Petroleum & Coal
ISSN 1337-7027

Available online at www.vurup.sk/petroleum-coal
Petroleum & Coal 57(4) 328-335, 2015

MODELING OF LIQUID SEPARATORS WORK IN GAS AND GAS CONDENSATE PREPARATION UNIT IN LOW-TEMPERATURE SEPARATION TECHNOLOGY

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May 15 8, 2015; Accepted June 26, 2015

Abstract

The urgency of the discussed issue is caused by the need to increase the quality of the prepared gas and to increase the competence of engineering staff of low-temperature gas separation plant using computer modeling systems. The main aim of the study: to create software package that simulates the changing technological performance of low-temperature separation unit in real time study the effect of single unit work on the system as a whole. The methods used in the study: chemical processes mathematical modeling method. The results: a program of three-phase separator calculating - one of the most important elements of low-temperature separation - considering the influence of the control parameters of the system (control valves for gas and liquid), the geometric dimensions of the unit and generally accepted principles of the separation of the three-phase mixture (Stokes' law, the laws of the phase equilibrium and so on) was created. Developed module allows to create interactive software package that simulates the work of low-temperature separation in real time.

Keywords: Gas, gas condensate, low-temperature separation, liquid separator, mathematical model, prediction.

1. Introduction

In today's world there is a great demand for energy, including environmentally friendly forms of energy and fuel. Natural gas and gas condensate produced in almost the entire northern part of our country corresponds to the highest environmental standards. Due to this these types of fossil fuels are increasingly in demand on the market of energy, accounting for tangible competitive oil.

When operating the existing commercial of gas and gas condensate production plants (GPP) technological problems are constantly emerging arising. In the first place these problems are connected with depletion of reserves of gas condensate field, the change in the component composition of mixture, requirements to quality of commercial products, etc. This determines the need for continuous analysis of basic technological parameters and overall production efficiency. Currently, these problems are solved with use of experimental and statistical approach of physical modeling method. However, the most effective solution to this problem is the use of simulation technology systems based on the physico-chemical basis of processes and mathematical modeling method based on the accumulated experience of GPP operation [1-2].

Now are developed and widely used for calculation and prediction of various information - modeling systems, such as, HYSYS, HYSIM, PRO-2, PROSYM, GIBBS, «GazKondNeft" and others, which are universal and are used mainly during the project calculations at arrangement and modernization of gas fields.

In general, these programs include means of static simulation of the main processes of hydrocarbons field treatment (gas and liquid separation, flash evaporation and condensation, throttling, heat exchange, rectification and others) based on phase transformations, as well as means for calculating of geometric dimensions and structural characteristics of main devices [3-9].

The main disadvantage of these modeling systems is the lack of installation performance parameters change consideration in real time.

To solve the problems of existing production efficiency increase, more cost-effective and practically acceptable is application of specialized information-modeling systems (IMS), which can adapt to the processes under study and reflect the specific nature of gases and gas condensates preparation technology.

This raises the need to apply computer technological system of commercial gas and gas condensate, which allows a qualitatively new level to analyze technological solutions and key performance indicators, to forecast commercial gas and gas condensate plant operation, as well as to solve the problems of the existing processes and technology reconstruction designing [10].

Thus, improving the quality of gas preparation is an urgent task that can be solved with use of mathematical models of physical and chemical processes occurring in gas treatment devices.

Therefore, the aim was to create a software package that simulates the change in technological performance of low-temperature separation in real time to investigate the influence of operating modes separate unit to technological system as a whole. In particular, this article is devoted to modeling work liquid separators installation of gas and gas condensate in the low-temperature separation technology.

2. Experimental

2.1 Methodology of computational experiment

One of the most common methods of gas and gas condensate in the Russian Federation is a low-temperature separation (fig. 1). It has established itself as a reliable and relatively simple technology.

