The Analysis of Gas-liquid Separation Technology Research Progress

Yupeng Yuan

College of Electromechanical Engineering, Wuhan University of Technology; Wuhan China.

Abstract—Gas-liquid separators are commonly utilized in the energy and chemical industries. This paper briefly introduces the separation principles and research progress of the primary gas-liquid separation equipment domestically and internationally. The paper briefly summarizes the working principles of gravity separation, filtration separation, and centrifugal separation equipment. Next, attention is focused on optimizing the separation performance of centrifugal separation equipment, which offers advantages of small size and high separation efficiency. Finally, a comparative analysis of these gas-liquid separators is provided.

1. Introduction

Gas-liquid separation is a technology used to separate the liquid phase from the gas phase through physical or chemical means. It finds wide applications in the oil and gas industry, chemical industry, energy production, environmental protection, etc. It primarily aims at separating and removing undesirable substances while enhancing the recycling efficiency of valuable ones [1]. For instance, in the oilfield extraction process, gas-liquid separation enhances oil extraction efficiency, facilitating the extraction of pure crude oil for subsequent processing and transportation [2]. Similarly, in chemical processes, gas-liquid separation facilitates the obtainment of pure chemicals and organic solvents. Moreover, in refrigeration systems, gas-liquid separation technology ensures the normal circulation and operation of the refrigerant, preventing the occurrence of liquid strike phenomena [3]. This paper introduces the current state of the main gas-liquid separators, focusing on their advantages, disadvantages, and research progress. The principles of commonly used gas-liquid separation, namely gravity separation, filtration separation, and centrifugal separation, are discussed. Furthermore, existing issues are analyzed. Emphasis is placed on optimizing the separation performance of centrifugal separation equipment, which boasts small equipment size and high separation efficiency. Finally, a comparative analysis of these gas-liquid separation devices is conducted, aiming to provide insights into future research directions and the prospects of gas-liquid separation technology.

2. Gravity Gas-Liquid Separator

2.1 Separation principle

The gravity gas-liquid separator is the most common gas-liquid separation device. Its separation principle relies on the density difference between the gas and liquid phases. When the gas-liquid two-phase mixture passes through the equipment, the heavier liquid phase precipitates to the bottom under the influence of gravity, forming a liquid layer, while the lighter gas phase rises to the top, forming a gas layer. This separation results in distinct layers of gas and liquid phases, achieving the separation of the gas-liquid mixture. Gravity gas-liquid separators are primarily categorized into vertical and horizontal forms [4], as illustrated in Fig. 1.

![Figure 1. Gravity gas-liquid separator.](image)

2.2 Research status

Gravity gas-liquid separators are characterized by simple structures, easy fabrication, and low resistance. However, they necessitate long residence times, resulting in large,
bulky separators with poor separation efficiency. They are typically capable of separating only larger droplets, with a typical limit of 100μm [5]. Optimization of performance has always been at the core of research endeavors. Researchers have sought to enhance separation efficiency, minimize pressure drops, and cater to diverse operational scenarios by refining the design and operational parameters of the separator. Yushan Zhang [6] identified the key factors influencing the processing capacity of gravity gas-liquid separators through a study of their structure and operational principles. Meanwhile, Xindong Lu [7] assessed the offshore adaptability of both vertical and horizontal separators through numerical simulations of their internal flow fields under transverse rocking conditions. Secondly, the utilization of hydrodynamic simulation technology is progressively emerging as a pivotal research approach. Numerical simulations offer comprehensive insights into the flow dynamics of gas and liquid phases within the separator, thereby furnishing robust support for optimized design strategies. Weidong Ye [8] conducted an analysis of the working principle of gravity gas-liquid separators through numerical simulations, quantifying the impact of structural parameters on separation efficiency. Meanwhile, Yang Qin [9] investigated the internal flow field using the particle model of the Eulerian-Eulerian method within a multiphase flow framework. The simulation results were in good agreement with experimental findings, demonstrating the feasibility of the turbulence model and algorithm.

3. Filtered gas-liquid separator

3.1 Separation principle

The filtered gas-liquid separator separates the liquid phase medium from the gas phase medium using a filtering medium. Its core component is the filter element, typically made of metal wire mesh or glass fiber [10]. Fig. 2 illustrates the schematic diagram of the wire mesh. The wire mesh gas-liquid separator is a typical filtration separation equipment. As the gas-liquid two-phase mixture enters the separator, larger liquid particles are trapped within the internal tiny gaps of the wire mesh structure. These trapped liquid particles gradually aggregate to form droplets, which, under the influence of gravity, eventually collect at the bottom of the separator in the liquid collection chamber. Meanwhile, relatively pure gas passes through the wire mesh structure at the top or side of the separator, thus achieving the separation of the gas-liquid two-phase mixture. The relatively pure gas passing through the screen structure is released at the top or side of the separator, thereby achieving the separation of gas and liquid.

