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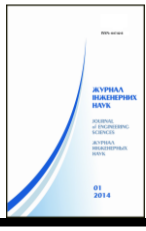

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Calculation of optimal design of heat-mass transfer separation vortex trays

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Growing interest in the use of contact stages of vortex type is due to their high efficiency. Using vortex and highly turbulent flows allow the reduction of size and amount of workspace of an apparatus due to intensification of heat-mass transfer processes. Latest analysis research in the field of design improvement of contact devices shows that in modern technologies drying and purification of natural gas are increasingly using mass transfer vortex trays with different ways of creating swirling flows (on canvas tray and other elements). Use of vortex contact devices significantly reduces the amount of liquid entrainment, decreases the flow resistance and increases the surface of contact phases.

In this work the method of the optimization calculation of heat and mass transfer- separation element (HMTSE) of vortex trays is examined. Criteria of selecting optimal designs of tray elements for gas cleaning are shown. A computer program for calculating the optimal design of the vortex stage gas cleaning is presented.

Research object – vortex tray with HMTSE for gas cleaning processes. Research subject – hydrodynamic and technological conditions for the functioning of the vortex tray with HMTSE.

To the base of program «Vortex tray» the mathematical model, considering the influence on the size of the HMTSE of technological parameters of the columnar apparatus, is put. .

The hydrodynamics influence of the gas flow and physicochemical properties of the liquid on the size of HMTSE is investigated. On the basis of analytical relationships optimization design calculation of vortex tray with HMTSE is held. Results of the graphic dependences, based on computer calculations, which allow the influence of the liquid amount, its velocity, thickness and other characteristics on the size of HMTSE are obtained.

Computer simulation results is allowed for designing of the vortex tray with optimal design and determining the range of the effective work in different hydrodynamic regimes without expensive physical experiment.

Prospects for further research are: study of separation and heat-mass transfer characteristics of the vortex tray with HMTSE for gas cleaning.

Key words: vortex tray, heat-mass transfer separation element (HMTSE), computer simulation, optimization.

1. INTRODUCTION

Growing interest in the use of contact stages of vortex type is due to their high efficiency. Using vortex and highly turbulent flows allows the reduction of size and amount of workspace of an apparatus due to intensification of heat and mass transfer processes. Latest analysis research in the field of design improvement of contact devices [1 – 4] shows that in modern technologies drying and purification of natural gas are increasingly using mass transfer vortex trays with different ways of creating swirling flows (on canvas tray and other elements). Use of vortex contact devices significantly reduces the amount of liquid entrainment, decreases the flow resistance and increases the surface of contact phases [5 – 7].

A considerable amount of work, extensive experimental data is devoted to the study on hydrodynamic vortex contact devices . But to the problems of analysis and design of vortex contact devices not much attention is given. Till now it does not exist a universal algorithm of calculation of vortex contact devices, which would allow to predict accurately and optimize the settings for different modes of mass transfer and separation processes.

Research object – vortex tray with HMTSE for gas cleaning processes. Research subject – hydrodynamic and technological conditions for the functioning of the vortex tray with HMTSE.

2. METHODOLOGY

For optimal diameter and height of the HMTSE of vortex contact stage the following conditions should be satisfied: a uniform distribution of the liquid film on the inner surface of the element; uniform contact of the gas stream with a liquid film; minimum entrainment from contact stage.

Optimization calculation of design of the HMTSE with using computer simulation allows getting optimal size without expensive physical experiment.

To the base of program «Vortex tray» (Figs. 1, 2) the mathematical model considering the influence on the size of the HMTSE of technological parameters of the columnar apparatus is put [8].

For a software implementation, the results of mathematical modeling are used:

– height of the HMTSE (Fig. 3):

$$L = \frac{s}{g} \cdot \frac{W_{\phi}^{2}}{R}. \qquad (1)$$

– liquid film thickness, rising through the inner wall of contact tube (Fig. 3):

$$s = \frac{1}{2} \cdot \frac{C \cdot R}{\rho_L}, \qquad (2)$$

where W_{ϕ} – angular speed of component of the liquid film, m/s; R – the radius of the contact tube, м (Fig. 3); g – acceleration of gravity, m/s²; C – the amount of liquid per unit volume of the contact tube, kg/m³; ρ_L – liquid density in kg/m³.

