Design and Research on online Monitoring of Liquid Flooding in Distillation Towers

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Abstract: The phenomenon of liquid flooding, as a special flow state in gas-liquid countercurrent processes, can cause adverse effects such as reduced production efficiency and increased energy consumption, seriously restricting the operation and design of gas-liquid mass transfer equipment. Real time monitoring of the operation status of the packed tower not only ensures its normal operating conditions, but also helps to improve equipment efficiency, which has important practical significance and industrial application prospects. This article first reviews the current research status of liquid flooding monitoring, and proposes to use the key variable of tower pressure difference as an important variable for liquid flooding monitoring to monitor and regulate the pressure difference inside the tower. The effectiveness and superiority of monitoring have been verified through experiments, which can achieve indirect monitoring of liquid flooding.

Keyword: Pressure Difference; Flooding; Online Monitoring; Distillation Tower

1. Introduction

Distillation tower is a widely used heat transfer and separation equipment in production processes such as petroleum, chemical, food, pharmaceutical, and environmental protection. It mainly relies on the volatile differences of each component in the liquid mixture, that is, at the same operating temperature, the light components in the material are gasified and transferred to the gas phase, while the heavy components are condensed and transferred to the liquid phase, achieving the ultimate goal of separation. The distillation equipment consists of multiple components, including a distillation tower, reboiler, condensing equipment, cooling equipment, reflux storage tank, and loop pump. The distillation of tower equipment cannot be separated from the participation of multiple physical parameters, including flow reference values: feed rate, residual flow rate in the tower kettle, output flow rate at the top of the tower, reflux rate, lateral extraction rate, condensation rate, and overall evaporation rate. In addition, there are parameters such as the reflux tank liquid level, tower kettle liquid level, temperature and pressure at different heights in the device, reflux height difference, tower top product composition, and bottom tower kettle product composition.

Distillation towers can be divided into three types based on their different operating pressures, namely pressurized distillation, vacuum distillation, and atmospheric distillation. The most important operational indicator for distillation tower control is the operating pressure of the tower. Stable operating pressure is the foundation of distillation tower operation. The composition, temperature, thermal state of the raw materials, as well as fluctuations in reflux ratio, heating capacity of the reboiler, and condensation capacity of the condensing equipment, can cause unstable pressure in the distillation tower during the distillation process. The distillation separation process will be greatly affected, resulting in a decrease in product quality. In the normal operation of a distillation tower, due to the complexity of its operation and the influence of many factors. Liquid flooding caused by factors such as unstable heating source pressure, sudden increase, excessive return flow rate, excessive feed rate, rapid increase in gas phase load, unstable and slow adjustment of tower kettle liquid level, high tower kettle liquid level, and excessive heating rate can all affect the normal operation of the distillation tower. In the distillation process, there are a large number of variables that make the mechanism data dynamics more complex. In actual production, process parameters and design requirements will have a certain constraining effect on the distillation unit. The most common problem in the operation of distillation towers in industrial production is liquid flooding inside the tower. Liquid flooding can seriously disrupt the normal operation of the tower, potentially affecting the final quality of the product and the smooth operation of the overall device, as well as causing equipment failures, greatly increasing the operating cost of the project. If real-time online monitoring and timely warning can be carried out on the operating status of the distillation tower, it can not only ensure the safety of the process and product quality, but also reduce energy consumption and improve efficiency, effectively prevent liquid flooding, and maintain the quality of material products and the long-term normal operation of equipment.

2. The Causes, Phenomena, and Treatment Methods of Liquid Flooding

Due to unreasonable parameters and operations during the operation of the tower, the accumulation of liquid phase inside the tower far exceeds the range of the space it is located in, which can lead to liquid flooding in the tower. Mist entrainment flooding and downcomer flooding are the two most common flooding phenomena in towers. The entrainment of liquid flooding by mist is due to the fast gas flow rate in the opening space of the tray. When the flow rate reaches a certain level, the liquid phase in the lower tray cannot fall due to gravity, and is adsorbed and carried by the rising gas into the upper tray. The liquid flooding in the downcomer refers to the inability of the liquid inside the downcomer to flow into the lower tray in a timely manner, gradually accumulating in the upper tray. Due to the high gas-liquid phase load in the tower, the pressure difference between the upper and lower trays continuously increases. The flow rate of liquid in the downcomer flowing into the lower tray decreases, causing the liquid in the downcomer to continuously rise. When the pressure drop reaches a certain value, the liquid phase in the downcomer will fill the upper tray, causing the liquid in adjacent two or more trays to be connected as a whole. Flooding can lead to a decrease in product output at the bottom of the tower, an increase in pressure difference between the bottom and top of the tower, and a decrease in temperature difference between the bottom and top of the tower. The liquid flooding of the tower is a frequent adverse phenomenon that occurs during distillation operations. If not properly treated, it can lead to a wide range of fluctuations in various operational indicators of the tower. The phase balance, thermal balance, and material balance of the distillation operation will be disrupted, ultimately resulting in substandard product quality at the top and bottom of the tower.

