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Determination Of Barbotage Pipeline Hydraulic Resistance In The Bio-Reactor Receiving Bio-Gas

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Abstract- In many chemical and biotechnological devices the systems of barbotage type hashing, during which high work performance and extent of hashing is reached, are applied. One of the key hydraulic parameters of barbotage type hashing system is gas pressure on escaping openings to define which it is necessary to consider pressure losses in the barbotage pipeline. Theoretical and pilot researches for determining hydraulic resistance of the barbotage pipeline executed in the form of vertical spiral turned base down are conducted. The analytical dependence for local resistance coefficient determination of the barbotage pipeline considering pressure losses in a gas current in the side openings presence on opening discharge in the passing stream presence, as well as loss at gas current turns in spiral turns is received. Value of the bio-reactor lrc barbotage pipeline of received bio-gas of 20 l., received according to the experimental data makes 7,75, and the design value received on the offered equations 7,31, i.e. tolerance makes 5,6%.

Keywords: barbotage hashing, hydraulic resistance, bio-reactor, bio-gas.

Introduction

In many chemical and biotechnological devices the systems of barbotage type hashing, during which high work performance and extent of hashing is reached, are applied [1 … 3].

In the course of receiving barbotage hashing bio-gas process for the purpose of homogeneous mass creation, which does not have sites of deposit and crusting congestion, providing the uniform distribution of bacteria population and temperature on all volume of the bio-reactor, an intensification of microbiological processes is made; it also promotes intensive removal of the formed bio-gas vials [4, 5].

Many works of domestic and foreign scientists are devoted to hydraulic processes research proceeding in barbotage devices [6 … 9].

One of the key hydraulic parameters of barbotage type hashing system is gas pressure on escaping openings to define which it is necessary to consider pressure losses in the barbotage pipeline.

Therefore, carrying out theoretical and pilot studies by determining the hydraulic resistances in the barbotage pipeline executed in the form of vertical spiral with openings for gas discharge is timely.

Research methods

In the work methods of mathematical model operation, design of experiments and result statistical processing were applied.

We used the 20 l bio-reactor with system of barbotage type hashing to carry out the pilot studies. For air pressure forcing we used the compressor 550 W with consumption of 0,0026 m^3/s. For pressure losses measurement in the barbotage pipeline we used a Testo 511 differential pressure gage.

Main part

The bio-reactor of an original design intended for receiving bio-gas when processing an organic wastage is developed (fig. 1). Novelty of this bio-reactor consists in use of barbotage type hashing system [10].

Fig. 1 The bio-reactor with barbotage pipeline in the form of spiral

The barbotage pipe is placed in the bio-reactor bottom and is executed in the form of vertical spiral which rounds form the cone turned base down. The admission line through which gas from a source arrives is adjusted to barbotage pipe.

The offered barbator design provides space uniform of the bubbling gas distribution, reduces constraint of emerging gas bubbles line-ups movement that leads to inter-facial interaction strengthening of bubble column with light fermentation mass.

As for barbotage hashing the made bio-gas consisting for 65% methane and 35% - carbon dioxide therefore values of density ρg [rho] and viscosity γg [gamma] of bio-gas accepted according to its structure are used: ρ_g=1,158 kg/m^3 , γ_g=11,05·10^{-6} m^2/s.

Thus, as an assumption we will accept the following: as the barbotage pipeline represents a vertical spiral which rounds form the cone turned base down, we will determine geometrical parameters by effective round diameter. Thus the average radius of barbotage pipe rounds r_r^{av} equals ½ radiuses of the R_b bio-reactor (m) and is expressed in a form:

$$r_r^{av} = \frac{R_b}{2}. \quad (1)$$

Height of the barbotage pipe H_{bp}, level of the first round installation Z_0, the greatest radius of the first round R_1, the least radius of the last round R_2 and quantity of rounds n_r are set taking into account the bio-reactor sizes. Then radial h_R and axial h_z steps between rounds are calculated on formulas:

$$h_R = \frac{R_1 - R_2}{n_r}, \quad (2)$$

$$h_z = \frac{H_{bp}}{n_r}. \quad (3)$$

Length of the barbotage pipe l_{BP} is defined by expression:

$$l_{bp} = \frac{\pi}{h_R}\left(R_1\sqrt{h^2 + R_1^2} - R_2\sqrt{h^2 + R_2^2} - h^2 \ln\frac{R_2 + \sqrt{h^2 + R_2^2}}{R_1 + \sqrt{h^2 + R_1^2}} \right), \quad (4)$$

The distance between the next rounds is defined:

$$h^2 = (h_R^2 + h_z^2) / 4\pi^2 \quad (5)$$

The least radius of the last round is expressed:

$$R_2 = R_1 - h_z \cdot n_r \quad (6)$$

Pressure losses Δp_{bp} in the barbotage pipeline executed in the form of a spiral we will calculate through the local resistance including the following pressure losses: in a gas current in the presence of side openings, on opening discharge in the presence of passing stream and loss at gas current turns in spiral turns.

$$\Delta p_{bp} = \zeta_{bp} \frac{\rho_g \cdot \upsilon_{bp}^2}{2} \quad (7)$$

where ζ_{bp} [zeta] –coefficient of the barbotage pipeline local resistance; υ_{bp} – gas speed in barbotage pipeline, m/s.

