COMPARATIVE STUDY OF HEAT TRANSFER PROCESSES IN A VORTEX APPARATUS AND OTHER WET GAS CLEANING DEVICES.

Akhmatov Abdumalik Abduvakhob o‘g‘li
Associate Professor, Department of Automation and Control, Navoi State University of Mining and Technology
E-mail: a.a.axmatov@gmail.com
Nayimov Ma’murjon Nasim o‘g‘li
Master's student, Navoi State University of Mining and Technology

Annotatsiya. Ushbu ishda uyurmali apparat va an’anaviy nam gaz tozalash apparatlarida issiqlik almashinish jarayonlarining solishtirma eksperimental tadqiqot natijalari keltirilgan. Tadqiqotning maqsadi - issiq suv va sovuq havo bevosita kontaktda bo‘lganida oqimning aylanish darajasining issiqlik almashinuv jadalligiga miqdoriy ta’sirini aniqlashdir. Eksperimentlar maxsus ishlab chiqilgan laboratoriya qurilmasida, adabiyotlarda keltirilgan ma’lumotlar va ishlov berish metodikasiga muvofiq, sinchkovlik bilan nazorat qilingan rejim parametrlarida o‘tkazildi. Tadqiqot natijalariga ko‘ra, gaz oqimining tezligi va suyuqlik sug‘orish zichligi ortishi natijasida turbulentliging kuchayishi va fazalararo sirtning yangilanishi hisobiga issiqlik almashinish koeffitsienti sezilarli darajada oshadi. Suyuqlik va gazning massaviy sarfi nisbati 2,9÷3,1 bo‘lganda va gaz tezligi 12 m/s dan 26 m/s gacha oshirilganda, issiqlik uzatish koeffitsienti 2,2 dan 8,0 kVt/(m²·K) gacha ortadi. Apparatlarda olingan natijalar bilan solishtirganda, uyurmali apparat turbulent almashinuvning kuchayishi va fazalararo kontakt yuzasining ortishi hisobiga yuqoriroq issiqlik uzatish koeffitsientini ta’minlashi aniqlangan. Shu bilan birga, gaz tezligini optimal qiymatlardan ortiq oshirish maqsadga muvofiq emasligi, chunki bu holda gidravlik qarshilik va suyuqlik olib ketilishi ortishi aniqlandi.

Kalit so‘zlar: uyurmali apparat; nam gaz tozalash; kontakt issiqlik almashinuvi; issiqlik uzatish koeffitsienti; turbulentlig; aylanishli oqim; issiqlik almashinuv jadalligi; gidravlik qarshilik.

Аннотация. В работе представлены результаты сравнительного экспериментального исследования процессов переноса тепла во вихревом аппарате и традиционных аппаратах мокрой газоочистки. Целью исследования являлось количественное определение влияния закрученного движения потока на интенсивность теплообмена при непосредственном контакте горячей воды и холодного воздуха. Эксперименты проведены на специально изготовленной лабораторной установке при тщательно контролируемых режимных параметрах, соответствующих данным и методике обработки, опубликованным в литературных источниках. Показано, что увеличение скорости газового потока и плотности орошения

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приводит к существенному росту коэффициента теплопередачи вследствие усиления турбулентности и обновления межфазной поверхности. При соотношении массовых расходов жидкости и газа 2,9÷3,1 и росте скорости газа с 12 до 26 м/с коэффициент теплопередачи увеличивается от 2,2 до 8,0 кВт/(м²·К). Сравнение с результатами, полученными для осевых аппаратов, показало, что вихревой аппарат обеспечивает более высокие значения коэффициента теплопередачи за счёт интенсификации турбулентного обмена и увеличения удельной поверхности контакта фаз. Определено, что дальнейшее увеличение скорости газа выше оптимальных значений нецелесообразно из-за роста гидравлического сопротивления и уноса жидкости.

