Mathematical model for determining the optimal location of the biomethane plant

D Y Suslov and D O Temnikov
Department of Heat and Gas Supply and Ventilation, Belgorod State Technological University named after V.G. Shukhov, Kostyukov St., 46, Belgorod, 308012, Russia
Email: Suslov1687@mail.ru

Abstract. The work is devoted to the actual problem of using an alternative energy source - biomethane in gas supply systems. When developing and designing gas supply systems using biomethane, an important task is to determine the optimal location for biomethane plants. For the research, the methods of graphs and parametric optimization were used from the condition of minimizing the total transport costs. A mathematical model has been developed to determine the coordinates of the location of the biomethane plant depending on the production capacity and location of agricultural enterprises. Using the developed model, the location of a biomethane plant with a total volume of digesters of 5000 m³, located in the Viedelevsky district of the Belgorod region, was determined. This unit can process 315.9 t/day of organic waste and produce 504.64 m³/h of biomethane with a methane content of more than 98%. As a result of the calculations, the coordinates of the location of the biomethane plant were determined (X = 11.82; Y = 22.35), and the location of the biomethane plant was adjusted, taking into account the relief conditions of the terrain and the presence of a road transport system.

1. Introduction
At present, the level of gasification of the Russian Federation with natural gas is 70.1%. Gasification of cities and urban-type settlements is 73%, and rural areas - 61.8%. At the same time, the priority program for the development of the gas supply system is gasification of the country's regions placed far from the main gas pipelines [1, 2].

A promising direction in the development of gas supply systems is the use of biomethane. Biomethane is biogas purified to form natural gas. The production and consumption of biomethane has become widespread in Europe and other countries of the world [3-6]. The largest amount of biomethane is produced in Germany, France, Great Britain, Sweden, the Netherlands, Denmark and Switzerland [7-9]. The number of biomethane plants (BMP) by country is shown in Figure 1. Most of the biomethane plants supply biomethane to the main or distribution gas networks [10, 11]. However, the majority of biomethane plants in Finland, Sweden, Norway and Iceland do not supply biomethane to gas networks, but are used as fuel for vehicles and other needs [11, 12]. To supply biomethane to transport gas pipelines, it is necessary to provide large volumes of gas with high excess pressure (5-7 MPa). This requires the installation of an additional compressor station and will lead to increased capital costs. Considering that when receiving biomethane, the pressure of the gas leaving the station reaches 0.3 MPa, it is more expedient to supply biomethane to medium pressure distribution gas pipelines.
Currently, 2 main schemes for obtaining and supplying biomethane are used: centralized and decentralized [13, 14].

The choice of the scheme depends on the productivity and location of agricultural enterprises and gas networks. The centralized scheme provides for one large biomethane plant that recycles waste from most agricultural businesses. This scheme is used in areas with a large number of agricultural and processing enterprises located close to each other. The centralized scheme is characterized by high costs for the delivery of the initial substrate from agricultural enterprises to the biomethane plant. At the same time, waste, as a rule, is delivered by road transport in tank tractors.

When agricultural enterprises are located at a great distance from each other, a decentralized scheme is used, in which a biomethane plant is located near each agricultural enterprise, which supplies biomethane to the nearest gas pipeline. At the same time, the costs of building biomethane plants are increasing, which significantly increases the cost of biomethane produced.

For the Belgorod region and other developed agro-industrial regions of the country, it is advisable to use a centralized scheme for obtaining and supplying biomethane.

When developing and designing gas supply systems using biomethane, an urgent problem is to determine the optimal location for biomethane plants. Domestic and foreign scientists were engaged in finding the optimal location of objects in gas supply systems [15-21].

The purpose of this work is to develop a design scheme and a mathematical model to determine the optimal location of biomethane plants.

2. Materials and Methods
When developing a mathematical model to determine the optimal location of biomethane plants on the territory of the administrative region, the theory of graphs, methods of mathematical modeling and parametric optimization from the condition of minimizing the total transport costs were used.

To solve the mathematical model, we used the engineering mathematical software Mathcad, which allows you to make calculations and visualize the results of calculations.
To determine the location of the biomethane plant on the territory of the Veidelevsky district of the Belgorod region, the coordinates of the location and the amount of organic waste of agricultural enterprises were used.

3. Results and Discussion

The rational location of the biomethane plant is to find a location in which the cost of transporting the initial substrate from the agricultural enterprise to the biomethane plant will be minimal.

Let's draw up a calculation scheme to determine the coordinates of the location of the biomethane plant \((X, Y)\). Agricultural enterprises with the corresponding coordinates are denoted by \(1(x_1, y_1)\), \(2(x_2, y_2)\), \(3(x_3, y_3)\), \(N(x_i, y_i)\) (Figure 2).

![Figure 2. Calculation scheme for choosing the location of a biomethane plant.](image)

Weber's model has been widely used to determine the optimal location of objects [22]. According to Weber's model, the coordinates of the location of the BMP biomethane plant \((X, Y)\) are determined from the system of equations:

\[
\begin{align*}
A &= c \sum a_i l_i; \\
l_i &= \sqrt{(X - x_i)^2 + (Y - y_i)^2},
\end{align*}
\]

(1)

where:

- \(A\) - total costs of waste delivery, rubles;
- \(c\) - is the cost of waste delivery, rubles;
- \(a_i\) - is the volume of waste, t;
- \(l_i\) - is the distance from agricultural enterprises to the biomethane plant, km;
- \(x_i, y_i\) - coordinates of agricultural enterprises.

