Petroleum & Coal
ISSN 1337-7027

Available online at www.vurup.sk/petroleum-coal
Petroleum & Coal 56(2) 182-187, 2014

MODES OF GAS AND GAS CONDENSATE PREPARATION UNIT IN LOW-TEMPERATURE SEPARATION TECHNOLOGY MODELING

Igor M. Dolganov, Michael O. Pisarev, Elena N. Ivashkina, Irena O. Dolganova*

Institute of Natural Resources, Tomsk Polytechnic University, Russia

Received February 7, 2014, Accepted May 11, 2014

Abstract

On the basis of mathematical modeling method and physical-chemical nature of gas from liquid hydrocarbons and water at low temperatures due to the Joule-Thompson effect separation, a mathematical model of separator was created. This model allows tracing changes in technological parameters of low temperature separation process in real time. It is implemented as a software product that allows one to study transient processes occurring in apparatus of chemical technological system and also provides an opportunity to examine the effect of control parameters on technological parameters of the system. It was shown that the opening degree of gas valve is gradually reduced (from 28% to 10% in 40 seconds) while pressure in system increases from 7,082 MPa up to 7,633 MPa. On the basis of developed mathematical model a simulator for training of technical personnel of low-temperature separation can be created.

Keywords: Hydrocarbon gas; gas condensate; mathematical modeling; industrial facilities; real-time mode.

1. Introduction

In the world the share of use of hydrocarbon gas as a fuel and raw materials for petrochemical synthesis is constantly growing. This is due to, primarily, its relatively low cost as well as high environmental performance. However, there is a problem in the annual burning of a huge amount of associated gas at oil fields, causing significant damage to the economy.

Low-temperature separation technology (LTS) is one of the most effective ways to prepare the gas to further its use as a fuel and raw material for chemical industry. Review of the modern periodic and patent literature showed that the technology LTS remains today one of the most economically viable ways of gas field treatment [1]. The technological scheme is simple. However, to maintain the required depth of gas drying it is necessary to maintain the required pressure and temperature conditions that must be corrected with a decrease in reservoir pressure.

At present there are a lot of computer modeling systems capable of determining the optimal technological parameters of LTS unit depending on the requirements to the product quality. However, none of them is able to display real-time transient processes in devices when control parameters (valves position, coolant flow, etc.) are changing. Under transient processes in this case we understand developing in time changes of LTS unit operating parameters, when passing from one steady state (corresponding to the previous values of control parameters) to another (corresponding to the new values of control parameters).

In addition, before date there were no modeling systems suitable for predicting modes of devices of LTS technological scheme, considering transient processes with changes in raw materials composition supplied to the installation of hydrocarbons and thermobaric parameters of its work.

An important task in design and management of installation is minimizing of transient processes time and smoothing of possible deviations of devices when operating modes differ from the ideal line.

Thus, the aim of the studies was to create non-stationary mathematical models of devices included in the LTS flow diagram, capable of simulating the real industrial object and displaying the transient physical and chemical processes, depending on the process control parameters and time.

To achieve this goal it was necessary to solve a number of problems:

1. to determine the structure of LTS process technological scheme and to determine the number of objects that require mathematical model creation;
2. to justify the choice of methods of physical properties (viscosity, density, etc.) of the components included in the mixture at the entrance to apparatus (separators, heat exchangers, etc.) calculation;
3. to justify the choice of methods of thermodynamic parameters of the processes occurring in LTS plant apparatus (enthalpy, constant of phase equilibrium, saturated vapor pressure, etc.) calculation;
4. to build mathematical models of devices based on physical and chemical regularities of processes occurring in LTS plant apparatus; these models should take the changes in composition of raw materials, fuel input and output streams of apparatus, temperature and pressure into account;
5. to identify and take factors of processes non-stationary caused by changes in temperature and pressure conditions, raw materials phase and hydrocarbon composition in into account,;
6. to define the principle of devices technological parameters automatic regulation (flow, pressure, liquid level, etc.);
7. to perform a software implementation of developed mathematical models using the modular principle of simulation system creation;
8. to check the software-based mathematical models adequacy in displaying of physical and chemical processes occurring in the apparatus of LTS technological scheme.

