DETERMINATION OF THE HEAT TRANSFER COEFFICIENT IN THE VERTICAL CYLINDRICAL PART OF A SMALL CAPACITY BIOREACTOR.

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ОПРЕДЕЛЕНИЕ КОЭФФИЦИЕНТА ТЕПЛООТДАЧИ В ВЕРТИКАЛЬНОЙ ЦИЛИНДРИЧЕСКОЙ ЧАСТИ БИОРЕАКТОРА МАЛОЙ МОЩНОСТИ.

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ABSTRACT

This study focuses on developing a model to calculate the convective heat transfer coefficient in the vertical cylindrical section of a low-capacity bioreactor. The authors emphasize the need for a stable correlation between Nusselt and Rayleigh numbers for liquid biomass. Experimental tests were conducted using a bioreactor with specific dimensions and temperature conditions, revealing that existing equations for gases are inadequate for liquid biomass. A modified correlation was proposed, validated for Rayleigh numbers between 3·1010 and 1·1013. The results highlight the importance of temperature gradients and aspect ratios in optimizing heat transfer, providing insights for improving biogas production efficiency in anaerobic digestion systems.

АННОТАЧИЯ

В этом исследовании основное внимание уделяется разработке модели для расчета коэффициента конвективного теплообмена в вертикальной цилиндрической секции биореактора малой мощности. Авторы подчеркивают необходимость стабильной корреляции между числами Нуссельта и Рэлея для жидкой биомассы. Экспериментальные испытания проводились с использованием биореактора с определенными размерами и температурными условиями, показывая, что существующие уравнения для газов неадекватны для жидкой биомассы. Была предложена модифицированная корреляция, проверенная для чисел Рэлея между 3·1010 и 1·1013. Результаты подчеркивают важность температурных градиентов и соотношений сторон для оптимизации теплопередачи, предоставляя информацию для повышения эффективности производства биогаза в анаэробных системах сбраживания.

Key words: bioreactor, heat transfer, Nusselt and relay numbers, correlation, biomass, temperature, vertical cylinder.

Ключевые слова: биореактор, теплопеача, числа Нуссельта и Реле, корреляция, биомасса, температура, вертикальный цилиндр.

Introduction

The global community places significant emphasis on expanding the use of renewable energy sources, conserving hydrocarbon fuels and energy resources, and producing biogas and biofertilizers through the anaerobic processing of organic waste. Currently, in developed countries, biomass energy accounts for 4-10% of the total energy sector. It is projected that by 2040, biogas production will reach 75 million tons. Our analysis suggests that these figures can likely be increased through the use of highly efficient biogas plants. In this context, enhancing the efficiency of biogas and biofertilizer production through the anaerobic processing of organic waste is of paramount importance [1,2,3,4].

It is well-established that for the effective digestion of a mixture of organic waste under anaerobic conditions, the waste must first be converted into liquid biomass [2,5,8,13]. In this study, we aimed to develop a model capable of calculating the convective heat transfer coefficient from liquid biomass to the external environment during the effective fermentation process at a specific temperature in a bioreactor.

Research Methodology

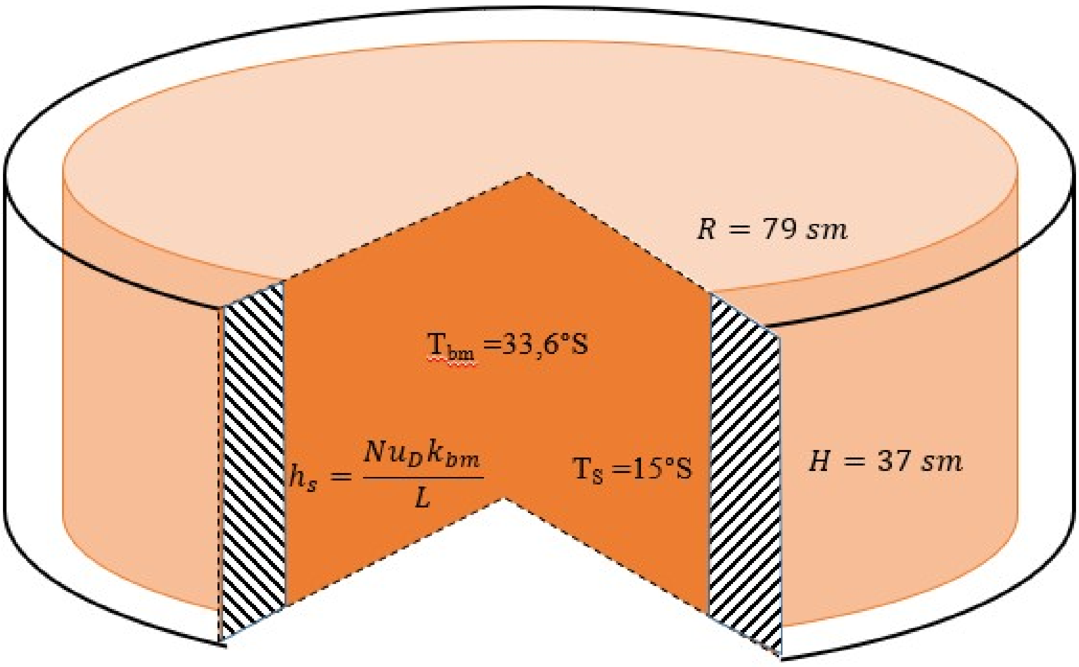
Temperature plays a critical role in regulating microbiological activity in anaerobic digestion, as the efficiency of digestion is highly dependent on the temperature of the biomass. Extensive research has been conducted to develop heat transfer models for anaerobic processes, with many of these models successfully tested in warm climates. These models have demonstrated excellent agreement between predictions and field data, with some even achieving theoretical predictions of slurry temperatures that match field data within 2.6 °C [1].

