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Study of Direct Compression Heat Pump Energy-saving Technology

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Abstract

Analyzed the feasibility and necessity of the application of heat pump distillation in the gas separation unit. Through the comparison of the results of different heat exchanger, this paper verified the advantages of the heat exchanger with aluminum porous surface tube. Calculated the power consumption of the compressor by Aspen Plus steady-state process simulation, then the value of COP of the heat pump is obtained, and analyzed the economy of the heat pump distillation, the result shows that utilities and operating cost could be decreased by using heat pump distillation in gas separation unit, and the energy utilization efficiency economic benefits and energy-saving effects could be enhanced.

Keywords: Heat pump distillation; Energy saving; Simulation

1. Introduction

The energy consumption of distillation takes up 60% in the total energy consumption of the petrochemical installations [1]. Distillation is the most important and the most widely used separate operation in chemical process, and it is the most energy consumption operating unit. Due to the low thermodynamic efficiency of distillation, the overall efficiency of the distillation workshop section in many factories is less than 10% [2]. Owning to the applied universality and superiority, distillation cannot be replaced by any athermal separation method, so distillation energy conservation is imperative [3].

The energy conservation of distillation has many ways, such as reduce reflux ratio, multiple-effect distillation, lateral line heat transfer distillation, heat pump distillation and so on. Among all of these, heat

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pump distillation is identified as one of the most development potential ways. Meanwhile, in energy integrated strengthening aspects, heat pump distillation has unique characteristic of energy conservation. Besides, heat pump well enough reduces the discharge of CO_2 and thermal pollution to protect environment.

Gas separation process is a multicomponent distillation process with quite high energy consumption. If it is required to separate propylene of purity ≥ 99.5%(molar fraction) in propylene - propane separation tower， because of the high purity , reflux ratio of the tower is very large, whose energy consumption accounts for 40%～50% of the entire device; at the same time top condenser consume a lot of cooling water. Therefore in the point of energy-saving view, it is of great importance to use heat pump distillation instead of conventional distillation [4-5].

Based on previous research on heat pump distillation, this paper makes use of Aspen Plus software to proceed systematic simulation analysis and calculation for the practical application of heat pump distillation in propylene - propane separation unit ,which is open A type direct vapor compression heat pump distillation using top steam (propylene) as the cycle fluid. All of these further validate the economical efficiency of heat pump distillation in practical application.

2. Process Analysis

Tower liquid flash reboiling direct heat pump distillation system flow is shown in Figure 1. Raw materials enter into distillation tower and they are separated propylene in the tower top and propane in the tower bottom. Compressed by the compressor , the temperature rise of distillation tower top gas enter into the bottom reboiler–condenser, whose heat of condensation makes the bottom liquid reboil.

Cooled and decompressed by the throttle valve, liquor condensate enter in return tank, a part of them is discharged as product, and another part is acted as backflow of distillation tower top. This type of heat pump distillation system use tower bottom reboiler replaced overhead condenser, this is actually to use a heat exchanger doubles as overhead condenser and bottom reboiler [6].

Tower liquid flash reboilingdirect heat pump distillation system’s characteristics are:

- Heat-carrying agent is not required alone.
- It only need a heat exchanger (i.e., reboiler -condenser), so the compressor's compression ratio is usually lower than those circulating system of one working substance.
- This system is simple, stable and reliable.

Tower liquid flash reboilingdirect heat pump distillation system is suitable for the small temperature difference between top and bottom or the distillation system which adopt larger reflux ratio because the components of separated substance is difficult to separate for their near boiling point. The latter consume a large amount of heating steam or top condensate to be low-temperature cooling [6].

3. The choice of reboiler – condenser

Heat exchanger is a traditional energy conversion device. On condition that it meet fixed exchange heat ,the exchanger is asked for more compact, saving materials, cheap, safe, reliable and durable [7]. The most important classification way of heat exchanger is on the basis of the method of energy transport. There are partitions type, hybrid and regenerative.

In the petrochemical production process, it is often required heating or cooling, that is, the heat transfer. When a fluid and other fluids proceed heat exchange and are not allowed to mix, it is required to proceed in dividing wall type heat exchanger, in which hot and cold fluids are separated by solid heat transfer surface. There are many kinds of partitions type heat exchangers, among shell-and-tube heat exchanger unit volume can provide greater heat transfer area, and has better heat transfer efficiency and adaptability, so that it is most widely used in production.

