Research of Physical and Mechanical Properties of Raw Materials for a Biogas Plant

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Abstract: The Address of President N.A. Nazarbaev to the people of Kazakhstan identified the contemporary challenges to Kazakhstan, among which the fifth challenge was the global security of energy supply. Production of biogas and construction of biogas plants are currently growing worldwide; more investments are made in the alternative, "green" energy technology. By the middle of 21st century, usage of such technology is expected to allow generating up to 50% of the total produced energy. In Kazakhstan, there are over 182 thousand peasant and husbandry farms; the total livestock numbers nearly 60 million heads; they produce up to 2 billion tons of manure, which allows to produce 1,177-8,118 million m³ of methane by recycling manure in biogas plants. With the current price of natural gas in Kazakhstan, the economic benefit from using methane can reach 25-174 billion tenges even without using such materials as fat, fallen stock, sugar beet and silage, which provide methane output much greater than manure. Therefore, improvement of efficiency of biogas plants is timely and the research in this sphere is important and significant for the economy.

Key words: Biogas plant • Efficiency • Raw material • Physical and mechanical properties

INTRODUCTION

Biogas production is of great economic importance for production of biofuel, thermal and electrical power, fertilizers, as well as for production of car fuel and allows preventing emission of methane into the atmosphere [1-9]. The EU countries adopted a bill on the climate protection called "20-20-20", which means reduction of emission by 20% and reaching a 20% share of alternative power sources by 2020 [10]. As many literary sources cover this issue, we will restrict ourselves with a brief reminder of its importance.

The technology of producing biogas is a complex process influenced by multiple factors and the important aspect of efficiency substantiation is the interaction of the operating devices of a biogas plant with raw material. It is important at transporting organic material in a receiver hopper, at its interaction with the screw conveyor at its bottom, at mixing in a reactor (a methane tank) and homogenization, at moving through pipelines at unloading and at its division into liquids and solids.

The organic raw material of livestock farms in the North of Kazakhstan contains a large number of materials various by their physical and mechanical contents: animal manure, straw and other substances not specified by the technology. Such structure of the raw material relates to solid materials, i.e. particles of solid content show viscoplastic properties when processed by the operating devices.

MATERIALS AND METHODS

An experimental plant was produced for studying the physical and mechanical properties of the raw material of a biogas plant (Figure 1). The guides of the plant ensure motion of the puncheon in the set direction and prevent it from rotating around its axis.
Fig. 1: Plant for detection of the physical and mechanical properties of solid materials

Table 1: The saturated plan of the experiment

<table>
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<tr>
<th>Experiment No.</th>
<th>X1</th>
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<th>X4</th>
<th>X5</th>
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</table>

Torque transmission from the electric motor to the cylinder is provided using chain gear.

Minimize(Y, X1, X2, X3, X4, X5) =

\[
\begin{bmatrix}
1 \\
1 \\
3.619 \times 10^{-9} \\
-1.416 \times 10^{-9}
\end{bmatrix}
\]

Maximize(Y, X1, X2, X3, X4, X5) =

\[
\begin{bmatrix}
-2.639 \times 10^{-9} \\
4.699 \times 10^{-10} \\
-3.232 \times 10^{-9} \\
1 \\
1
\end{bmatrix}
\]

Y(X1, X2, X3, X4, X5) ≈ 978.437

The calculation was made by the methodology of A.V. Gorbatov [12]:

Electrical heating of the cylinder housing is provided using electrodes fixed on the frame. Under the influence of electric current, the cylinder is heated to the set temperature. Remote measurement of the temperature is provided by using a radiation pyrometer, which uses infrared (thermal) emission of the studied object.

Implementation of the experiment was supported by the Rechtshafner's saturated plan of the experiment for five factors on three levels [11].

The levels of varying the factors that significantly influence the power capacity of the process are provided in Table 2.

The optimization parameter is the power expenditure for driving the plant; it was measured on the electric motor with a kilowatt meter.