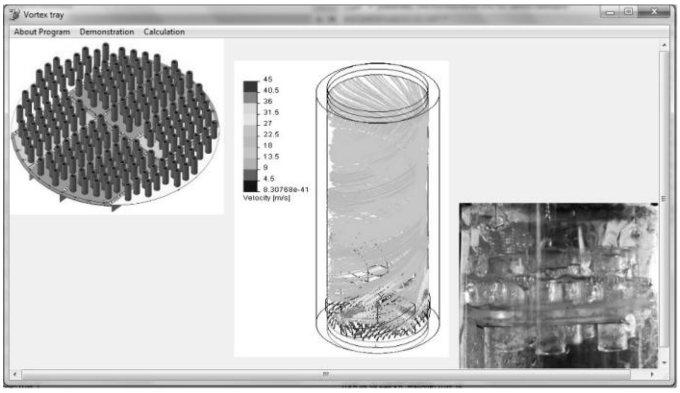

Fig. 1. The interface of program «Vortex tray»

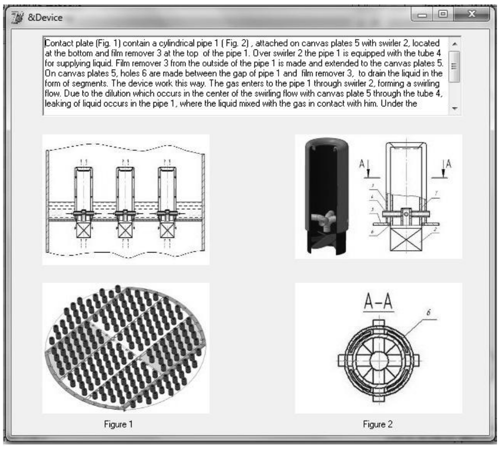

Fig. 2. A window with an explanation of the device and the operating principle of heat and mass transfer-separating element

Formula (1) and (2) were obtained by analyzing the effect of external forces on the liquid film in the contact tube. Optimum radius R should provide maximum value of upward velocity component of the gas stream, which performs balance of forces.

3. RESULTS AND DISCUSSION

The results of computer simulation under various conditions are shown in Figs. 4-8.

The graphic dependences, based on computer calculation result, are shown in Figs. 9-15. We carry out analysis. With increasing angular velocity of the gas flow at a constant value of liquid film thickness monotonic increase in the height of the tube occurs (Fig. 9). Increasing the value of force, that pushes the liquid film to the wall, the intensity of its spin increases. This requires a greater height of tube to avoid unwanted entrainment with contact stage. Increasing swirl of gas stream liquid will be distributed along the inner surface of the tube at regular intervals. Decreasing the tube radius, growth in height of tube runs with a large increase. Decreasing the section of tube it occurs increment in the speed of gas flow and in the buoyant forces, which leads to a more intense entrainment.

The graphic dependences, based on computer calculation result, are shown in Figs. 9-15. We carry out analysis. With increasing angular velocity of the gas flow at a constant value of liquid film thickness monotonic increase in the height of the tube occurs (Fig. 9).

Increasing the value of force, that pushes the liquid film to the wall, increases the intensity of its spin.