A. Process Conditions of Heat Transfer Equipment Design

Process conditions of heat transfer equipment design are shown in Table Ⅰ.

Table Ⅰ: Design Conditions Of Heat Exchanger

	q_m/（kg/s）	t_{in} / ℃	t_{out}/ ℃
heat flux	58.5	63.5	55.9
cold flux	54.5	45.67	-
	p_{in} / MPa	r /（m^2·K/W）	Δp / MPa
heat flux	2.4	0.00035	0.1
cold flux	1.6	0.00017	0.1

B. Heat Transfer Computation

The design of heat exchanger can be used heat exchanger design software HTFS, which is part of Aspen Plus software, to design and calculate, thus we can process the cost estimates and supply device design drawing. In addition, the heat exchanger's design and calculation can be on the basis of empirical value and formula, after selecting the type of heat exchanger, we can check calculations and then complete the design of heat transfer equipment.

Calculation method of shell and tube heat exchanger heat transfer coefficient has been very mature; this text will not go into the computational formula of shell and tube heat

exchanger tube heat transfer coefficient and detail refers to reference [8].

In order to improve heat transfer performance and improve heat transfer coefficient, this text adopts aluminum porous surface heat to strengthen boiling heat transfer in the boiling side. Aluminum perforated pipe strengthen boiling heat transfer tubes have many advantages, such as small boiling temperature difference, large coefficient of heat transfer and strong resistance to dirt. Therefore, it has a significant effect [9-10] on strengthening boiling heat transfer.

The heat transfer film coefficient of shell side (boiling side) in smooth pipe is calculated by Mostinski equation [11],

$$h_o = 1.163\left[0.10\left(\frac{p_c}{9.81\times10^4}\right)^{0.69}\left(1.8R^{0.17}+4R^{1.2}+10R^{10}\right)\right]^{3.33}(\Delta t)^{2.33} \quad (1)$$

Where:

$$\Delta t = \frac{q/S}{h_o} \quad (2)$$

After finishing Equation (1) is as follows,

$$h_o = 1.046\left[0.10\left(\frac{p_c}{9.81\times10^4}\right)^{0.69}\left(1.8R^{0.17}+4R^{1.2}+10R^{10}\right)\right]\left(\frac{q}{S}\right)^{0.7} \quad (3)$$

Equation (3) applies to the following conditions,

p_c> 3000kPa ,

$R = p / p_c = 0.01 \sim 0.9$,

$q / S < (q / S)_c$

Where:

$$\left(\frac{q}{S}\right)_c = 0.38 p_c R^{0.35} (1 - R)^{0.9} \pi D_i \frac{L}{S_o} \quad (4)$$

Calculation method of the film coefficient of heat transfer of the boiling side according to the correlation equation is showed in literature [10, 12].

We designed and calculated the performance parameters of carbon steel tubes heat exchanger and aluminum porous surface heat exchanger in the paper, and the results are shown in Table Ⅱ. By comparing the heat transfer in the same conditions, it can be seen aluminum porous surface heat exchanger can reduce the size of heat exchanger and improve heat transfer efficiency, and can save investment costs.

4. The selection of compressors and COP of heat pumps

Compressor is the core of the heat pump system equipment and at the same time is the main cost of system. Therefore, in the rational design of selecting highly efficient compressors on the basis of reasonable design can effectively reduce the device of energy consumption and costs. Generally we select centrifugal compressors in heat pump distillation system, the reason is that the flow rate of heat pump compressor is large and its compression ration is small. Application of Aspen Plus software we simulate steady-state process. On the basis of the steady state process simulation can obtain results that when the compressor power is 1513 kW can make the fluid flow of import and export of compressor meet the design requirements.

In heat pump distillation system, the coefficient of performance of heat pump is expressed as the ratio of heat (Q) of reboiler – condenser on the bottom of supply tower and the actual input power (P_C) of compressor:

$$\text{COP}=Q/P_C \quad (5)$$

According to the equation (5), COP of the heat pump distillation system is 10.65.

