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Substance of Oil Vapor Recovery Technology Using Ejector System for Vertical Cylindrical Storage Oil Tanks

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Abstract: In this paper the efficiency of gas-liquid ejector usage to reduce hydrocarbon emissions from storage tanks into the atmosphere is demonstrated by comparing Ka-criterion for different loss reduction means. The experimental research to prove the fundamentals of the phase equilibrium theory when applied to gas-liquid ejectors is carried out. Data on the efficiency range of different oil loss reduction means is obtained through analysis.

Key words: Oil losses · Oil evaporation · A steam-air mix · Standing · Emptying · Filling of tank · Design procedure of oil losses · Steam concentration · Ejector.

INTRODUCTION

Crude oil is valuable and expandable material, yet considerable losses occur while transporting and during storage. Evaporation is the major factor of such losses. For instance, about 10 tons of oil evaporate and are emitted (as air-vapor mixture) into the atmosphere from the vertical cylindrical tank (RVS) with 20000 m^3 volume (RVS-20000), when full, during summer period at standard conditions. According to Russian Federal State Statistics Service, 5.2 million tons of hydrocarbons were emitted in 2011 from stationary facilities. It is the imperfection of technology and methods of transportation and storage that causes such loss.

To reduce the loss of oil due to evaporation such means as baffles, gas line piping and gas equalizing systems, as well as floating roofs and pontoons are commonly used [1]. A wide range of alternative means and methods of loss reduction are also introduced, though, unfortunately, not applied or seldom applicable. The efficiency of such means is usually low.

The mechanical means of loss reduction (by covering the surface of evaporation) are most common. Protective emulsions and plastic microballoons that float on the oil surface and prevent evaporation are used as coatings; pontoons and floating roofs are also used. The gas piping system (connecting tank's gas space with the oil) and gas equalizing system that has a gas collector are used. But, unfortunately, neither of those systems can cover losses 100% [2].

The problem of air-vapor mixture (AVM) emission into the atmosphere and, therefore, of oil loss, can be dealt with by introducing different light hydrocarbon fractions recovery (LFR) systems [3, 4]. Such systems are widely used in many countries [5, 6] and, in recent years, there is a growing interest in them in Russia. The type of LFR system is determined by the hydrocarbon separation method for AVM used; it can be adsorption, absorption, condensation, or compression. LFR systems that use adsorption and absorption methods are very complex; condensation systems are costly; systems using compression are capital-intensive and prone to fire and explosion hazards. The consideration of these factors led to a wide application of the ejector LFR systems [7]. The main element of such systems is the gas-liquid ejector. The simplicity and reliability of these systems, as well as the availability of parts are their main advantages. Their maintenance does not require additional personnel.

To recover vapors from air-vapor mixture above the crude or mineral oil surface, a hydrocarbon liquid with lesser vapor pressure can be used in the ejector system, to allow for hydrocarbons absorption. Diesel oil can be used for that purpose, but this proves to be costly. Buying fresh and the disposal of spent diesel oil would be

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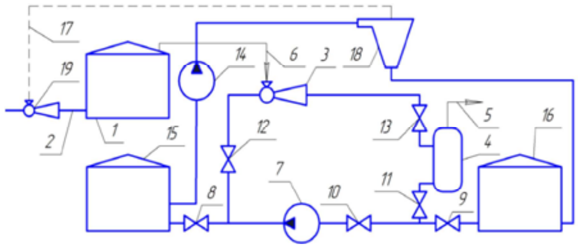

Fig. 1: Ejector LFR system with oil regenerating system;motive fluid is diesel oil (ELFR-1).

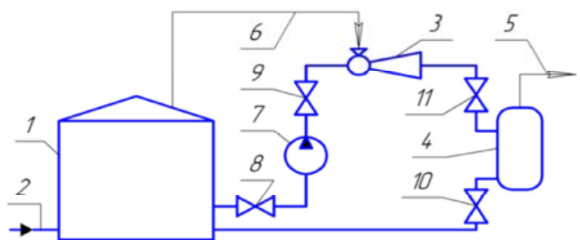

Fig. 2: Ejector LFR system with additional pump (ELFR-2)

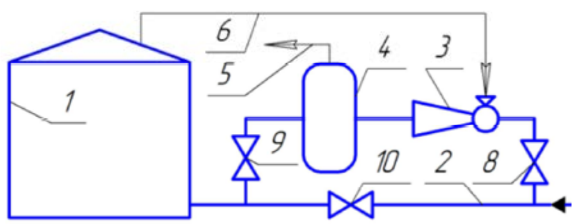

Fig. 3: Ejector LFR system utilizing the energy of injected medium (ELFR-3) 1 - Oil storage tank; 2 - Oil pipeline; 3 - Gas-liquid ejector; 4 - Separator;5 - Air venting pipe; 6 - AVM supply pipe; 7, 14 - Pump; 8…13 - Gate valves; 15, 16 - Diesel oil storage tanks; 17 - Recovered oil vapors withdrawal pipe;18 - Hydrocyclone; 19 - Ejector

the major expenses. To substantially reduce the amount of diesel oil required, oil regenerating system must be included in the scheme, using a hydrocyclone, for instance (Fig. 1).