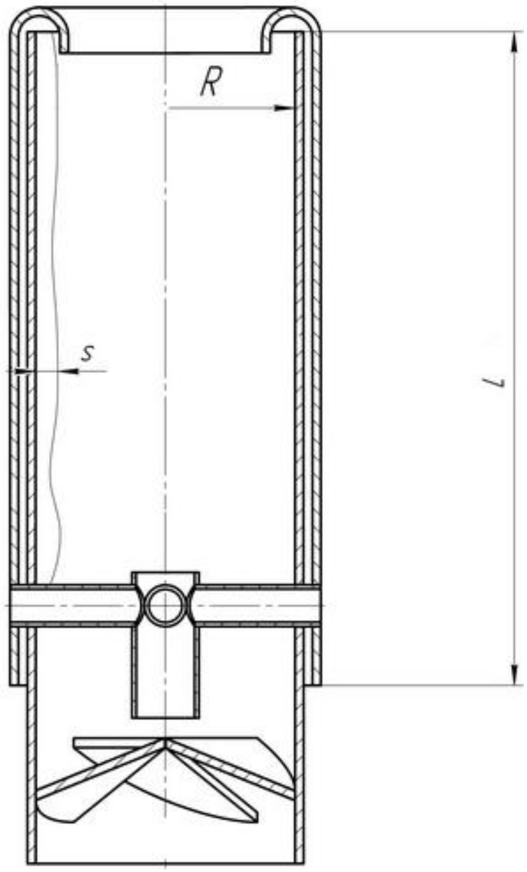

Fig. 3. Heat and mass transfer-separation element of contact trays

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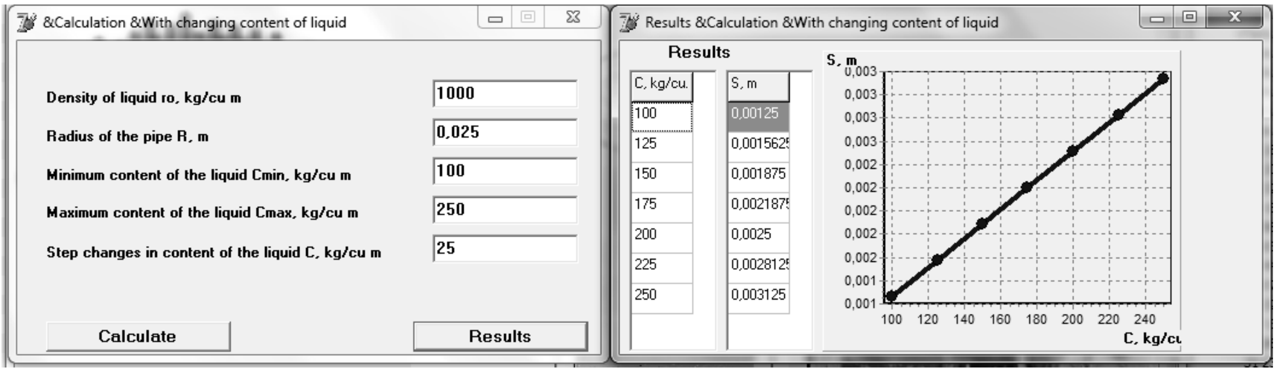