Despite the wealth of research [2] providing data on biomass temperatures measured throughout the year, there remains a lack of sufficient literature to develop reliable emission calculation protocols. According to a study by Rennie, Balde, Gordon, Smith, and Vander Zaag [3], there is no fully developed model for predicting the temporal and spatial distribution of temperature during liquid biomass storage.

Based on experimental and numerical data, various expressions and correlations have been developed to predict heat transfer during natural convection. Vertical cylindrical bioreactors have been the focus of numerous studies over the past two decades. These bioreactors typically contain a rectangular cavity with two side walls at different temperatures, while the remaining surfaces are adiabatic (hot wall-cold wall configuration) [3-9]. However, less attention has been paid to natural convection with volumetric heating, where boundary conditions vary significantly. As a result, there is no standardized approach to this issue. Research often focuses on cylindrical shapes, as seen in the cited articles [5-10], as well as rectangular spaces [3-8].

In theoretical studies, the horizontal boundaries are partly isothermal and partly adiabatic, while the vertical boundaries are mostly isothermal. In experimental setups, however, wall temperatures depend on conductive heat transfer. Additionally, variations in aspect ratios complicate comparisons between different studies. This study addresses safety concerns related to the cooling of exothermic chemical reactions and radioactive processes, where reliable correlations are crucial. Therefore, it is essential to clarify the influence of various boundary conditions on laminar and turbulent natural convection flows.

Since the publication of the review article [10], significant attention has been devoted to the vertical direction in the context of analyzing plates subjected to symmetric or asymmetric thermal effects under isothermal or steady flow surface conditions. In the case of symmetrically heated isothermal plates, Elenbaas derived the following semi-empirical correlation:



Rice. 1. Vertical cylindrical part of a low-power biogas plant.

(1)

where the average Rayleigh numbers and heat transfer coefficient are defined as follows

(2)

(3)

Equation 1 was developed for gases as working fluids and its field of application.

(4)

Results of experimental tests

Testing the application of equation (3) for biomass located in a cylindrical part of a bioreactor with a diameter of 158 sm, a height of 37 sm and an internal wall temperature of 15°C: it is known that the dynamic viscosity of liquid biomass is high. at a temperature of 33.6ºC. the specific heat capacity of liquid biomass is equal to ;Thermal expansion coefficient ; Density of liquid biomass ; the thermal conductivity of liquid biomass is equal to From the initial data we obtain that , the range of values of which goes beyond the conditions for applying the equation for the Rayleigh number. From the above results it is clear that a more stable correlation between the Nusselt and Rayleigh numbers should be considered for liquid biomass located in a vertically oriented cylindrical part of the bioreactor. In this test, it was used for the first time to determine the heat transfer correlation for an ideal case, which is a cylinder with adiabatic horizontal walls, isothermal vertical walls and a completely uniform distribution of heat sources[11,12,13].

(5)

where are designated as Rayleigh averages,

(6)

where $3 \cdot 10^{10} < \ < 1 \cdot 10^{13}$. The influence of the aspect ratio on the process under study corresponds to the results of studies by Kulatsky and Richardson, where [12]. These data take into account similar conditions and are consistent with the results obtained in the case of a hot wall and a cold wall without internal heat sources. M. Holzbecher and A. Steiff [11] It is noted that equation (5) usually assumes isothermal side walls, but in real experiments this situation cannot always be achieved. Therefore, it will be necessary to determine the effect of temperature gradients on the inner wall, taking into account constraints and idealized experimental conditions.

Table 1

Grashof, Prandtl, Rayleigh, Nusselt numbers and heat transfer coefficient on the inner surface of the wall of a cone-shaped bioreactor depending on the temperature difference between the liquid biomass and the surface of the bioreactor wall at a temperature of 33.6°C.

