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HYDRODYNAMIC FEATURES OF TUBULAR TURBULENT DEVICES WORK ACCORDINGLY TO EXTRACTION OF HIGH-BOILING HYDROCARBONS FROM ASSOCIATED PETROLEUM GAS

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Abstract. The way of perfection of after-extract process of high-boiling hydrocarbons of associated petroleum gas using the small-sized tubular turbulent device of diverging-converging construction at stage of absorption by degassed oil has been suggested.

Keywords: absorption, extraction of high-boiling hydrocarbons, associated petroleum gas, the tubular turbulent device.

1. Introduction

An associated petroleum gas (APG) is an accompanying agent during developments of oil and oil-and-gas deposits for crude oil production. Many various schemes of the APG utilization have been developed at present, in particular pumping to reservoir with the purpose of increase of petrol feedback for underground storage, electric power generation, GTL technology, *etc.* [1].

The APG flaring is a common practice due to remoteness of the majority of the deposits from possible gas consumers. The fat gas containing significant amounts of high-boiling hydrocarbons is received to low-pressure flares from the last separation stages in this case. Non-productive losses of valuable hydrocarbons raw material increase in summer. This is an especially burning issue in crude oil-producing countries of the Persian Gulf where average annual air temperature is 303 K, which is close to the boiling temperature of pentanes fraction.

One of the effective ways of target use of hydrocarbons fractions of associated petroleum gas is their absorption by degassed oil from gases of the last separation stages [2]. On the one hand, it allows reducing a density of the APG being burnt on low-pressure flares; on the other hand, it allows cutting losses of crude oil low-boiling fractions and therefore increasing volumes of extractive well production.

The key parameters increasing efficiency of hydrocarbons after-extract process from associated petroleum gas via the absorption by degassed oil are decrease of a mix temperature, increase of pressure and mass transfer intensification (creation of big phase interface and mass output from liquid and gas phases). The problem is complicated by the fact that it is economically reasonable to use 10–20-fold surplus of the gas stream to crude oil during hydrocarbons after-extract from the APG. A work of an absorber under conditions of guaranteed elimination of outfit (stratified) mode of the gas-liquid mix movement, which considerably reduces the phase interface and absorption intensity, is necessary in this case. One of the ways of technological implementation of the APG absorption stage by degassed oil in field conditions is the usage of the small-sized tubular turbulent device of diverging-converging construction [3]. Small size of the device allow to generate developed turbulent mode in the whole volume of the device, while the intensification of convective heat exchange allow to cool the gas-liquid mix through a metal wall effectively.

The tubular turbulent device of diverging-converging construction is used effectively in a number of technologies, *e.g.* during production of chlorine-butyl rubber by chlorination of a butyl rubber solution by gaseous chlorine, ammonium phosphates fertilizers at ammonization of extraction phosphoric acid, ethylene chloride at chlorination of ethylene by gaseous chlorine, *etc.* [3]. The above mentioned processes are fast chemical reactions occurring in diffusing field, whose velocity is determined by mass-exchange laws. Effective reduction of diffusing restrictions under conditions of twenty-fold surplus of gas phase determines the possibility of device construction perfection at the stage of light fractions absorption by petroleum hydrocarbons.

2. Experimental

An experimental study of regularities of gas-liquid mix movement in the tubular turbulent device with modeling water-air system has been carried out in order to optimize design of the device and hydrodynamic modes of its work. Laboratory installation (Fig. 1) included eight-section tubular turbulent devices of diverging-converging constriction differing by profile depth of channel d_d/d_c = 1.6; 2.0; 3.0 (d_d and d_c – diameter of wide (diverging, the diffusor) and narrow (converging, the confusor) parts of the device, respectively). Compressed air has been fed continuously to the device from gas vessel with volumetric flow rates up to W_g = 800 ml/s. Water stream flow rate was being changed from 2 to 60 ml/s, *i.e.* the ratio of the phases was from 13 to 400.

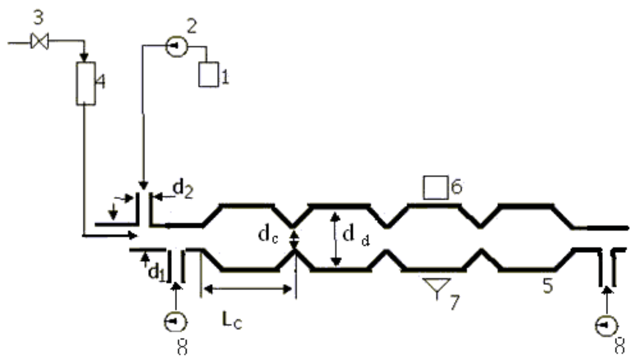

Fig.1. Scheme of experimental installation for two phase flow systems studying: gas vessel with air and P = 50 atm (1); pump (2); dispersive phase line flow (3); block for fluid flow measuring by rate-of-flow meter (4); tubular turbulent device (5); camera (6); light source (7) and manometer (8)

Fulfillment of the condition of gas-liquid mix stream formation with the developed phases interface, the guaranteed elimination of the stratified mode of flows movement, and choice of optimum differential pressure allow to define the device design and the hydrodynamic mode of its work with regard to the absorption of the APG by degassed oil.

