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Increasing the Efficiency of Heat Exchanging by Improving the Design of Heat Exchanger Devices

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Abstract. Oil and natural gas are crucial global resources, serving as the primary sources of energy and fuel production. The products derived from these resources are integral to various sectors, including industry, agriculture, transportation, and daily life. They significantly influence the economic strength and technological capabilities of nations. Advancements in oil and gas processing technology are essential for producing high-quality products that adhere to international standards. A key area for improvement is the design of heat exchangers used in natural gas processing. Enhancing the design of these heat exchangers and optimizing the hydrodynamic conditions of raw material flow can extend maintenance intervals and boost economic efficiency. One effective strategy for improving heat exchange efficiency involves enhancing the distribution of raw materials within the distribution chamber. This can be achieved by incorporating a fixed structural element that generates centrifugal forces at the inlet fitting of the shell-and-tube heat exchanger. This modification promotes a more uniform distribution of materials through the exchanger pipes, thereby improving the overall heat exchange process.

Keywords. Shell-and-tube heat exchanger, hydrodynamic regimes, coolant, Reynolds criterion, flow.

INTRODUCTION

Today, one of the most important tasks facing oil and gas processing enterprises is to produce quality products that meet the requirements of international standards with using energy and resource-saving modern technologies. Several advanced research works are being carried out by experts and scientists in the field of creating energy and resource-saving devices and structures. In this regard, scientific research aimed at increasing the thermal parameters of heat exchange devices and pipes adjacent to them and increasing the thermal parameters of the moving flows and organizing optimal hydrodynamic regimes, extending the time between repairs of the device and increasing the efficiency of heat exchange in it, is of great importance.

Oil and gas processing technology often use gas and electric energy produced from the decomposition of crops as a direct heat source, substances that take heat from such heat sources and give its heat to the environment heated by the walls of the equipment are called intermediate heat transfer agents. Intermediate heat-carrying agents include water vapor, hot water and high-temperature heat-carrying substances (mineral oils, organic liquids and their vapors, liquefied salts, liquid metals and their alloys). [1].

When choosing the agents used to give and receive heat in heat exchange equipment, their below attributes is paid attention:1) the degree of heating and cooling of the desired environment and the ability to control it; 2) Achieving a high rate of heat exchange with minimal mass and volume consumption; 3) low viscosity, high density, heat capacity and heat of steam generation; 4) non-corrosive, non-toxic, heat-resistant; 5) heat exchange equipment should not damage the prepared material; 6) It should not be cheap and cheap. [2].

Heat exchange processes in industry are carried out for the following purposes:

1) maintaining the process temperature at a given level;

2) heating of cold products and cooling of hot products;

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3) condensing them;

4) fumigation of solutions and so on. It was carried out on two technological equipments in separate heat exchange equipment by Japan. Heat exchange equipment makes up a large part of the technological equipment used in gas and gas processing and chemical industries.

The heating equipment used in the chemical industry makes up 15-18% of the total equipment on average, while in the oil and gas processing industry this figure is equal to 50%. Different types of heat exchange equipment are used in industry. According to the working principle, heat exchange equipment is divided into three types:

1) surface heat exchangers;

2) cooling heat exchangers;

3) regenerative heat exchangers. Pipe furnaces widely used in the oil and gas processing industry are a separate type. [3].

Heat exchanger equipment is classified according to its designation: according to its structure - equipment made of pipes (cobble-pipe, “pipe-in-pipe” type, spiral and others); equipment with a heat exchanger surface made of sheet material (plate, spiral and others); equipment used in the preparation of the heat exchange surface from non-metallic materials (graphite, plastic, glass and so on). Depending on the purpose of use - refrigerators, heaters, evaporators, condensers are used. Depending on the direction of the movement of heat-carrying agents, equipment with perpendicular, opposite, intersecting, and opposite directions. [4].

