Installation of separation of methane-containing gas mixtures of the bioenergy station "Eco-Volt-Agro"

V V Bukhmirov¹, N F Kokarev² and A V Sadchikov³

¹ Department of Theoretical Foundations of Heat Engineering, Ivanovo State Power University named after V.I. Lenin, Ivanovo, Russian Federation
² LLC "Integrated Recycling Systems", Orenburg, Russian Federation
³ Department of Electrical and Thermal Power Engineering, Orenburg State University, Orenburg, Russian Federation

E-mail: lyohantron@mail.ru

Abstract. The article shows the possibility of using the energy potential of biomass in the process of processing of organic waste at the bioenergy station "Eco-Volt-Agro". A brief description of the installation for purification and separation of methane-containing gas mixtures is given. It is shown that the separation of carbon dioxide is carried out by the method of short-cycle, non-heated adsorption. To increase the efficiency of the process of regenerating the adsorbent in the desorption mode, increasing the speed of the process and reducing energy costs, a vertical cylindrical adsorber with a variable internal volume is proposed. A special feature of the adsorber operation is the elimination of the volume of the column from the process of desorption, which is unfilled by the adsorbent, as a result of which the energy costs in the desorption process are reduced by 26%, the desorption time is reduced by 23% and the quality of the adsorbent regeneration is increased.

1. Introduction
At present, the development of alternative energy is connected with the search for new technologies for the use of renewable energy resources. The most favorable from the point of view of the stability of education and accessibility is the energy potential of biomass [1–4].

Anaerobic processing of organic waste at the bioenergy station "Eco-Volt-Agro" in Orenburg (Figure 1) allows receiving environmentally friendly products of processing and energy resources – biogas, electric and thermal energy [5].

2. Statement of the problem
Part of the biogas produced in the process of waste processing is used as a gas engine fuel. To do this, it is necessary to improve the quality of biogas, clearing it of ballast impurities and increasing the methane component. As a result of separation and purification of biogas, a biomethane gas with a methane content of 96% and above is obtained.

At the bio-energetic station "Eco-Volt-Agro", the separation of carbon dioxide and the production of biomethane is carried out at a facility whose schematic diagram is shown in Figure 2.

Removal of hydrogen sulphide and water vapor is carried out with the help of a ferrooxid filter FOF, the separation of carbon dioxide is carried out by the method of short cycle free adsorption using two
vertical cylindrical adsorbers A1 and A2. The purification process of the binary mixture includes two successive regimes: the adsorption regime and the desorption regime [6, 7].

![General view of the production site of bioenergy station "Eco-Volt-Agro".](image)

**Figure 1.** General view of the production site of bioenergy station "Eco-Volt-Agro".

![Schematic diagram of obtaining biomethane](image)

**Figure 2.** Schematic diagram of obtaining biomethane

- R – reactor; A1, A2 – adsorbers; FOF – ferrooxid filter; GF – gravel filter; T – throttle;
- GA – gas analyzer; M – manometer; GB – gasholder biomethane;
- GC – gas holder of carbon dioxide; K – compressor.

This method, based on the relative selectivity of adsorption of methane and carbon dioxide, is characterized by high purification efficiency. The main advantage of the method of short-cycle no-heat adsorption is the absence of stages associated with heating and cooling the adsorbent.

The adsorption stage of the cycle usually proceeds quickly and with a high degree of efficiency. The magnitude of the specific energy consumption of the adsorption separation process depends mainly on the desorption process, which is the most inefficient stage of the process. In this paper, we propose a method for increasing the efficiency of the process of regenerating the adsorbent in the desorption regime using the example of a separation unit for methane-containing gas mixtures of the bioenergetic station "Eco-Volt-Agro".

**3. Vertical adsorber with variable internal volume**

To increase the efficiency of the process of regenerating the adsorbent in the desorption regime, increasing the speed of the process and reducing energy costs, the present work proposes the construction of a vertical adsorber, which is a cylindrical column with a variable volume.
The principal difference lies in the fact that in the proposed vertical adsorber with variable internal volume a fixed partition with movable flap in the form of a truncated cone is installed. In the desorption mode, by reducing the internal volume of the adsorption tower, the load on the vacuum pump is reduced, the process time is shortened and the efficiency of regeneration is increased.

Figure 3 shows the proposed vertical adsorber with a variable internal volume.

Figure 3. Longitudinal section of vertical adsorber with variable internal volume

a) – in the adsorption regime; b) in the desorption mode

NSC – non sorbable component; SC – sorbable component

1 – exit valves for the non sorbable component; 2 – fixed guides; 3 – movable flaps in the form of a truncated cone; 4 – mesh cylindrical container filled with adsorbent; 5 – outlet valve for the sorbable component; 6 – volume of the column is unfilled with adsorbent; 7 – inlet valve for a binary mixture consisting of a sorbable component and nonsorbable component; 8 – adsorption tower casing; 9 – fixed partitions.

