broad. The characteristics of molecular distillation technology determine

that it is a separation technology worthy of vigorous promotion, especially in the aspects closely related to people's food, clothing and use, and it can be widely used. Molecular distillation, as a special liquid-liquid separation technology, can be carried out at a temperature far below the boiling point of liquid, and it is much superior to ordinary distillation for the separation and purification of high boiling point, heat-sensitive and easily oxidized systems. The application of molecular distillation technology in foreign countries has been very extensive, and there are more than one hundred kinds of products produced by molecular distillation technology. The popularization of this technology in industrial application in China also fully shows its great role. The combination of molecular distillation technology with other advanced technologies can solve more practical problems. However, the research on the mechanism of fluid mechanics and mass and heat transfer process in molecular distillation apparatus is not comprehensive enough, and the corresponding mathematical model should be established through further research to provide theoretical basis for molecular distillation technology to solve practical problems. At the same time, we should vigorously develop molecular distillation equipment with low cost and high throughput, so that the molecular distillation technology can realize large-scale industrial application. Due to the oversimplification of the model and the lack of key data, there is still a big gap between the model and the actual multi-component system in industrial production. At present, the design and technological conditions of molecular distillation equipment mainly depend on experience or experimental research, and it is difficult to determine the best design scheme of molecular distillation. In order to promote its industrial application process, it is urgent to perfect and deeply study related basic theories.

Acknowledgements

This work was supported by the Key scientific research projects of colleges and universities in Henan Province (20B150009) and the School level project of Henan Technical Institute (2020-KJ-20).

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