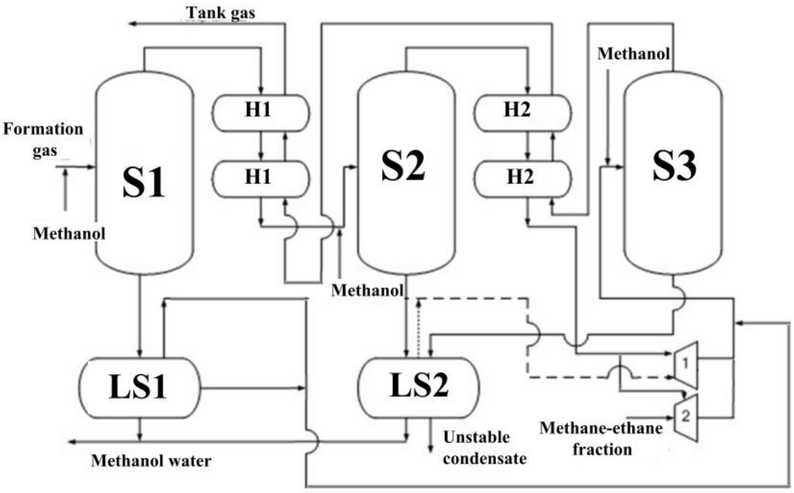

Figure 1 Technological scheme of gas condensate preparation: S1, S2, S3 - separators; LS1, LS2 - liquid separators; H1, H2 - heat exchangers

In the three-step gas and gas condensate preparation process (fig. 1) one of the main elements is three-phase liquid separator for separating mixture of gas [11-13], unstable gas condensate and methanol water. Scheme of first stage of gas condensate separation with liquid level and pressure in apparatus controlling valves is the shown in fig. 2.

The efficiency of liquid separator depends on the internal device, which may be different. It can be devices with simple overflow partitions or with additional pockets of selection of condensate, have inside nozzle eliminators, and other internals. Type of device to be selected depends on many factors (incoming flow and product properties etc.). For simplification of a task and coverage of all possible designs of devices additional parameters of mathematical model are used - ablation coefficients which allow to approach results of calculations to indicators of operation of concrete devices. In this case the device with a simple weir, baffle and demister nozzle is accepted (fig. 3).

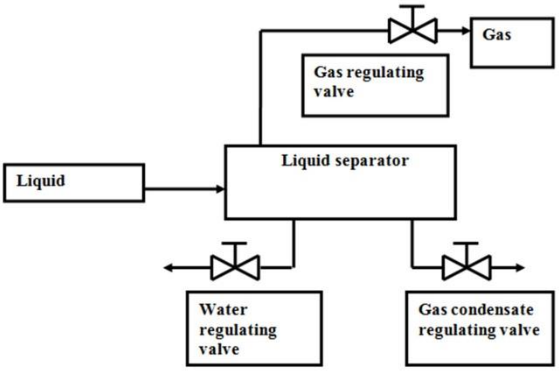

Fig. 2 Scheme of first stage of gas condensate separation with liquid level and pressure in apparatus controlling valves

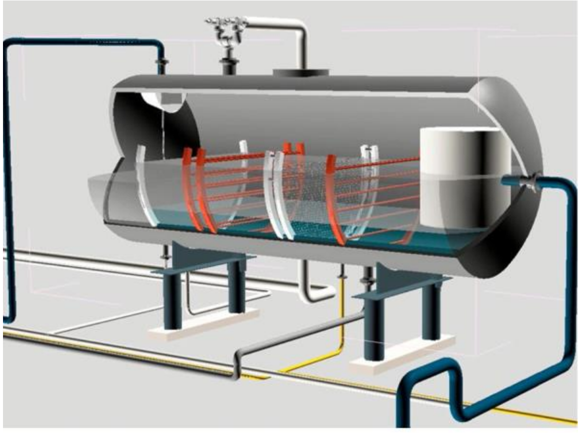

Figure 3 Adopted design of three-phase separator

The initial data for of output streams (gas, gas condensate and methanol water). Mathematical model are characteristics of input stream (tab. 1), process parameters, and characteristics