When choosing the type and design of the heat exchanger, the factors are taken into account [5]: the purpose of the device and the processes that occur in it; the specific heat amount of the device (the amount of heat supplied per unit of time through the heat exchange surface in the specified heat regime); hydraulic resistance; chemical aggressiveness of heat carriers to construction material; the degree of pollution of heat carriers and the nature of the particles; thermodynamic parameters (mass, pressure, volume and state of heat carriers); physical and chemical properties; temperature stresses that cause distortion in various parts of the heat exchanger under the influence of heat; structural excellence, simplicity of construction, weight and overall dimensions, technological constructions [7].

Recent research has explored various techniques to enhance convective heat transfer. The effectiveness of these methods is influenced by factors such as the shape of the heat exchanger surface, channel dimensions, surface roughness, and channel placement. To optimize heat transfer, it is often beneficial to combine several advanced and constructive approaches. Key methods for intensifying heat transfer include:

1. Surface Geometry Modification: Altering the shape of the heat exchange surface to impact flow dynamics and improve heat transfer efficiency.
2. Turbulization Enhancement: Using additives or modifications to increase turbulence within the channels, which can enhance heat transfer.
3. Surface Area Expansion: Increasing the heat exchange surface area on the side of the working medium where heat dissipation is low.
4. Mechanical Methods: Applying mechanical forces such as rotating the heat exchanger, vibrating the heat exchange surface, introducing pressure pulsations, or mixing the fluid to improve heat transfer.
5. Field Effects: Utilizing electric, acoustic, or magnetic fields to influence the heat transfer process.
6. Surface Treatment and Fluid Dynamics: Employing techniques like sheet recycling, leveraging surface tension effects, or creating static electric fields to manipulate droplet condensation and flow behavior.
7. Porous Surfaces: Enhancing heat transfer through the spraying or suction of the working medium with a porous surface.
8. Additive Agents: Dissolving solid particles or gas bubbles into the liquid to boost heat transfer.

The selection of an appropriate intensification method depends on several factors, including:

1. Size and Weight Reduction: The need to minimize the dimensions and mass of the heat exchange device.
2. Energy Costs: The permissible energy expenditure for enhancing heat transfer and the type of energy sources available.
3. Heat Flow and Temperature Distribution: Managing heat flow density and temperature distribution within the heat exchanger.
4. Manufacturing and Reliability: Ensuring the device's manufacturing feasibility, reliability, and operational dependability.

Additionally, the evaluation of construction and process considerations, including permissible energy consumption (often related to pump power), is crucial. To maintain constant pressure in the heat transfer process, intensification methods should focus on reducing overall dimensions while ensuring technical and economic feasibility. Enhancing heat transfer is a practical approach to reducing the size and mass of heat exchangers and related devices.

When compare to the flow of single-phase heat carriers, flow turbulizers on the surface, spherical surfaces, advanced surfaces with fins, spiral fins, screw devices, turned by turning devices, mixing gas bubbles in liquid flow and solid particles in gas flow are used. Liquid drops, rotation of the heat exchange surface, surface vibration, pulsation of the cooling liquid, the effect of static fields on the flow, withdrawal of the flow from the boundary layer. [11].

The use of co-intensification methods often leads to high efficiency (combining turbulizers with surface filters, using spiral ribs that rotate the flow at the same time, using rotating devices for inter suspension flow, activating the turbulizers by rotating the flow) [12].

Pipes with round fins (Figure 1) show the process of heat exchange between the wall and the liquid in the pipe descriptive internal heat transfer. It is used when it is much bigger than the outside. In such a case, heat exchange causes a significant increase in the heat flow through the outer surface of the pipe wall.

Channel pipes have advantages over heat-conducting gas pipes (small) to water

In order to increase the efficiency of heat exchange between the pipes, methods of influencing the flow with devices that transfer the flow in the pipe to the turbulent regime are used different types, their options are shown in the table figure 2 [13-14].