,	,			,
28,6	5	1,09E+12	206,04	339,7
23,6	10	8,98E+11	198,1755	326,7218
18,6	15	7,08E+11	188,8522	311,3509
13,6	20	5,18E+11	177,256	292,2328
8,6	25	3,27E+11	161,553	266,3442
3,6	30	1,37E+11	135,4466	223,3039
-1,4	35	5,33E+10	111,8791	184,4493
-6,4	40	2,44E+11	152,175	250,8832
-11,4	45	4,34E+11	171,037	281,98
-16,4	50	6,24E+11	184,1014	303,5185
-21,4	55	8,14E+11	194,2891	320,3144
-26,4	60	1E+12	202,724	334,2207

Checking the application of equation (6) for biomass located in the cylindrical part of the bioreactor with a diameter D = 158 sm, height H = 37 sm and an internal wall temperature of 5°C, dynamic viscosity of liquid biomass at a temperature , specific viscosity of the heat capacity of liquid biomass equal to ;Thermal expansion coefficient ; Density of liquid biomass the thermal conductivity of liquid biomass is equal to . From the initial data we obtain , the range of values of which is within the conditions for applying the equation for the Reley number[13]

Nusselt number, . Thus, the heat transfer coefficient is equal to We can see this from the graph presented in Fig. 2.

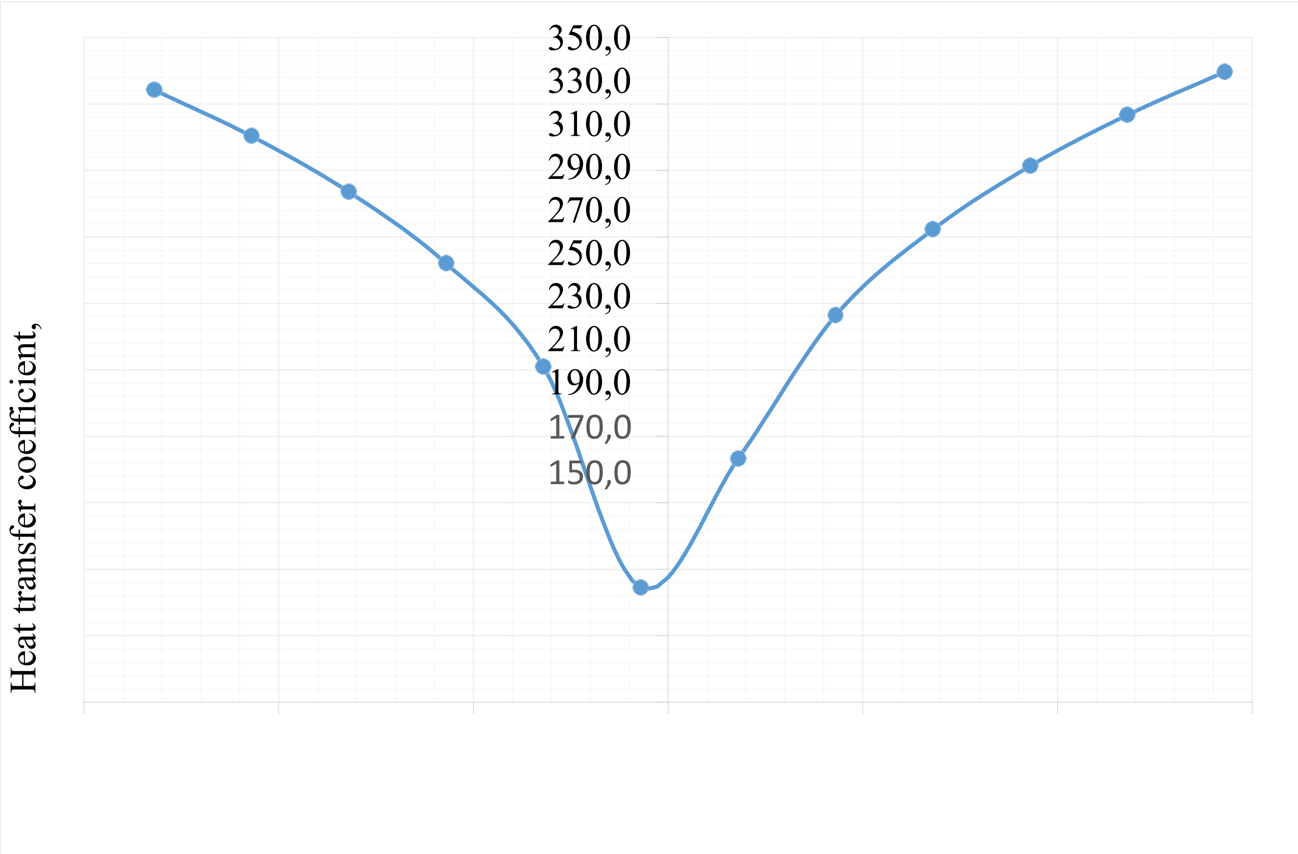


Fig.2. Dependence of the heat transfer coefficient on the inner surface of the wall of the cylindrical part of the bioreactor on the temperature difference between the liquid biomass and the surface of the bioreactor wall.

Summary

Taking the constant temperature of the vertical cylindrical part of a low-power BGU as 33.6°C in mesophilic mode, it is established that the heat transfer coefficient is and we calculate it using a one-dimensional model.

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