Table 1 Initial data for creation of mathematical model and calculation of indicators of three-phase separator performance

Parameter	Unit	Component	Value
Temperature	^{o}C	-	15,00
Pressure	MPa	-	5,26
The fluid inlet	t/day	-	233,50
Inlet fluid composition	% mas.	CO_2	0,35
		N_2	0,28
		CH_4	5,38
		C_2H_6	4,72
		C_3H_8	9,07
		iC_4H_{10}	5,14
		C_4H_{10}	8,27
		iC_5H_{12}	5,04
		C_5H_{12}	5,81
		C_{6+}	47,98
		H_2O	7,40
		CH_3OH	0,57
Three-phase separator value	m^3	-	25,00

While simulation of separation processes in three-phase separator the following assumptions were taken into account:

1) There is phase equilibrium between liquid and gas, which can be described by Raoul-Dalton law:

$$y_i = K_i \cdot x_i \tag{1}$$

2) The laminar fluid flow is considered, which allows to calculate the speed of droplets surfacing and precipitation (condensate in water and water in the condensate, deposition of droplets of condensate and water in the gas phase) by Stokes law:

$$U_p = \frac{g \cdot d^2 \cdot (\rho_c - \rho_d)}{18 \cdot \mu_c \cdot \lambda} \tag{2}$$

To take into account different design features of three-phase separators used in different technologies of gas condensate preparation the ablation factors (condensate and gas with water, water and gas with condensate, condensate and water with gas), defined by the following expressions are used (tab. 2) [14].

Table 2 Equations for ablation factors calculation

Ablation factor	Equation
Condensate with gas	$K_{\lg} = \frac{Q_{\lg}}{Q_g};$
Gas with condensate	$K_{gl} = \frac{Q_{gl}}{Q_l};$
Water with gas	$K_{vg} = \frac{Q_{vg}}{Q_g};$
Gas with water	$K_{gv} = \frac{Q_{gv}}{Q_v};$
Condensate with water	$K_{lv} = \frac{Q_{lv}}{Q_v};$
Water with condensate	$K_{vl} = \frac{Q_{vl}}{Q_l};$

The material balance equation of three-phase separator can be represented as:

$$F = W + L + G \tag{3}$$

When modeling the control valve (its capacity) the following equation was used:

$$Q = K_V \sqrt{\Delta P \cdot \frac{1000}{\rho}} \tag{4}$$

Thus

$$\alpha_1 \cdot K_{V1} \cdot \sqrt{\Delta P_1 \cdot \frac{1000}{\rho_1}} = \alpha_2 \cdot K_{V2} \cdot \sqrt{\Delta P_2 \cdot \frac{1000}{\rho_2}} + \alpha_3 \cdot K_{V3} \cdot \sqrt{\Delta P_3 \cdot \frac{1000}{\rho_3}} + \alpha_4 \cdot K_{V4} \cdot \sqrt{\Delta P_4 \cdot \frac{1000}{\rho_4}} + \delta; \tag{5}$$

Given the accepted assumptions mathematical model of liquid separator was created. It is based on the principles of three-phase systems separation, is implemented as a separate calculation module, capable of working both independently and integrated into software systems, designed to calculate the chemical processes of separation of three-phase mixtures – gas, condensate and methanol water.

The developed mathematical model takes physical and chemical laws of separation process in the apparatus into account and can be used to calculate the change in parameters of any three phase separator in real time, allowing to talk about the interactivity of the module with the appropriate implementation of graphical user interface.

3. Results and discussion

For testing the created mathematical model studies on the influence of pressure on the mixture separation efficiency were carried out. The pressure regulation was achieved by changing of control parameters (gas and liquid valve opening degree regulating). As initial data parameters listed in tab. 1 were used.