3.2 Research status

The screen type gas-liquid separator offers advantages of a simple structure, small volume, high separation efficiency, and minimal pressure drop loss. For droplets with diameters greater than 5μm, the separation efficiency can reach 98% to 99.5%, with a pressure drop of only 250 to 300Pa [11]. Experimental research by Hisham [12] indicates that, for achieving the same separation effect, the silk screen separator exhibits the lowest total pressure loss compared to cyclone separators, fiber silk beds, and vane inertial separators. Yonghong Shi [13] has conducted a detailed analysis of the separation mechanism of the silk screen gas-liquid separator, providing quantitative insights into the different separation mechanisms affecting gas-liquid separation. There has been extensive research on factors that primarily influence the separation efficiency of screen-type gas-liquid separators, including the density of the gas-liquid two-phase, the diameter of liquid droplets, gas flow rate, etc., leading to the development of relatively mature methods and theories. Guocheng Guo [14] investigated the effects of various factors, such as the two-phase flow rate, screen material, diameter, density of the screen grid, droplet diameter, and gas stream distribution density, on the separation efficiency. However, the wire mesh gas-liquid separator is not suitable for two-phase separation with large gas-liquid two-phase flow rates and high carryover liquid content, as this may lead to wire mesh clogging. Additionally, cleaning the metal wire mesh is challenging, resulting in higher operational costs. Furthermore, there is a lack of research on the variation in separation efficiency and the model prediction of liquid droplet separation efficiency after secondary carryover.

4. Centrifugal gas-liquid separator

4.1 Separation principle

The centrifugal gas-liquid separator primarily utilizes centrifugal force to separate the gas and liquid phases. Due to the centrifugal force being dozens of times or even more powerful than gravity, centrifugal gas-liquid separation exhibits higher efficiency compared to gravity separation. Moreover, it features a shorter gas-liquid retention time, smaller equipment volume and footprint, easy installation, flexible operation, stable and continuous operation, as well as easy maintenance, making it the most researched method of gas-liquid separation [10].
cyclone separator is a typical centrifugal separation equipment, commonly featuring a tangential reversal inlet structure, as depicted in Fig. 3. Upon entry into the separator in a straight line, the gas flow containing liquid droplets is constrained by the cylindrical wall, transitioning into a downward spiral motion along the wall, forming an “outer vortex flow”. During this process, droplets with higher density are propelled towards the wall due to the action of centrifugal force. Upon contact with the wall, these droplets descend along it under the combined effect of centrifugal force and gravity, eventually exiting through the discharge port at the bottom. Upon reaching the cone part, the contraction of the wall surface leads to a dramatic increase in velocity. As the diameter decreases, the pressure on the outer wall increases, creating a low-pressure area at the center of the cone. Influenced by the high-pressure area, the airflow moves towards the low-pressure area at the center, spiraling upward from the bottom until discharged through the exhaust pipe, forming an "inner vortex flow". This process achieves high-efficiency separation of the gas and liquid phases [15].

Figure 3. Schematic structure of tangential reversing cyclone separator

4.2 Research status

Separation efficiency and pressure loss are two primary indicators of the performance of gas-liquid cyclone separators, and they are often positively correlated [16]. Researchers primarily investigate and analyze the characteristics of the flow field inside the separator through both experimental observation and numerical simulation to provide a theoretical basis for enhancing separation performance. For experimental studies, LDA (laser Doppler anemometer) and PIV (particle image velocimetry) are commonly employed to measure the internal flow field [17-20]. For numerical research, many researchers at home and abroad utilize CFD (computational fluid dynamics) techniques to investigate the internal flow characteristics of the separator, providing theoretical support for enhancing separation efficiency. The author summarizes various numerical simulation methods in the literature, including turbulence models (RSM, Reynolds Stress Model), pressure-velocity coupling methods (SIMPLE, Semi-Implicit Method for Pressure Linked Equations; SIMPLEC, SIMPLE Consistent), and discrete formats (QUICK, Quadratic Upstream Interpolation for Convective Kinetics; PRESTO, Pressure Staggering Option), as presented in Table 1.