Thus, although the heat pump system consumes a certain high-grade energy (electricity), the higher COP values can be sure that obtain the heat of the fuming liquid evaporation on the basis of consuming less energy.

5. Conclusions

● Using distillation heat pumps in gas fractionation process can reduce the amount of public works and reduce the cost of separation Heat pump distillation technology for an adequate supply of affordable electricity, while the steam and cooling water supply is shortage and high temperature conditions. In this paper, one reboiler – condenser replace two sets of heat exchanger in the conventional gas separation device.

● The application of enhanced heat transfer technology in the heat exchanger heat pump distillation system can improve the heat transfer efficiency; reduce the number of heat transfer equipment and save investment costs. In this paper, applying the porous surface of aluminum tube heat exchanger can save one heat exchange compared with using ray tube heat exchanger.

● In order to improve energy efficiency of heat pump distillation system during gas fractionation, should use efficient compressor and enhanced heat transfer techniques. Higher heat pump system COP can improve energy efficiency, save operating costs, reduce production costs, which can obtain higher economic benefits and energy savings

NOMENCLATURE

A	theory area of heat transfer, m^2
A_d	actual area of heat transfer of heat exchanger selected, m^2
COP	coefficient of performance of heat pump
h_o	heat transfer film coefficient of shell side (boiling side), $W/(m^2 \cdot K)$
K	heat transfer coefficient, $W/(m^2 \cdot K)$
p	operating pressure. Pa
p_c	critical pressure, Pa
P_C	actual input power of compressor, kW
p_{in}	inlet pressure of heat exchanger, MPa
Δp	allowable pressure drop of heat exchanger, MPa
Q	heat load of heat exchanger, kW
q_m	mass flow, kg/s
r	fluid fouling resistance, $m^2 \cdot K/W$
R	comparative pressure, Pa
t_{in}	inlet temperature of heat exchanger, ℃
t_{out}	outlet temperature of heat exchanger, ℃
Δt	total temperature difference, ℃

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Table Ⅱ: Comparision of Calculation Result Of The Heat Exchanger

Heat Exchanger	Q / kW	A / m^2	A_d / m^2	Δ t/ ℃	h_o / W m^{-2} K^{-1}	K / W m^{-2} K^{-1}
Carbon steel tubes calculated value	16110.2	3269.6	3852	11.2	1456.1	439.9
Aluminum porous surface tubes calculated value	16110.2	2195.6	2568	11.2	13775.9	655.1

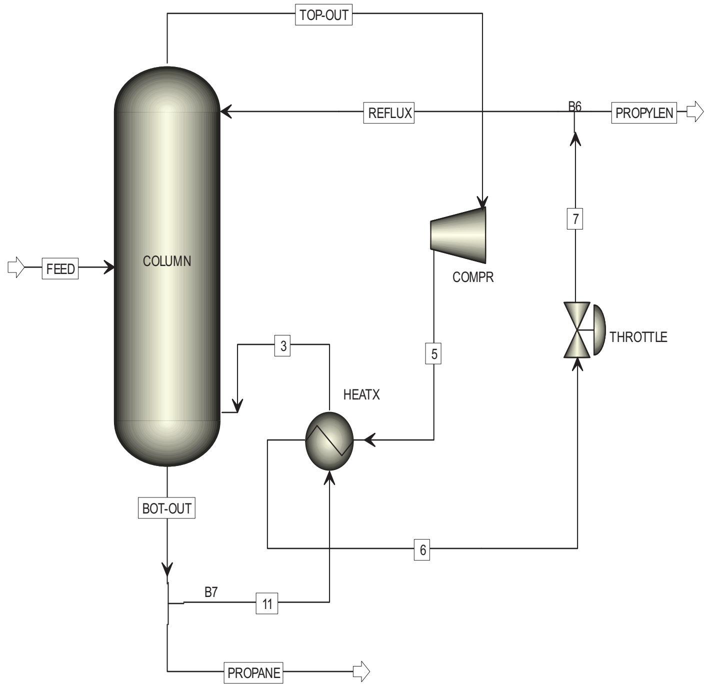

Figure 1. Flowchart of tower liquid flash reboiling heat pump distillation system by Aspen Plus