Fig. 4. The thickness of the liquid film at variable value *C*

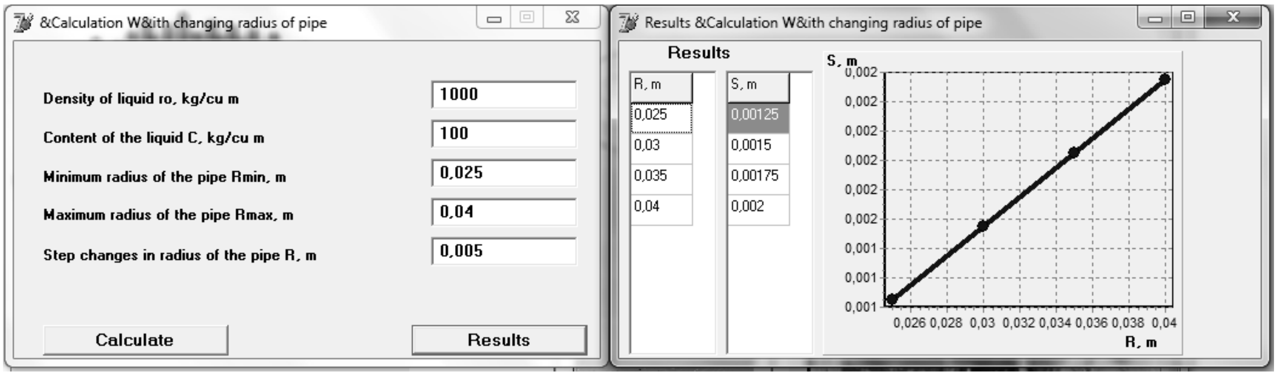

Fig. 5. The thickness of the liquid film at variable value *R*

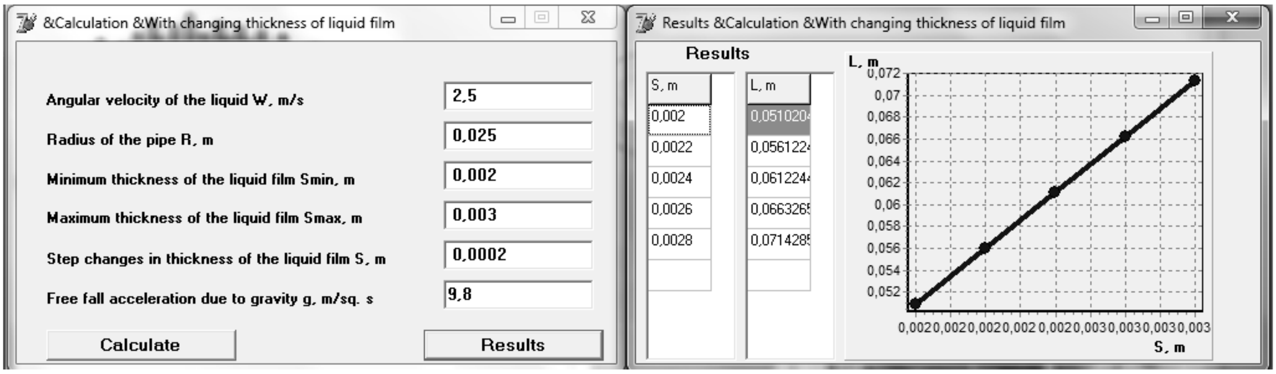

Fig. 6. The height of the contact tube at variable value *S*

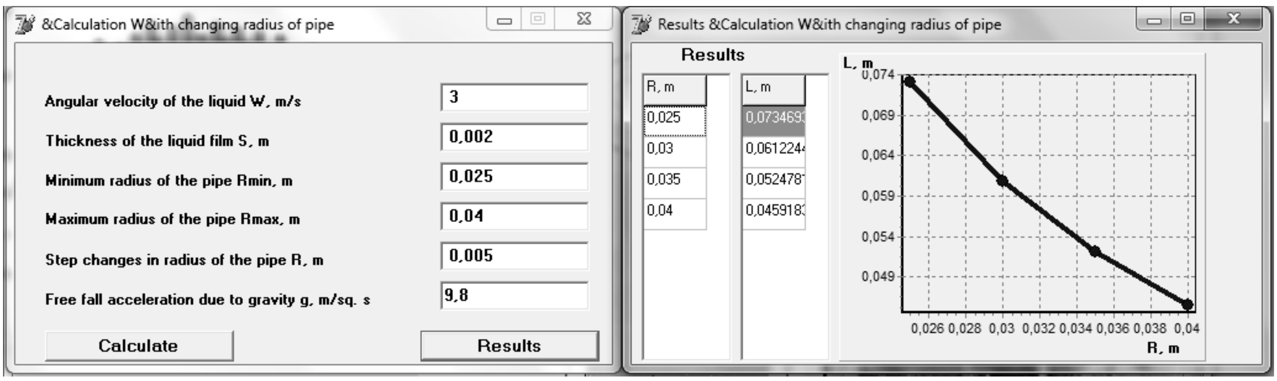

Fig. 7. The height of the contact tube at variable value *R*

B

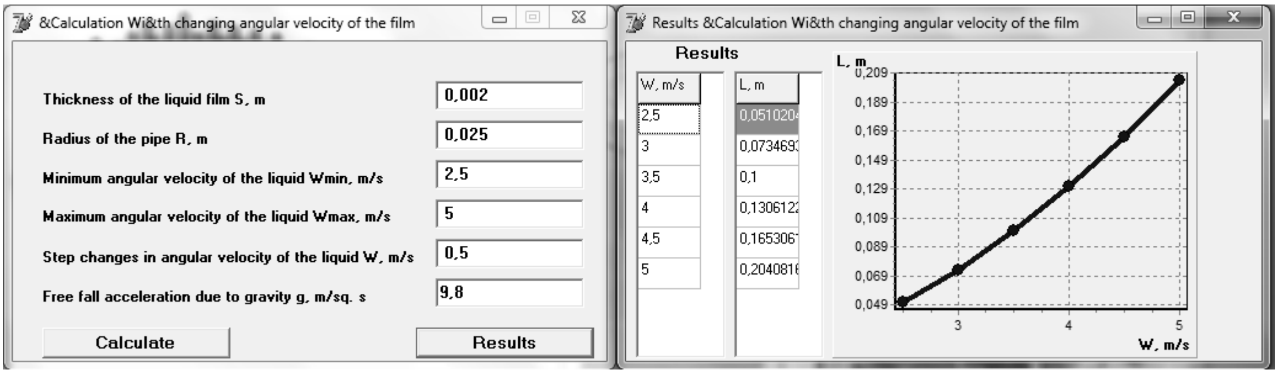

Fig. 8. The height of the contact tube at variable value W_ϕ

This requires a greater height of tube to avoid unwanted entrainment with contact stage. Increasing swirl of gas stream liquid will be distributed along the inner surface of the tube at regular intervals. Decreasing the tube radius, growth in height of tube runs with a large increase. Decreasing the section of tube it occurs increment in the speed of gas flow and in the buoyant forces, which leads to a more intense entrainment.

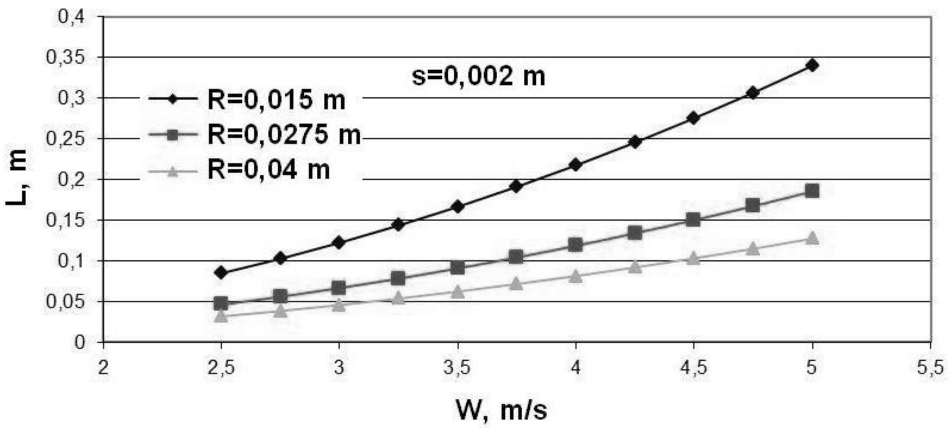

Fig. 9. Dependence of the tube height from angular speed in the liquid film at a constant film thickness

Increasing angular speed of gas flow at a constant radius of the contact tube it occurs monotonic increase in tube height (Fig. 10). Increasing load on the liquid phase and increased swirl gas stream of liquid film thickness increases the entrainment (occurs film layer separation from the wall). It is necessary to increase the height of the contact tube for preventing increased entrainment. The growth rate in height of the contact tube with the liquid film thickness shows increased amount of liquid that can be imposed from outside of contact stage.

Increasing the contact tube radius at constant angular speed of the liquid film, the liquid film thickness reduction in the height of the contact tube occurs (Fig. 11). This is due to the increase of centrifugal force and decrease of the buoyant forces on the liquid film.

