The Mathematical Descriptions of the Natural Gas Phase State in Nozzle Separator System

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Abstract—**The article presents the mathematical descriptions of liquid –gas phase ratios in the nozzle separator systems at the primary gas treatment unit. When compiling the mathematical descriptions, the following conditions shall be met: double-phase gas passing through the separator unit; unchanged amount of gas at all points of the gas treatment unit; stability of pressure decrease on technological lines; solution of material balance equation of gas and liquid phases; the heat on the walls of the pipes and equipment is taken into account. A formula is given to determine the quantity and the density of the liquid phase separated from the gas phase.**

Keywords—nozzle, separator, liquid-gas flow, equilibrium, temperature, pressure, mathematical recording, gas consumption, humidity, material balance, heat balance

I. INTRODUCTION

Determining the effectiveness of the process of separation of gas is of great importance. The efficiency of the separation process depends on many factors, as well as on the structure of the gas-liquid flow into the separator, the phase ratio, the speed, the amount and temperature of free liquid so on. In this regard, the study of the mathematical description of gas-liquid systems is of practical importance. Currently, the mathematical descriptions of gas-liquid systems are well developed. However, it shall be noted that before entering the gas treatment facilities, the gas passes through the regulating nozzles, where the temperature decreases due to the pressure drop, and the vapor liquid components in the gas phase become condensed. This liquid is separated from gas in collectors and pipes upstream of the separator. At present, this is not taken into account when calculating the separate devices in the process of designing gas treatment units. This is proved by our research to determine the effectiveness of technological equipment operating systems at gas-condensate fields[2].

II. EXPERIMENTAL TECHNIQUE

The article considers the mathematical recording of the liquid-gas ratio in the nozzle separator system in primary gas treatment units for the processing of gas produced from the fields.

The following conditions have been considered for the purpose of mathematical recording:

- the two-phase gas-liquid state of gas passing through the separator unit;
- unchanged amount of gas consumption in all facilities of gas distribution unit;
- Stability of pressure drop along the technological line of gas distribution unit;
- solution of equation of material balance in case of theoretical equilibrium of liquid and gas phase;
- not considering the heat accumulated on the walls of pipes and equipment.

Effective operation of a nozzle separator system depends on gas pressure and temperature drop.

The principle of operation of the separation process is mainly based on the phase change of the gas-condensate mixture depending on the change of system parameters (p, t). As a result of lowering the gas temperature at a constant pressure, some of the heavy hydrocarbons enter the liquid phase. Thus, the condensation rates of the components are inversely proportional to their equilibrium constant.

It is known that the equilibrium constant of the gas mixture and the separate components depends on the pressure [1-3].

When the natural gas flow enters the nozzle separator system, liquid phase contains pentane and hydrocarbons of higher molecular weight $q_{C_{5+}}$), water in gas flow q_{H_2O} , inhibitors (metanol) q_{me} injected to the gas flow for prevention the formation of hydrates.

As it is known, after the natural gas passes throttle, the phase equilibrium changes, resulting in passing some components in the gas phase into the liquid phase, allowing additional fluid separation in the separator [4].

III. EXPERIMENTAL PART

Suppose that the composition of the gas entering the nozzle separator is known, then the molecular density of the 1st hydrocarbon component in the liquid is determined by the following equation:

$$x_i = \frac{x_{0i}}{k_i - (k_i - 1)L} \qquad (1)$$

Where x_i -is the molar portion of component i in the liquid phase; x_{0i} — molar portion of component i before gas parameter values change; k_i- equilibrium constant of component i in case of equilibrium; L- molar portion of the fluid phase.

Equilibrium coefficient k_i is defined by the following expression :

$$k_i = f(p_s, t_s, x_1, x_2, \dots x_n) \qquad (2)$$

Here, p_s, t_s - are the values of pressure and temperature in the separator.

Then, the molar density of the component i of hydrocarbons in the liquid phase will be as follows:

$$q_{im} = x_i GL = \frac{x_{0i} GL}{k_i - (k_i - 1)L} \qquad (3)$$

Here, G is the mass of liquid hydrocarbons.

