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Calculation of the Pump-Ejecting Systems Characteristics for SWAG Injection Using Flue Gas

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Abstract. This paper is devoted to determining the main technological parameters of pump-ejecting systems for exhaust (flue) gases utilization. The possibility of using exhaust gases from electric generating gas turbines and gas piston units built near oil fields is considered. We calculate pressure distribution in water supply lines and injection wells during water-gas mixture injection, determine the values of the required pressure at the outlet of the pump and ejector systems and the main characteristics of pump-ejecting systems, and select multistage electric centrifugal pumps and liquid-gas ejectors.

1. Introduction

In the process of addressing the problems of enhancement of oil recovery and optimization of the process of oil production, as well as transport of hydrocarbons, researchers propose different variants of technological systems, in which one of the main elements is a jet apparatus (ejector) [1-4].

There are many works devoted to studying the characteristics of the liquid-gas ejector (LGE). The most significant contribution to the development of the LGE theory was made by E. Y. Sokolov and N. M. Zinger [5], K. G. Donets [6], L. D. Berman and G. I. Efimochkin [7], Б. К. Кореннова [8], Е. К. Спиридонова [9], A. V. Podzerko [10], A. N. Drozdov [11], Y. A. Sazonov [12]. The methods for calculating the performance characteristics of the LGE developed by these authors are based on experimental research data.

Foreign experience in studies of jet apparatuses is devoted to the influence of the ejector design and its geometrical parameters, as well as numerical research to improve the efficiency of the liquid-gas ejector [13-16].

Technological solutions in the works [11, 17-18] are aimed at increasing oil recovery in the fields by injecting associated petroleum gas (APG). This technology is easy to implement and operate due to the advantages of the equipment used. Studies [19-21] are aimed at determining the parameters of pump-ejecting systems under various conditions.

In the above-mentioned works it was proposed to use associated petroleum gas to increase oil recovery due to the need to reduce its flaring. In the modern world with high requirements in reducing harmful emissions into the atmosphere and decarbonizing the industry, the use of exhaust gases is relevant. Gas turbine and gas piston power generating units operating on APG can become a source of exhaust gases in the field.

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2. Materials and methods

In this paper an analysis of number of gas turbine and gas piston power generating plants installed at the fields of Russian oil and gas companies was carried out. Based on the capacity and characteristics of the plants used, the daily flow rate of exhaust gases which can be utilized by injecting them as a water-gas mixture in field injection wells was determined.

Based on the experience of developing pump-ejecting systems for enhanced oil recovery in Russian fields [17, 22-23] a principal diagram suitable for utilization of exhaust gases (77007 kg/h) generated from the Taurus-603-7001 gas turbine unit has been selected.

According to the methodology described in [24] the pressure distribution in the water supply lines and injection wells during water-gas mixture injection, the required pressure values at the outlet of pump-ejecting systems and the basic characteristics of pump-ejecting systems were calculated. Both technological parameters of the system operation and geometrical dimensions of the ejector flow path (pressures of water-gas mixture injection into the well, pressures developed by ejectors and electric centrifugal pumps, ejector injection coefficients, diameters of working nozzles, diameters and lengths of mixing chambers, etc.) were determined

3. Discussion

In order to increase the share of useful utilization of associated petroleum gas, as well as to obtain additional electric and thermal power, power plants are created at a number of fields. Basic information on some of the power plants running on both natural and APG at Russian fields is given in Table 1.

Table 1. Characteristics of electric generating facilities in the Russian Federation.

No	Name of the electric power plant	Company	Condition	Total power	Fuel	Other characteristics
1.	Energy center of the Yaraktinskoye field	Irkutsk Oil Company	in operation since 2016	72 MW	APG	3 power units: 6 gas turbine units
2.	Gas turbine power plant at the Novoportovskoye field	Gazprom Neft-Yamal LLC	in operation since 2013 and 2016	26,5 MW (96-144 MW)	natural gas, APG	7 gas-fired modular power plants based on Cummins GPUs
3.	Energy Center of the Yaregskoye field	LLC LUKOIL-Komi	in operation since 2017	75 MW	natural gas, APG	3 power units based on a gas turbine unit
4.	Gas turbine power plant at the Vostochno-Messoyakhskoye field	Messoyakhaneftegaz JSC	in operation since 2016	84 MW	APG	6 Titan 130 gas turbine units (Solar Turbines Inc.)
5.	Gas-turbine power plant of the Zapadno-Poludennoye field	OAO Tomskneft VNK	in operation since 2007.	10 MW	APG	10 MW GTPP OAO AK Yuzhtransenergo

The units with "Taurus-603-7001" gas turbine are used at Konitlorskoye and Tyanskoye fields. The pump-ejecting system is selected for the emitted amount of exhaust gas from one such gas turbine with a nominal capacity of 5.2 kW. Figure 1 shows such a diagram.