Increasing the angular speed of the film contributes to a uniform distribution of liquid over the inner surface of the contact tube and reduces the ablation with a contact stage.

Liquid film thickness at constant value and increasing angular velocity of film leads to monotonic decrease in the tube height (Fig. 12). This is due to the increase in force, which pushes the liquid film to the inner surface of the contact tube and prevents the increased entrainment.

Increasing the thickness of the liquid film at a constant tube radius, angular speed of the liquid film leads to the increase in the tube height (Fig. 13). An increase in angular speed and in the thickness of liquid film results in an intense swirling of gas flow and in entrainment. To reduce the entrainment it is necessary to increase the height of the tube.

With an increase in volume, which holds the liquid inside the tube increases the film thickness (Figs. 14, 15). With an increase in volume of the contact tube (at quadratic dependence from the contact tube radius) growth in inner surface extends linearly from the radius, with increasing the volume of liquid in the tube the liquid film thickness increases.

4. CONCLUSIONS

The hydrodynamics influence of the gas flow and physicochemical properties of the liquid on the size of HMTSE was investigated. On the basis of analytical relationships optimization design calculation of vortex tray with HMTSE was held. Based on computer calculation results the graphic dependences, which allows the influence of the liquid amount, its velocity, thickness and other characteristics on the size of HMTSE were obtained.

Computer simulation results allowing to design the vortex tray with optimal design and determining the range of the effective work in different hydrodynamic regimes without expensive physical experiment were given.

Prospects for further research – study of separation and heat-mass transfer characteristics of the vortex tray with HMTSE for gas cleaning.

Results of computer simulation allow creating the vortex tray with optimal design of HMTSE and determining its effective work in different hydrodynamic regimes.

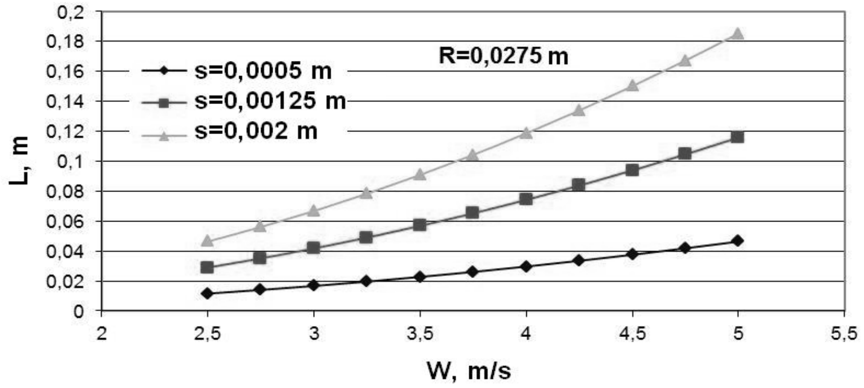

Fig. 10. Dependence of the tube height from angular speed of liquid film at a constant tube radius

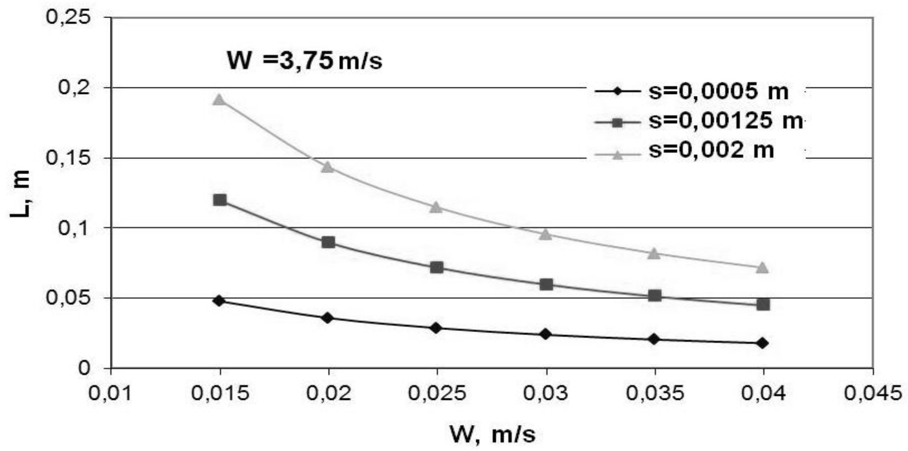

Fig. 11. Dependence of the tube height from the tube radius at constant angular velocity of the liquid film

