Device for increasing the efficiency of the packed heat and mass transfer column and manufacturing method

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ABSTRACT

The article presents the developed design of the heat and mass transfer column device with contact elements made of skewed sheets, which makes it possible to mitigate the disadvantages of using structural nozzles. The results of the study of the method of manufacturing the device from polymeric materials are presented.
Key words: Rectification, Heat and mass transfer column, Distribution devices, Polymers.

INTRODUCTION

At present, the most noticeable occurrence in the design of heat and mass transfer machines operating on the gas (steam) – liquid system has been a sharp increase in the competitiveness of packed columns compared to tray-type columns, since they surpass the latter in a number of indicators, such as efficiency, productivity, and stability.

Theoretical and experimental studies of the process of continuous rectification in the packed contact device of the cryogenic machine, on the basis of which it is possible to improve the design of air separation units (ASU), including military ones, are of practical importance and essential for the uninterrupted provision of the needs of aircraft in service in Aerospace forces in compressed and liquefied gases.

RESEARCHES

After analyzing the patent and scientific literature, the following advantages of structural nozzles over tray-type contact devices can be distinguished:

- permissible steam speeds in machines with a structural nozzle are significantly higher, which allows to reduce the transverse dimensions of the machines;

- operation of heat and mass transfer columns is stable in a wide range of loads with steam and liquid, because the design of the structural nozzles eliminates the possibility of the liquid "falling through" under the sudden changes in the vapor velocity or temporary cessation of reflux;
- a relatively low hydraulic resistance (on average by 30% lower than in the tray-type machines) allows to significantly reduce the specific energy consumption in air separation units, to intensify the work of a heat-exchange equipment;
- high local holding capacity and features of the continuous process of mass transfer can reduce the start-up period of the separation units, since it does not take time to accumulate the liquid, as in the tray-type column;
- unification, i.e. the ability to manufacture many sizes of columns from unified elements or blocks, which simplifies the technology and reduces the complexity of installation of the devices;
- high strength characteristics under vibration loads [1,2].

The main disadvantages of using the structural nozzles are:
- poor wettability of the nozzle under low irrigation densities;
- significant ablation of the liquid along the walls of the heat and mass transfer column, since the liquid flowing onto the walls of the column along the nozzle plates does not return to the nozzle. Figure 1 shows a model of the distribution of the fluid flows through the channels of the skewed nozzle.
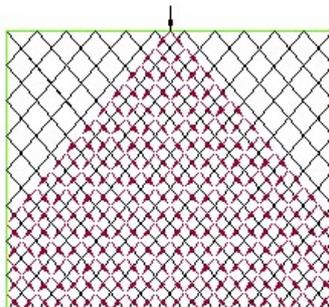

Figure 1. Model of fluid distribution in nozzle channels

When supplying the fluid from one infinitesimal point of irrigation, it is observed that in the channels formed by two adjacent corrugated sheets in the nozzle, only 66% of the channels are wetted. And if we observe the entire nozzle package as a whole, then no more than 11% of all the nozzle channels will be wetted. At the same time the fluid streams flowing down to the edge of the nozzle get on the walls of the heat and mass transfer column and do not return to the nozzle. In the example considered, the entrainment of the liquid along the walls of the heat and mass transfer column is 23%. The use of the structural nozzle packages requires the introduction of the fluid distributors. If the whole stream in the model shown in Figure 1 is divided into three infinitely small streams equal in diameter and placed at equal distances from each other, 91% of the channels formed by two adjacent corrugated sheets in the nozzle will be wetted. However, liquid entrainment along the walls of the heat and mass transfer column will be

increased up to 54%. An increase in the number of supply points leads both to the improvement in the wettability of the nozzle package and to the increase in the fluid entrainment along the walls of the heat and mass transfer column. The distribution of the liquid flow only cannot fully ensure the good operation of the nozzle contact device. Redistribution and stabilization of the steam stream, especially at its entrance to the nozzle layer, is also necessary [3]. The authors have developed a group of inventions that eliminates the disadvantages of using the structural nozzles.

