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To cite this article: V Prohorov *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **537** 062044

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Analysis of landfill gas thermo-physical properties for communal services

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Abstract. In this paper, we analyzed the thermo-physical properties of landfill gas, which can be used in the system of communal services of the city from specialized landfills for collecting municipal solid waste. Authors do not yet consider ways of delivering this type of fuel to subscribers, but imply as an option of possible technologies that there is a storage facility and an industrial factory for cleaning and condensation landfill gas for further use in the communal system of the city. There are Graphs of changes in various indicators of landfill gas in this article. This study can be used to predict energy conservation not only of large cities, but also of small settlements from the use of an alternative energy source - landfill gas. Its main characteristic (in terms of thermal physics) is the lower calorific value of the fuel. It depends on the composition and moisture of the gas. The report discusses the methodology for studying the lower calorific value of landfill gas, based on the chemical balance of this fuel. Another important characteristic is the environmental effect. Reducing emissions of landfill gas decrease the greenhouse effect, which has a negative impact on the Earth's atmosphere, biosphere and hydrosphere. It could be provided for the production of electrical energy, as well as a combination of electric and thermal. There is the possibility of producing hydrogen for a fuel cell. However, this requires independent economic, environmental and energy comparison of various technologies for using of landfill gas in the engineering infrastructure of the city, as well as different methods of transporting and producing energy-efficient condensate compressed landfill gas (the best option when the methane content in this fuel is like natural gas).

1. Introduction

People continue to look for ways to reduce energy consumption to provide comfortable conditions for their existence in the 21st century. Until the 20th century, humanity has learned to develop and use mechanical thermal and electrical energy from different natural appearances: from wind - wind power plants; from the sun - photovoltaic cells and solar water heaters; from the flow of rivers - hydroelectric power stations and hydraulic drives of pumps; from plants - biofuel; from the heat of the Earth and wastewater - heat pumps;

All these sources are called alternative renewable energy sources in the literature[1,2]. Landfill gas as well as wastewater can be attributed to renewable sources. The development of landfill gas in the countries of the European Union and the United States began in the 1980s [3,4]. Landfill gas is a biogas, which is formed as a result of the anaerobic methane decomposition of organic matter from MSW under the influence of bacteria for a certain period of time. This biogas is a mixture of methane (from 35% to 55%), carbon dioxide (from 10 to 45%) and other volatiles (from 1 to 30%) [1,5].



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Methane (CH_4) emissions from landfill gas to the atmosphere relative to the total mass of CH_4 emissions are 67.6% [6]. If we solve the problem of recycling these emissions, we improve the ecology of the Earth. There are a number of problems in the Russian Federation which are not related to the technology of landfill gas production [7] and this significantly hinders its use in the energy saving of the country. But over time, with the help of the Russian Department of Natural Resources and Ecology and the Russian Department of Energy, these problems will be resolved.

2. Methods of lower calorific value determination

According to some laboratory records, the lower calorific value of landfill gas ranges from 3.3 to 5.5 kWh per 1 m^3 of landfill gas (or from 11880 to 19800 kJ / m^3), and the production potential is 70-100 m^3 per 1 ton of municipal solid waste [1,8,9]. There is the area in figure 1 where shows' changing's in the number of domestic rubbish from 1 person and the quantity of landfill gas which released from 1 ton of domestic rubbish. It has been investigated that 1 person (for the Moscow region) throws out 150–300 kg of domestic rubbish per year in some sources [1, 10, 11, 12]. The information for other regions could be different because of natural conditions. The differences in the fractional composition of domestic rubbish for regions at different latitudes has shown in detailed research [1]. A person in the northern regions needs more energy because of climatic influence.