$\zeta_{bp}= \zeta_f+ \zeta_h+ \zeta_{sl}$ (8)

where ζ_f [zeta] – coefficient of local resistance in a gas current in the presence of side openings; ζ_h [zeta] – coefficient of local openings resistance in the presence of passing stream; ζ_{sl} [zeta] – coefficient of local resistance on turns of a gas current in spiral turns.

Coefficient of local resistance in a gas current in the presence of side openings are defined from expression [5]:

$$\zeta_h = \frac{l_{bp}}{d_{bp}} \left[\lambda \left(1 - \alpha_0 + \frac{\alpha_0^{\ 2}}{3} \right) + 8\varepsilon' \frac{\alpha_0}{\bar{f}} (1 - 0{,}5\alpha_0) \right],$$

(9)

where d_{bp} – diameter of the barbotage pipeline, m; λ [lambda] – friction coefficient; α_0 [alpha] – the coefficient depending on a flow rate at the beginning υ_b and at the end of pipeline υ_e; ε' [varepsilon] – fractional porosity of the barbotage pipeline; $\bar{f}$ – relation of the cooperative area of openings S_h^t to a pipeline sectional area S_{bp}, $\bar{f} = \frac{S_h^t}{S_{bp}}$.

The coefficient depending on a flow rate at the beginning υ_b and at the end of the pipeline υ_e is defined:

$$\alpha_0 = 1 - \frac{\upsilon_e}{\upsilon_b}. \quad (10)$$

The fractional porosity of the barbotage pipeline is defined by the relation of total openings area to the area of the pipeline walls S_w:

$$\varepsilon' = \frac{S_h^t}{S_w} \quad (11)$$

The coefficient of openings local resistance in the presence of passing stream is a function of the flow rate relation in the pipeline υ_{bp} to gas speed in opening υ_h:

$$\zeta_h = f(\frac{\upsilon_{bp}}{\upsilon_h}). \quad (12)$$

For calculation of the local resistance coefficient in turns of the barbotage pipeline rounds, executed in the form of a vertical spiral, we will consider ¼ part of an average spiral turn as the smoothly varying turn on 90 °.

The common resistance in the smoothly varying turn can be presented as the raised friction drag at which the resistance coefficient is a function of number Re, roughnesses, and the relative radius of curving $\frac{R_o}{D_o}$:

$$\zeta = f(Re, \varepsilon, \frac{R_0}{D_0}), \quad (13)$$

whereas

$$\zeta_{sl} = 0{,}0175 \cdot \delta_{sl} \cdot \lambda_{sl} \frac{r_r^{av}}{d_{bp}}, \quad (14)$$

where δ_{sl} [delta] – corner of the smoothly varying turn , °; λ_{sl} [lambda] – resistance coefficient of the smoothly varying turn sliding friction.

The resistance coefficient of the smoothly varying turn sliding friction depends on the stream current mode and is defined by expression:

$$\lambda_{sl} = \frac{5}{Re^{0.45}} \cdot \left(\frac{d_{bp}}{2 \cdot r_r^{av}} \right)^{0.275} \quad (15)$$

Thus, resistance coefficient in turns of one round ζ_r consists of four smoothly varying turns resistance, thus it is necessary to consider their interference.

$\zeta_r= \zeta_{sl.} \cdot 4 \cdot n_r \cdot \psi$, (16)

where ψ [psi] – the coefficient considering interference of the smoothly varying turns.

Using expressions (8, 9, 12, 14, 16) we will receive the equation for determining coefficient of the barbotage pipeline local resistance:

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$$\zeta_{bp} = \left(\frac{l_{bp}}{d_{bp}} \left[\frac{1}{3} \lambda \left(1 + \frac{\upsilon_e}{\upsilon_b} + \left(\frac{\upsilon_e}{\upsilon_b} \right)^2 \right) + 4 \frac{S_{bp} - S_{bp} \frac{\upsilon_e}{\upsilon_b}}{S_w} (1 + \frac{\upsilon_e}{\upsilon_b}) \right] + f(\frac{\upsilon_{bp}}{\upsilon_h}) + 0{,}0175 \cdot \delta_{sl} \cdot \frac{5}{\mathrm{Re}^{0.45}} \cdot \left(\frac{d_{bp}}{2 \cdot r_r^{av}} \right)^{0.275} \frac{r_r^{av}}{d_{bp}} 4 \cdot n_r \psi \right). \quad (17)$$

For the experimental 20 l bio-reactor. the local resistance coefficient (lrc) made ζ_{bp} =7,31.