2. Theory and experiment

LTS technological scheme includes three separation stages (fig. 1).

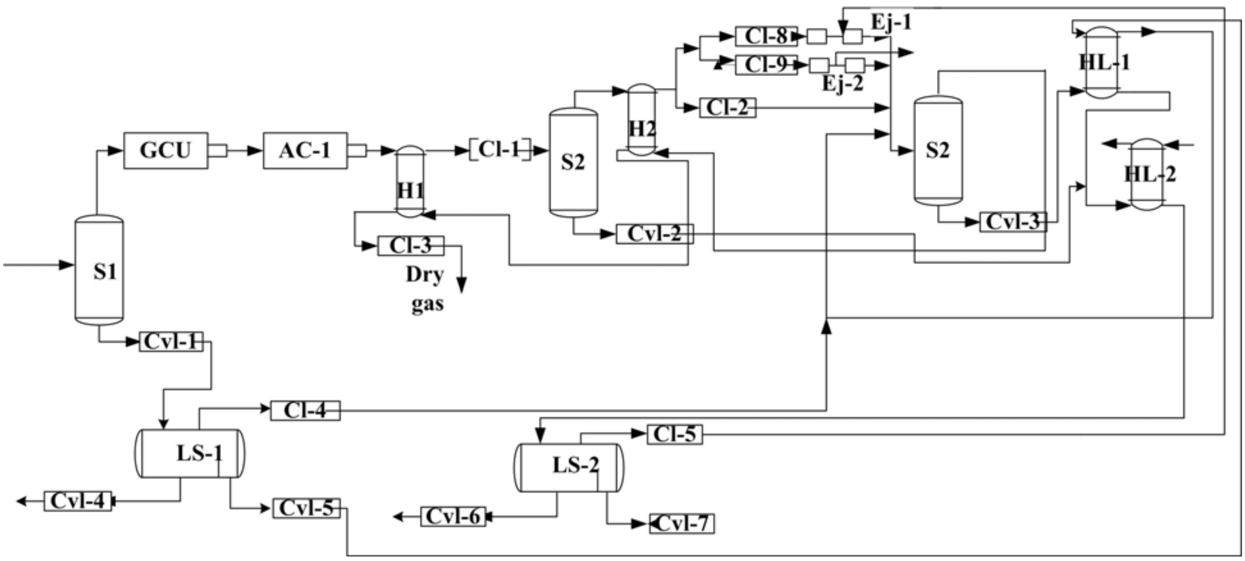

Figure 1. Technological scheme of gas treatment by low-temperature separation: S-1, S-2, S-3 - vertical gas separators; H1, H2 - heat exchangers such as "gas-gas", TL-1, TL-2 - type heat exchangers "liquid-liquid"; LS-1, LS-2 - three-phase separators - liquid separators; Cv-1, Cv-2, Cv-3, Cv-4, Cv-5 - control valves for gas; Cvl-1, Cvl-2, Cvl-3, Cvl-4, Cvl-5, Cvl-6, Cvl-7 – control valves for liquid; GCU - gas compressor unit - gas turbine; AC-1 - air cooler; Ej-1, Ej-2 - gas ejectors.

For creating models of separators and liquid separators the laws of phase equilibrium calculation (Shilov and Teka-Style methods) and tabulated values of phase equilibrium constants were apply [2-3]. To determine the valves capacity the equation of medium flow through the valve dependence on pressure difference, medium density, consumption ratios and opening degree was used. In addition we calculated the hydrodynamic resistance of pipelines and apparatus using Bernoulli's equation, Darcy-Weisbach formula, etc. [4].

When modeling the gas separation it is assumed that during the separation the phase equilibrium state is achieved. It is such a condition in which rates of transition of particles from gas into liquid phase and vice versa are equal.

Separator material balance equation can be written as:

$$F = L + G \quad (1)$$

Or

$$F \cdot u_i = G \cdot y_i + L \cdot x_i \quad (2)$$

Accepted proportion of distillate *e* can be calculated as

$$e = \frac{G}{F} \quad (3)$$

In the calculation of mass transfer processes we generally use laws by which one can calculate the separated phase compositions. Modeling low-temperature separation process is based on the description of the system using the laws of Dalton, Raoul and Konovalov [3].