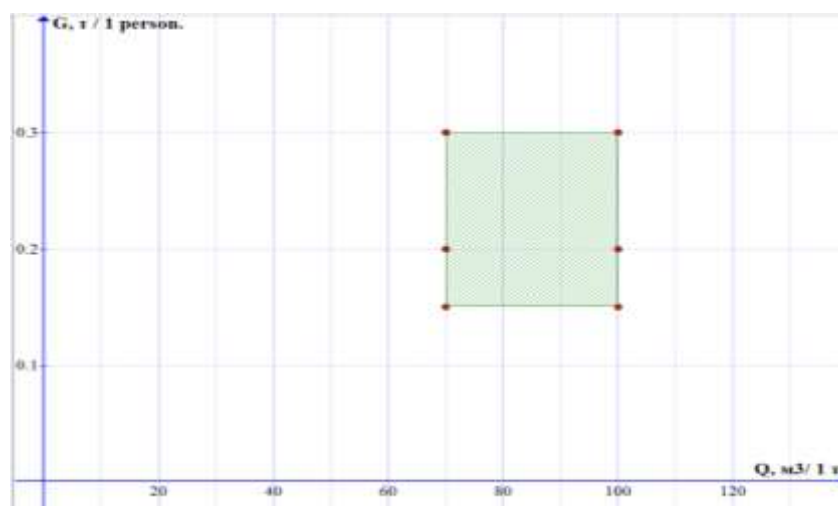


Figure 1. Area of quantity change of landfill gas volume (G) from domestic rubbish (Q) for 1 person.

Area, which has shown figure 1, is valid for the European part of Russia and all information has based on Moscow region. The main factors for determining the minimum and maximum values of the domestic rubbish volume from 1 person for the year are: climate; people's age; the composition of municipal solid waste; delivery time of MSW from the trash can in the person's house to the landfill of domestic waste; density of rubbish before transportation to the MSW landfill. The volume of landfill gas released from 1 ton of domestic rubbish also depends on the same factors [12].

Landfill gas is gaseous fuel. Its chemical composition is very different from the composition of natural gas. Any gaseous fuel is a mixture of combustible and non-combustible gases.

The combustible part consists of hydrocarbons, hydrogen, carbon monoxide and hydrogen sulphide. The non-combustible part includes nitrogen, carbon dioxide, oxygen [13,14]. The composition of the gas fuel is presented in equation (1):

$$\sum_{i=1}^{i=m} C_n H_{2n+2} + \sum_{i=1}^{i=m} C_n H_{2n} + H_2 + CO + H_2S + O_2 + N_2 + CO_2 = 100\%; \quad (1)$$

Where H_2 , CO , CH_4 , etc. - volume content of individual combustible components in gas fuel, vol. %;

n - the carbon number;

m - the upper limit of the heavy hydrocarbons number summation (for $n > 1$, $m > 4$);

i - the lower limit of the heavy hydrocarbons number summation;

The main measure for determining the thermal potential of biogas for the city is calorific value. Calorific value is the quantity of heat released during complete combustion (in this case) of 1 m³ of gas under normal conditions (0 ° C and 101.3 KPa). Low calorific value takes into account the heat consumed by evaporation of moisture during combustion and the high does not do this [15].

Authors were used the information from reference books [11,12,13] in the calculating of low calorific value. It's according for dry gas by the formula (2):

$$Q_l^d = 257H_2S + 107,9H_2 + 126,4CO + 358,8CH_4 + 643C_2H_6 + 931,8C_3H_8 + 1235C_4H_{10} + 1227C_4H_{10}^* + 1566C_5H_{12} + 595C_2H_4 + 884C_3H_6 + 1138C_4H_8, \text{ MJ}; \quad (2)$$

Where H₂, CO, CH₄, etc. - volume content of individual combustible components in gas fuel, vol. %;

