About the effectiveness of absorbers

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Abstract: This paper discusses the issue of reducing the mass and dimensional characteristics of absorbers used in the chemical industry and refrigeration equipment. As a solution to the problem, a method of intensified heat and mass transfer is proposed. Experimental data obtained using a carbonization column and a shell-and-tube irrigation absorber are analyzed. Calculations are performed for various effective pipe packages at constant values of Reynolds number, irrigation density, average solution concentration, pipe diameters, and apparatus dimensions. To determine heat transfer in a wider range of these values, it is necessary to conduct experiments. The use of tube-lattice nozzles in the refrigeration zone of the apparatus can either increase its productivity or reduce its weight and dimensions.

INTRODUCTION

The differences in the scale of numerous chemical industries and their specific features have led to the use of a relatively large number of absorber designs and absorption refrigeration machine schemes, none of which can be considered universal [1–9]. Despite the variety of absorbers and absorption units, they share a common drawback: bulkiness and large material capacity.

One possible way to reduce mass dimensions is to intensify heat and mass transfer processes in devices. The staff of the Department at Tashkent state technical university addressed the problems of creating compact condensers and evaporators. The purpose of this work is to analyze the method of intensification of heat and mass transfer and to discuss its possible application in absorbers. The task of this work is to intensify heat and mass transfer processes by introducing additional turbulence and increasing the time of interfacial contact through the use of pipes with a developed effective surface in the tube-lattice packings of the refrigerating zone, thereby enhancing the device's productivity.

OBJECTS AND METHODS OF RESEARCH

The carbonization column of the chemical industry and the shell-and-tube irrigation absorber of the refrigeration machine are the objects of this study. Both devices are equipped with tube-lattice nozzles proposed by us [10].

Calculation of heat transfer on the absorbent and desorbent sides is a method of this study, which is necessary for the design, selection, and comparison (under different operating conditions) of absorbers. Let's calculate the heat transfer coefficient in a horizontal shell-and-tube irrigation absorber.

A tube-lattice packing is a package of pipes consisting of ordinary smooth pipes with a diameter D and pipes with a developed effective surface with a diameter $d \approx D/2$. Each package consists of staggered pipes as follows: an ordinary smooth pipe is placed with a pitch $3l$, and between them are two pipes with an effective developed surface with a pitch l, and each package is installed relative to the next one at an angle of 90^o. Five package options were developed and studied. A pipe with an effectively developed surface features spirally smooth grooves on the outside and protrusions on the inside of the pipe.

Such a heat and mass transfer surface, combined with the design of the tube pack, enables the intensification of heat dissipation during the reaction, maintains the required temperature of the outer surface of the pipes, and enhances the absorption of the absorbent.

The temperature of the cooling water at the inlet to the apparatus is $t = 18°C$. The water flow rate is $G = 1{,}5$ kg/s. The flow rate varies within the range of the Reynolds number is $Re = 2500 \div 9800$. In both absorbers, the process conditions in the tube spaces are the same.

The device will be calculated for the following operating conditions of a water-ammonia absorption refrigerating machine with a cooling capacity of $Q_o = 2500$ kW. The main parameters characterizing the heat transfer surface of a horizontal shell-and-tube irrigation absorber: steel pipes are solid drawn smooth; internal diameter of the pipe $d_{in} = 0.05$ m; Outer diameter of the pipe $d_{out} = 0.057$m.

TABLE 1. Pipe package options

No Package	1	2		3		4		5	
Tubing	Smooth	Smooth	with an effective surface	Smooth	with an effective surface	Smooth	with an effective surface	Smooth	with an effective surface
Pipe pitch	$3l$	$3l$	$l = 0{,}5(d + D) + 5$	$3l$	$l = 0{,}5(d + D) + 10$	$3l$	$l = 0{,}5(d + D) + 15$	$3l$	$l = 0{,}5(d + D) + 25$

The coefficient of heat transfer from the solution side, related to the inner surface of the pipe, is determined according to [4]:

$$\alpha_s = K \cdot \alpha_w(d_{in}/d_{out}) \quad (1)$$

where $\alpha_w = 5395(1 + 0.004t_s)\Gamma_l^{-0.23}$ – is the heat transfer coefficient for clean water, W/(m^2·K);

$K = [(c_s/c_w)^{0.4}(\lambda_s/\lambda_w)(\rho_s/\rho_w)^{0.67}(\mu_w/\mu_s)^{0.33}]$ – a multiplier that takes into account the thermophysical properties of the solution;

$t_s = T_s - 273$ – average temperature of the solution, °C;

$\Gamma_l = 0.0222$ is the accepted flow rate of the solution per 1 m of the length of one straight pipe taking into account its two-way washing (irrigation density), kg/(m·s).

