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Column Pressure Control for Micro-Positive Pressure Distillation

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Micro-positive pressure distillation is commonly used in processes where the feed stock or products are oxygen sensitive. It is critical to keep column pressure stable for such process as pressure fluctuations may lead to dramatic changes in product quality. Pressure is typically controlled by manipulating condenser heat removal which is termed as temperature control. Stable column pressure can also be maintained by compensating pressure fluctuations in the distillation system. In this study, both temperature control and pressure compensation strategies are introduced including hot vapour bypass, floating-pressure control and inert current control system. Features and potential problems of different pressure control mechanisms are carefully analyzed. This paper provides a guideline for selecting proper control methods.

Key Words: Micro-positive pressure, Hot vapour bypass, Floating-pressure, Inert current system.

INTRODUCTION

Most distillation column control systems assume that the tower operates at a constant pressure because pressure fluctuations make control more difficult and reduce unit performance. Stable column pressure is essential for micro-positive pressure distillation. Pressure variations alter column vapour loads and temperature profiles. The variations also change relative volatilities and affect fractionation performance[1]. Other, less common problems can arise from pressure fluctuations. A normally single-phase feed can be turned into a flashing feed and a two-phase feed in a column designed for single-phase feed into flooding due to pressure drop. Conventionally, pressure is controlled by manipulating condenser heat removal or occasionally by manipulating reboiler heat input[2]. This is an indirect method to maintain desired composition of a low pressure column. Though changing condenser configurations such as flow rate of the cooling medium and heat transfer area are feasible, sometimes it is not adequate for micro-pressure distillation column which need tight pressure control because either the response time is too long or the pressure deviation is too large[3]. Instead, pressure compensation of the distillation column is a suitable choice.

Control of hot vapour bypass: This method can be used in processes where net vapour rate is zero. As is presented in Fig. 1, control of hot bypass flow to condenser receiver is achieved by varying condensing surface area and sub cooling surface area. The two surface areas are affected by condenser pressure. To maintain pressure, the control valve DP is manipulated. When column pressure is lower than set, the control valve DP is open larger, thus more hot vapour enters into the condenser which increases the condenser pressure. The pressure balance between the bypass and the condenser flows varies the liquid level in the condenser. This changes the allocation of condensing and subcooling surface available and finally decreases the amount of hot vapour condensed. As less hot vapour is condensed, the column pressure increases to the normal state. Besides, a thin layer of hot liquid separates the bulk liquid pool from the vapour[4]. This essentially allows for maintaining drum pressure with a blanketing layer of tower overhead vapour instead of externally supplied vapour. It is noted that liquid from condenser must enter the drum in the liquid layer so that control valve can affect liquid level in the condenser. Preferred application is liquid entry into the drum from below.

Features of hot vapour bypass control:

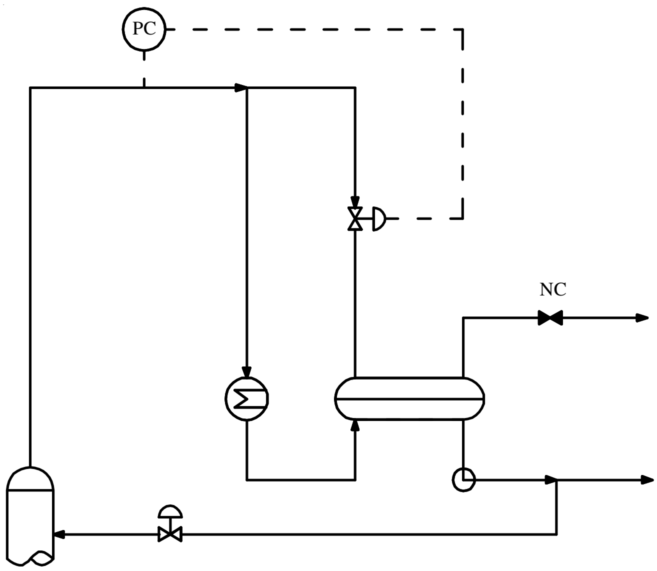
(1) Large and heavy condensers are often needed. Some units have worked very well, but others have failed.

(2) Condenser may be mounted below condensate drum.