Ключевые слова: вихревой аппарат; мокрая газоочистка; контактный теплообмен; коэффициент теплопередачи; турбулентность; закрученное течение; интенсивность теплообмена; гидравлическое сопротивление.

Abstract: The paper presents the results of a comparative experimental study of heat transfer processes in a vortex apparatus and traditional wet gas cleaning devices. The aim of the study was to quantitatively determine the effect of swirling flow motion on the intensity of heat transfer during direct contact between hot water and cold air. The experiments were carried out on a specially designed laboratory setup under carefully controlled operating parameters corresponding to the data and processing methods published in the literature. It is shown that an increase in the gas flow velocity and irrigation density leads to a significant increase in the heat transfer coefficient due to increased turbulence and renewal of the interphase surface. With a liquid to gas mass flow ratio of 2.9÷3.1 and an increase in gas velocity from 12 to 26 m/s, the heat transfer coefficient increases from 2.2 to 8.0 kW/(m²·K). Comparison with the results obtained for axial devices showed that the vortex device provides higher values of the heat transfer coefficient due to the intensification of turbulent exchange and an increase in the specific contact surface of the phases. It was determined that further increase of gas velocity above optimal values is not advisable due to the increase in hydraulic resistance and liquid carryover.

Keywords: vortex device; wet gas cleaning; contact heat exchange; heat transfer coefficient; turbulence; swirling flow; heat exchange intensity; hydraulic resistance.

Introduction.

In order to improve the efficiency of contact processes in wet gas cleaning devices and heat and mass transfer units, interest in intensifying heat and mass transfer by means of swirling (vortex) flow motion has increased in recent years [1]. Thus, the authors [2] demonstrated that in a device with counter-flowing gas-

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liquid motion and swirling, it is possible to achieve several theoretical stages of concentration in a single contact element, which indicates an increase in mass and, indirectly, heat exchange.

The study emphasizes that at a height-to-radius ratio of the chamber < 0.6-0.7 and high gas circumferential velocities, a significant intensification of interphase exchange is observed due to an increase in the velocity gradient on the droplets and the interphase surface.

In the field of heat transfer specifically applicable to vortex and swirling systems, an article [3] was published that investigated the heat and mass transfer dynamics in an enthalpy heat exchanger with vortex generation. The authors demonstrated that the introduction of turbulent swirl leads to a significant improvement in heat and mass transfer coefficients compared to a laminar regime. Although the article is not directly devoted to wet gas cleaning devices, its conclusions on the influence of flow swirl and turbulence on the exchange of hot/wet gas environments can be directly applied to the designs of contact devices.

Additionally, the review [4] examines modern passive methods for enhancing heat transfer (including swirls, spiral channels, swirl inserts, etc.). The authors note that the use of "spiral/vortex inserts" allows for increased heat transfer coefficients without significantly increasing energy consumption. Although the review is not devoted exclusively to wet gas cleaning devices, it does provide a general direction: vortex flow structure is a promising approach to intensifying heat transfer. Studies [5] and [6] have made it possible to establish the dependence of heat transfer and mass transfer coefficients in axial contact devices with foaming and bubbling. In [5], the process of heat and mass transfer in foam devices with a high moisture content of the vapor-gas mixture was modeled; the range of the heat transfer coefficient was 200–1400 W/(m²·K) at gas velocities of 4–11 m/s, which limits their use in more intensive modes. The study [6] showed that during the bubbling layer, the efficiency of interphase exchange decreases sharply due to an increase in the thickness of the boundary layer of non-condensable gases and the uneven distribution of bubbles.

A later study [7] significantly expanded our understanding of contact processes through direct measurements in setups with direct contact between water and air. The authors demonstrated that in devices with axial gas flow, the heat transfer coefficient reaches 1.0–1.4 kW/(m²·K); however, further increases in velocity lead to a sharp increase in hydraulic resistance and liquid entrainment. Finally, the study [8]—"Towards responsive gas-solid operations: Oscillating and vortex flows"—examines the potential applications of vortex chambers and rotational/oscillating conditions at the gas-solid interface. The authors emphasize

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that high interfacial velocity and swirl can be used to intensify heat and mass transfer processes, which is also relevant for gas-liquid wet gas scrubbers.