Thus, according to Raoul-Dalton law,:

$$y_i = K_i \cdot x_i \quad (4)$$

By joint solution of equations (1) - (4) we obtain:

$$x_i = \frac{u_i}{1 + e\left(K_i - 1\right)} \quad (5)$$

Equation (5) contains two unknown parameters: mass proportions of components in the liquid phase (x_i) proportion of distillate *e*. To solve the equation (5) we used the method of iterations. Thus on each iteration following condition should be satisfied: $\sum x_i = 1$.

Having received the values x_i we can calculate the composition of gas phase, i.e. to determine y_i [2].

However, for industrial devices, equation (5) cannot be used, since in real systems equilibrium concentrations of components in liquid and vapor phases are not reached.

Furthermore, due to the presence in the gas phase of liquid hydrocarbons in the form of droplets of small size, their precipitation process is complicated, so separation of liquid and vapor phases in the separator is not clear.

To account factors of liquid carry with gas and the gas carry with liquid, in models of separators coefficients reflecting this phenomenon are used.

Coefficient of liquid carry with gas:

$$K_l = \frac{Q_{\lg}}{Q_g}; \quad (6)$$

Coefficient of gas carry with liquid:

$$K_g = \frac{Q_{gl}}{Q_l}; \quad (7)$$

When modeling the regulating valve (its capacity) the following equation was applied [5]:

$$G = K_V \sqrt{\Delta P \cdot \frac{1000}{\rho}}; \quad (8)$$

The Peng-Robinson equation for determining the density of gases at separation conditions [3] was also been used.

When modeling of heat transfer equipment was used the basic equation of heat transfer, while the heat capacities of substances were described polynomial dependence on temperature.

Mathematical model of gas ejector was created with taking the compression ratio for passive gas flow and throttling process with effect Joule-Thompson [6] into account.

Temperature change with a small change of pressure (differential effect) is defined by derivative:

$$\mu_{JT} = \left(\frac{\partial T}{\partial P}\right)_H . \quad (9)$$

The main devices in LTS technology are gas separators.

Thus, the mathematical description of entire technological system which represents a comprehensive gas treatment unit, includes a description of separation, heat exchange, compression, throttling processes occurring in respective devices.

3. Results and discussion

The most important step of modeling the complex processes occurring in LTS unit apparatus is comparison of simulation results with real industrial data.

So, to test created mathematical models were used data from an industrial LTS installation of one of the fields in Western Siberia. Schematic diagram of the gas first separation stage with valves of liquid level and pressure in apparatus control is shown in fig. 2.

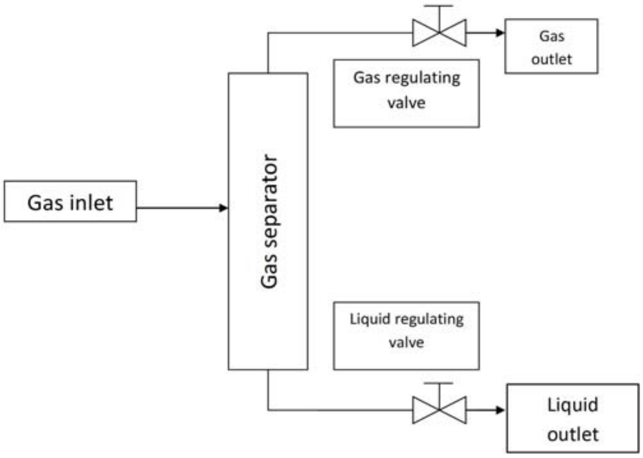

Figure 2. Schematic diagram of the gas first separation stage with valves of liquid level and pressure in apparatus control

The gas composition at the inlet to the first separator separation stage is shown in **tab. 1.**

Table 1 The gas composition at the inlet to the first separator separation stage

Component	Mass concentration,% by weight.	Component	Mass concentration,% by
CO_2	0,539	C_4H_{10}	1,016
N_2	2,645	iC_5H_{12}	0,409
CH_4	84,809	C_5H_{12}	0,419
C_2H_6	3,809	C_{6+}	2,705
C_3H_8	2,526	H_2O	0,317
$i\text{-}C_4H_{10}$	0,776	CH_3OH	0,024

The inlet gas temperature is equal to 15 ° C, the pressure is 7,082 MPa. The gas flow at the inlet to apparatus is 2070 t/day.