The essence of the group of inventions is illustrated by the figures.
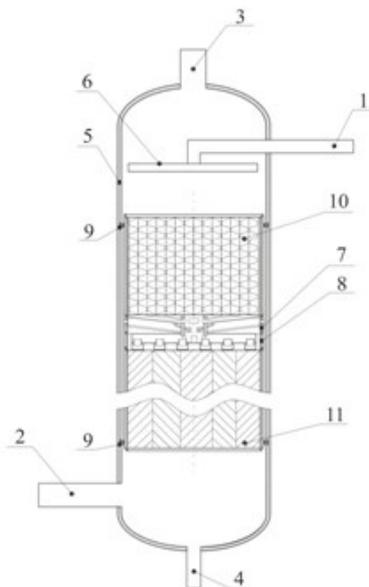

Figure 2. Heat and mass transfer column
1– input for the liquid phase; 2– input for the gas phase; 3– selection of the gaseous product; 4– selection of the liquid product; 5– casing of the heat and mass transfer column; 6– liquid phase distributor; 7– collector; 8– liquid distributor; 9– sealing rings; 10– upper package of corrugated skewed nozzle; 11– lower package of corrugated skewed nozzle.
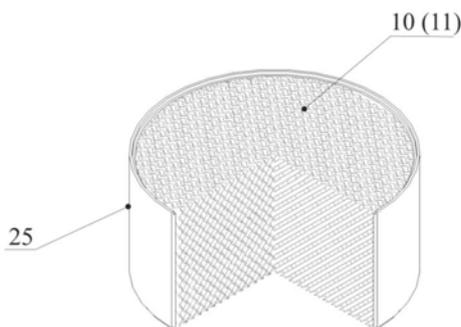

Figure 3. Corrugated skewed nozzle package in the shell
25– shell of the nozzle

Fig. 4 shows the collector where: 15 – upper level of the gutters, 16 – shell of the collector, 17 – lowering pipe, 18 – lower level of the gutters, 19 – T-shaped walls of the gutters, 26 – holes.
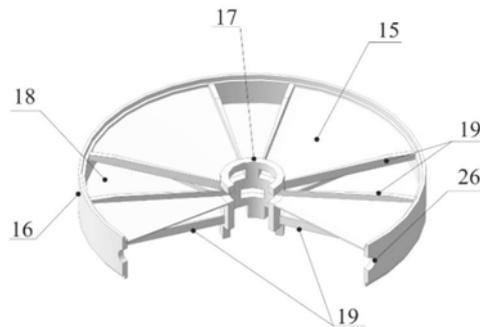

Figure 4. Collector

Fig. 5 shows the liquid distributor where: 21– primary gutter, 22 – secondary gutters, 23 – overflow pipes, 24 – shell of the liquid distributor.
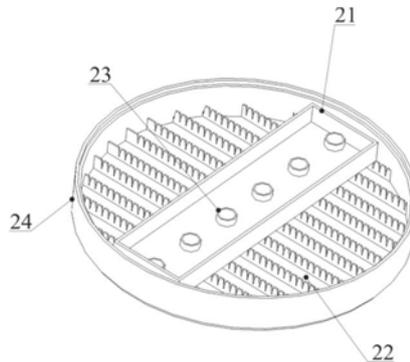

Figure 5. Liquid distributor

The heat and mass transfer column comprising casing with N coaxially mounted on top of one another nozzle packs of skewed sheets $M \leq N - 1$ collectors, and $M \leq N - 1$ liquid distributors, where each nozzle package, each collector, and each liquid distributor are installed in the shell with an outer diameter:

$$d = (0,9...0,99)D \qquad \text{Eq. (1)}$$

where D– inner diameter of the casing of the heat and mass transfer column, m.