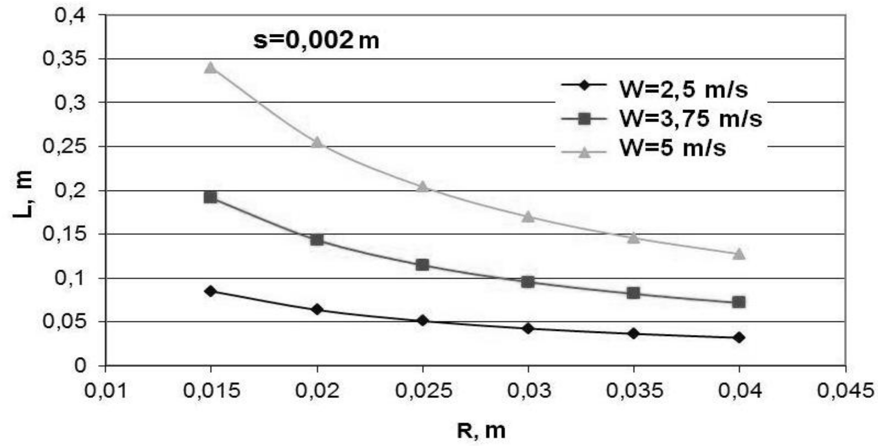

Fig. 12. Dependence of the tube height from pipe radius at a constant liquid film thickness

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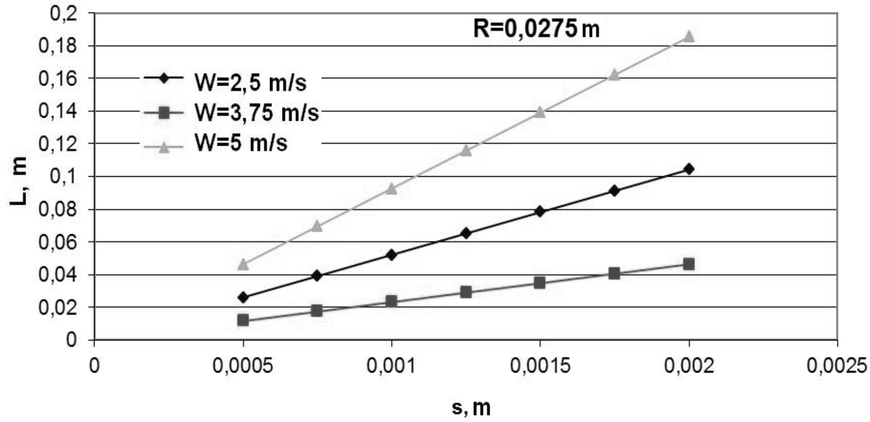

Fig. 13. Dependence of the tube height from the liquid film thickness at constant pipe radius

