

Justification of the Use of Technical Butane for Consumers Gas Supply

N N Osipova¹, K V Dyachenko¹

¹ Yury Gagarin Saratov State Technical University, 77 Politekhnicheskaya str., Saratov, Russia

e-mail: osnat75@mail.ru

Abstract. Nowadays people face lots of problems concerning gas supply especially in those regions, where there is a hostile terrain and the population density is rather poor. There are many individual households and plenty of temporary gas supplied objects, which can't be gasified with piped natural gas in the future as a result of economic inopportunity. Self-inclusive gas supply systems based on the tank equipment using propane/butane mix can be a solution of this problem. Application of the commercial butane for gas supply requires a detailed research because during the exploitation the contents of this mix change and the share of butane increases heavily. Therefore, we need to explain our technical decisions which can enhance the whole gas supply system if we use butane.

The peculiarities of the commercial butane application in gas supply are studied; mathematic simulation methods are used; the peculiarities of commercial butane and soil mass heat change are taken into account; the functional solution for gas supply with the usage of commercial butane is suggested.

Recommendations to increase the sufficiency of such gas supply systems are given; the functional solution for gas supply systems using commercial butane is explained and proved, as it provides enough pressure for tank equipment and prevents possible vapour mix condensation in the distribution gas pipelines.

In order to provide enough pressure for tank equipment it's needed to be heat insulated at the access and flange of a tank to avoid heat change with the environment. Commercial butane vapour mixed with the air will let to prevent condensation in the distribution gas pipelines if the restrictions according to Wobbe number variation are taken into account. Functional solutions concerning formation of gas supply system based on commercial butane which can be successfully mixed with air are suggested.

1.Introduction

As practice shows, the systems of autonomous gas supply in most cases are not designed for the use of liquefied gas with a high content of butane fractions. The most significant disadvantages of such gas supply systems are:

- low steam capacity of tanks;
- condensation of the vapor phase in the distribution pipelines;
- difficulties with the plum-filling operations due to the low overpressure of the steam phase in the tanks in the winter.

At the same time, the adaptation of autonomous gas supply systems to based on butane fractions work will improve the efficiency of systems and eliminate the shortcomings, mentioned earlier.

To solve this problem, it is necessary to consider a set of interrelated tasks, such as:

- buildup of overpressure in tanks to ensure stable operation of regasification units;
- the vapor phase condensation prevention in winter in the distribution pipelines;
- efficient gas combustion with a high content of butane in the burners of household gas appliances.



Technical butane is a multicomponent mixture, which according to [1] is characterized by the contents of:

- methane, ethane, ethylene, propane, propylene in total no more than 40%;
- butane and butylene in total more than 60%.

For such mixture, the superpressure in the tanks is formed mainly at positive temperatures for the selection of the steam phase (table 1).

Table 1. Values of the vapor pressure of technical butane

Temperature (K)	Pressure (MPa)	Temperature (K)	Pressure (MPa)
250	0,06	290	0,25
260	0,095	300	0,345
270	0,13	310	0,458
280	0,19	320	0,6

The easiest solution is to install submersible pumps in tanks for the liquid phase of gas in regasification. However, the expediency of using pumps is determined by the range of pressures in the tank from 0.1 MPa to 0.3 MPa. If the pressure in the tank is above 0.3 MPa, the need for pumps doesn't exist anymore, since the excess pressure of the steam phase is enough to move it to the consumer through the pipeline system. Thus, the use of forced feed during the regasification should be made only in winter, which is inefficient for year-round use.

At the same time, storage of liquefied gas in underground tanks is usually carried out at the temperature of the local soil, which in winter isn't below plus 50°C. Thus, if the temperature of the steam phase is not lower than the temperature of the soil in the elements of the gas supply system, an excess pressure of more than 0.1 MPa will be maintained.

For overpressure providing, the elements contacting with the outside air must be covered with thermal insulation. Heat transfer issues are considered in various works of scientists Tudora C, Zainal Z, Kuritcin B N, Usachev A P, Sotnikova O A, Pavlutin M V, Maksimov S A, Chendorain M, Brigton P W, Dezellus O, Durr C A [2-13].

