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SUBSTANTIATION OF USE OF BUTANE FOR GASIFICATION OF OBJECTS

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Statement of the problem. The variable composition of liquefied petroleum gas has a significant impact on the operation of autonomous gas supply systems. The presence of the butane fraction under conditions of sub-zero temperatures leads to the cessation of the generation of the vapor phase in the tank, moisture condensation and the formation of ice and hydrate plugs.
Results. The features of the use of technical butane in gas supply systems are considered. The composition of the gas-air mixture is recommended, taking into account the restrictions on deviations in the Wobbe number, ensuring the completeness of combustion of the mixture in gas-using installations of the consumer. The level of filling underground tanks with technical butane is justified, taking into account the coefficient of volume expansion of gas in the presence of extreme operating temperatures.
Conclusions. The composition of butane-based gas-air mixtures for gas supply to consumers was determined that meets the condition for the interchangeability of combustible gases and provides lower dew point temperatures; the level of filling of ground and underground tanks with technical butane is justified.

Keywords: gas supply system, butane, gas-air mixture, Wobbe number, interchangeability, tank filling level, dew point.

Introduction. Currently autonomous systems for the supply of liquefied hydrocarbon gas using a mixture of propane and butane have become widespread [1, 2, 4, 6, 9]. As the vapor phase is consumed from the reservoir, the gas composition changes and the butane content in the liquid and vapor phases increases [3, 10, 14, 15]. This determines the fractional nature of evaporation of the liquid propane-butane phase and variable gas composition supplied for combustion in gas-using equipment. Simultaneously, the transfer of gas-using equipment to

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work on natural gas does not seem possible if centralized gasification is provided with no replacement of burners.

According to existing practice, autonomous gas supply systems with natural regasification are mostly not designed to use liquefied gas with an increased content of butane fractions [3, 10]. Besides, recommendations for the operation of systems using technical butane are not mentioned in the known literature whatsoever.

Butane is known to have a boiling point of the liquid phase minus 0.5 °C, which completely excludes its use as a gas fuel in gas supply systems - ground (in all climate zones of operation) and underground (in cold and very cold climate zones) [3, 10, 11].

The dew point temperature of the vapor phase of butane depending on the pressure in the tank starts from minus 1 °C (at 0.1 MPa) and covers a positive temperature range. Hence, even in warm and moderately cold climate zones, when the butane vapor phase moves from the reservoir through the pipeline piping, the temperature of the latter is below the dew point temperature, which contributes to condensation and formation of ice and hydrate plugs.

Scholarly studies [12, 14, 15, 17, 18, 20] have shown that gas supply to consumers based on butane is possible using gas-air mixtures. The use of a gas-air mixture based on technical butane as a gas fuel will allow one:

— to stabilize the composition of the combustible mixture supplied for combustion;

— to reduce the dew point and the formation of condensate in the gaseous mixture for the non-hydrated reduction of the gas-air mixture;

— to fully adapt the gas-air mixture for subsequent replacement with natural gas with no replacement of gas-using equipment;

In order to identify the required parameters of gas supply systems using butane, more research needs to be conducted.

1. Justification of the composition of the gas-air mixture. The criterion which is crucial for interchangeability of combustible gases is the Wobbe number. The replaceability is defined by the possibility of using an alternative gas without disrupting the normal operation of gas-burning devices and their design solutions [13, 16, 21].

The Wobbe number of a gas-air mixture “butane-air” is given by the formula:

$$W_0 = \frac{(Q_{н}^{р})_{см}}{\sqrt{d}}, \tag{1}$$

where $(Q_{н}^{р})_{см}$ is the net calorific value of butane, MJ/m^3; d is a relative density of the gas-air mixture in relation to the air, kg/nm^3.

The calorific value of the gas-air mixture using butane is given by the formula:

$$(Q_{н}^{р})_{см} = (Q_{н}^{р})_{б} \cdot k_{б}^{0}, \qquad (2)$$

where $(Q_{н}^{р})_{б}$ is the net calorific value of butane, MJ/m^3 [10]; $k_{б}^{о}$ is the volumetric concentration of butane in the gas-air mixture, %;

The relative density of the gas-air mixture in air is given by the formula

$$d = (\rho_{б} k_{б}^{о} + \rho_{в} k_{в}^{о})/\rho_{в}, \qquad (3)$$

where $k_{в}^{о}$ is the volumetric concentration of butane in the gas-air mixture, %; $\rho_{в}$ is the specific air density assumed to equal 1.29 kg/nm^3; $\rho_{б}$ is the specific air density assumed to equal 2.7 kg/nm^3.