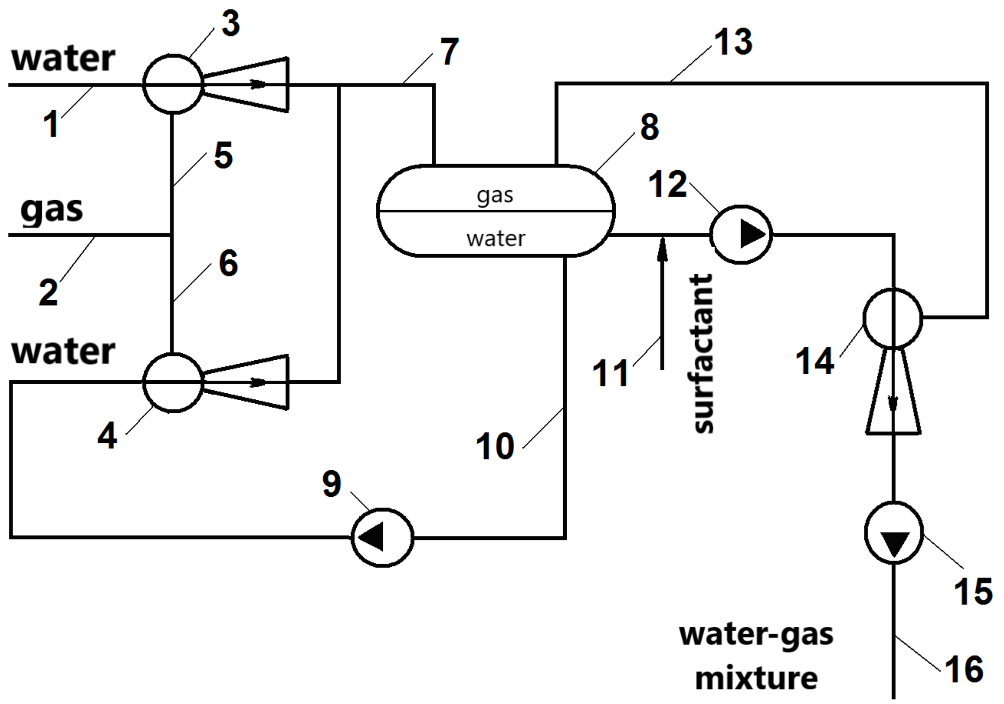

Figure 1. Technological diagram of the pump-ejecting system for exhaust gas utilization: 1 - high-pressure water supply line from pumps of water-injection pumping stations, 2 - low-pressure exhaust gas line, 3, 4 - ejectors of the first compression stage, 5, 6 - gas supply lines to the ejectors 3 and 4, 7 - water-gas mixture supply line after the first compression stage, 8 - water-gas separator, 9 - pump for the ejector drive 4, 10 - water supply line to pump 9, 11 - foaming surfactants supply line, 12 - pump for the second compression stage, 13 - gas line at the outlet from the first compression stage, 14 - ejector for the second compression stage, 15 - multistage centrifugal pump, 16 - high-pressure water line from water-injection pumping stations to water distribution point.

This diagram works in as follows. Water along line 1 from the pumps of the water-injection pumping station enters the nozzle of the first compression stage 3, which pumps out part of low-pressure exhaust gases along lines 2 and 5. A high-pressure water-gas mixture is sent to the water-gas separator 8, where the mixture is separated.

Then some volume of water from separator 8 is directed to pump 9, which drives the second ejector 4 of the first compression stage, pumping out the rest of low-pressure exhaust gas. The water-gas mixture after ejector 4 is sent to the line 7 and to the water-gas separator 8. Two ejectors in the first compression stage are necessary to ensure pumping of gas at high flow rate.

Another part of the water from the separator 8 comes to the inlet of the pump 12. In the same line 11 a foaming surfactant is supplied to maintain stability of the fine water-gas mixture. Pump 12 pumps water with surfactant into the nozzle of ejector 14 of the second compression stage. The ejector 14 evacuates the exhaust gas from the water-gas separator 8 in line 13 and delivers the water-gas mixture to the intake pump 15 of the third stage of the system. Pump 15 boosts the mixture to the required discharge pressure. Then the water-gas mixture flows through the water supply line to the water distribution point, from where it is distributed to the injection wells through a distribution manifold.

Table 2 shows the initial data for calculating the characteristics of pump-ejecting systems for water-gas mixtures injection with exhaust gases.

Table 2. Initial data for calculation.