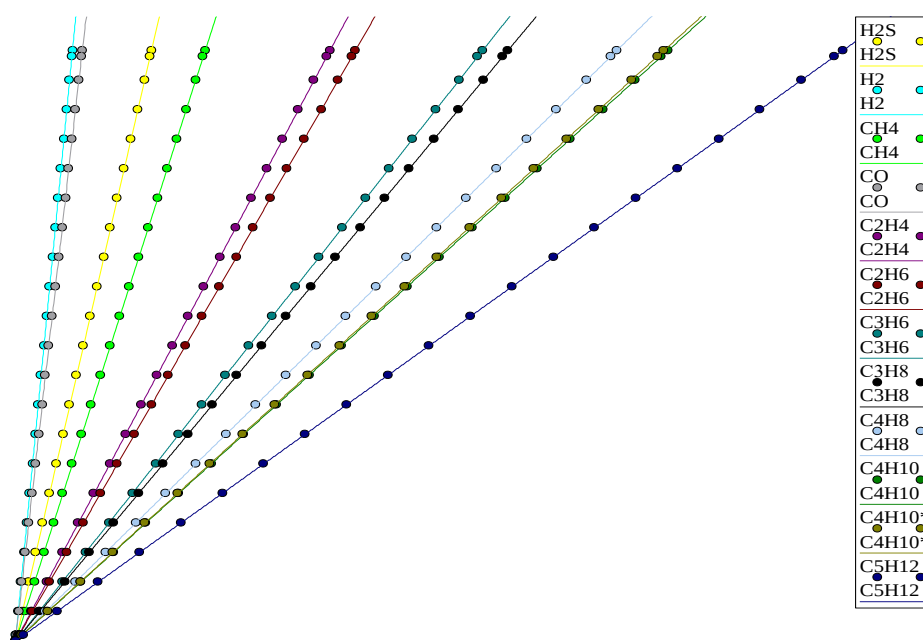


Figure 2. Chart for determining the Low calorific value of 1 m³ of complex dry landfill gas.

Chart in figure 2 is based on formula 1. It is possible to exclude some hydrocarbon compounds (besides of methane) from chart 2 because of small quantity in components at the landfill gas. They are presented in the research results part of this paper.

When we calculate the quantity of fuel for its further use in gas-consuming equipment in communal service, we do not use the dry mass (volume) of fuel, we use the working one. Formula 3.

$$Q_l^w = Q_l^d \times k, \text{ MJ} \quad (3)$$

Q_l^w - low calorific value of gas, MJ/m³;

Q_l^d - low calorific value of gas to dry fuel mass, MJ/m³;

k - index which considers the moisture of the gas (Formula 4).

$$k = \frac{0,804}{0,804 + d} \quad (4)$$

d - absolute moisture of gas (It is in the range 0,005-0,008 hg/m³).

The index k , which taking into account the moisture of the gas, is changing insignificantly: from 0,994 to 1.

In addition to formulas 1 and 2, it could be used formula (5):

$$Q_l^d = 0,01 \times \sum Q_{li}^d \times r_i, \text{ MJ} \quad (5)$$

Q_{li}^d - low calorific value of gas to dry fuel volume i gas component MJ/m³ (determined by special literature or chart 2 with 100% volume percentage of the i gas component);

r_i - volume percentage of the i gas component, % (for landfill gas components are presented in the previous chapter);

The chemical composition of the combustible component of landfill gas according to [8] for different regions may be different. There are compositions for biogas from Orenburg and Samara region in figure 3 and 4. The composition of CH₄ varies from 41 to 46%, CO from 30 to 32%, N₂ from 22 to 24%, other components of landfill gas from 2 to 5%.

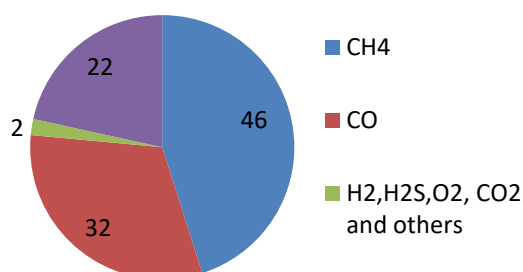


Figure 3. Diagram of the chemical composition of the landfill gas sample at the municipal waste landfill in Orenburg.

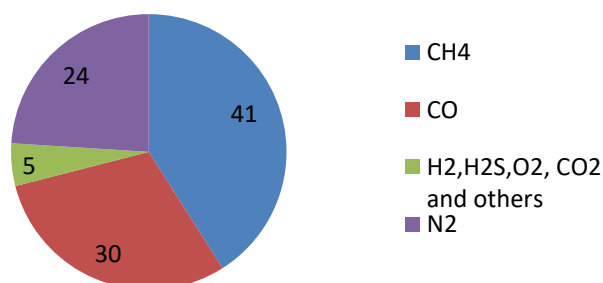


Figure 4. Diagram of the chemical composition of the landfill gas sample at the municipal waste landfill in Samara region.