To justify the composition of the gas-air mixture “butane – air”, the corresponding calculations were performed. The following data were used in the calculations:

— net calorific value of butane assumed to be 118.53, MJ/m^3;

— change in the content of butane grade БТ in hot water supply (from 1 to 100 %).

The calculation results are presented in Fig. 1.

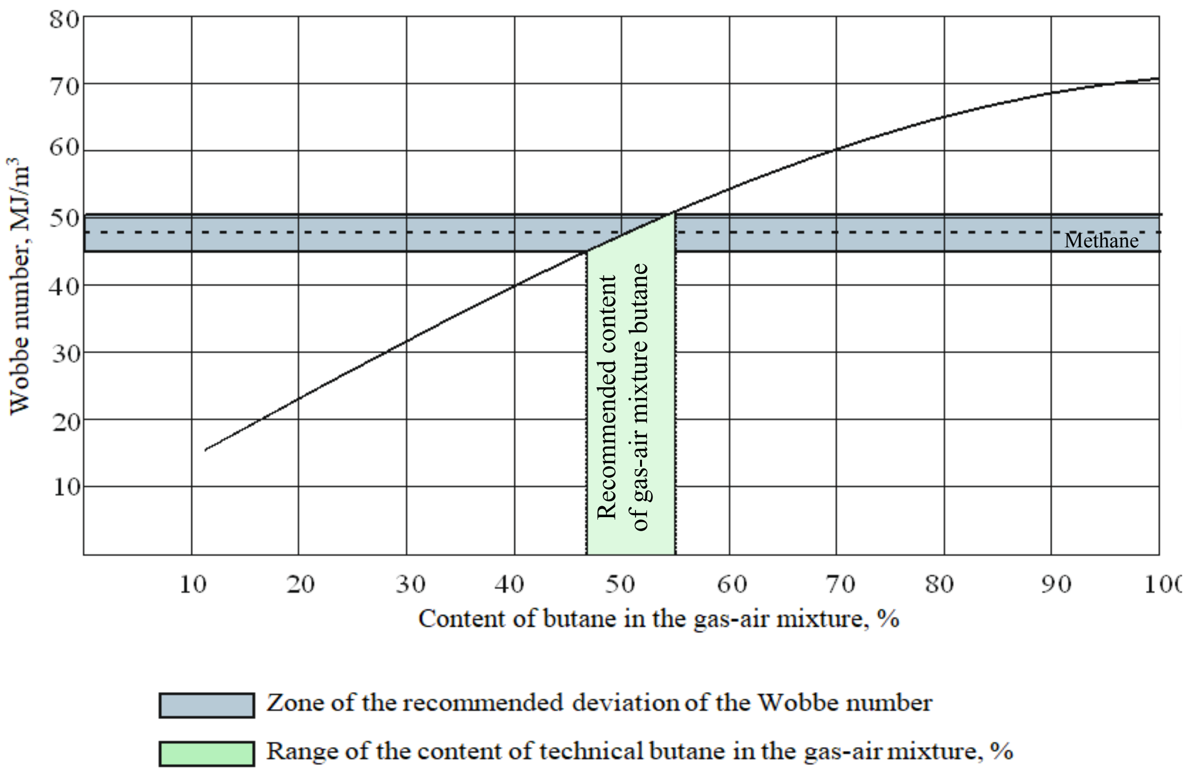

Fig. 1. Identifying the optimal percentage of a mixture of technical butane with air when identifying the interchangeability of combustible gases

As can be seen from the graph (Fig. 1), the butane content in the gas-air mixture should be at least 48 % and not more than 54 %. The mixture of the specified composition is in full compliance with the requirements for interchangeability of combustible gases.

2. Identifying the dew point temperature of the gas-air mixture. As noted earlier, when using gas-air mixtures, the dew point temperature decreases having a positive impact on the non-hydrated operation of gas supply systems.

The partial pressure of saturated vapor of butane according to the Antoine correlation [1, 19] is given by the expression:

$$P_б(t) = 10^{A_б - \frac{B_б}{C_б + t}}, \quad (4)$$

where $A_б$, $B_б$, $C_б$ are the constants of equations whose the values for n-butane are presented in [7, 11].