Excessive feed rate during the operation of the distillation tower results in the gas-liquid load exceeding the design capacity of the tower, causing excessive liquid drop resistance and resulting in liquid flooding. The method of reducing feed rate can be adopted to control the appropriate load within the design capacity range. When the operating reflux rate is too high, it causes an increase in the liquid layer and causes flooding, which can be adjusted by reducing the reflux rate. When the heating steam pressure is unstable and suddenly increases, the heating amount is too large, and the amount of gas rising inside the tower increases. The pressure drop caused by the airflow passing through the tower plate also increases, thereby increasing the resistance of the liquid flowing through the downcomer. To suddenly increase the gas-phase load and cause liquid flooding, heating steam pressure and temperature interlocking can be adopted to control the appropriate liquid to gas ratio and reduce heating amount. When adjusting the liquid level in the tower kettle too quickly or too forcefully, or if the liquid level in the tower kettle is too high, resulting in liquid flooding, the operator can be trained to proficiently master distillation operation techniques and the phenomenon of liquid flooding. Slowly adjust or lower the liquid level in the tower kettle, and control the liquid level in the reflux tank at the top of the tower to avoid lowering. When there is dirt inside the tower, the distillation liquid is not clean, low surface tension liquid is affected, easy to foam, and the packing is corroded, resulting in tower blockage. In addition, the downcomer or inlet weir breaks, causing gas short circuits and directly rising above the upper tray through the downcomer, causing liquid flooding. The cause should be identified and dealt with in a timely manner to ensure that the liquid is clean, not foaming, and that each tray is clean and pollution-free.

For a fixed distillation tower, the top pressure should be kept as constant as possible, and the pressure difference between the top and bottom of the tower should be controlled within a certain range. If the pressure difference between the top and bottom of the tower is too large, the speed of the rising gas inside the tower will be too high, and the gas mist will be carried seriously, leading to liquid flooding of the tower and disrupting normal operation; On the contrary, if the pressure difference between the top and bottom of the tower is too small, the inside of the tower will rise

3. Traditional Detection Methods for Liquid Flooding

The flooding point of the tower is an important design parameter. When operating near the liquid flooding point, the distillation tower has a high mass transfer efficiency. When liquid flooding occurs in the tower, the pressure difference inside the distillation tower will sharply increase, disrupting the normal operation of the tower and reducing mass transfer efficiency. Severe flooding can even cause the entire device to shut down. Therefore, real-time monitoring of liquid flooding points during tower distillation is particularly important. The traditional methods for detecting liquid flooding include liquid holding measurement, visual inspection, pressure change monitoring, and acoustic emission measurement. These methods each have their own advantages and disadvantages. The defect of hysteresis in visual inspection is very serious. The premise of visual monitoring is that when the monitored tower must be transparent and visible, the liquid accumulation on the surface of the internal components of the tower and the process of liquid flooding can be directly observed. However, the disadvantage of visual inspection is that it cannot be reflected in a timely manner. When liquid flooding is observed, it has already caused serious damage and losses. In addition, such hysteresis phenomenon will delay the normal operation of the tower. However, the existence of hysteresis phenomenon will cause the continuous occurrence of liquid flooding until the liquid flow rate is far below the critical flow rate, making it more difficult to restore normal operation of the tower. Moreover, the necessary condition for visual inspection is the need for a transparent distillation tower, which is relatively small in laboratory equipment, not complicated in operating conditions, and can still be achieved. However, in large-scale industrial production, the tower used is basically an opaque metal container, and even with a mirror or observation port, real-time observation in all aspects cannot be achieved. Therefore, visual observation is only applicable to small laboratory equipment and cannot achieve large-scale industrialization in places.

However, liquid holding detection requires equipment shutdown and cannot monitor liquid flooding in real-time online. The basis for determining the occurrence of flooding is to observe changes in liquid holding capacity and the continuous increase in liquid holding capacity. In order to measure the liquid holdup during production, it is necessary to simultaneously shut down the gas-liquid two-phase fluid and drain all liquids remaining in the tower. This type of testing in industrial production greatly reduces production efficiency and cannot meet the continuous production of equipment. Therefore, observing changes in liquid holding capacity is not suitable for industrial online monitoring.