Body of the Work: The following regression equation was formulated in the result of the experiments:

\[
Y = 840 + 194.063x_1 + 19.688x_2 - 8.437x_3 - 6.562x_4 - 27.188x_5 - 38.438x_1x_2 + 0.938x_1x_3 - 8.438x_1x_4 + 8.438x_1x_5 - 6.562x_2x_3 - 10.313x_2x_4 + 2.813x_2x_5 + 10.313x_3x_4 + 8.438x_3x_5 - 0.938x_4x_5 + 44.063x_1^2 - 34.688x_2^2 + 8.437x_3^2 + 21.563x_4^2 - 17.812x_5^2
\]

(1)

Check of the coefficients significance was carried out by the Student's test; the model (1) adequacy was evaluated by the Fisher's ratio test [11]. At processing the results of the research using the MathCAD11 software, the minimum and maximum values of the function were found.

The graphic dependencies of the process are provided in Figure 2. In the result of the experiments, the interrelation between the power capacity and the effective viscosity, on the one hand and the yield stress of the raw material of the biogas plant, on the other hand, were found.
Fig. 2: Dependencies of the effective viscosity and the yield stress on the power

Table 2: The levels of factors varying

<table>
<thead>
<tr>
<th>Factors</th>
<th>Pressure, Pa X 10^2 (X_1)</th>
<th>Spin rate, rpm (X_2)</th>
<th>Humidity, % (X_3)</th>
<th>Clearance, mm (X_4)</th>
<th>Temperature, °C (X_5)</th>
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<tr>
<td>Main level (X = 0)</td>
<td>65</td>
<td>82.5</td>
<td>25</td>
<td>5.25</td>
<td>110</td>
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<tr>
<td>Upper level (X = +1)</td>
<td>100</td>
<td>120</td>
<td>32</td>
<td>8</td>
<td>140</td>
</tr>
<tr>
<td>Lower level (X = -1)</td>
<td>30</td>
<td>45</td>
<td>18</td>
<td>2.5</td>
<td>80</td>
</tr>
<tr>
<td>Variation interval (∆X)</td>
<td>35</td>
<td>37.5</td>
<td>7</td>
<td>2.75</td>
<td>30</td>
</tr>
</tbody>
</table>

\[ \eta_{ef} = \frac{K \cdot M}{N}, \quad \theta_0 = K_0 M_0 \]  

(3)

where K and K₀ are constants depending on the geometrical dimensions of the plant;

M is the torque, Nm; N is the cylinder rotation rate, rpm. The constant coefficients K and K₀ are equal to:

\[ K = \frac{g \cdot R_{sh}}{8 \cdot \pi \cdot \left( \frac{R_i^2 - R_p^2}{R_i^2 - R_p^2} + \frac{R_i^2 R_p^2}{R_i^2 - R_p^2} \right)} \]  

(4)

\[ K_0 = \frac{g \cdot R_{sh}}{2 \cdot \pi \cdot R_p^2 \cdot (h + \pi \cdot R_p / 4)} \]

where \( R_s \) is the sheave radius, m; \( R_i \) is the cylinder inner radius, m; \( R_p \) is the piston radius, m; \( h \) is the depth of the piston immersion in the product, m; \( g \) is the acceleration of gravity, m/sec².

If we substitute the values in (3), we find:

\[ \eta_{\text{ef,min}} = 1.19 \text{ Pa} \cdot \text{sec} \quad \theta_{\text{min}} = 0.000146 \text{ Pa} \]

\[ \eta_{\text{ef,max}} = 1.22 \text{ Pa} \cdot \text{sec} \quad \theta_{\text{max}} = 0.000149 \text{ Pa} \]

(5)

CONCLUSION

In the result of the experiments, the optimal values of the effective viscosity and the yield stress of the raw material of the biogas plant were found. These values are very important at calculation of the machines capacity and power capacity of the processes of raw material processing in the biogas plant.

Summary: Development of non-traditional power supply sources is one of the promising lines of the contemporary science; improvement of efficiency of the processes of biogas production is important for fully-fledged replacement of raw hydrocarbons. The technological process of biogas plants includes the functioning of standalone machines and their performance depends on the physical and mechanical properties of raw material. The suggested methodology and the obtained results allow qualitative assessment of the conditions and the indexes of raw material and biogas plant parts interaction.

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REFERENCES