Carried out calculations have shown that reducing of gas valve opening degree from 33% to 10% (fig. 4) leads to increase of pressure in separator from 5.26 MPa to 5.36 MPa. This is due primarily to reduced capacity for gas valve (cross-sectional area decreases), and consequently, there is a part of the separated gas in the accumulation unit.

Gas flow is first reduced from 54.3 ton/day to 18.25 tons/day, followed by increasing of pressure in the apparatus, and hence the pressure difference of gas at the inlet and outlet of the valve is increased to 21.96 tons/day (fig. 5). Thus by increasing the pressure and the pressure difference of condensate at inlet and outlet of the valve flow rate of condensate also increases from 164 to 218 tons/day (fig. 6).

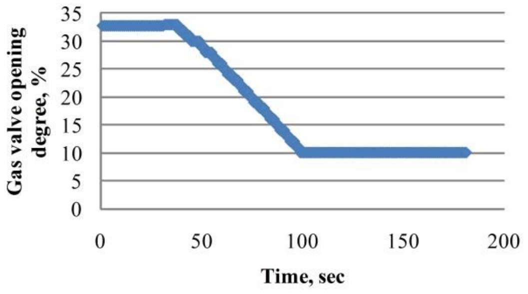

Fig. 4 Dependence of gas valve opening degree on time

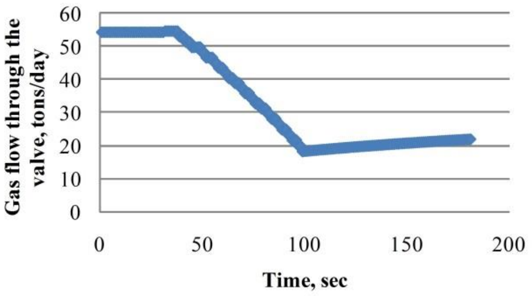

Fig. 5 Dependence of gas flow through valve on time

The consequence of increasing of flow rate of condensate from apparatus is reduction of its level in the separator from 50.7% to 41.6% (fig. 7).

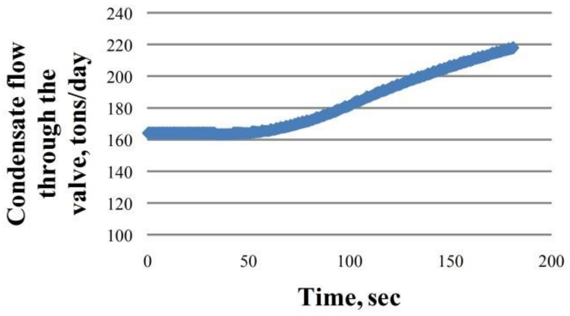

Figure 6. Dependence of condensate flow through valve on time

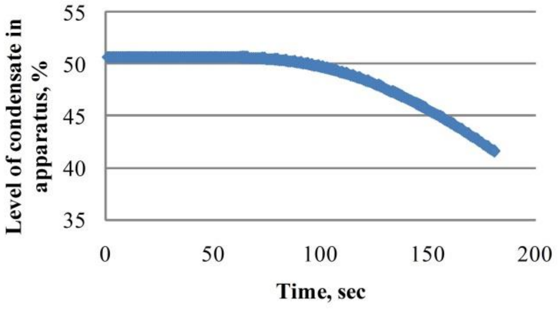

Figure 7. Dependence of condensate level in apparatus on time

The calculated results are in qualitative agreement with regularities observed in real industrial devices when controlling parameter change, as the developed three-phase separator mathematical model is based on physical and chemical laws of separation processes [15-23].

For example, when closing the control valve for gas there will actually be an increase in partial pressure due to accumulation of separated gas in apparatus. This in turn would facilitate the shift of phase equilibrium, and the process of separating of gas from liquid the will be less intensive. In order to improve the calculations adequacy for a particular apparatus, the inverse problem of finding ablation coefficients on the basis of known industrial or experimental data should be solved [24-32].