Thus, an analysis of recent publications shows that:

The use of vortex flow motion (swirl, turbulence, high peripheral velocity) contributes to a significant increase in heat and mass transfer coefficients;

Specifically for wet gas cleaning devices, such systematic comparisons are still insufficient; there is potential for transferring methodological approaches from studies of swirling flows in heat exchangers and gas-liquid systems to the problems of wet gas cleaning contact devices.

RESEARCH METHODOLOGY

This study aims to fill this gap: an experimental comparative study of heat transfer intensity in a vortex device in the context of wet gas cleaning, with a comparison to traditional contact devices.

To experimentally study the contact heat transfer process in a vortex device, a pilot setup was constructed in which heat and mass transfer intensity was measured during direct contact between hot water and cold air. The experiments were conducted under carefully controlled operating and initial parameters, corresponding to the data and processing methods previously published in [9]. These works also provided a detailed examination of the design features of the experimental setup, the test sequence, and the methods for statistical processing of the results.

The results of experiments on the intensity of heat transfer in a vortex apparatus during water cooling with air are shown in Fig. 1 as a dependence of the heat transfer coefficient on the air velocity.

RESULTS AND DISCUSSION

Experimental results showed that the higher the gas flow velocity and spray density, the higher the heat transfer intensity. This pattern of change in heat transfer intensity is explained by increased flow turbulence and the emergence of relative velocities between the liquid and gas, which facilitates rapid renewal of the water film surface, leading to an increase in the driving force of the heat transfer process and, consequently, the efficiency of water cooling. Experimental values of heat transfer coefficients in a vortex device were compared with the results of subsequent studies obtained for axial devices [5-7]. The heat transfer intensity in the vortex device is significantly higher than in the studies [5-7]. This picture can be explained by an increase in the specific surface area of phase contact, flow turbulence in the vortex device, and an increase in the driving force due to intensive renewal of the phase contact surface, compared to devices without swirling. It is known that vortex devices operate intensively at higher gas velocities than devices with axial gas flows.