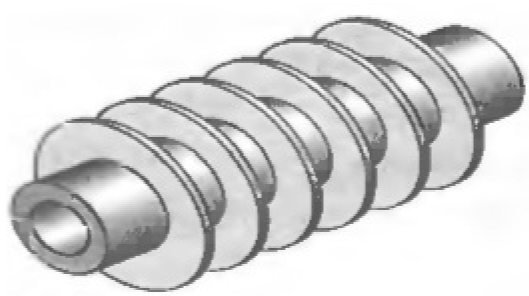
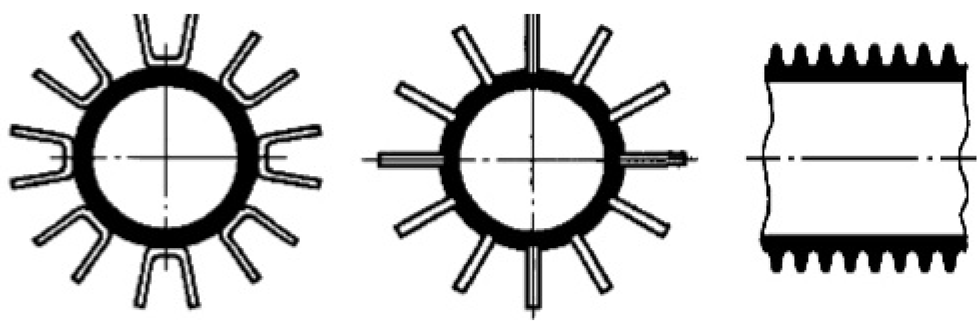


FIGURE 1. Pipe with round fins.

To increase the efficiency (with the increase of suction), steel pipes with folded ribs are used. With their help, the heat transfer coefficient increases by 50-80%. At different angles (from 20° to 50°) the effectiveness of heat exchange processes in cubic and tube installations with segmental and spiral coils was studied experimentally.



a) b) c)

FIGURE 2. Ribbed pipes: a - barriers are welded; b - twisted; c - shaped channels are opened

Below methods made it possible to evaluate the effect of the parameters of the method on the tune (20° to 50°). It is shown that the intensity of heat transfer in this type of devices is the most effective in comparison with the heat exchanger with two segmented tubes with an inclination angle of 20∠°, 30∠° and 50∠°. A method for developing the construction of heat exchanger devices with internally regularly placed porous elements is offered [14-17].

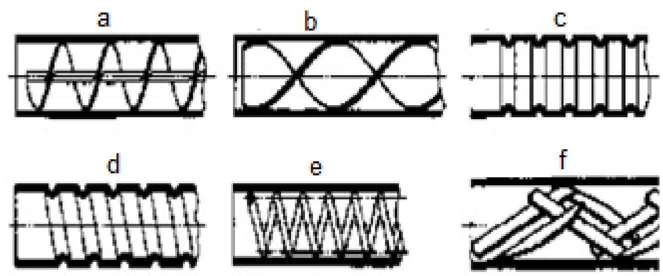


FIGURE 3. Pipes with turbulators: a - screw twist; b - band twist, c - vertical diaphragm tubes; d - spiral diaphragm tubes; e - spiral wire tubes; f - turbulizer of "Sulzer" company

The application of this technology is shown in the example of creating twenty-one heat exchanger prototypes, each of which has eight hexagonal elements. using computer analysis methods, the effect of changing flow structures on convective heat exchange and pressure drop in advanced test devices was evaluated [14, 17].

Screw (figure 3, a) or belt (figure 3, b) swirlers installed along the entire length of the pipe provide swirling of the flow, which is one of the effective methods for intensifying heat exchange in pipes. Tape swirlers have become widespread [18]. due to the ease of manufacture. At the same time, the most effective flow spinning is realized if the tape is inserted into the pipe with practically no gap. An additional effect in this case is that the screw insert increases the heat exchange surface and the heat received by it by means of thermal conductivity is transferred to the pipe wall.