Let us consider the theoretical background for the solution of the problem.

2. Theoretical formulation of the problem.

The specified temperature of the liquefied gas during its storage is taken equal to the temperature of the natural temperature on the axis of the reservoir. The sizes of the tank are represented as the radius of the tank R and the length l.

Allowance which is made in the problem:

- the length of the tank exceeds its diameter;
- the heat transferred from the ground is completely absorbed by the liquid phase of the gas (there is no resistance to heat exchange between the tank wall, the liquid and heat transmission);
- the soil is a homogeneous medium thermal conductivity λ ;
- resistance to heat transfer at the ground-air boundary is taken into account by the additional layer method.

Then the full depth of the reservoir is determined by the formula:

$$h = h_0 + \lambda \left[h_{sn} \lambda_{sn}^{-1} \right] + \alpha_{int}^{-1} \quad , \quad (1)$$

where h_0 is the depth of the ground reservoir, (m); h_{sn} is snow depth, (m); λ_{sn} is snow thermal conductivity, ($W \cdot m^{-2} \cdot K^{-1}$); α_{int} is a heat transfer coefficient into the environment, ($W \cdot m^{-2} \cdot K^{-1}$).

The calculation scheme of the problem is shown in the 1st figure.

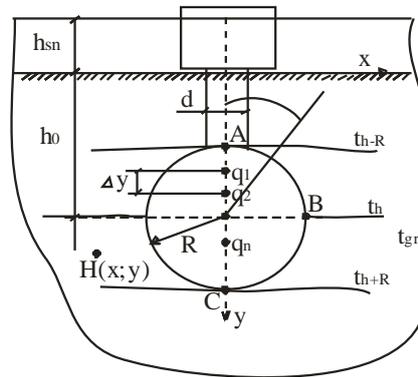


Figure 1. The calculation scheme of the problem

The problem is solved by applying temperature fields method.

Let us distinguish the proper temperature field of the soil, which has a given temperature distribution in depth $t(y)$. The temperature on the cylindrical surface of the tank will have the following magnitude:

- on the upper generatrix t_{h-R} ;
- on the axis of laying t_h ;
- on the lower generatrix t_{h+R} .

The second temperature field is represented by heat sources of some intensity q_1, q_2, \dots, q_n , located on the y axis by some step Δy , as in the 1st figure.

According to F. Forchheimer, the temperature at the point $H(x, y)$ of the heat source i is determined by

$$t_H = \frac{q_i}{2\pi\lambda} \ln \left\{ \frac{x^2 + (h_i + y)^2}{x^2 + (h_i - y)^2} \right\}^{-2}. \quad (2)$$

If there are multiple sources $i=1, 2, \dots, n$ their resultant action can be described by the expression

$$t_H = t_{H1} + t_{H2} + \dots + t_{Hi} + t_{Hn}, \quad (3)$$

$$t_H = \frac{1}{2\pi} \sum_{i=1}^n \frac{q_i}{\lambda} \ln \left\{ \frac{x^2 + (h - R) + i\Delta y + y^2}{x^2 + (h - R) + i\Delta y - y^2} \right\}^{-2}. \quad (4)$$

The choosing an arbitrary point H method of solving the system of equations, located on the cylindrical part of the tank circuit is presented in detail in [5, 6, 14]. When the number of equations $n \rightarrow \infty$, the most accurate solution of the temperature distribution on the contour of the tank is determined. According to Gauss's Theorem, the total heat input to a body with an isothermal surface in the array is numerically equal to the total intensity of the heat sources enclosed within the body. Thus, the resultant value of the heat flow on the tank circuit is zero.

The total effect of heat sources q_1, q_2, \dots, q_n is described by the expression

$$q_1 + q_2 + \dots + q_n = 0. \quad (5)$$

3. Practical part.

To solve this problem, the initial conditions were:

- tank volume $V=5 \text{ m}^3$, radius $R=0,7 \text{ m}$;
- the soil laying depth, $h_0=1.3 \text{ m}$, the snow cover height $h_{sn}=0.1 \text{ m}$;
- the study is carried out on the tank circuit from A to C (Figure 1);
- the ground temperature at the axis of the laying of the tank equals minus $3,6 \text{ }^\circ\text{C}$.