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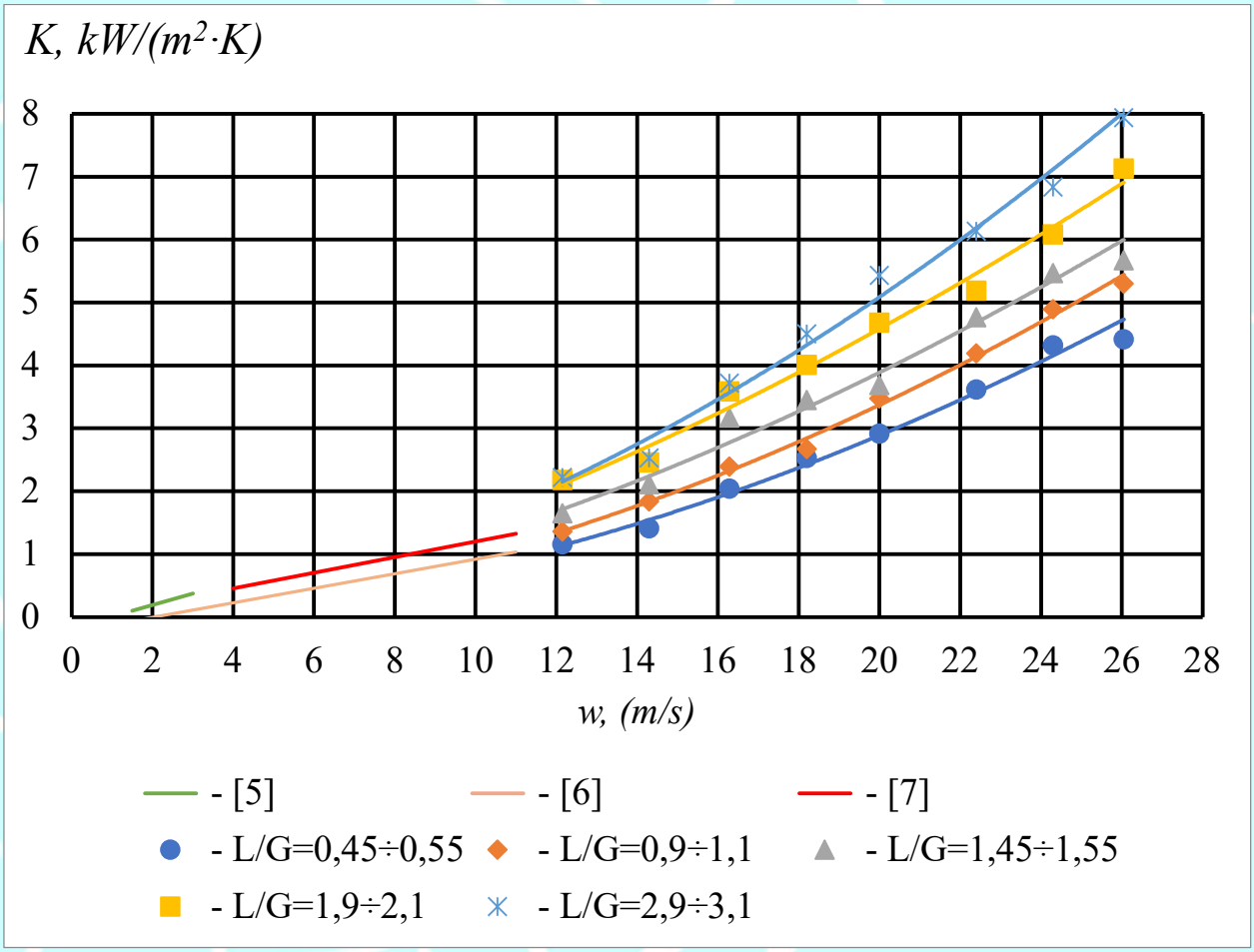


Fig. 1. Dependence of the heat transfer coefficient Kt on the gas velocity w0 for different ratios of liquid and gas mass flow rates L/G

The authors of [5] and [6] studied the process of cooling a steam-air mixture and condensing moisture in the air. Under these conditions, a boundary layer with an increased concentration of air (non-condensable gases) forms, which worsens heat transfer conditions. The results of experimental studies in [7] are presented, where water evaporated into the air flow, and the aforementioned phenomenon was absent. In addition, the axial contact heat exchangers studied in [5-7] operate stably at low values and narrow ranges of air velocities, i.e. at 4-11 m/s, and the heat transfer coefficient reaches from 200 to 1400 W/(m²·K).

As the gas velocity in the vortex apparatus and the liquid flow rate increase, the heat transfer coefficient increases rapidly. For example, at L/G = 2.9-3.1, with an increase in gas velocity from 12 m/s to 26 m/s, the heat transfer coefficient increased from 2.2 to 8.0 kW/(m²·K). Further increases in air velocity are ineffective, as they significantly increase the apparatus's hydraulic resistance and liquid carryover.

Conclusion. The study confirmed the high efficiency of vortex devices in contact heat transfer processes during wet gas cleaning. Experimental results showed that the heat transfer rate in a vortex device significantly exceeds that of axial contact devices examined in previous studies. It was established that the main

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factors intensifying heat transfer are flow swirling, increased turbulence, and an increase in the specific contact surface area of the phases. Optimum operating conditions are achieved at gas velocities of 20–25 m/s and an *L*/*G* ratio of 2.5–3.0, which results in the maximum increase in the heat transfer coefficient with a moderate increase in hydraulic resistance. The obtained results can be used for the design and optimization of compact vortex devices in wet gas cleaning systems and industrial waste heat recovery systems.

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