With use of developed mathematical models the changes of technological parameters of gas separator were calculated, namely a pressure, a gas flow inlet and outlet, the liquid flow at the outlet, liquid level.

Calculations showed that in steady state (at constant pressure of 7,082 MPa, temperature of 15 °C, flow rate of gas at the inlet to apparatus of 2070 t/day, gas valve opening degree of 28%, liquid valve opening degree of 25%) separator performance remains unchanged (the gas flow from separator is 2004 t/day, flow rate of fluid from apparatus is 66 t/day), but when opening degree of control valves changes (both gas and liquid outlets) the transition from one steady-state of the separator to another begins.

Developed algorithm of mathematical description the system allows to simulate real process of opening degree of control valves change. In particular, any change in the opening degree does not occur instantaneously, and for example, when changing degree of gas valve withdrawal the pressure change occurs in the device, and it is caused by changing the speed of outflow from gas separator.

Separator performance indicators is calculated over time, so that it is possible to consider the changes in parameters and analyze non-stationary (transient) modes.

Thus, fig. 3 shows calculation results of gas control valve opening degree over time (manual control). It is seen that gas valve opening degree is gradually reduced (from 28% to 10% in 40 seconds). The pressure in the system increases from 7,082 MPa to 7,633 MPa (fig. 4).

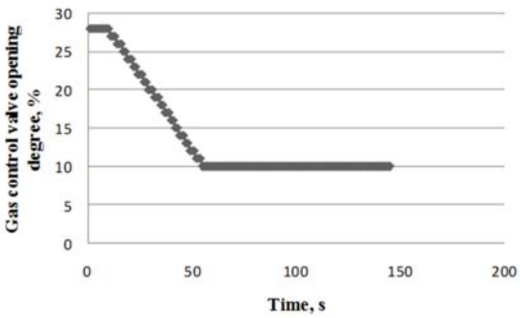

Fig. 3. Changes of gas control valve opening degree against time (manual control)

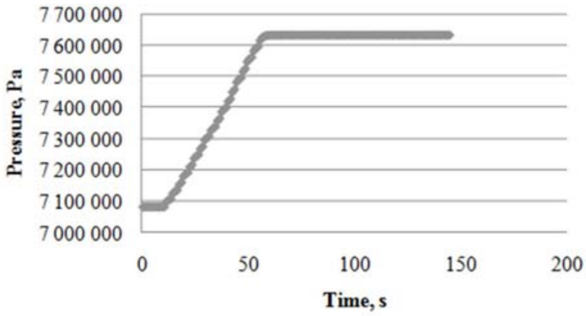

Fig. 4. Dependence of pressure in separator on time

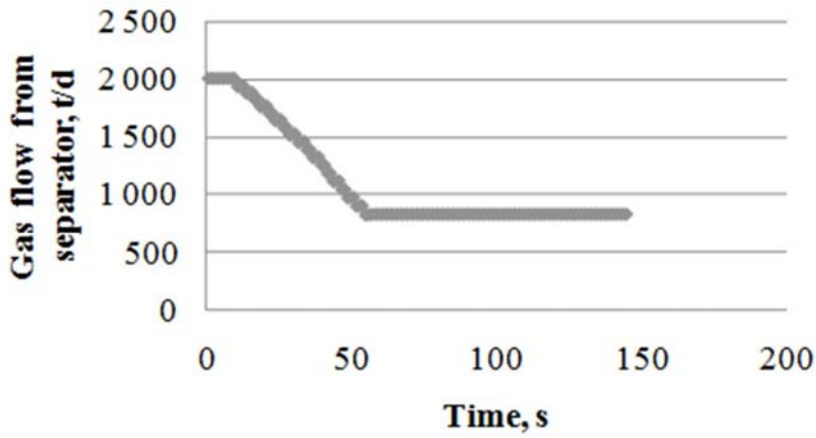

Figure 5. Gas flow rate from separator depending on time

When closing the gas valve the gas outlet from apparatus is reduced (**fig. 5**).