The results of solving the problem are presented in table 2.

Table 2. Values of temperatures on the tank circuit

Angle β ($^{\circ}$)	0	22,5	45	67,5	90	112,5	135	157,5	180
Estimated temperature distribution ($^{\circ}$ C)	-4,97	-5,08	-5,16	-5,05	-4,97	-4,88	-4,78	-4,86	-4,97

As you can see in the table, the calculated temperature of the gas in the tank can be taken as minus 4.97 $^{\circ}$ C, the difference with the soil temperature is 1.37 $^{\circ}$ C. The maximum margin of error in case of such temperature difference is 0.005-0.006 MPa, which does not affect the accurate determination of the operational characteristics of the tank installations.

Heat exchange neck contact with the environment plays a very important role in the process of moving the steam phase.

Let us consider the effect of its heat exchange with the environment on the vapor phase temperature. According to the features of the ground tanks the part of the neck is surrounded by a soil massif, and part of it exchanges heat with the outside air.

Thus the total heat transfer is described by the expression:

-for underground part:

$$Q_{\text{utn}} = \frac{h_{\text{utn}} - h_{\text{sn}} \quad t_{\text{LPG}} - t_{\text{min}} \quad \pi d}{h_{\text{utn}} \lambda^{-1} + h_{\text{sn}} \lambda_{\text{sn}}^{-1} + \alpha_{\text{int}}^{-1}}; \quad (6)$$

- for the aerial part:

$$Q_{\text{otn}} = k_{\text{int}} \pi d [h_{\text{otn}} - h_{\text{sn}}] + 0.25 \pi d^2 (t_{\text{LPG}} - t_{\text{min}}), \quad (7)$$

where h_{utn} is the height of the underground part of the tank neck, (m); h_{otn} is the height of the above-ground part of the tank neck, (m); k_{int} is the heat transfer coefficient of liquefied gas vapors to the outside air, ($\text{W} \cdot \text{m}^{-2} \cdot \text{K}^{-1}$) [15]; d is the diameter of the neck, m; t_{min} is the temperature of the coldest days, ($^{\circ}$ C).

The initial data used to determine the heat loss:

- the height of the underground part of the neck is 0,6 m;
- the height of the above-ground part of the tank neck is 0,1 m;
- the diameter of the neck is 0,4 m;
- the temperature of the coldest days is minus 40 $^{\circ}$ C.

Substitution in formulas (6) and (7) and summation of the results determined heat loss through the neck as 240 W, which determines the decrease in temperature by 7.1 $^{\circ}$ C according to the formula (4). Thus, the temperature in the neck area will be $t = -4.97 + (-7.1) = -12.07$ $^{\circ}$ C. At this temperature, the steam phase pressure is reduced to the minimum value, at which the gas vapor movement for the consumer is provided, the gas supply is stopped.

To prevent the steam phase temperature decrease, it is proposed to cover the neck of the tank and the cap-flange with thermal insulation. Insulation thickness is chosen in accordance with the mathematical model described in [14] and taken 0,15 m.

For the possibility of using butane, it is necessary to ensure the completeness of the mixture combustion in household gas burners. With incomplete fuel combustion, the efficiency of household gas appliances decreases, the formation of carbon monoxide in gasified rooms increases. The adaptation of gas burners requires some design changes in the nozzles for the gas supply to the combustion. Without any constructive intervention this problem is simply solved if we use air mixtures, butane-air.