3. Results of calculations

The primary calculations for landfill gas is valid too by excluding some components because of their low volumetric content parts of landfill gas (the formula 6 has obtained from formula 2):

$$Q_l^d = 257H_2S + 107,9H_2 + 126,4CO + 358,8CH_4, \text{ MJ}; \quad (6)$$

Three components of landfill gas are not taken into account in some works [1,8], when determining the low calorific value (Hydrogen Sulfide (H₂S); - Hydrogen (H₂) and moisture) in determining potential thermal productivity. All calculations for the use of released heat should be carried out on the working mass, and not on the dry. The other two components are ignored because of their low content in the mixture [1,16,17, 18,19]. The percentage of pure hydrogen in landfill gas does not exceed 1%, and hydrogen sulfide does not exceed 3% [17]. Unlike hydrogen sulfide and hydrogen, other gases are always present in landfill gas, but they are related to the ballast part. The general balance equation is presented in the previous section (Formula 1). A chart, which is in figure 5, shows for determining the lower calorific value of 1 m³ of dry gas in relation to landfill gas.

This chart is identical to chart 2, but with the above changes in the elemental composition of landfill gas. Charts 6-8 were built to facilitate the determination of the low calorific value of landfill gas because of the low volume fraction of chemical elements in the overall composition of the gas fuel.

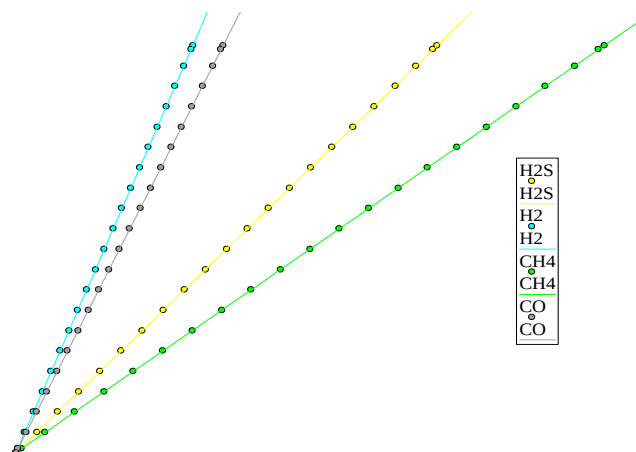


Figure 5. Chart for determining the low calorific value of 1 m³ of dry landfill gas.

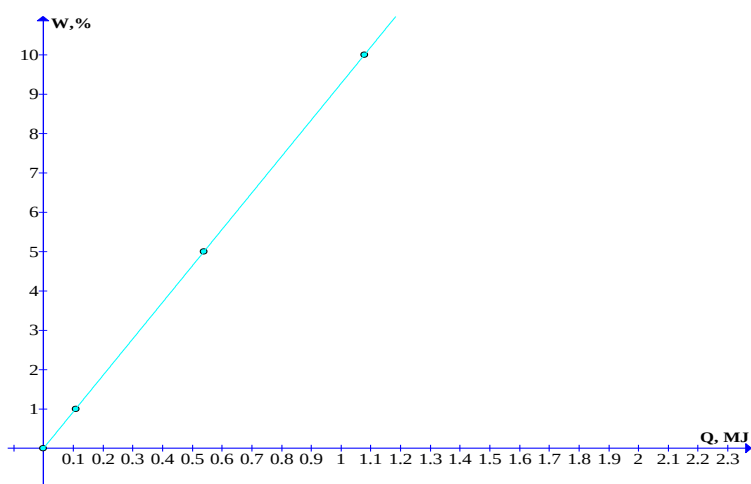


Figure 6. Increased chart of the low calorific value of the 1 m³ component (H₂) of dry landfill gas.