In the future we plan to use the developed mathematical model of complex processes occurring in apparatus of LTS unit in order to organize the automatic control; that would require model complicating with equations describing the principles of PID control. Ultimately it will allow protecting of technological system from unstable operation of devices [7-8] associated with changes in reservoir pressure during gas production.

4. Conclusions

1. A mathematical model of complex processes taking place in apparatus of a gas preparation unit was developed. This model is based on physical and chemical laws of liquid and vapor phases separating processes.
2. The mathematical model can be used to determine the optimal operating conditions LTS unit at raw materials composition as well reservoir pressure changing.
3. The influence of control parameters on technological characteristics of LTS installation in real time was determined. It allows transient processes in devices forecasting and risks of emergency situations minimizing.
4. The quantitative dependence of performance LTS process parameters (temperature, pressure, outlet of gas and liquid, etc.) on control parameters (the valve opening degree, the liquid level in the apparatus, etc.) was revealed.
5. On the basis of developed mathematical model a simulator for training of LTS unit technical staff can be created.

List of symbols

F feed mixture flow rate, kg /s;
G steam flow rate, kg /s;
L liquid phase flow, kg /s;
u_i concentration of the *i*-th component in the mixture;
x_i concentration of the *i*-th component in the liquid phase;
y_i concentration of *i*-th component in the gas phase;
e proportion of distillate;
K_i phase equilibrium constant;

K_l coefficient of liquid carry with gas;
Q_g gas flow from the apparatus when the equilibrium concentrations of the components in vapor and liquid phase are achieved, kg /h;
Q_{lg} liquid entrained with gas flow from the apparatus, kg /h;
K_g коэффициент of gas carry with liquid;
Q_l liquid flow from the apparatus when the equilibrium concentrations of the components in vapor and liquid phase are achieved, kg /h;
Q_{gl} gas entrained with liquid flow from the apparatus, kg /h;
K_v characteristic of valve capacity (conventional volumetric flow rate of water through fully opened valve), m^3/s;
ρ density of liquid, kh/m^3;
G_l liquid expenditure, m^3/s;
ΔP pressure drop across the fully opened valve, bar;
μ_{JT} Joule-Thomson coefficient, K/Pa;
H enthalpy, J;

References

[1] Kravtsov A.V., Usheva N.V., Moises O.E., Kuz'menko E.A., Anufrieva O.V. Analysis of the influence of process parameters and process optimization of low temperature separation / Bulletin of Tomsk Polytechnic University, 2009, 315(3), P. 57 – 60.
[2] Kravtsov A.V., Usheva N.V., Beshagina E.V., Moises O.E., Kuz'menko E.A. Gavrikov A.A. Technological bases and modeling of field oil and gas. Textbook. - Tomsk: Tomsk Polytechnic University, 2012, 128 p.
[3] Reid R., Prausnits J., Sherwood T. Properties of gases and liquids. 3rd edition, revised and enlarged. English translation edited by B. I. Sokolov. – L.: "Chemistry",1982, 592 p.
[4] Chugaev R.R. Hydraulics. – L. Energoizdat, Leningrad Department, 1982, 627 p.
[5] RD 51-0220570-2-93. "Safety valves. Selection, installation and payment".
[6] Kafarov V.V. Separation of multicomponent systems of chemical technology. Methods of calculation, Moscow: Moscow Institute of Chemical Technology, 1987. – 84.
[7] Dolganova I.O., Dolganov I.M., Ivashkina E.N., Ivanchina E.D. Development of computer modeling system as a tool for improvement of linear alkylbenzene production / Petroleum and Coal. 2011, 53(4), 244-250.
[8] Dolganova I.O., Dolganov I.M., Ivashkina E.N., Ivanchina E.D., Romanovsky R.V. Development of Approach to modelling and optimization of non-stationary catalytic processes in oil refining and petrochemistry / Polish Journal of Chemical Technology, 2012,Vol. 14(4), 22-29.

*Corresponding author, address: Design Institute, Tomsk Polytechnic University, 51, Belinsky Str., Tomsk, 634050, Russia; tel.: (+7-3822) 70-56-61; fax: (+7-3822) 705-611; e-mail: dolganovim@tpu.ru