In formula (1), α_s depends on the heat transfer coefficient from the cooling water side. Therefore, under the conditions corresponding to the condition of the obtained formula (1), it is sufficient to know α_w, i.e., α_s is determined indirectly, without conducting experiments.

The calculation α_s will be made with constant Reynolds numbers $Re = 2415$ and the average mole $x = 0.239$ mol/mol solution concentration.

The water velocity and the number of pipes in one passage of the apparatus are assumed to be equal to the values of the corresponding values given in [11].

RESULTS AND DISCUSSION

Experimental experiments were conducted in the carbonization column, with the results presented below.

According to the package 1. The tube-lattice packing of the refrigerating zone is made of smooth pipes with a diameter of D. The solution with the temperature of $t = 40$ °C moves from top to bottom, and the absorbent with the temperature of $t = 36$ °C moves from bottom to top and is in contact with the pipes of the refrigeration zone.

Cooling process water with a temperature of $t = 18$ °C is supplied to the tube space of the tube-lattice packing. At the same time, the process of mass transfer between the solution and the absorbent is carried out, as well as the transfer of heat from the solution to the cooling water. Water consumption is 3.5 kg/s. Solution temperature is 32−34

°C. Intensification of heat exchange is $\alpha/\alpha_{sm} = 1$. Increase in hydraulic resistance is $\xi/\xi_{sm} = 1$. The degree of gas utilization is 83%.

Part of the pipe surface is covered in some places with local salt deposits.

According to package 2. The tube-lattice packing is made of smooth pipes and spiral-knurled tubes with a knurling pitch $s = 1.1d$, which are arranged in a checkerboard pattern – smooth tubes with a pitch of $3l$, and between them two spiral-knurled tubes with a pitch of placement $l = 0.5(d + D) + 5$. The solution with the temperature of $t = 40$ °C moves from top to bottom, and the absorbent with the temperature of $t = 36$°C moves from bottom to top and are in contact on the pipes of the refrigerating chamber.

Cooling process water with a temperature of $t = 18$ °C is supplied to the tube space of the tube-lattice packing. At the same time, the process of mass transfer between the solution and the absorbent, as well as the transfer of heat from the solution to the cooling water, takes place. Water flow rate to $G = 2.35$ g/s. Solution temperature is 32 °C. Intensification of heat exchange is $\alpha/\alpha_{sm} = 2.14$. Increase in hydraulic resistance $\xi/\xi_{sm} = 1.12$. The degree of utilization of the absorbent is 85%.

The heat exchange surface of the tubes is generally clean, but there are point deposits in five locations, resulting in a 1.5 times reduction in cooling water consumption.

According to the package 3. Similar to the package 2. The arrangement of the pipe in a checkerboard pattern - smooth pipes with a pitch $3l$, and between them, two spiral-knurled pipes with a placement step $l = 0.5(d + D) + 10$. The solution with the temperature of $t = 40$ $°C$ moves from top to bottom, and the absorbent with the temperature of $t = 36$ $°C$ moves from bottom to top and are in contact on the pipes of the refrigerating chamber.

Cooling process water with a temperature of $t = 18$ °C is supplied to the pipe space of the tube-mesh packing. At the same time, the process of mass transfer between the solution and the absorbent is carried out, as well as the transfer of heat from the solution to the cooling water. Water consumption is $G = 1.95$ kg/s. Solution temperature is 29 °C. Intensification of heat exchange $\alpha/\alpha_{sm} = 2.55$. Increase in hydraulic resistance $\xi/\xi_{sm} = 1.21$. The degree of gas use is 86%.

The heat exchange surface of the tubes is generally clean, but there are point deposits in 2 places. Reduction of cooling water consumption by 1.8 times.

According to the package 4. Similar to the package 2. The arrangement of the pipe in a checkerboard pattern - smooth pipes with a pitch $3l$, and between them, two spiral-knurled pipes with a placement step $l = 0.5(d + D) + 15$. The solution with the temperature of $t = 40$ ℃ moves from top to bottom, and the absorbent with the temperature of $t = 36$ °C moves from bottom to top and are in contact on the pipes of the refrigerating chamber.