3. Results and Discussion

The increase of gas and liquid phases flow rates in a single-phase stream is accompanied by the increase of differential pressure on the ends of the tubular turbulent device (Fig. 2). Differential pressure is the function of the stream density and square of linear velocity of its motion. Therefore, the left branch of hydraulic resistance increase during the movement of the two-phase mix is defined by the growth of its density due to enrichment by the liquid phase. Growth of differential pressure in the right branch, obviously, is connected with high velocity of the gas-liquid mix movement (up to 2 m/s) due to its enrichment by the gas phase. This effect amplifies at joint flow of liquid and gas. Obviously, further increase of gas content in a stream (movement of gas on basic volume of the device and liquid as a film on walls in an extreme case) will lead to the decrease of differential pressure. Formation of homogeneous gas-liquid mix movement mode with minimal differential pressure on the ends of the tubular turbulent device in the considered interval of liquid and gas flow rates is observed in the interval W_g/W_{liq} from 5 to 15.

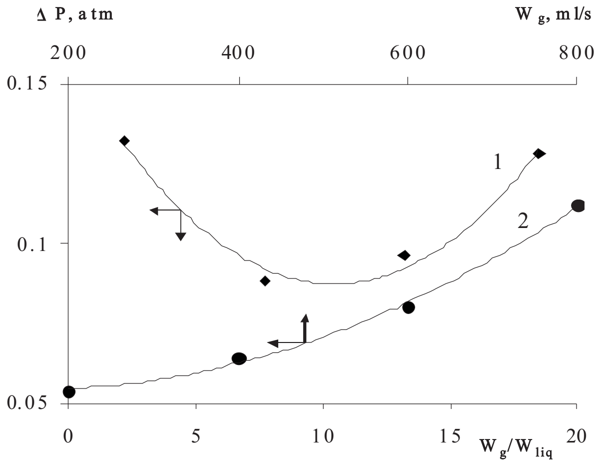

Fig. 2. Dependence of pressure differential ΔP on the ends of the tubular turbulent device on W_g/W_{liq} ratio (1) and the gas phase flow (2) for the lower boundary of homogeneous stream formation

An important parameter in the conditions of degassed oil preparation is differential pressure in the device since in the final stage of separation low pressure is provided in order to ensure the necessary pressure of hydrocarbons saturated vapor. Use of the device with greater differential pressure will promote incomplete separation and, as the consequence, production of unstable oil.

The method stated in the work [4] is used for calculation of differential pressure in the device during the turbulent mixing of gas-oil mix. Differential pressure during the turbulent mixing of gas-oil mix is defined by the following equation:

$$(\Delta P/L)_{mix.} = Y_L . (\Delta P/L)_{liquid}$$

where $Y_L = 1 + 20/X + 1/X^2$;

$$X = \left[\frac{(\Delta P/L)_{liquid}}{(\Delta P/L)_{gas}} \right]^{1/2} .$$

For **a smooth** pipe:

$$(\Delta P/L)_{liquid} = \lambda \rho w^2 / 2d ;$$

$$(\Delta P/L)_{gas} = \frac{G^2 RT}{M} . \frac{\lambda}{d} \left(\frac{1}{P_1 + P_2} \right) ,$$

where λ – friction factor for turbulent flow, $\lambda = 0.3164/\sqrt[4]{Re}$; Re – Reynolds number, $Re = \rho dw/\mu$; L – length of the device, m; ΔP – differential pressure, Pa; g – acceleration of gravity (9.81 m/s^2); w – velocity , m/s; ρ – density, kg/m^3; d – diameter, m; G – mass flux, kg/s·m^2; μ – dynamic viscosity, Pa·s; T – temperature, K; R – a gas constant (8.31 J/mol·K); M – molecular weight.

Calculation of the device of diverging-converging construction has been performed considering local hydraulic resistances at gas-liquid mixes movement on the channel of variable cross-section.

For **diffusor**:

$$\Delta P = K_1 \rho L_V,$$

where $L_V = (w_k^2/2)(1 - S_k/S_d)^2$

If $\alpha \leq 45°$ $K_1 = 2.6\sin(\alpha/2)$.

For **confusor**:

$$\Delta P = K_2 \left(\frac{8w_k}{d_k}\right)\left(\frac{1}{6\tan(\alpha/2)}\right)\left[1 - \left(\frac{d_k}{d_d}\right)^3\right].$$

where S_k – confusor cross section, m^2; S_d – diffusor cross section, m^2; α –diffusor aperture angle.

If $\alpha \leq 45°$ $K_2 = (0.0049 \cdot \mu \cdot \mathrm{Re}^{\frac{3}{4}})$

The general pressure differential is equal to the sum of pressure differentials in smooth pipe, expansion (the diffusor) and restriction (the confusor).