(3) Selection of bypass rates and exchanger surface required is mostly empirical.

Some general problems are listed as follows[5]:

High purity products: This method does not work well with high purity products that have narrow boiling bands. The liquid insulating layer between the bulk condensate pool and the vapour space fails to adequately insulate the liquid.



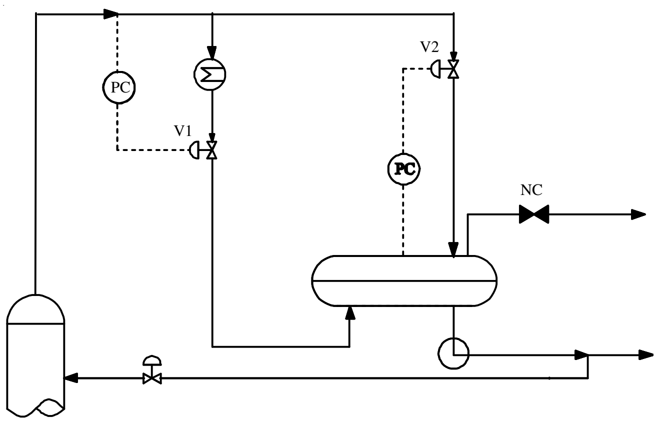
NC: Normally Closed Valve

Fig. 1. Control of hot vapour bypass

Self-refluxing condensers: Heavy material in the overhead vapour condenses first. Some liquid falls to the bottom of the exchanger and runs along it to the outlet. This may change the composition of the vapour enough that, at the outlet of the condenser, the vapour is no longer fully condensable.

Dual control of bypass and condensate: In this scheme net vapour rate is zero and the condensate drum pressure is lower than column pressure. This method is often used with very large and heavy condensers or with equipments requiring recurring cleaning or maintenance[6]. It is the preferred system to use with cooling boxes as condensers, as cooling boxes have too high an internal heat capacitance on the cooling water side to allow for rapid changes in cooling water level.

As is presented in Fig. 2, there are two valves related with pressure control, one installed in the pipe of the hot vapour bypass, another in the upstream of the reflux tank. They work cooperatively in maintain a stable column pressure.



NC: Normally Closed Valve

Fig. 2. Dual control of bypass and condensate

Features of dual control of bypass and condensate:

(1) Large and heavy condensers are often needed. Some units have worked very well, but others have failed.

(2) Condenser may be mounted below condensate drum.

(3) Selection of bypass rates and exchanger surface required is mostly empirical.

(4) Condensate drum runs at a lower pressure than tower pressure.

Some general problems are listed as follows:

High purity products: This method does not work well with high purity products that have narrow boiling bands[7]. The liquid insulating layer between the bulk condensate pool and the vapour space fails to adequately insulate the liquid.

Self-refluxing condensers[8]: Heavy material in the overhead vapour condenses first. Some liquid falls to the bottom of the exchanger and runs along it to the outlet. This may change the composition of the vapour enough that, at the outlet of the condenser, the vapour is no longer fully condensable.

Corrosion of internal pipe: If a top entrance of liquid into the drum is used, the internal pipe must not corrode through. A hole corroded in the internal pipe above the liquid level can lead to mixing of the topmost hot liquid layer and, thus, to unstable operation[9].

Sub-process control of hot vapour bypass: When net vapour rate is below 2-5 %[10] of the total tower overhead rate or net vapour is produced discontinuous, sub-process control of hot vapour bypass is used. The scheme is presented in Fig. 3.