METHODS

In order to study the operation of the heat exchange process in gas absorption purification technology, a heat exchange device with a hollow pipe was installed. the dynamics of temperature change in the process of heating the diethanolamine that has been regenerated with diethanolamine was studied (Fig. 4) 2 According to the literature, there is no information about the temperature of the heat exchange process, the consumption of raw materials in the process, and the change of movement modes as a result of the movement of the heat-carrying agent to the distribution chamber of the device in a circular manner. [19].

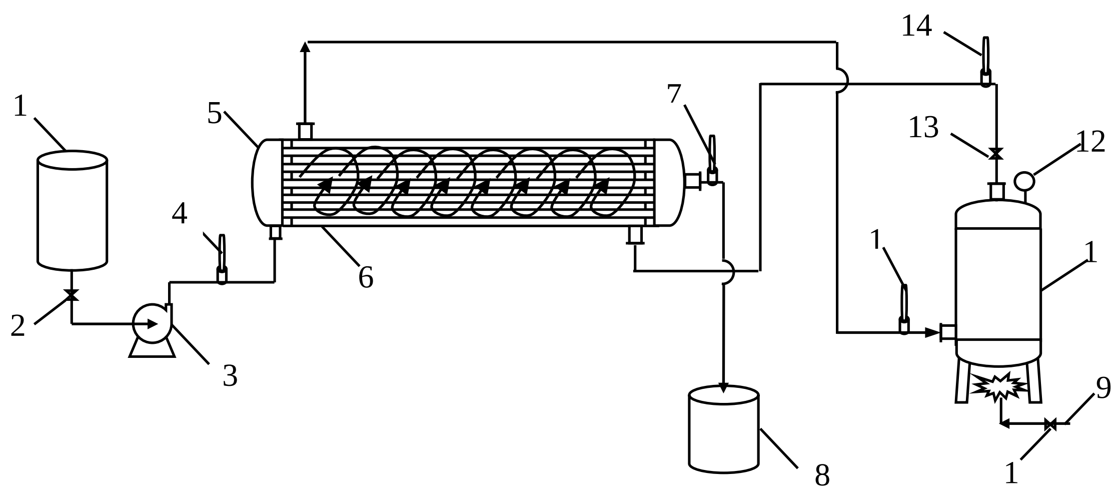


FIGURE 4. Technological scheme of a shell-and-tube heat exchanger with a structure in which the flow movement in the distribution chamber is directed under the influence of centrifugal force.

1 - container raw materials; 2 - raw material consumption management system; 3 - centrifugal pump; 4.7 - thermometers; 5 - a centrifugal camera; 6 –shell and tube heat exchanger device; 8 - a container for high temperature raw materials 8 - capacity container; 9 - natural gas; 10 - gas tank; 11 - generator for heating agent; 12 - manometer for measuring pressure; 13 - a spring for correcting the consumption of heat carrier; 14,15 - therometers for measuring the temperatures at the inlet and outlet of the heating agent to the shell and tube heat exchanger device.

To investigate the impact of flow dynamics on temperature variations during heat exchange, a thermal exchange device was designed and tested based on a review of scientific literature and internet sources. The focus was on understanding how circular flow movement in a cubic pipe heat exchanger affects the heat exchange process.

The experimental setup functions as follows: a heating agent, specifically saturated diethanolamine, is introduced into a raw feed container. The raw feed is then gradually transferred to a centrifugal pump (Pump 2) using a secondary pump. This raw feed is directed into the internal pipe of a cubic pipe heat exchanger, which is equipped with five chambers to facilitate flow circulation. The heated raw material exits the heat exchanger and is collected in a tank.