Thus, the tool is designed for research of the effect of control parameters on three-phase separator work with ability to track operation data in real time. It allows to study the transition processes resulting from the indignation transferred to system, in particular, at valve opening degree change for a certain period of time to obtain the estimated values of three-phase separator operation parameters. In addition, the developed model can be used to determine the control parameters of the automation system three-phase separator to achieve the necessary technological parameters of the device with the ability to assess the time required to reach a new steady-state operation. In addition, the developed model can be used to determine the control parameters of three-phase separator automation system to achieve the necessary technological parameters of the device with the ability to evaluate time required to reach a new steady-state operation.

4. Conclusions

1. The developed mathematical model of gas separation, based on the physical and chemical laws of the three-phase mixture (condensate, methanol water and gas) separation

processes is the basis for creation of low-temperature separation simulator, the main unit of technological scheme of which is a three-phase separator.

2. The developed mathematical model allows determining the effect of control parameters on technological performance of low-temperature separation in real time, predicting transient processes in devices (three-phase separators) and minimizing the risks of emergency situations.
3. On the basis of developed mathematical model creation of simulator for training of technical staff of low-temperature separation unit is possible.

List of symbols

K_i	phase equilibrium constant;
x_i	concentration of *i*-th component in liquid phase;
y_i	concentration of *i*-th component in gas phase;
U_p	rate of drops ascent or subsidence, m/sec;
g	acceleration of gravity (9,81 m/sec^2);
d	droplets diameter, m;
ρ_c	density of continuous medium, kg/m^3;
ρ_d	density of disperse phase, kg/m^3;
μ_c	viscosity of continuous medium, Pa·sec;
Q_g	gas flow from the apparatus at equilibrium concentrations of components in vapor and liquid phase, kg/h;
Q_{lg}	condensate flow carried from apparatus with gas, kg/h;
Q_l	condensate flow from the apparatus at equilibrium concentrations of components in vapor and liquid phase, kg/h;
Q_{gl}	gas flow carried from apparatus with condensate, kg/h;
Q_{vg}	water flow carried from apparatus with gas, kg/h;
Q_v	water flow from the apparatus at equilibrium concentrations of components in vapor and liquid phase, kg/h;
Q_{gv}	gas flow carried from apparatus with water, kg/h;
Q_{lv}	condensate flow carried from apparatus with water, kg/h;
Q_{vl}	water flow carried from apparatus with condensate, kg/h;
F	feed mixture flow rate, m^3/sec;
G	vapor flow rate, m^3/sec;
L	liquid phase (condensate) flow rate, m^3/sec;
W	liquid phase (water) flow rate, m^3/sec;
K_v	characteristic valve capacity (conventional volumetric flow rate of water through the fully open valve at a differential pressure of 0.1 MPa under normal conditions), m^3/sec;
ρ	density of liquid, kg/m^3;
Q	flow rate of liquid or gas, m^3/sec;
K_{v1}, K_{v2}, K_{v3}, K_{v4}	throughput characteristics of valves on the inlet line, on the water output line, on the condensate output line, on the gas output line of three phase separator respectively, m^3/sec;
ρ_1, ρ_2, ρ_3, ρ_4,	density of mixture, water, condensate and gas respectively, kg/m^3;
ΔP_1, ΔP_2, ΔP_3, ΔP_4,	pressure drop across the fully open valve on the water output line, on the condensate output line, on the gas output line of three phase separator respectively, bar;
a_1, a_2, a_3, a_4	valve opening degree on the condensate output line, on the gas output line of three phase separator respectively, %.
ΔP	pressure drop across the fully open valve, bar.
δ	value which is responsible for accumulation or overrun in device due to inertia and system unstationarity, m^3/sec;
P	pressure in apparatus, Pa;
N_g	amount of gas in apparatus, mole;
$V_{ap}^{'}$	volume of gas in apparatus, m^3;

V_{ap}	volume of liquid in apparatus, m^3;
L_f	level of liquid in apparatus, %.
t	process time, sec.

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