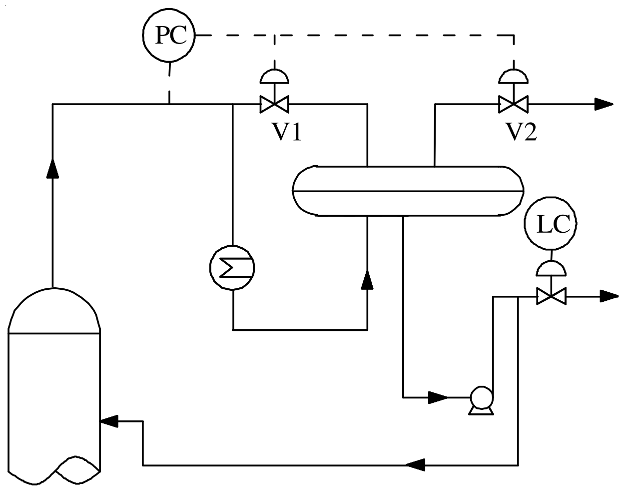


Fig. 3. Sub-process control of hot vapour bypass

In this scheme, one regulator controls two regulating valves, one installed in the pipe of the hot vapour bypass, another in the non-condensable gas pipeline of the reflux tank. Normally, V_2 is closed. When starting a process or in case that the reboiler fails to work, column pressure fluctuates dramatically and as the non-condensable gas accumulates, the efficiency of the condenser decreases. In this case, adjusting V_1 makes little difference. Constant column pressure can be maintained through discharging non-condensable gas by adjusting V_2.

Features of sub-process control of hot vapour bypass:

(1) The condition of the regulating valves is related to the range of the pressure fluctuation.

(2) The condenser can be installed under the reflux tank[11], so this scheme is most suitable for processes with large condenser that needs to be cleaned and repaired regularl.

(3) It is not suitable for the separation of high purity products[12]. It is critical to keep a stable liquid film above the

surface of the reflux tank. As there is no vapour-liquid equilibrium between the bulk liquid in the tank and the hot vapour bypass, the thin liquid film would be quite unstable due to dramatic temperature changes in the reflux tank. The narrow boiling band of high purity products makes it difficult to isolate the bulk cold liquid and the hot bypass vapour.

(4) Cryogenic cooling device with surplus surface area is needed in the condenser in order to prevent flashing and vapourization of the liquid.

Floating-pressure control: Floating pressure control works at a minimum pressure, so the heat required at the reboiler is minimized, its capacity is increased and fouling is reduced[13]. If the distillate is in the liquid phase and the amount of inert is negligible, the column pressure can be controlled by modulating the cooling water flow through the condenser.

As is presented in Fig. 4, a valve regulator VPC makes floating-pressure control different from constant pressure control. VPC sets the value of PC according to the range of the pressure fluctuation. The adjusting process is quite slow and steady which makes the slow-loop adjustment. The PC makes the corresponding fast-loop adjustment. PC works by proportional Integral so that column pressure can be restored in case of dramatic fluctuations caused by bad weather, while VPC works by pure integral. Normally, VPC sets PC at a steady value. Column pressure changes slowly under this circumstance. Finally it reaches the lowest pressure that the condenser can maintain, so it is more energy efficient[14].

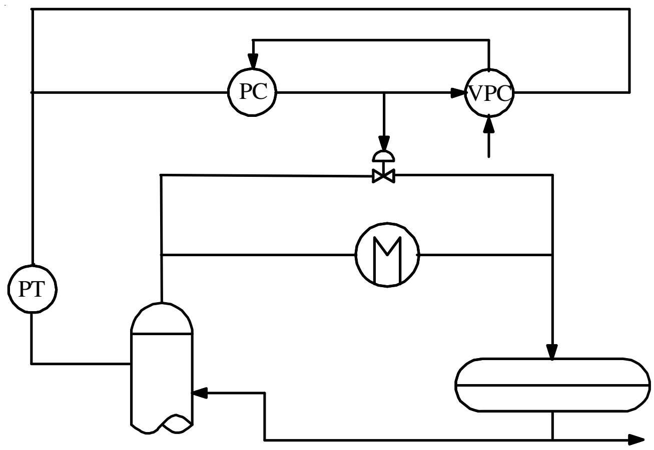


Fig. 4. Floating-pressure control

Features of floating-pressure control:

(1) The control system is recommended only when the cooling water is treated, because high temperatures can cause condenser tube fouling.

(2) Reboiler load should change according to the floating of column pressure.

(3) To separate some liquid mixtures, the temperature required to vapourize the feed at atmospheric pressure would be so high that decomposition would result.

(4) The overhead vapour from the distillation column is compressed to a pressure greater than the boiling point of the process liquid at the tower bottoms to improve energy efficiency[15].

Pressure compensation with makeup vapour supply: The methods introduced above are all based on energy balance of the heat exchanger[16].