Temperature measurements are taken at the inlet and outlet of the heat exchanger using thermometers placed at designated points (Thermometers 4 and 7). The volumetric flow rate is determined by measuring the volume of raw material collected in the tank over time. The cubic pipe experimental unit has a length of 2000 mm and a diameter of 76 mm, with five internal pipes each having a diameter of 10 mm. Experiments were conducted with raw material flow speeds ranging from 0.5 to 1.0 m/s.

Table 1 presents the results of heating saturated diethanolamine with regenerated diethanolamine using the cubic pipe heat exchanger, showcasing the efficiency and effectiveness of the device under the tested conditions.

TABLE 1. Dependence of the flow temperature in the cubic tube heat exchange installation on the raw material grade

Consumption of raw materials V l/min	the temperature of the heated substance, °C		Heating agent temperature,°C	
	t_1	t_2	t_3	t_4
1	25	87	108	81
2	25	85	108	82
3	25	82	108	84
4	25	78	108	86
5	25	71	108	89

The data presented in Table 1 illustrate the performance of the cubic pipe heat exchanger with saturated diethanolamine as the heating agent. At the end of the pipe, the temperature of the heating agent (regenerated diethanolamine) was observed to be t=25°C, while the temperature of the heating agent exiting the heating boiler was t=108°C.

The temperature variation of the raw material, heated within different volumetric flow rates, is summarized as follows: At a flow rate of V=1 l/min, the temperature of the raw material increased from 25°C to 87°C. During this process, the temperature of the heating agent decreased from t_4=108°C to 81°C.
When the flow rate of the raw material was increased to V=5 l/min, the temperature of the raw material rose to 89°C, while the temperature of the heating agent at the exit increased to 71°C.

The results indicate that increasing the raw material flow rate from 1 l/min to 5 l/min min led to a decrease in the temperature of the heating agent by 16°C. Despite this, the total energy consumption for heating increased fivefold.

These findings highlight a trade-off between the flow rate of the raw material and the efficiency of the heating process. While higher flow rates improve the temperature of the raw material, they also result in a significant increase in the total heating cost.

The centrifugal force in the distribution chamber of the cubic pipe experiment of the heat exchange device in Fig. 4 was calculated. to the technical parameters of the construction of this experimental facility: the diameter of the upper pipe of the heat exchange facility D=72/76 mm; diameter of internal pipes d=10/13 internal pipe length L =1800 mm; number of internal pipes n=5; The height of the distribution chamber H=55 mm; heat exchanger surface of experimental device F=0,565 m²; Pipe diameter d=20 mm for the entrance of raw materials;

Raw as materials mass in the device distribution chamber. [20]:

$$m = (\pi \cdot D^2/4)H \cdot \rho \quad (1)$$

Speed in the pipe for raw materials to enter the distribution chamber of the experimental heat exchange device:

$$\upsilon = 4 \cdot V/(3600 \cdot \pi \cdot d_п^2) \quad (2)$$

It was determined the magnitude of the centrifugal force slows down at different radii corresponding to 0,1÷0,5 percent of the internal diameter of the device distribution chamber:

$$C_1 = m\upsilon^2/R = 0{,}26 \cdot 0{,}23^2/R_1$$

The ratio of centrifugal force and rotational force, which determines the efficiency of distribution of raw material in the internal pipes of the heat exchange device, is determined with the help of formula 2:

$$K = C_1/G = (m \cdot \upsilon^2/R)/m \cdot g = \upsilon^2/R \cdot g$$

from the data given in table 2 it can be seen that under the influence of centrifugal force, the flow movement in the distribution chamber of the device increases by 7,4 % when the internal pipes are filled with raw material, as a result, the distribution of the amount of heat given by the heating agent is reduced and the thermal efficiency of the raw pipe increases.