In this case, the constancy of the Wobbe number is taken as the condition of interchangeability of combustible gases. According to the studies of [16], the Wobbe number is determined by the formula:

$$W = \frac{(Q_h^1)_{\text{pr}} \Psi_{\text{pr}} + (Q_h^1)_{\text{b}} \Psi_{\text{b}}}{[\rho_{\text{pr}} \Psi_{\text{pr}} + \rho_{\text{b}} \Psi_{\text{b}} + \rho_{\text{air}} (1 - \Psi_{\text{pr}} - \Psi_{\text{b}})] \rho_{\text{b}}^{-1} \cdot^{-2}}, \quad (8)$$

where $(Q_h^1)_{pr}$, $(Q_h^1)_b$ are the low heat of propane and butane combustion, ($\text{MJ} \cdot \text{m}^{-3}$); ρ_{pr} ; ρ_b ; ρ_{air} are propane, butane and air density, ($\text{kg} \cdot \text{m}^{-3}$); ψ_{pr} is the volume content of propane and butane in gas-air mixture, (%).

As theoretical and experimental studies show, stable and efficient operation of gas-fired devices is provided with a deviation of the Wobbe number by no more than 5% of the Wobbe number of traditional fuel.

The results of the study are presented in table 3.

Table 3. The contents of the studied gases in the gas-air mixture

Gas brand	The contents of the studied gases in the gas-air mixture, %	
	optimum	recommended
Propane	43	40-47
Butane	34	31-37
Propane-butane	38	35-42

As it can be seen from table 3, the required content for technical butane in the gas-air mixture varies from 31% to 37%. Having a gas mixture with the specified composed air, the standard deviation of the Wobbe number is provided, which will allow to obtain an effective combustion of gas fuel without changing the burner designs of household gas appliances.

To obtain the gas-air mixture, the scheme shown in figure 2 is proposed.

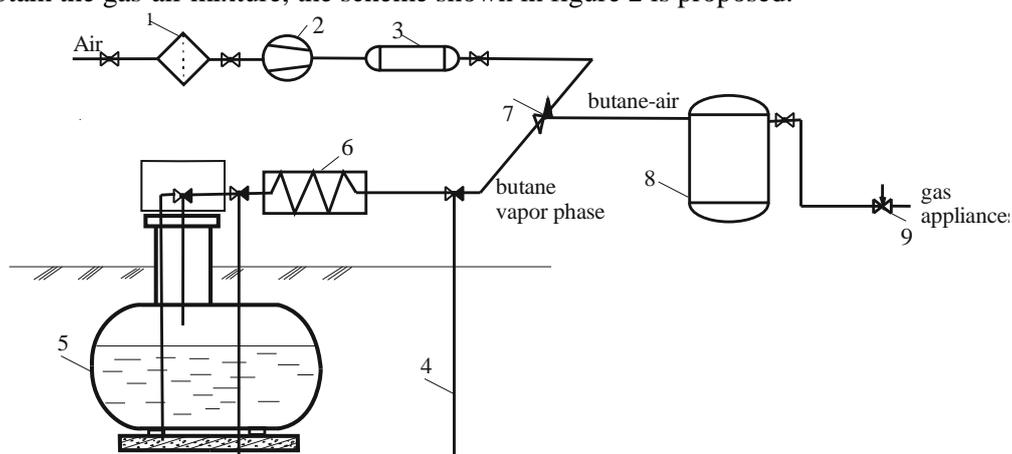


Figure 2. Scheme of air-gas installation: 1 - filter, 2 - compressor, 3 - receiver, 4 – pipe of butane vapor phase, 5 - tank, 6 - regasifier, 7 - mixing valve, 8 - intermediate gas tank, 9 - pressure regulator

The scheme works the following way. The air compressor 2 through the filter 1 is carried to the receiver 3. The liquid phase of the gas from the tank 5 is conveyed to the regasifier 6 to form butane vapor phase. Then, butane vapors from the regasifier 6 and compressed air from the receiver 3 are fed to the mixing valve 7. The formation of the gas-air mixture takes place and its supply to the intermediate gas tank 8 is carried out. From the gas storage tank, the gas-air mixture is reduced in the pressure regulator 9 and fed to the gas-using equipment.

This scheme of obtaining a gas-air mixture allows to use the equipment on the air supply line in the usual way, to ensure the formation of gas-air displacement at low inlet gas pressures in winter, to provide a gas inventory during the periods of maximum consumption.

4. Conclusion

1. To provide overpressure in the tank, it is necessary to apply thermal insulation to the neck and flange of the tank with a thickness of 150 mm to avoid heat exchange with the environment.