In the casing of the heat and mass transfer column, on the inside, there are slots with a diameter $D_{\text{пр}}$, satisfying the expression:

$$D_{\text{пр}} = (1,02...1,03)D \qquad \text{Eq. (2)}$$

in which sealing rings 9 made of fluoroplastic (PTFE), with an external diameter equal to $D_{\text{пр}}$, internal diameter equal to d and height $h_{\text{к}}$ are installed

$$h_\text{к} = (0{,}98...1{,}02)(D_\text{пр} - d) \qquad \text{Eq. (3)}$$

The distances between the rings are selected based on the vertical dimensions of the heat and mass transfer column, so that the lower sealing ring is located on the lower boundary of the shell of the lower nozzle, and the upper one is located on the upper boundary of the shell of the upper nozzle. Sealing rings 9 impede the free movement of liquid and gas along the wall space of the heat and mass transfer column and create heat-insulating space between the casing of the heat and mass transfer column and the shells: nozzles 25, collectors 16, liquid distributor 24. The above design of the heat and mass transfer column increases the intensity of rectification processes due to the complete elimination of the occurrence of the wall liquid entrainment.

The collector consisting of the shell of the collector 16, gutters 15, 18 made in the form of truncated sectors mounted obliquely at a predetermined angle to the longitudinal axis of the heat and mass transfer column, while the angle of inclination of the gutters is selected from the conditions of fluidity of the liquid, and lowering pipe 17 installed along the longitudinal axis of the heat and mass transfer column. The gutters are located in two levels: the upper level 15 and the lower level 18 – one below the other at a given distance, as determined depending on the properties of the liquid and gas interacting in the heat and mass transfer column, the distance between the levels is chosen so that the hydraulic resistance of the collector is less than the hydraulic resistance of one nozzle package.

The lowering pipe 17 is made in the form of a hollow cylinder, in the walls of which there are holes made in two levels, in the amount equal to the number of gutters 15, 18, each gutter is rigidly fixed along the arc – that of a larger diameter is fixed to the collector shell 16, and that of a smaller diameter is fixed to the bottom of the hole in the outer diameter of the lowering pipe 17. The lower level of the gutters 18 is installed with overlapping in relation to the upper level of the gutters 15 in order to eliminate the through-flow of the liquid after the nozzle 10.

The walls 19 of the gutters 15, 18 are fixed in a T-shaped way with respect to the bottom of the gutters. The walls 19 of the gutters have a dual purpose. On the upper side of the gutters, the liquid overflow is eliminated, and on the lower side thereof, they create a separation occurrence when the movement direction of the rising gas is changed [4].

In the shell of the collector 16 under the upper gutters 15 at a given distance from the upper gutters, holes 26 are made through which the inter-wall space is filled with gas and, thereby, an additional thermal insulation is created.

The liquid distributor consists of one primary gutter 21, any number of the secondary gutters 22 and the shell of the liquid distributor 24. The liquid flows from the primary gutter 21 to the secondary gutters 22 through the overflow pipes 23 located in the bottom of the primary gutter 21 above each secondary gutter 22.

In order to exclude the possibility of the liquid overflow over the primary gutter 21, the overflow pipes 23 are made of a lower height than the side walls of the primary gutter 21, and the inner diameter of the overflow pipes:

$$d_{\text{пт}} \geq \sqrt{\frac{d_{\text{вн}}^2}{L}} \qquad\qquad \text{Eq. (4)}$$

where $d_{\text{вн}}$– inner diameter of the overflow pipe 17, m, L– number of secondary gutters 22.

For the convenience of mounting of the whole device, slots in which central overflow pipes 23 are included during assembly are made directly in the heat and mass transfer column in the lower part of the lowering pipe 17.

Slots are made in the side walls of the secondary gutters to distribute the liquid to the nozzle 11. The shape and number of slots are selected based on the liquid flow rate [4].

In the shells of the nozzle, collector, and liquid distributor, ribs are made on the upper side, and slots to match them are on the bottom side to eliminate the occurrence of wall ablation of the liquid and simplify the installation in the heat and mass exchange column, as well as to provide the ability to rotate the nozzle, collector, and liquid distributor to any angle relative to one another, achieving the best irrigation of the lower nozzle.

The liquid is continuously supplied through the inlet 1 located closer to the upper part of the heat and mass transfer column, which is connected to the liquid phase distributor 6. The 6 liquid phase dispenser is widely known from the level of technology and is not disclosed in detail. After the distributor 6, the liquid phase flows evenly onto the nozzle 10 installed in the shell of the nozzle 25. As in the previous case, the use of such a nozzle is well known from the level of technology and is not disclosed in detail.