<table>
<thead>
<tr>
<th>Author</th>
<th>Turbulence model</th>
<th>Pressure-velocity coupling</th>
<th>Discrete format</th>
</tr>
</thead>
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<tr>
<td>Kun Fang[21]</td>
<td>RSM</td>
<td>SIMPLE</td>
<td>First Order Upwind</td>
</tr>
<tr>
<td>Baoyu Cui[22]</td>
<td>RSM</td>
<td>SIMPLE</td>
<td>QUICK</td>
</tr>
<tr>
<td>K.Elsayed[23]</td>
<td>RSM</td>
<td>SIMPLEC</td>
<td>QUICK/PRESTO</td>
</tr>
<tr>
<td>Lei Li[25]</td>
<td>RSM</td>
<td>SIMPLEC</td>
<td>QUICK</td>
</tr>
<tr>
<td>S.B.Kuang[26]</td>
<td>RSM</td>
<td>SIMPLE</td>
<td>Second Order Upwind</td>
</tr>
<tr>
<td>L.Huang[27]</td>
<td>RSM</td>
<td>Coupled</td>
<td>QUICK</td>
</tr>
<tr>
<td>M.Azadi[28]</td>
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<td>Wenjing Li[29]</td>
<td>RSM</td>
<td>SIMPLE</td>
<td>QUICK</td>
</tr>
<tr>
<td>Liedong Li[30]</td>
<td>RSM</td>
<td>SIMPLE</td>
<td>QUICK</td>
</tr>
</tbody>
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Juan Li [31] compared the tangential and axial velocities in the internal flow field predicted by different turbulence models, discrete formats, and pressure-velocity coupling methods with experimental data [32]. The study concluded that: the RSM turbulence model provides more accurate predictions of the cyclone's flow field; the prediction results of the discrete formats QUICK and Second Order Upwind are relatively similar; the SIMPLE algorithm is more suitable for pressure-velocity coupling approaches in calculating the flow field.

The internal flow field of the separator constitutes a complex turbulent flow field. External rotation plays a positive role in droplet trapping, while internal rotation consumes energy [33]. Consequently, a preliminary mechanism to enhance separation performance can be derived: to bolster the rotational strength of external cyclones while suppressing the development of internal cyclones. Research on optimizing separation performance primarily revolves around four aspects: geometry optimization, geometry parameter optimization, operational parameter optimization, and internal component optimization.

1) Geometry Optimization: Geometric structure optimization modifies the original design concept to optimize separation performance. By appropriately altering or optimizing the inlet structure, this improves the stability of the inlet structure and strengthens the stability of the internal flow field, thereby enhancing separation efficiency. Zhao B[34] employed the RSM turbulence model to compare the separation performance of tangential and helical dual inlet structures. The results indicate that the latter structure enhances flow symmetry and increases separation efficiency. M. Wasilewski [24] investigated the impact of inlet angle and other factors on separation performance, which showed a significant effect on pressure drop changes.
2) Geometric parameter optimization: Optimization of geometric parameters solely alters the separator's geometry. The separator has the following eight crucial dimensions: inlet height (a), inlet width (b), exhaust pipe diameter (Dx), exhaust pipe insertion length (S), column height (h), total height (Ht), and cone tip diameter (Bc), as depicted in Fig. 4.

![Figure 4. Tangential reversal geometry](image)

Adjustment of part size can enhance separation performance. The influence of five distinct inlet sizes on flow pattern and performance was examined utilizing the Reynolds Stress Turbulence Model (RSM). Findings revealed that with increasing inlet size, the maximum tangential velocity decreases, along with a reduction in pressure drop, albeit resulting in lower overall separation efficiency [23].

3) Optimization of operating parameters: Optimization of operational parameters can enhance separation performance by adjusting the velocity or concentration of the gas-liquid two-phase flow. Gao.Z [35] analyzed the internal flow under different inlet velocity conditions, revealing that flow stability was superior at 12 m/s compared to 15 m/s and 18 m/s, consequently leading to improved separation performance.

Internal component optimization: Optimization of internal components entails adding additional components to the original basic framework to enhance separation performance. In the event of equipment failure, instead of replacing the entire equipment, only the faulty components need replacement, thereby reducing maintenance costs and labor. Currently, internal components are primarily categorized into 8 types: center body structure, drag reducing rod, guide plate, drag reducing frame, guide vane, centerpiece, and vortex stabilizer [36]. In conclusion, despite the cyclone separator's simple structure, its flow characteristics are complex, necessitating further research for accurate simulation of its internal flow field. Additionally, during the separation process, droplets may undergo phenomena such as liquid film formation, secondary droplet formation, and crushing, yet there is relatively scant research in this domain. Finally, structural optimization is frequently multifaceted, necessitating exploration of the influence of each factor, which remains a research hotspot.

5 Conclusions

In summary, gas-liquid separation is required in many instances, with a variety of methods and equipment available. Table 2 summarizes the advantages and disadvantages of each.

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<th>drawbacks</th>
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Table 2 Advantages and disadvantages of gas-liquid separators

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Through the introduction and comparison of various gas-liquid separation methods and equipment, it becomes apparent that each type of equipment has certain limitations, and their scope of application is relatively narrow and not universal. Therefore, the development of high-efficiency and low-resistance gas-liquid separation technology with universal applicability, along with the combined application of multiple separation technologies, will be the focus of research. Moreover, secondary carryover of liquid droplets, a significant factor affecting separation efficiency, has received limited attention in terms of studying its mechanism, influencing factors, and strategies to minimize it.

References