Cooling process water with a temperature of $t = 18$ °C is supplied to the tube space of the tube-grate packing. At the same time, the process of mass transfer between the solution and the absorbent is carried out, as well as the transfer of heat from the solution to the cooling water. Water consumption $G = 1.75$ kg/s. Solution temperature is 27 °C. Intensification of heat exchange $\alpha/\alpha_{sm} = 3.16$. Increase in hydraulic resistance $\xi/\xi_{sm} = 1.34$. The degree of gas use is 88 %.

The heat exchange surface of the tubes is generally clean, even in the absence of local point deposits. Reduction of cooling water consumption by 2.0 times.

According to the package 5. Similar to the package 2. The arrangement of the pipe in a checkerboard pattern is smooth pipes with a pitch $3l$, and between them, two spiral-knurled pipes with a placement step $l = 0.5(d + D) + 25$. The solution with the temperature of $t = 40$ °C moves from top to bottom, and the absorbent with the temperature of $t = 36$ °C moves from bottom to top and are in contact on the pipes of the refrigerating chamber.

Cooling process water with a temperature of $t = 18$ °C is supplied to the tube space of the tube-grate packing. At the same time, the process of mass transfer between the solution and the absorbent occurs as we well heat transfer from the solution to the cooling water. Water consumption G = 1.5 kg/s. The solution temperature is 25 °C. Intensification of heat exchange $\alpha/\alpha_{sm} = 3.46$. Increase in hydraulic resistance $\xi/\xi_{sm} = 2.5$. The degree of gas utilization is 89%.

The heat exchange surface of the tubes is clean, even without local point deposits, resulting in a 2.3 times reduction in cooling water consumption.

From the above-mentioned process conditions and the results given in the carbonization column and absorber of the refrigerating machine, it is clear that the cooling processes on the water side in the two apparatuses are similar. The intensification of heat exchange during water flow in the pipes is the same for the two compared devices.

Intensification of cooling on the water side will result in increased absorption of the absorbent. But the degree of absorption is different for carbon dioxide, with which experiments were carried out, and for ammonia (or water vapor). The degree of absorption for refrigerants must be determined using similarity criteria or through experimental testing.

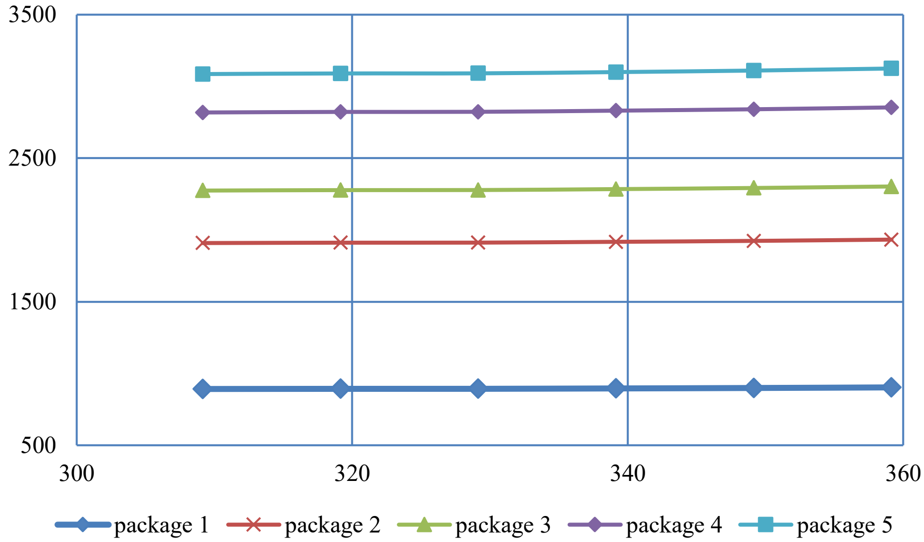

FIGURE 1. Dependence of heat transfer on absorption temperature

The results of calculating the heat transfer coefficient using formula (1) for various pipe packages are presented. The figure shows that for all pipe packages; there is an increase in heat transfer from the solution. The most significant increase corresponds to the pipe package No. 5. For identical pipe packages in the studied temperature range, the value of the heat transfer coefficient changes slightly.

CONCLUSIONS

The use of the considered package of pipes in absorbers enhances heat exchange on both sides of the cooling water and in the carbonization column and absorber of the refrigerating machine.

The coefficient of heat transfer from the side of the solution in a shell-and-tube irrigation absorber with adequate heat and mass transfer surfaces is calculated. The coefficient of heat transfer is determined by the semi-empirical formula (1), which is valid within the range of values obtained from the experiments carried out. To determine α_s the pipe diameters, irrigation density, mortar concentration, etc., which go beyond the areas of validity of formula (1), it is necessary to conduct experiments.

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