TABLE 2. Production process efficiency of distribution of raw material in the inner tube of the heat exchanger with a hollow tube under the influence of centrifugal force

Centrifugal force	Work of rotation of centrifugal force in the raw material distribution chamber				
	R_1 (0,1·D)	R_2(0,2·D)	R_3(0,3·D)	R_4(0,4·D)	R_5(0,5·D)
Magnitude of centrifugal force *C*, Pa	1900	951	634	475	380
Increase of centrifugal force j_m, %	100	50,0	33,6	25,0	-
Raw material distribution efficiency in the pipeline *K*, %	7,4	3,7	2,4	1,8	1,4

RESULTS

Centrifugal force magnitude C (Pa), increase of centrifugal force on the internal pipes of the cubic pipe experiment j_C, the distribution efficiency of raw materials in the pipeline is presented in table 2. From the data presented in table 2, it can be seen that under the influence of centrifugal force, the flow movement in the distribution chamber of the device under the influence of centrifugal force, the level of supply of internal pipes with raw material increases by 7,4%, as a result, the amount of heat given by the heating agent increases. the distribution is reduced and the heat efficiency increases, and the efficiency of the production process increases on the inner surface of the pipe.

Based on the above information, the results of the process of soaking sulfur-saturated diethanolamine with regenerated diethanolamine, which is used as an absorbent in the gas purification process, are presented in table 3.

TABLE 3. Temperature dependence of the heating of saturated diethanolamine with regenerated diethanoamine (pressure of heating agent is 50÷200 kPa)

Consumption of raw materials V l/min	Regenerated diethanoamine		Saturated diethanolamine	
	Temperature at pipe inlet t_1, °C	Temperature at pipe exit t_2°C	Temperature at pipe inlet t_3, °C	Temperature at pipe exit t_4, °C
50 kPa				
1	88	46	20	67
3	88	45	20	64
5	87	45	20	63
7	86	44	20	62
10	86	44	20	60
100 kPa				
1	103	68	20	89
3	103	66	20	86
5	103	64	20	82
7	103	62	20	81
10	103	60	20	78
150 kPa				
1	106	72	20	91
3	105	71	20	89
5	105	69	20	86
7	105	67	20	83
10	105	65	20	80
200 kPa				
1	114	76	20	94
3	113	74	20	91
5	113	71	20	88
7	112	69	20	85
10	110	68	20	80

During the heating process, the pressure of the heating agent is P=50÷200 kPa, the pressure of the heat source V=1÷5 l/min.

The temperature of the heating agent (regenerated diethanolamine) at the exit from the heating cauldron exceeded the range of t_1 = 86-114 °C, corresponding to the change of the transmitted pressure in the range of P=50÷200 kPa Hg. accordingly, the temperature of the heating agent at the exit from the heat exchange installation is t_2 = 45-76 °C. As a result, the temperature of the regenerated dietanolamine to the initial temperature of t_3 = 20 °C, corresponding to the change of its volume ratio (V=1÷10 l/min.), was determined as a result of experiments to t_4 = 60-94 °C.

It can be observed that the change of raw material in the range of V=1÷10 l/ min, the speed of the heated raw material flowing through the internal pipes of the heat exchange device, the increase of the pressure of the heating agent in the device chamber to P=50÷200 kPa leads to an increase in the average temperature in the device, Δt, °C. including raw material consumption 1÷10 l/min. when the pressure of the heating agent increased to 50 kPa, the average temperature was 23,5÷24 °C, while at 100 kPa, this temperature was 31÷32,5 °C, at 150 kPa, it was 33÷35 °C, and at 200 kPa, it was 38÷39 °C. I can observe it. it can be seen that as a result of the increase in the pressure of the blowing agent and the temperature of the raw material, the chaotic behavior of the moisture in the pipes is observed, and the process of heat exchange in the device accelerates.

It is possible to see that the speed of the raw material heated in the heat exchange device in the internal pipes of the device changes in accordance with the temperature and pressure of diethanolamine entered into the regenerator. in addition, when the temperature of the heat transporter (regenerated diethanolamine) in the boiler cavity is 88 °C and the pressure is 50 kPa, the speed of heated raw material (saturated diethanolamine) in each internal pipe of the boiler increases from 0,017 m/s to 0,176 m/s.