According to the expression (4) and nomograms for identifying the dew point temperatures [3, 10], the dew point temperatures of the proposed gas-air mixture and technical butane were identified. To compare, the table shows the dew point temperatures of the recommended air-gas mixture based on butane and technical butane.

Table

Dew point temperatures while using air-gas mixture butane

Pressure, MPa	Dew point temperature, °C		
	content of butane in the gas-air mixture (recommended), %		Technical butane
	lower limit (48 %)	upper limit (54 %)	
0.405 (4 atm)	15	20	41
0.304 (3 atm)	17	11	30
0.203 (2 atm)	–3	1	18
0.182 (1.8 atm)	–5	–2	15
0.162 (1.6 atm)	–8	–5	12
0.142 (1.4 atm)	–12	–9	8
0.122 (1.2 atm)	–16	–12	3
0.101 (1.0 atm)	–20	–18	–1

As the table suggests, the use of the air-gas mixture considerably lowers the dew point temperature. Therefore, e.g., the use of technical butane causes condensation of water vapor and the gaseous phase even at minus 1 °C, and when the pressure is on the rise, it covers the range of positive temperatures, which completely excludes the use of technical butane even in the warm season.

The use of a gas-air mixture shifts the line of saturation of the vapor phase with moisture vapor, making it possible to take the vapor phase of butane from an underground tank at positive temperatures and transfer it with a decrease in temperature to negative numbers, bypassing the hydrate formation zone at any recommended level of butane content in the gas-air mixture.

This is central to why the use of gas-air mixtures for gas supply to consumers in a year-round operation mode is preferred.

3. Justification of the tank filling level with technical butane. In compliance with the rules for safe operation of liquefied petroleum gas tanks SP (СП) 62.13330.2011*, the recommendded level of filling with the liquid phase should not exceed 85%. This is due to the high coefficient of volumetric expansion when the gas is heated in the ground tank. In this case, the indicated filling level is presented in the calculation of the gas with a higher coefficient of volumetric expansion, i.e., propane. At the same time, in accordance with the GOST R (ГОСТ Р) 52087–2018, liquefied hydrocarbon gases are produced by about five main grades with different proportions of propane and butane. Thus, for gases based on butane, the tank at maximum heating will not be completely filled, which leads to ineffective use of the LPG tank. It should be noted that the filling level of ground and underground tanks must be assumed in the differentiated form due to different maximum heating temperatures. To calculate the volumetric expansion in surface tanks, the maximum temperature is taken as plus 55 ° C, for underground tanks — plus 40°C [3]. Underground tanks, due to the lower temperature heating from the soil massif, can have a greater degree of filling.

In order to identify the degree of filling the reservoir with liquefied gas with an increased content of butane fractions, the state diagrams will be employed and a study will be conducted [3]. The time of the year has a considerable effect on the degree of filling the container with the liquid phase. Thus the dynamics of the degree of filling the tank with gas must be considered given the year-round use of the LPG tank.

The degree of filling the container is given by the ratio:

$$k_{нр} = \frac{\upsilon_{ж}^{t}}{\upsilon_{ж}^{t\max}}, \tag{5}$$

where $\upsilon_{ж}^{t}$ is the specific volume of liquid at the moment of filling at the corresponding temperature of liquefied gas, m^3/kg; $\upsilon_{ж}^{t\max}$ is the specific volume of liquid at the maximum temperature of LPG heating in the tank, m^3/kg [10].

The specific volume of technical butane in a tank in a liquid state at any temperature is given by the expression:

$$\upsilon_{\text{ж}}^{t} = a\upsilon_{\text{пр}}^{t} + b\upsilon_{\text{б}}^{t}, \quad (6)$$

where a, b is the content of propane and butane in liquefied petroleum gas, % (weight); $\upsilon_{\text{пр}}^{t}$, $\upsilon_{\text{б}}^{t}$ is the specific volume of propane and butane liquid at the corresponding temperature at the moment of filling, m^3/kg.

In order to identify the possible filling level of the tanks, calculations were performed for the ground and underground location of the LPG tanks for the gas composition corresponding to the GOST R (ГОСТ Р) 52087–2018 brand of technical butane. The LPG temperature at the time of filling the tanks varied from minus 10^{0}C to the maximum temperature with the appropriate location of the tanks [10].

The calculation results are shown in the graphs (Fig. 2).