Table 1

Minimum water flow rates and pressure differential in the device during the initial moment of gas liquid mixture turbulence

Air flow rate, ml/s	400	600	800
Water flow rate, ml/s	52	45	43
Pressure differential, MPa Experimental Calculated	0.0088 0.0083	0.0096 0.0098	0.0128 0.0118

At the firs stage pressure differential during the turbulization of water-air mixes with the following initial data: pressure 0.11 MPa, temperature 283 K, density of water 1000 kg/m^3, density of air 1.26 kg/m^3, dynamic viscosity of water 1 mPa·s, dynamic viscosity of air 0.0185 mPa·s, number of diverging-converging sections 8, was calculated with the purpose of the model adequacy definition. The calculated pressure differentials are presented in Table 1. As can be seen, the calculated values satisfactorily describe the experimental data.

According to the technology of oil preparation at Rumaila oil field (South of Iraq) up to 0.84 ton/h of the associated petroleum gas is fed to flares at the final stage of separation at temperature 333 K and pressure 0.18 MPa. The results of the laboratory researches have allowed to choose the optimal geometric parameters of the turbulent device working on mixture of stable degassed oil-gas mix as well as the required oil flow needed for absorption of the mentioned gas volume. The optimization criterion was pressure differential on the ends of the device within 0.02 MPa. Taking into account the oil preparation conditions in Rumaila oil field it is recommended to use a five-section tubular turbulent device of diverging-converging construction with diameter of diverging part 240 mm and diameter of converging part 80 mm.

Calculation of pressure differential has been performed for preparation of the stable degassed oil-hydrocarbon gas mix under the following conditions: pressure 0.16 MPa, temperature 298 K, density of oil 791 kg/m^3, density of gas 3.94 kg/m^3, dynamic viscosity of oil 12.6 mPa·s, dynamic viscosity of gas 0.0075 mPa·s. The results confirm that the tubular turbulent device of diverging-converging construction has sufficiently wide range of steady operation with small pressure differentials in the conditions of the absorption of high-boiling hydrocarbon components of the APG by stable degassed oil (see Table 2).

Table 2

Flow rates and pressure differential in the device at turbulent mixture of oil-gas mix

Gas flow, t/h	0.56	0.84	1.12
Oil flow, t/h	14.61 16.00 18.00	12.74 14.00 16.00	12.16 14.00 16.00
Pressure differential, MPa	0.0076 0.0083 0.0095	0.0098 0.0108 0.0140	0.0126 0.0145 0.0165

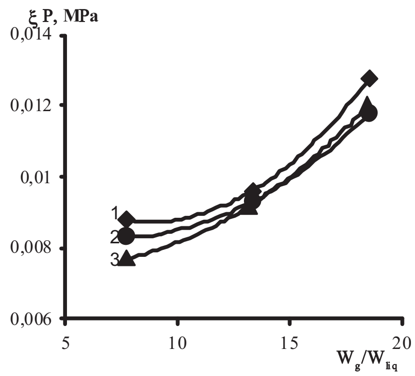

Fig. 3. Pressure differential in tubular turbulent apparatus of homogeneous gas-liquid mixture: experimental data (water-air, line 1); calculated data (water-air, line 2); calculated data (oil- gas, line 3).

Comparison of the calculated data received for conditions of fat hydrocarbon fraction absorption of the associated petroleum gas by degassed oil correlate with data the data for differential pressure in water-air modeling system device (Fig. 3, line 3).

4. Conclusions

The method of perfection of after-extract process of high-boiling hydrocarbon components from associated petroleum gas by using the small-sized tubular turbulent device of diverging-converging construction at the stage of stable degassed oil absorption has been proposed. The studies of hydrodynamic features of the absorption process under conditions of gas phase surplus demonstrate the effectiveness of usage of the tubular turbulent device with more than four diverging-converging sections. For the device with the profile depth of channel $d_d/d_c = 3$, characterized by high dispersive capability, the optimal ratio of gas and liquid phases W_g/W_{liq}, at which homogenous gas-liquid stream and minimal differential pressure are formed, is ranging from 5 to 15. The process is characterized by homogeneous gas-liquid mix formation with low pressure losses on local hydraulic resistance with approach of mass transfer to equilibrium state.

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ГІДРОДИНАМІЧНІ ОСОБЛИВОСТІ РОБОТИ ТРУБЧАТИХ ТУРБУЛЕНТНИХ АПАРАТІВ СТОСОВНО ВИЛУЧЕННЯ ВИСОКОКИПЛЯЧИХ ВУГЛЕВОДНІВ З ПОПУТНОГО НАФТОВОГО ГАЗУ

Анотація. *Запропонований спосіб удосконалення процесу довилучення висококиплячих вуглеводнів попутного нафтового газу внаслідок використання малогабаритного трубчатого турбулентного апарату дифузор-конфузорної конструкції на стадії абсорбції знегазованою нафтою.*

Ключові слова: *абсорбція, вилучення висококиплячих компонентів, попутний нафтовий газ, трубчатий турбулентний апарат.*