It was determined that the amount of transferred heat increased by 3,3 times in the range of 2191÷7319 Watt, and when the temperature of the heat carrier was 103 ° C and the pressure was 100 kPa, the amount of transferred heat increased by 3241÷10341 Wt, i.e., by 3,2 times. As a result of increasing the temperature and pressure of the device to 105 °C and 150 kPa, the amount of heat transferred at the above flow rates increases to 3748÷12759 Wt. As a result of increasing the temperature to 114 ° C, increasing the pressure to 200 kPa and increasing the raw material speed from 0,017 to 0,176 m/s, it was determined that the amount of heat transferred increased from 5326 Wt to 15914 Wt, that is, it increased by 2,9 times. In these obtained results, it can be seen that the temperature of the heat carrier and the increase in the movement of the raw material in the pipeline increases the amount of heat transferred by 7,2 times (fig. 4).

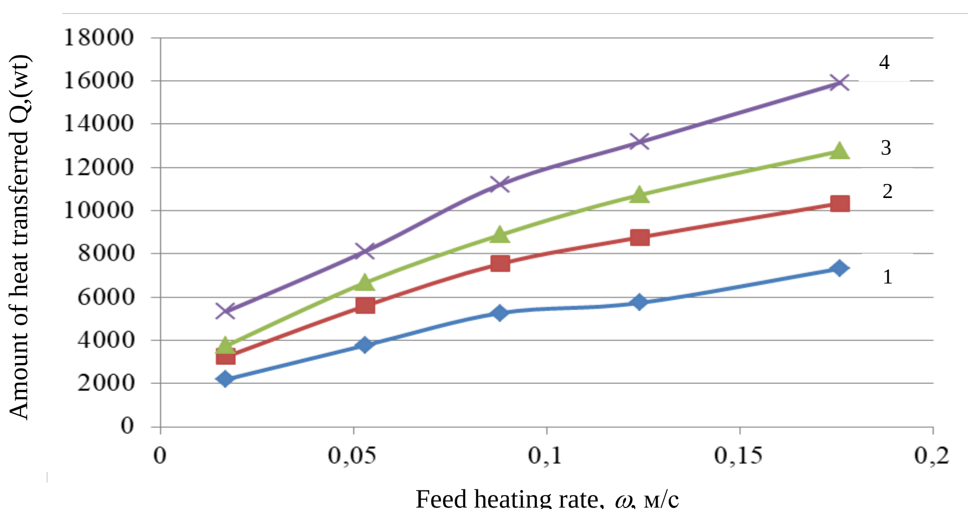


FIGURE 5. Influence of the rate of heated feedstock on the amount of heat transferred

1- at a regenerated diethanolamine temperature of 88 ° C and a pressure of 50 kPa; 2- at a regenerated diethanolamine temperature of 103 ° C and a pressure of 100 kPa; 3- at a regenerated diethanolamine temperature of 105 ° C and a pressure of 150 kPa; 4 at a regenerated diethanolamine temperature of 114 ° C and a pressure of 200 kPa.

Summarizing the data, it can be concluded that as a result of increasing the temperature of the heating agent (regenerated diethanolamine) at the entrance to the heat exchanger from 88 °C to 114 ° C, the pressure in the shell of the device increases from 50 kPa to 200 kPa. As a result, the temperature of the heated raw material (saturated diethanolamine) at the outlet of the heat exchanger increased from 0,017 m/s to 0,176 m/s as a result of exceeding its flow rate in the pipeline from 60 ° C to 94 °C, Reynolds number - up to 11,8, the heated raw material from the inner wall of the pipe increases the heat supply coefficient by 5,11 times, the heat transfer coefficient – 4,3 times, amount of transferred heat – 7,2 times.