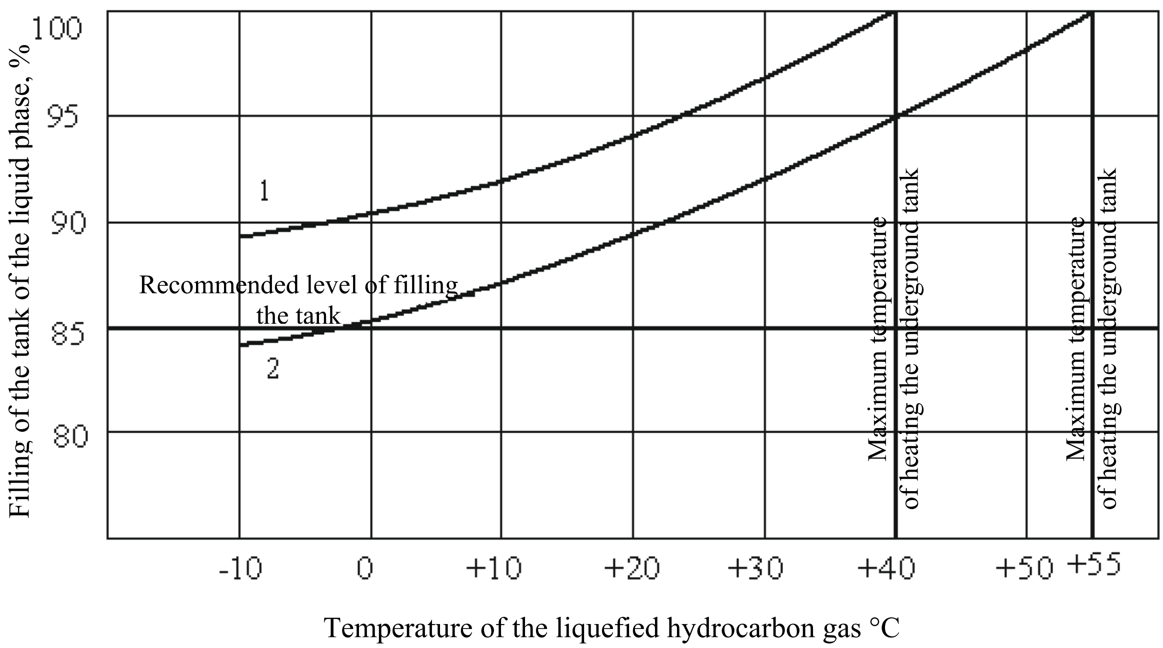

Fig. 2. Justification of the filling level of the tanks:
1 is the underground tank filled with technical butane, 2 is the ground tank filled with technical butane

The analysis of the graphs (Fig. 2) showed that regardless of the composition of the liquefied gas and the initial initial temperature, the filling of the underground tank can be increased compared to the above-ground one. Thus, e.g., for a surface tank, the maximum filling level at a liquefied gas temperature of +20 °C is 89 %, and for an underground tank under similar conditions, 95 % can be adopted. The difference in filling levels at different temperatures is from 4.7 % at a liquefied gas temperature of minus 10 °C to 15 % at a liquefied gas temperature of plus 40 °C.

This will make it possible to accommodate an additional 170 kg to 203 kg of technical butane per container with a volume of $5m^3$ as well as to increase the operating range of the container between neighboring gas stations while using gas fuel for the needs of heating, hot water supply and food preparation up to 3.5 days in the cold season and up to 20 days during the warm period for food preparation and hot water supply with no heating.

Conclusions

1. The composition of the butane-based gas-air mixture for gas supply to consumers should include 48—54 % butane and 52—46 % air, respectively. This composition complies with the condition of interchangeability of combustible gases and is within 5 % deviations in the Wobbe number.
2. The use of gas-air mixtures "butane-air" reduces the temperature of condensation of water vapor by 10 degrees or more in relation to the vapor phase of technical butane, which has a positive impact on gas consumption during the cold season.
3. While filling a liquefied gas tank, it is essential to employ a differentiated approach to the question of the degree of filling the tank with a liquid phase. The composition of the gas and placement of the container were found to have a considerable effect on the degree of filling. Considering the above factors makes it possible to increase the efficiency of gas supply systems while using technical butane providing an increased capacity of containers from 4.7 % at a liquefied gas temperature of minus 10 °C to 15 % at a liquefied gas temperature of plus 40 °C.

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