Waste delivery costs depend on the type of road transport and are determined by fuel consumption. The standard fuel consumption for a truck is determined according to the methodological recommendations "Norms of consumption of fuels and lubricants in road transport" (Order of the Ministry of Transport of Russia dated March 14, 2008 Н АМ-23-р):

\[
Q_n = 0.01 \cdot (H_{san} \cdot S + H_w \cdot W) \cdot (1 + 0.01 \cdot D),
\]

(2)
where:

- $S$ – vehicle mileage, km;
- $H_{san}$ – is the rate of fuel consumption per vehicle mileage, l / km;
- $H_w$ – is the rate of fuel consumption for transport work, l / 100 km;
- $W$ – is the volume of transport work, thousand km;
- $D$ – correction factor (total relative increase or decrease) to the% rate.

The fuel consumption rate is determined taking into account the mass of the trailer:

$$H_{san} = H_s + H_g \cdot G_{tr},$$

where:

- $H_s$ – is the base rate of fuel consumption per vehicle mileage, l / 100 km;
- $H_g$ – fuel consumption rate for additional trailer weight, l / 100 thousand km;
- $G_{tr}$ – unladen weight of the trailer, t.

The volume of transport work is determined from the expression:

$$W = G_w \cdot S_w,$$

where:

- $G_w$ – is the mass of waste, t;
- $S_w$ – run with waste, km.

The required number of towing vehicles is determined based on the volume of waste transported by one vehicle:

$$k_i = \frac{a_w}{m_{nom}},$$

where $m_{nom}$ – is the nominal volume of waste transported by one trailer, t.

Using equations (1-5), we compose a system of equations to determine the optimal location of the biomethane plant:

$$\{ A = K \cdot \sum_{i=0}^{n} (k_i \cdot (H_s \cdot 2 + H_g \cdot G_{tr} \cdot 2 + H_w m_{nom})) \cdot l_i \}
\text{ where } l_i = \sqrt{(X - x_i)^2 + (Y - y_i)^2},$$

where $K = 0,01 \cdot (1 + 0,01 \cdot D)$ – correction factor.

Using the developed mathematical model, we will determine the optimal location of a biomethane plant for processing organic waste from agricultural enterprises [23] located in the Veidelevsky district of the Belgorod region.

As the initial data, 6 poultry factories of the enterprise of OOO "Veidelevsky Broiler", as well as 2 enterprises for raising cattle: AO "Dolzhanskoe" and ZAO im. Kirov. The volumes of waste and the coordinates of the location of enterprises on the ground are presented in Table 1.

The total amount of organic waste generated in the Veidelevsky district is 315.9 tons / day. To process this amount of waste, we will use a biomethane plant, including 2 digesters with a volume of 2500 m3 each. The plant produces 504.64 m3 / h of biomethane with a methane content of more than 98%.

As a result of the calculations, the coordinates of the optimal location of the biomethane plant were determined ($X = 11.82; Y = 22.35$) and the design scheme was constructed (Figure 3). To transport the substrate to the biomethane plant, the number of trip was determined: from poultry factories 0.5 flights / day, from OOO "Dolzhanskoye" 2.5 flights / day, from ZAO im. Kirov 2.5 flights / day.
Table 1. Design parameters.

| Company number | Name Company | Coordinates | Type waste | Amount of waste, t / day |
|----------------|--------------|-------------|------------|-------------------------|
| 1              | Poultry factory number 1 | x=17.63, y=14.26 | Bird droppings | 20.7 |
| 2              | Poultry factory number 2 | x=17.78, y=12.75 | Bird droppings | 19.4 |
| 3              | Poultry factory Victoropol | x=13.97, y=6.42 | Bird droppings | 19.4 |
| 4              | Poultry factory Belyi Kolodez | x=26.63, y=1.69 | Bird droppings | 20.7 |
| 5              | Poultry Factory Kubraki | x=34.4, y=17.58 | Bird droppings | 19.4 |
| 6              | Poultry actory Degt-yarnoe | x=27.07, y=26.33 | Bird droppings | 19.4 |
| 7              | AO "Dolzhanskoye" | x=12.46, y=28.71 | Cattle manure | 100 |
| 8              | ZAO im. Kirov | x=2.1, y=13.34 | Cattle manure | 96.9 |
|               | **Total** | | | **315.9** |

Figure 3. Location map of agricultural enterprises and biomethane plant.
However, this scheme has disadvantages, since it does not take into account the natural conditions of the area and the road transport network.

To clarify the calculations, we will draw the resulting scheme on the geographical map of the Veidelevsky region. Then we determine the actual position of the biomethane plant, taking into account the local conditions. To do this, we will move the biomethane plant 2.1 km to the south, closer to the village of Bolshiye Lipyagi. Near the village of Bolshiye Lipyagi there is a road with an improved surface (Figure 4).

Figure 4. The actual location of the biomethane plant in the Veidelevsky district of the Belgorod region.

4. Conclusion
An alternative source of energy, biomethane, has become widespread in gas supply systems in developed countries and is one of the promising areas for the development of the gas supply system of the Russian Federation. For the Belgorod region and other developed agro-industrial regions of the country, it is advisable to use a centralized scheme for obtaining and supplying biomethane.

A mathematical model has been developed for determining the optimal location of biomethane plants on the territory of the administrative district. The model allows you to determine the optimal location of the biomethane plant, depending on the productivity and location of agricultural enterprises and the location of the gas pipeline.

The developed model was used to determine the location of a biomethane plant with a total volume of digesters of 5000 m³, located in the Veidelevsky district of the Belgorod region. The unit can process 315.9 t / day of organic waste and produce 504.64 m³ / h of biomethane with a methane content of more than 98%. As a result of solving the mathematical model, the coordinates of the location of the biomethane plant were determined (X = 11.82; Y = 22.35). Then the location of the biomethane plant was adjusted taking into account the natural conditions of the area and the road transport network (X = 11.82; Y = 20.25).
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