2. Technical butane vapors and air mix in the ratio of 31-37% butane, taking into account restrictions on fluctuations in the number of Wobbe, will allow to exclude constructive changes in the burners of the gas-using equipment and the condensation of the steam phase in the consumers' distribution pipelines.

3. For the formation of a gas supply system using technical butane, which usage gives the possibility of mixing gas with air, the scheme of gas-air mixture preparation is proposed.

References

- [1] GOST R 52087-2003 *Liquefied hydrocarbon fuel gases. Specifications*
- [2] Morge R Yerazunis S 1967 *Heat and Mass Transfer during Liquid Evaporation form Porous Material. Heat Transfer with Phase Change* pp 1–7.
- [3] Tudora C Lazar A Monica E 2013 *Possible thermal processes involved in the storage of liquefied petroleum gas TERMO TEHXICA (Stoic a oil-gas university of Ploiesti)* pp 63-6
- [4] Zainal Z Hanapi M Radzuan J Azeman M 2006 *Heat and mass transfer studies in luquefied petroleum gas storage operations Gas Fakulri Kejuruteraau Kimia & Kejuruteraau Surnber Asli Universiti Teknologi (Malaysia)* p 749
- [5] Kuritsyn B N Kuznetsov S S Osipova N N 2011 *Development of a mathematical model of combined regasification of liquefied hydrocarbon gas Bulletin of the SSTU* pp 218-24
- [6] Kuritsyn B Osipova N Maksimov S 2011 *Investigation of heat transfer during storage and re-gasification of liquefied hydrocarbon gas in underground tanks installations Bulletin of Civil Engineers* pp 82-7
- [7] Sotnikova O Kuritsyn B Yushin A 2003 *Modeling of the processes of non-stationary heat exchange of evaporative columns of liquefied gas of mine type with freezing soil Scientific herald of the Voronezh State Architectural and Construction University. Series: Engineering systems of buildings and structures* pp 15-18
- [8] Kuritsyn B Chirchinskaya G and Pavlutin M 2005 *Application of ground heat exchangers in re-gasification systems for liquefied hydrocarbon gases Gas of Russia* 1 p 31
- [9] Spinnler M Winter E Viscanta R 2004 *Studies on high-temperature multilayer thermal insulations Heat and Mass Transfer* pp 1305–12
- [10] Brighton P 1990 *Further Verification of a Theory for Mass and Heat Transfer from Evaporation Pools. Journal Hazardous Material.* pp 215 – 34
- [11] Dezellus O Hodaj F Janaqi S and Eustathopoulos N 2002 *Influence of Evaporation-Condensation in Reactive Spreading. Acta Materialia.* Vol. pp 47 – 40
- [12] Durr C A 1984 *Vapour Recovery from Liquid Hydrocarbon Storage Tank. Proceeding of 10th Gas Technology Conference. New York.* pp 521 – 26
- [13] Usachev A Shurayts A Rulev A and Pavlutin M 2017 *Development of the equation of thermal balance of the horizontal pipe heat exchanger of the ground heat pump Sci and technical problems of improvement and development of gas-energy supply systems: materials of Intern. scientific-practical. Conf. SSTU,* pp 146-51
- [14] Osipova N Pobery A 2017 *Influence of unstable temperature of gaseous mixture of propane-butane on stable operation of autonomous gas supply systems with natural regisification Scientific herald of the Voronezh State Architectural and Construction University. Series: Engineering systems of buildings and structures* pp 69-78
- [15] Bychkova I M, Pobery AA 2018 *To the determination of the coefficient of heat transfer during heat exchange of the neck of an underground reservoir with a surrounding soil massif Resource-energy-efficient technologies in the construction complex: materials of the VI International. scientific-practical. Conf. SSTU,* pp 282-88
- [16] Osipova N Bychkova I 2018 *Application of gas-air mixtures for gas supply facilities Sci and technical problems of improvement and development of gas-energy supply systems: materials of Intern. scientific-practical. Conf. SSTU,* pp 17-19