By varying heat exchanger surface area and the rate of heat exchanging, column pressure is indirectly controlled. However, the process of heat exchanging takes time and the result of the control is not so precise[17]. Pressure compensation is more sensitive to fluctuations and precise in pressure recovery compared with temperature control.

As is presented in Fig. 5, the inert gas is added to the condensate drum to make up vapour supply. This scheme is simple and fast responsive, however, a large amount of inert gas is needed. Adding makeup gas upstream of the condenser may reduce the gas rate required, due to partial vapour blanketing of the condenser.

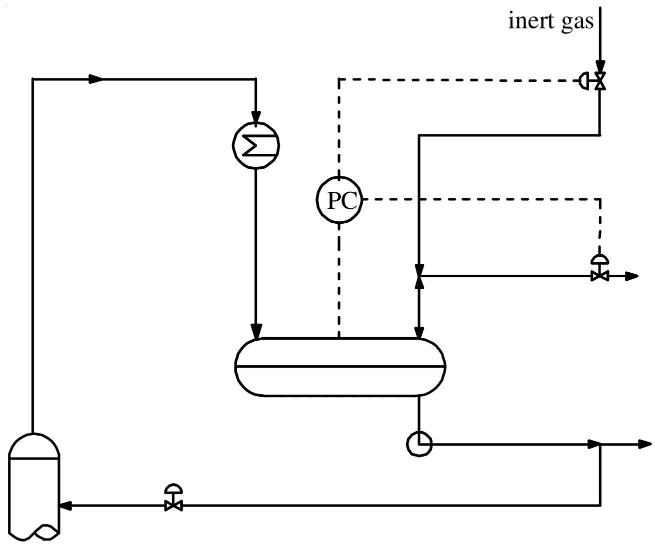


Fig. 5. Pressure compensation with makeup vapour supply to the condensate drum

Another pressure compensation control mechanism is presented in Fig. 6. Three tanks form the inert current system as is circled with the zigzag line in the box. While the constant pressure tank is charged with both the negative and the positive pressure tank, it is directly connected to the distillation column. The constant pressure tank acts as a buffer for column pressure fluctuations. Features of pressure compensation:

(1) It is more sensitive to pressure fluctuations and column pressure can be controlled instantly in a set range.

(2) Equipments needed are simple and easily obtained: a set of nitrogen pressure device and a vacuum unit.

(3) Suitable for the separation of substance that is easily oxidized, for the positive pressure can prevent the oxygen from entering the column.

(4) Note that the injecting gas must be compatible with the process.

(5) Fig. 6 is applied to distillation columns that conducted under both positive and negative pressure. In this case, pressure of the vacuum tank can be greater or less than 1atm because the effect of the tank is to relieve the pressure in the system.

Conclusion

So far, temperature compensation by controlling the amount of heat removed is widely used as an indirect method to keep stable column pressure. These methods balance pressure fluctuations by changing heat exchanger surface area and

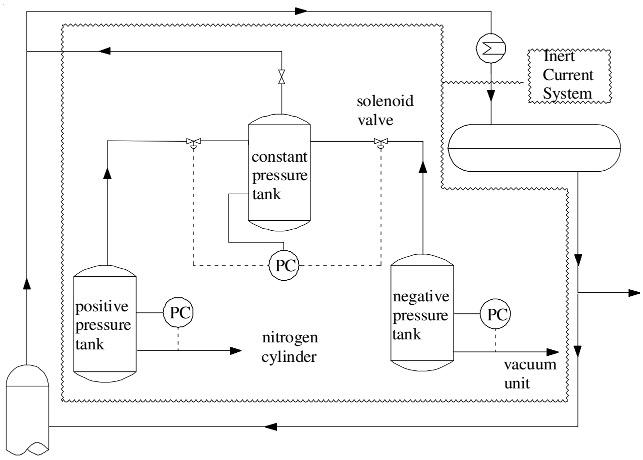


Fig. 6. Pressure compensation with inert current system

the rate of heat exchanging. Pressure compensation, for both the condensate drum and the column, is a new method with high sensitivity, prompt and precise reaction. Thus, this method is very promising in certain separation process. However, the choice of a control method should be decided on the bases of a specific unit operation.

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