For confirmation of theoretical research experiments by determining coefficient of the barbotage pipeline local resistance executed in the form of a vertical spiral were made.

Researches on lrc definition were conducted on the pilot unit which is turning on the 20 l bio-reactor, compressor and differential pressure gage. The scheme of installation is submitted in figure 3, a general view of installation – in figure 4.

For visual biomass hashing process observation the bio-reactor 1 is manufactured from transparent material. In the bottom of the barbotage pipeline bio-reactor 4 made from a copper pipe with caliber of 9 mm is located. On the top plane of the barbotage pipeline 15 openings with a diameter of 1,5 mm, a step between openings of 150 mm are drilled.

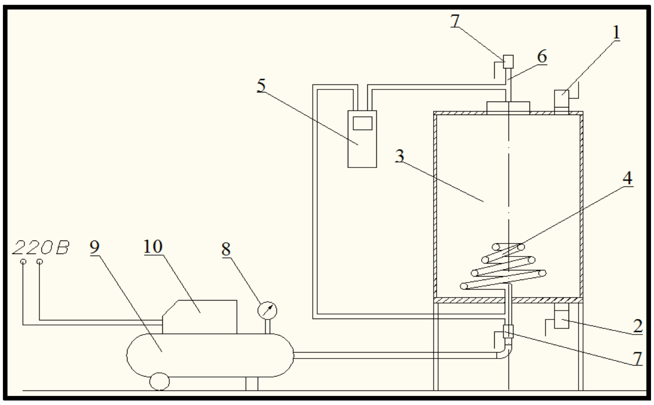

Fig. 2 The scheme of the pilot unit for defining hydraulic resistance of the barbotage pipeline:
1 – branch pipe of initial substratum loading; 2 – biomass drainage branch pipe;
3 – bio-reactor; 4 – barbotage pipeline; 5 – differential pressure gage; 6 – bio-gas exit branch pipe; 7 – globe valve; 8 – manometer;
9 – compressor; 10 – electric motor

Fig. 4 General view of the pilot unit

1 – bio-reactor; 2 – barbotage pipeline; 3 – compressor;

4 – admission line; 5 – manometer

Installation works as follows. By means of the compressor 9 in the bio-reactor 3 via the globe valve 7 air pressure p_1=4 kPa was passed through a barbotage pipe 4, escaping its openings, then it was removed through a bio-gas 6 exit branch pipe. Thus by means of differential pressure gage 5 was measured the difference of inlet pressure entering the bio-reactor and escaping it.

For reliability and accuracy of measurements the number of repeated experiences made 3 experiences, results of experiments are presented in table 1.

Table 1. Results of the pilot studies hydraulic resistance

No. experi-ment	Consumption $Q_в$, m³/s	Velocity υ_{bp}, m/s	Pressure p_1, Pa	Pressure losses in the barbotage pipeline Δp_{bp} , Pa
1	0.0014	9.56	4000	2530
2	0.0015	9.58	4000	2780
3	0.0013	9.52	4000	2350

As a result of data interpretation pressure losses in the barbotage pipeline are defined Δp_{bp} = 2553 Pa.

The coefficient of the barbotage pipeline local resistance was defined indirectly, using the size of pressure total losses Δp_{bp} [5]:

$$\zeta^E_{bp} = \frac{\Delta p_{bp}}{\frac{\rho_г \cdot \upsilon^2_{bp}}{2}} \quad (18)$$

Conclusion

The coefficient of the barbotage pipeline local resistance of the bio-reactor receiving bio-gas is defined. According to the equation (18) value the barbotage pipeline lrc according to the experimental data makes ζ^E_{bp} =7,75, thus the design value determined by a formula (17) – ζ_{bp} =7,31, i.e. the tolerance makes 5,6%.

Summary

Theoretical and pilot researches for determining the coefficient of the barbotage pipeline local resistance executed in the form of the vertical spiral turned base down are conducted. Results of experiment will well be coordinated with results of theoretical calculations, and the tolerance makes less than 6%. The obtained data allow to determine technological parameters of barbotage type hashing system: pressure and consumption of bio-gas, and also metabolic cost upon hashing.

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