The entire liquid flow from the liquid phase distributor 6 that has passed through the nozzle 10 can be divided into four probable flows: the flow getting onto the shell of the nozzle 25, the flow getting onto the lowering pipe 17 through the upper hole, the flow getting onto the upper level of the gutters 15, and the flow getting onto the lower level of the gutters 18 located between the upper level of the gutters.

The given design of the collector ensures the direction of all the four likely flows of the fluid flow into the lowering pipe 17, which completely eliminates the entrainment of the fluid along the walls of the heat and mass transfer column.

Through the lowering pipe 17, the liquid gets to the liquid distributor, where it fills the primary gutter 21 to the level of the overflow pipes 23, then it simultaneously flows through the overflow pipes 23 into the secondary gutters 22, which it fills to the lower edges of the slots of the side walls of the secondary gutters 22 and flows down through these slots.

After the liquid distributor, the liquid evenly gets to on the nozzle 11. After the uniform irrigation, the nozzle 11 is completely moistened, and therefore it works to the fullest without any significant zones of bypassing by the liquid.

Gas is continuously supplied through the inlet 2 located closer to the lower part of the heat and mass transfer column. Rising up the column, the gas gets to the lower nozzle 11, which is identical to the nozzle 10, where it contacts the liquid flowing down the surface of the nozzle and passes through the liquid distributor and the collector.

In the collector, a part of the gas fills the inter-wall space through the hole 26 ensuring the pressure equalization inside the shells and the casing of the heat and mass transfer column and the creation of additional heat-insulating space. Heat and mass transfer also takes place in the collector – the gas comes in contact with the liquid flowing down the gutters 15, 18 in the form of film. The gas passing through the collector changes its direction of motion several times, since the gutters 15, 18 are installed with an overlap excluding the free movement of the gas. On the lower part of the gutters 15, 18, there is an occurrence   of condensation of the low-volatility component from the gas, due to the difference in the boiling points of the liquid flowing down the upper surface of the gutters and the condensation of the gas rising on the lower surface of the gutters, and the moisture separation on the lower part of the T-shaped walls, due to the changes in the direction of the gas movement. The resulting droplet moisture flows down the lower surface of the gutters 15, 18 to the outer part of the lowering pipe 17, from where it gets to the primary gutter of the liquid distributor 21[4]. Next, the gas gets to the nozzle 10, where it comes in contact with the liquid flowing down.

The use of this device, in contrast to the well-known one [5], allows to intensify the rectification processes occurring in heat and mass transfer columns due to the exclusion of the wall entrainment of the liquid, the introduction of additional separation effect and additional thermal insulation required in cryoengineering.

Due to the fact that the shape of the device is complicated to manufacture by means of the well-known methods, the authors propose using the FDM *(Fused deposition method)* – modeling by means of molten filament sedimentation method (layer-by-layer building up). In this regard, on the basis of 24th Department for Cryogenic Machines, Mounts and Electro-Gas Equipment of Military Educational and Scientific Center of Air Forces "Air Force Academy named after Professor N. E. Zhukovsky and Yu. A. Gagarin", the experimental studies have been conducted on the resistance of some materials to the liquid oxygen. The parts similar to the real device, with the same ratio of the volume of the part to the surface contact area of the part with the liquid oxygen were printed. As an example, a similarly shaped part of PTFE (polytetrafluoroethylene) was taken. The results are shown in Fig. 6.
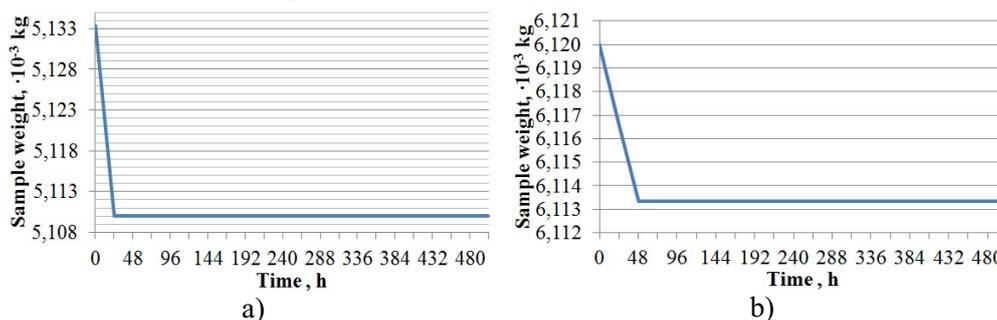