DISCUSSION

This study investigates methods to enhance the heat exchange efficiency of shell-and-tube heat exchangers, particularly those used for heating saturated absorbents with regenerated absorbents in the context of regenerating gas purification via absorption. The primary focus is on optimizing the hydrodynamic regimes within these heat exchangers to improve performance.

The efficiency of heat exchange can be significantly influenced by altering the flow conditions within both the internal pipes and the annular space of the shell-and-tube heat exchanger. In this study, it was found that the turbulent flow regime within these systems offers superior heat exchange efficiency compared to laminar or transitional flow regimes. This is due to the increased turbulence enhancing the mixing and heat transfer between the absorbent fluids.

A key innovation discussed in this article involves the strategic placement of the raw material inlet nozzle. By positioning this nozzle to create an impact on the elliptic cover circle of the horizontal one-way shell-and-tube heat exchanger, centrifugal forces are generated. This setup promotes better distribution of the raw materials within the distribution chamber, leading to a more uniform flow and improved heat exchange performance.

Overall, the results suggest that optimizing hydrodynamic conditions and carefully designing component placements can lead to significant improvements in heat exchanger efficiency. These modifications are expected to enhance the overall effectiveness of the regeneration process in gas purification technologies.

CONCLUSION

1. In the article, the dependence of the heating process of raw materials on its consumption was studied in detail. The addition of raw material to it at a rate of 1 l/min to 5 l/min will cause the temperature of the reducing agent to drop to 16 °C. but the total volume of the heated raw materials increases 5 times.

2. From the physical properties of the researched raw dense, kinematic and dynamic viscosity was studied. In addition, the density of saturated diethanolamine with a concentration of 25 % at a temperature of 20 °C is 1112 kg /m³, kinematic viscosity is 0,748 mm / s, and dynamic viscosity is $0{,}83 \cdot 10^{-3}$ Pa, while the density of unsaturated diethanolamine with a concentration of 26% at the given temperature is 1091 kg/m³. kinematic viscosity 0,697 mm/s, dynamic viscosity $0{,}76 \cdot 10^{-3}$ Pa·s, density of diethanolamine to 85% concentration 1092 kg/m³, kinematic viscosity 2,02 mm/s, dynamic viscosity $2{,}20 \cdot 10^{-3}$ Pa·s.

3. The specific heat capacity of raw materials in the temperature range of 20÷120 was calculated, the heat capacity of 25% saturated diethanolamine varies between 1536÷578 kJ/kg·K, while in unsaturated diethanolamine this indicator is 1556÷1627 kJ/kg·K, the change in heat capacity of 85% diethanolamine according to temperature is 1559÷1632 kDj/kg it was confirmed.

4. With increasing temperature from 20 °C to 120 °C, the thermal conductivity of 25% saturated diethanolamine decreased from 0,1214 to 0,1148 W/(m·K), while this indicator decreased from 0,1235 to 0,1168 Wt/(m·K) in unsaturated diethanolamine. The thermal conductivity of 85% diethanolamine at these temperatures was calculated from 0,1237 to 0,117 Wt/(m·K) using mathematical expressions.

5. The heat index of the experimental heat exchange device was calculated. according to it, the Reynolds number is 584 when the raw material flow rate is 0,21 m/s, the heat transfer coefficient from the heat carrier to the outer wall of the pipe α_1 = 2914 Wt/ (m^2·K), the heat transfer coefficient from the pipe wall to the heated liquid α_2= 321 Wt/(m^2·K), the heat transfer coefficient K = 289 Wt/(m^2·K), the transferred amount of heat was Q = 4766 watt. It was observed that these indicators increase accordingly with the increase of the speed up to 1,06 m/s. The formation of Re= 2952, α_1 = 3121 W/(m^2·K), α_2=894 W/(m^2·K), K=694 Vt/(м²·К), Q = 11456 Wt was determined.

In conclusion, the possibilities of increasing the energy efficiency will increase with the correct organization of the process in the shell and tube heat exchanger

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