The proposed adsorber works as follows.

In the adsorption mode, the binary mixture at elevated pressure enters the adsorption tower 8 through the inlet valve for the binary mixture consisting of the sorbed component and the non-absorbing component 7, then the gas mixture passes through a mesh cylindrical vessel filled with adsorbent 4, which under the action of the gauge pressure of the mixture is adsorbed to its surface sorbed component. The mixture passing through the adsorber is cleaned, the concentration of the nonabsorbable component is increased and the purified gas exits the adsorption tower casing 8 through the valves to exit the non-absorbing component 1. In this case, the movable shutters in the form of a truncated cone 3, with holes for the guides fixed to fixed guides 2, under the influence of the gauge pressure of the gas flow, move in a normal manner to the fixed partition 9 in the direction from the mesh cylindrical vessel filled with adsorbent 4, opening the way for gas. In this case, the valve for the outlet of the sorbing component 5 is closed.

In the desorption mode, the adsorbent is regenerated by removing the sorbed component under reduced pressure, while the valves for the exit of the non-absorbing component 1 are closed and the valve for the binary mixture consisting of the sorbent component and the non-absorbing component 7
opens the valve for the outlet of the sorption component 5. The movable flaps in the shape of the truncated cone 3, with holes for the guides fixed to the fixed guides 2, under the effect of the vacuum pressure generated by the pumping pump through the valve to exit the sorbing component 5 are drawn along the fixed guides 2 moving in a normal manner to the fixed partitions 9 towards the container with the adsorbent and are pressed against the fixed partitions 9 fixed to the ends of the mesh cylindrical vessel filled with adsorbent 4, decrease in the internal volume of the column by the volume of the column column unfilled by the adsorbent 6. A part of the volume of the column unfilled by the adsorbent 6 is shaded in FIG. As a result of the proposed design change, the load on the evacuation pump is reduced and the efficiency of the regeneration process of the adsorbent is increased. The removal of the sorbed component takes place through the valve to exit the sorption component 5. Then the process is repeated cyclically.

4. The discussion of the results
To remove a more sorbent component from the adsorbent in the desorption mode, the energy is expended to create the necessary vacuum in the adsorber chamber by means of a vacuum pump. The energy costs for creating a vacuum are determined by the pump's capacity:

\[ S = \frac{V}{t} \ln \left( \frac{p_a}{p_e} \right) F, \]

where:
- \( S \) – pump capacity,
- \( t \) – pumping time,
- \( V \) – volume of the pumped container (hermetically sealed),
- \( p_a \) – level of the initial vacuum,
- \( p_e \) – level of the necessary vacuum in the tank,
- \( F \) – coefficient of the pumping curve.

As can be seen from the formula, the energy costs in the desorption process are directly proportional to the volume of the adsorber in the pumping regime.

From the description of the adsorber operation (Figure 3) it follows that in the desorption mode the closing of the movable shutters 3 eliminates from the desorption process the region 6 of the column volume unfilled by the adsorbent, as a result of which the internal volume of the adsorber in the desorption mode is reduced by 32%. At the same time, energy costs in the desorption process are reduced by 26%, which is due to a reduction in the time of the desorption stage by 23%.

Conclusion
Thus, in a vertical adsorber with a variable internal volume, in comparison with a conventional adsorber, in a desorption mode, the volume of the column decreases, which allows to reduce energy costs for the operation of the vacuum pump in the desorption mode, and also to improve the regeneration of the adsorbent and shorten the desorption stage.

References
[1] Sadchikov A V, Kokarev N F 2016 Biogas stations as an environmentally friendly means for increasing the biological ability of natural and cultural landscapes. Advances in modern natural science 4 173–77
[2] Sadchikov AV 2016 Increase of energy efficiency of biogas plants. Fundamental research 10(1) 83–7
[3] Sadchikov A V, Kokarev N F, Sokolov V Yu and Naumov S A 2016 Ensuring energy independence and ecological safety of MSW landfills. Int. Sc. J. for Alternative Energy and Ecology 15-18(203-206) 104–11
[4] Sadchikov A V, Kokarev N F, Idigenov B B 2014 The use of substrates with rapid cleavage to increase the methane output of biogas plants with combined loading. Modern problems of science and education 6
[5] Bukhmirov V V, Kokarev N F and Sadchikov A V 2018 Bioenergetic station "Eco-Volt-Agro" for processing of organic waste. *Agrotechnics and power supply* 1(18) 60–9
[6] Shumyatsky Yu I 1989 Types and principles of organization of non-heated adsorption processes for purification and separation of gas mixtures. *Chem. prom.* 8 586–90
[7] Alekhina M B 2007 *Industrial adsorbents: a manual* (RHTU named after D I Mendeleyev) pp 113–15