In addition, the method of observing pressure drop changes is to predict liquid flooding by monitoring the pressure drop changes in the tower through pressure sensors, based on the intuitive and visible characteristics of pressure changes before flooding occurs. Pressure change monitoring needs to prevent liquid intrusion from damaging the pressure sensor. Acoustic emission measurement is a method of detecting the occurrence of liquid flooding through the detection of acoustic signals. Several acoustic receivers are installed outside the tower to collect and analyze the acoustic signals of fluid flow inside the tower. The changes in the acoustic signals are used to detect the occurrence of liquid flooding inside the tower. This method can help determine the operation inside the tower, but lacks effective statistics, analysis, and control. There is still a need to rely on a large number of empirical parameters for modeling, making it difficult to make accurate judgments. At the same time, the anti-interference ability of acoustic emission measurement is not strong.

4. Experiment on Real-Time Monitoring of

Liquid Flooding based on Acoustics

Like other process reactions, the gas-liquid two-phase convection inside the packed tower also emits specific frequency sound waves. On site, experienced operators can even judge whether the tower is working properly by listening to the sound emitted inside the tower. When the tower is operating normally, the liquid flows downwards through the packing and forms convection with the upward flowing gas. The gas rises along a curved path, and the gaps in the packing are eventually filled by the gas. At this point, the gas is in a continuous phase. The rising gas affects the falling liquid in an aerodynamic resistance manner. This resistance and gravity have the opposite effect, slowing down the downward flow rate of the liquid. When the resistance is greater than or equal to gravity, the liquid stops descending inside the tower. At this point, the liquid is a continuous phase with bubbles passing through, and the upward bubbles pull a lot of liquid upwards, causing unexpected axial mixing inside the tower. Bubbles vary in size, some nucleate, some expand, some aggregate, and some randomly rupture. Causing bubble flow to become a random and disordered process. It can be imagined that the change in gas-liquid state will cause a change in the corresponding position sound wave, so this may be a good means of detecting the occurrence of liquid flooding.

During testing, piezoelectric microphones are mounted on the surface of the packed tower to monitor changes in sound waves. The installation and placement of microphones is simple and non-destructive. The sound waves formed by pressure imbalance in fluid flow cause deformation of piezoelectric materials, resulting in changes in voltage. Subsequently, statistical analysis methods were used to calculate and analyze the collected voltage signals.

The method used in the study was to take 60 seconds of sound wave data in both normal and flooded states. Standard deviation and information entropy methods were used to statistically analyze these data, and the conclusion was drawn that there is a significant numerical change in the information entropy of sound wave voltage during flooding. Therefore, this significant change can be used as an alarm signal for predicting flooding.

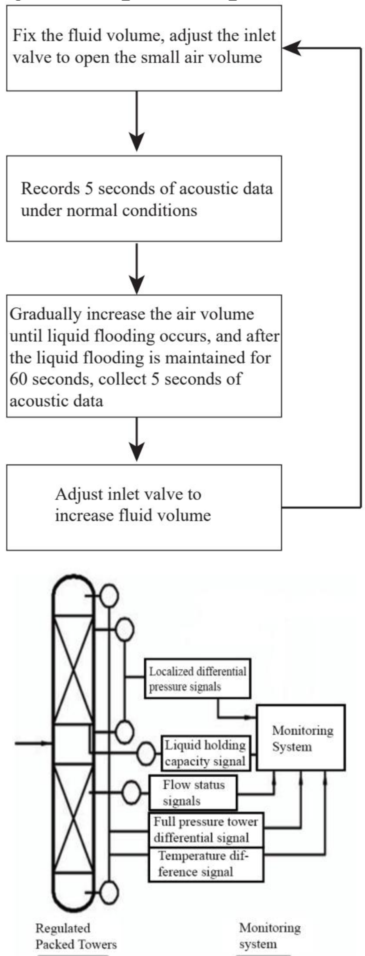

Figure 1. Monitoring Flowchart

Table 1. Experimental Monitoring Data

spraying density m3/m2·h	Flood point fan Frequency kHz	Actual pan point	T2 monitoring pan point (integrated with ISOMAP)	SPE monitoring hotspots (integrated with ISOMAP)	T2 monitoring pan point (ISOMAP)	SPE monitoring pan point (ISOMAP)	T2 monitoring Panpoint (PCA)	SPE monitoring points (PCA)
38	32	211	212	211	213	210	244	212
39	31	212	213	211	214	210	215	212
40	31	182	185	176	186	178	214	222
41	31	192	194	192	192	187	245	208
42	31	190	192	188	194	185	246	213
43	30	165	161	151	160	140	212	221

4. Conclusion

Study the phenomenon of liquid flooding and monitoring techniques to ensure the smooth operation of the tower at the highest possible flux, avoiding the occurrence of solution loss or shutdown due to missed detection or delayed judgment of liquid flooding, resulting in huge economic losses. This research work is of great significance for improving the safe operation, economic efficiency, and energy conservation and emission reduction of the tower.

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