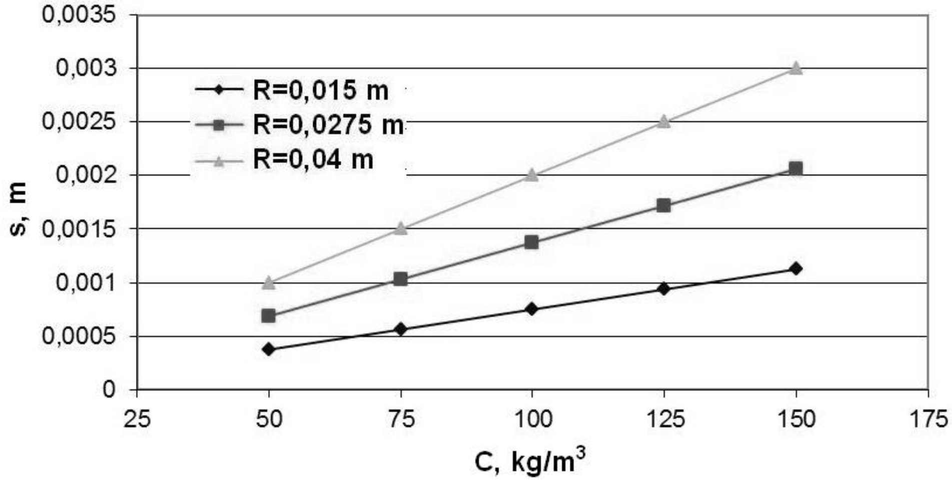

Fig. 14. Dependence of the liquid film thickness from volume that occupied liquid

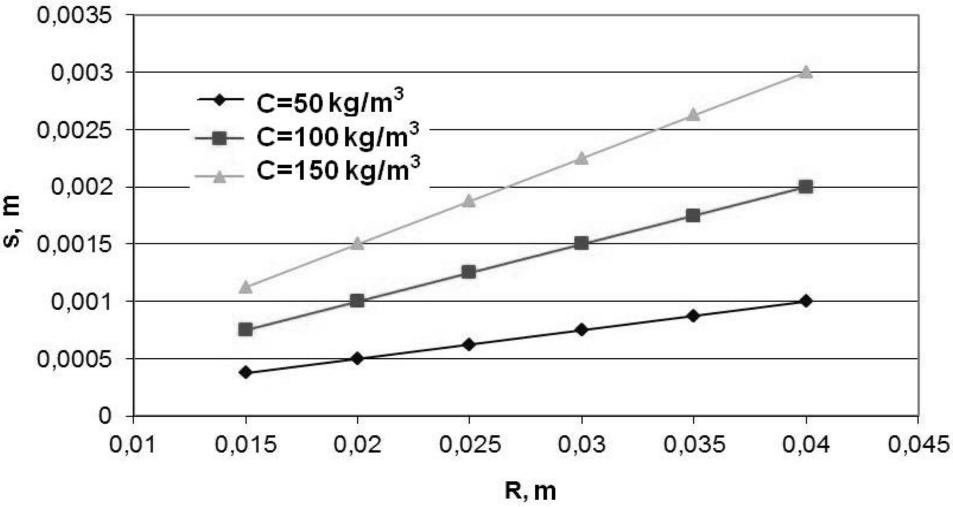

Fig. 15. Dependence of the liquid film thickness from tube radius

Расчет оптимального тепломассообменно-сепарационного элемента вихревой тарелки

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В работе рассмотрена методика оптимизационного расчёта тепломассообменно-сепарационного элемента вихревой тарелки. Приведены критерии выбора оптимальной конструкции элементов тарелки для очистки газов. Представлена компьютерная программа для расчёта оптимальной конструкции вихревой ступени очистки газа. Объект исследования – вихревая тарелка с тепломассообменно-сепарационными элементами (ТМСЭ) для процессов очистки газа. Предмет исследования – гидродинамические и технологические условия работы вихревой тарелки с ТМСЭ. Исследовано влияние гидродинамики газового потока и физико-химических свойств жидкости на размеры ТМСЭ. Впервые на основании аналитических зависимостей проведён оптимизационный расчёт конструкции вихревой тарелки с ТМСЭ. На основе результатов компьютерного расчёта получены графические зависимости, которые учитывают влияние количества жидкости, скорости её движения, толщины плёнки и других характеристик на размеры ТМСЭ. Результаты компьютерного моделирования позволяют спроектировать вихревую тарелку с оптимальной конструкцией и определить диапазон её эффективной работы в различных гидродинамических режимах без применения дорогостоящего физического эксперимента. Перспективы дальнейших исследований - исследование сепарационных и тепломассообменных характеристик вихревой тарелки с ТМСЭ для очистки газов.

Ключевые слова: вихревая тарелка, тепломассообменно-сепарационный элемент, компьютерное моделирование, оптимизация.

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