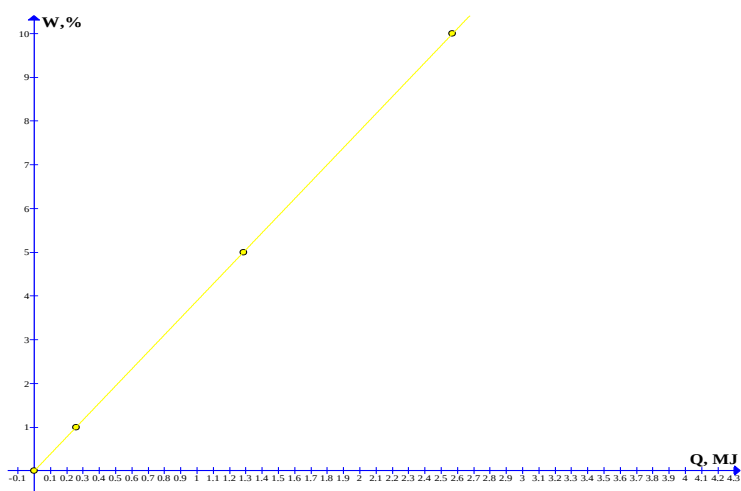


Figure 7. Increased chart of the low calorific value of the 1 m³ component (H₂S) of dry landfill gas.

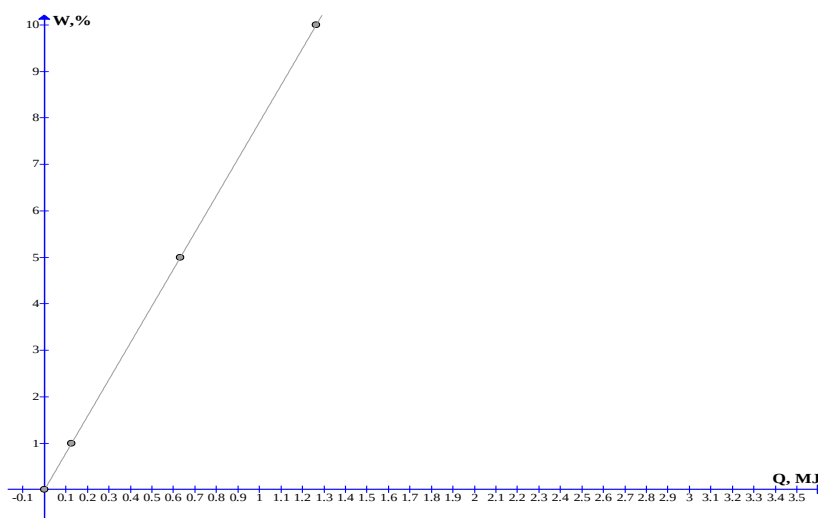


Figure 8. Increased chart of the low calorific value of the 1 m³ component (CO) of dry landfill gas.

According to the dry landfill gas in the Samara region, the minimum low calorific value of fuel at $O_2 = 5\%$ is 18502.8 kJ / m³, and at $O_2 = 1\%$ - 19312.7 kJ / m³. For Orenburg, the limits of change are less because of the landfill gas different chemical composition. The minimum of low calorific value of dry landfill gas is - 20549.6 kJ / m³ (at $O_2 = 2\%$) and 20771 kJ / m³ (at $O_2 = 1\%$).

4. Conclusion

The study analyzed how the real chemical composition of landfill gas affects to the low calorific value for landfill gas from the municipal solid waste in the Samara region and Orenburg.

Charts 5,6,7,8 described to help in evaluation of the energy landfill gas potential in any region when landfill gas is using as fuel for the heat supply system of locality. In view of the low concentration in the landfill gas of some chemical combustible components, their effects on low calorific value of fuel at the MSW landfill in the Samara region and Orenburg were investigated. This effect may be significant because of a different ratio in the chemical composition of the landfill gas. With an increase in the oxygen content by 4% and the absence of free hydrogen molecules, the low calorific value will decrease by 4% at the test site in the Samara region. The same pattern remains with a decrease in oxygen concentration by 1%, the low calorific value will increase by 1% in the landfill gas from the landfill in Orenburg. The paper also derived a simplified formula for determining the low calorific value of dry landfill gas.

The method presents the determining the value of the low calorific value for the cities power needs in life support systems and regions near the MSW landfill.

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