	Parameter measurement units	Parameter value
Initial exhaust gas pressure	MPa	0.4
Current value of exhaust gas flow rate under standard conditions	m^3/day	78419
Highest pressure value at the wellhead of the injection wells	MPa	10
Fluid flow rate at the water-injection pumping stations	m^3/day	5625
Length of water supply line from water-injection pumping stations to water distribution manifold	m	4101
Actual pressure drop from water-injection pumping stations to water distribution point during water injection	MPa	0.14
Outer (and inner) diameter of water supply line from pumps for water-injection pumping stations	mm	168 (130)
Fluid flow rate at water distribution point	m^3/day	1800
Length of water supply line from water distribution point to the well	m	1950
Water flow rate in the water supply line from the water distribution point	m^3/day	370
Actual pressure drop from the water distribution point to well during water injection,	MPa	0.3
Outer (and inner) diameter of water supply line from water distribution manifold	mm	114 (88)
Reservoir pressure	MPa	13
Density of exhaust gases at standard conditions	kg/m^3	0,982
Density of injected water	kg/m^3	1110
Viscosity of water	mPa*s	1.1
Water injection capacity of injection well	m^3/day	90
Depth of well to the top of the reservoir	m	1500
Outer (and inner) diameter of tubing	mm	73 (62)

The following results were obtained after calculating the pressure distribution in water supply lines and injection wells during water-gas mixture injection (Table 3).

Table 3. Results of pressure distribution calculation during water-gas mixture injection.

	Parameter measurement units	Parameter value
Gas-water ratio under standard conditions at current exhaust flow rate	R, m^3/m^3	43.56
Wellhead pressure in the injection well	P1, MPa	14.8
Water supply line pressure from water distribution point to the well	P2, MPa	15.23
Water supply line pressure from water-injection pumping stations to water distribution point	P3, MPa	17.9
Required discharge pressure at the outlet of the pump-ejecting system at current gas-water ratio	P4, MPa	17.9

As a result of selection of pumping equipment according to the catalog of Novomet-Perm JSC for the selected technological diagram, the standard sizes of multistage electric centrifugal pumps have been determined. A brief characteristic of multistage electric centrifugal pumps is given in table 4.

In order to select the flow part of the jet apparatus and to calculate the system operation performance, the injection coefficients were determined under the conditions of inlet to the jet apparatus. Using nomograms of [17], relative dimensionless pressure drops $\Delta P_c/\Delta P_p$, created by ejectors, and optimal ratios of mixing chamber diameter d_{mc} to nozzle diameter d_n of liquid-gas ejector were determined.

The results of calculation of parameters and determination of the flow path of the ejector are given in table 5. For convenience of further operation and regulation of the system parameters, it is reasonable to calculate the parameters of ejectors 3 and 4 in such a way that they are operated with the same values of working pressure and the same injection coefficients. The opening angle of diffusers of all three ejectors is set to 60, because the largest increase in pressure during the flow expansion is achieved at this value.

Table 4. Characteristics of multistage electric centrifugal pumps.

	Size of the pump	Inlet pressure	Outlet pressure	Developed pressure	Hydraulic head m	Number of stages, pcs	Power
		P_{inl}, MPa	P_{outl}, Mpa	Pd_p, MPa			N, kW
Pump 9	ESP8-2500E	2.52	11	8.48	764	59	326.2
Pump 12	ESP8-1600E	2.52	10.52	8	735	48	194.2
Pump 15	ESP8-2000E	5.48	17.9	12.42	1525	110	377.5

Table 5. Characteristics of liquid-gas ejectors.

	Gas injection coefficient	Relative dimensionless pressure drop	Optimal diameter ratio	Nozzle diameter	Mixing chamber diameter	Distance from the nozzle to the inlet of the mixing chamber	Optimal mixing chamber length
	U_g	$\Delta P_c/\Delta P_p$	d_{mc}/ d_n	d_n, mm	d_{mc}, mm	l, mm	$L_{mc.opt}$, mm
Ejector 3	4.56	0.2	2.3	17.67	40.64	60.96	1580
Ejector 4	4.56	0.2	2.3	20.83	47.9	71.85	1862
Ejector 14	1.73	0.37	1.54	18.96	29.2	43.8	637

4. Conclusion

As a result of the study, the technological diagram of the pump-ejecting system for creating a water-gas mixture with the exhaust gases from electric generating units was proposed. This technology is considered as a method to increase oil recovery and improve the environmental situation by reducing harmful emissions.

The pressures in water supply lines and injection wells required for efficient production, as well as the parameters of the main elements of the system such as multistage electric centrifugal pumps and liquid-gas ejectors are calculated.

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