The expression (3) will be written for the density of hydrocarbon components

$$q_m = \sum_{i=1}^{n} q_{im} \qquad (4)$$

The expressions (3) and (4) are for the weight density

$$q_q = \sum_{i=1}^{n} q_{im} M_i \qquad (5)$$

Very few of the hydrocarbon components of the gas contained in the water as a component of gas do not damage its total volume V_1, and this is not considered in the calculations. However, since some of the hydrocarbon components in the gas have passed into the liquid phase, the amount of gas V_2 entering the separator is calculated by the following formula:

Here M_i — is the molar mass of i component.

$$V_2 = V_1 - \Delta V \qquad (6)$$

Here, ΔV is the volume of hydrocarbons that pass from the total gas volume to the liquid phase, and is defined by the following expression:

$$\Delta V = N_A \sum_{i=1}^{n} q_{im} \qquad (7)$$

Here, N_A - is Avogadro number.

q'_2–the density in the unit volume of hydrocarbons that pass from the first volume of gas to the V_i fluid phase is calculated as follows:

$$q'_2 = \frac{\sum_{i=1}^{n} q_{im}}{V_1} \qquad (8)$$

The density q''_2 of separated liquid phase hydrocarbons is determined by the following expression:

$$q''_2 = \frac{\sum_{i=1}^{n} q_{im}}{V_2} \qquad (9)$$

In addition to liquid hydrocarbons, which are separated from gas, the composition of the total liquid also contains methanol solution injected into the gas to prevent water and hydration. The moisture content in natural gas is expressed in the following equation:

$$W = W_1 - W_2 = \frac{A}{p_1} + B_1 - \frac{A}{p_2} + B_2 \qquad (10)$$

Here W - is the amount of moisture released from natural gas; W_1, W_2- gas humidity at the input and output of the separator; A -moisture content in ideal gas; B_1, B_2- are empirical ratios and are derived from reference books; p_1, p_2 - is the pressure of the gas at the input and output of the separator, respectively.

Then the moisture content in the liquid phase in natural gas at the separator input will be determined by the following formula:

$$W' = \frac{W_1}{W_2} \qquad (11)$$

The amount of moisture content in the liquid phase separated out of separators will be W''

$$W'' = \frac{W}{W_2} \qquad (12)$$

If the density of hydrocarbons in the liquid phase separated out of total gas is equal to the density of hydrocarbons in the liquid phase separated out of separators $q_{C_{5+}} = q'_{C_{5+}}$, then the total ratio of fluid at the input of separator is calculated by the following expression:

$$q_{sg} = \frac{q_m}{V_1} + \frac{W_1}{V_2} + \frac{W C_2}{C_1 - C_2} \qquad (13)$$

The total density of liquid separated out of separator during the unit time will be:

$$q_{sm} = \frac{q_m}{V_2} + \frac{W}{V_2} + \frac{WC_2}{C_1 - C_2} \qquad (14)$$

Part of the fluid released in the nozzle separator system is transported to the main gas pipeline. The density of the liquid phase in the gas flow   at the output of the separator is as follows:

$$q_{s\varsigma} = q_{sm} k_{ef} \qquad (15)$$

Here, k_{ef} - the efficiency of the separator depends on the size of the equipment in the nozzle separator system:

for separators with the horizontal tangential nozzle

$$k_{ef} = f\left(\frac{I_s}{D_s}\right) \qquad (16)$$

for vertical gravity separators

$$k_{ef} = f(h_s) \qquad (17)$$

Here, I_s, D_s, h_s - are the separator's length, diameter, and height, respectively.

Using the expressions (14) and (15), we can calculate the density of liquid $dq_m/d\tau_s$ separated from natural gas.

$$\frac{dq_m}{d\tau_s} = \frac{dq_{sm}}{d\tau_s} - \frac{dq_{AG}}{d\tau_s} \qquad (18)$$

Here, q_m - is the density of the liquid phase separated from natural gas.

The expression $dq_m/d\tau_s -$ - characterizes the quality of the natural gas processing in the nozzle separator unit and at the same time shows the degree of dependence rate of liquid phase absorption on the phases relation.

Considering the above, the material balance of the nozzle separator system can be written as follows.

The amount of   fluid in the total gas V_1 injected into the unit during the unit time is as follows:

$$G_1 = V_1 \frac{dq_{mq}}{d\tau_s} \qquad (19)$$

At this moment, the amount of fluid transported by the separator gas and flowing into the main gas pipeline will be

$$G_2 = V_2 \frac{dq_{mq}}{d\tau_s} \qquad (20)$$

The amount of separated fluid will be

$$G_3 = V_3 \frac{dq_m}{d\tau_s} \qquad (21)$$

Then the material balance of the separators according to the liquids is as follows:

$$G_3 = G_1 - G_2 \qquad (22)$$

Thus, expressions (18) and (22) together reflect the general mathematical description of the nozzle separator unit.

IV. CONCLUSION

1.Mathematical notation of accumulation of fluid and liquid-gas phases correlation of hydrocarbon gas is provided in choke-separator systems.

 2.Double-phase hydrocarbon gases passing through separators, stability of pressure drop along process lines, solution to equation of material balance of gas and liquid phase in equilibrium, and the heat accumulated on the walls of pipelines and units have been taken into account.

3.A formula is provided for determining the quantity and concentration of the liquid phase in the gas phase in the considered condition.

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