Figure 6. Dependence of mass in samples from ABS (a) and PET-G (b) on the time spent in liquid oxygen

After 500 hours in the liquid oxygen, the mass of the PTFE sample was not changed and amounted to 10,337 $\cdot 10^{-3}$ kg. The mass of the ABS (acrylonitrile butadiene styrene) sample was decreased by 0.45% after the first day, the mass of the PET-G (polyethylene terephthalate glycol) sample was decreased by 0.11% after the first two days, and then the mass of the samples stabilized and remained unchanged until the end of the experiment. Also, the studies of the temperature shrinkage of the materials when cooled from 273 K to 90 K were carried out. The results are shown in Fig. 7. The temperature shrinkage of PTFE was 1.81%.

a)

b)
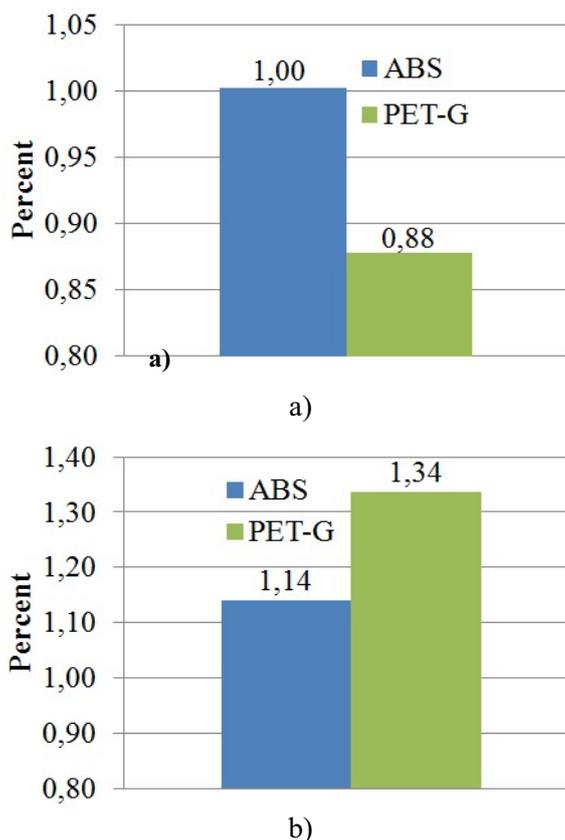
Figure 7. Temperature shrinkage of the materials along (a) and across the printing layers (b)

The manufacture of the distribution devices in the heat and mass transfer columns of PET-G is possible, but it requires a number of restrictions:
- the manufactured devices must be immersed for at least two days in liquid oxygen, so that the non-polymerized monomers would come in contact with oxygen and dissolve in it;
- the maximum temperature in the heat and mass transfer column with the installed devices of PET-G must not exceed the glass transition temperature of the polymer.

CONCLUSIONS

The developed device of the heat and mass transfer column almost completely eliminates the main disadvantages of using structural nozzles, such as poor wettability of the nozzle at low irrigation densities and significant liquid entrainment in the walls of the heat and mass transfer column. Based on the studies of the polymer materials, it is proposed to evaluate the possibility of using the PET-G material in practice in cryoengineering, in particular for the manufacture of distribution devices in heat and mass transfer columns by means of FDM-method.

NOMENCLATURE

N	number of contact packages of the nozzle made of skewed sheets	M	number of collectors and liquid distributors
D	inner diameter of the casing of the heat and mass transfer column (m)	$D_{\text{пр}}$	diameter of slots in the casing of the heat and mass transfer column (m)
d	outer diameter of the shell (m)	$h_{\text{к}}$	height of O-rings (m)
$d_{\text{вн}}$	inner diameter of the lowering pipe (m)	L	number of secondary gutters
$d_{\text{пт}}$	inner diameter of the overflow pipes (m)		

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