Not only diesel oil can be used as a motive fluid for the process of light hydrocarbon fractions recovery by the gas-liquid ejector. The crude oil being injected into the tank can be used as well. For this case the two schemes of the ejector systems are presented below (Fig.2 and Fig.3). Ejector LFR system (Fig. 3) can be applied when it is possible to increase pressure in the main oil pipeline (by increasing the outlet pressure at the oil pump station, outside the tank farm), in case it is underloaded. The RF patent #2445150 “Method Of Cleaning Gas-steam Medium Of Hydrocarbons” was obtained for this scheme (Fig. 3).

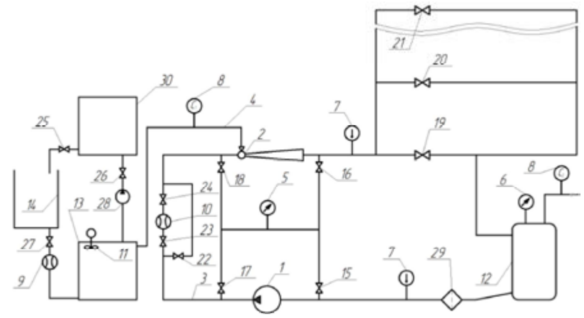

Fig. 4: The experimental assembly. 1, 28 - Pumps; 2 - Gas-liquid ejector; 3 - Pipeline; 4 - AVM supply pipe; 5 - Vacuum pressure gage; 6 - Manometer; 7 - Thermometer; 8 - Gas analyzer; 9 - Flow meter; 10 - Meter; 11 - Fan; 12 - Separator; 13 - Reservoir 1; 14 - Intermediate overflow weir; 15…27 - Gate valves; 29 - Filter; 30 - Reservoir 2

To predict the rate of hydrocarbons recovery using ELFR systems, the composition and the output of air-vapor mixture escaped (in the ejector two-phase stream separation) must be determined. We consider the application of the phase equilibrium theory to solve this problem to be appropriate, as the actual tests would prove to be very demanding. There are many methods of phase equilibrium calculations for natural hydrocarbon systems described [8]. But the authors of these methods, unfortunately, have carried out their researches mostly for oil and gas field development, processing and oil and gas separators. Presently, there is no published data on the phase equilibrium theory as applied to gas-liquid ejectors (GLE).

To prove the possibility of hydrocarbon recovery rate (S_e) prediction when absorption under pressure is taking place, the experimental assembly (Fig.4) was designed and built. It also allows us to investigate the effect different factors have on the recovery rate value.

The experimental assembly is a closed loop made of polypropylene pipes 25-40mm in diameter (3, see Fig.4). The assembly includes: the NMSh-2-40-1.6/16-10U gear oil pump (1) with three-phase asynchronous electric motor DAT90L4; the gas-liquid ejector (2); the MVTIf vacuum pressure gage (5) with measurement range from -1 atm to 24 atm, accuracy class 0.4; two TBN-100k thermometers (7), accuracy class 1.5; the Pressol 19702 diesel oil flow meter (10); and the separator (12). The 1 m^3 polyethylene reservoir (13) was used to model the oil storage tank. The gas-liquid ejector (2) was calculated using the method described in [9]; then designed and made out of 30HGSA steel; tempering and inside polishing were performed.

By applying the phase equilibrium theory, a theoretical prediction for the rate of hydrocarbon recovery from air-vapor mixture has been made, at the given conditions of the experiment. Low error value (the mean square error is 12.6%) of the vapor recovery rate calculation, when absorption under pressure is taking place, proves the validity of the phase equilibrium theory application in this case. It also proves the applicability of this method for vapor recovery rate calculation in real-life environment, when operating at storage depot or at oil-loading terminal.

Considering market environment, it is preferable to use the net present value (NPV) as the decisive criterion for the method of loss reduction selection. NPV is the sum of cash flows discounted back to their present values. As demonstrated in [10], the efficiency evaluation for means of oil loss due to evaporation reduction can be performed by calculating the dimensionless Ka-criterion, as follows:

$$\mathrm{Ka} = \frac{\mathrm{Ka}_1^*}{t_\mathrm{c}} = \frac{S}{t_\mathrm{c}} \cdot \left[\left(1 - \frac{\mathrm{E}_\mathrm{cost}}{s_\mathrm{n}^*} \right) \cdot F(i) - \frac{k_\mathrm{cost}}{s_\mathrm{n}^*} \right], \qquad (1)$$

where Ka* is the dimensionless criterion;

$$\mathrm{Ka}^* = \frac{\mathrm{NPV}}{s_\mathrm{n}^* \cdot G_\mathrm{L}} \qquad (2)$$

where NPV is the net present value;

s_n^* = Is the average price for 1 ton of oil;
G_L = Is the oil loss due to evaporation per year, with no LFR system;
t_c = Is the service life;
S = Is the oil loss reduction value, when ejector LFR system is engaged;
k_cost, E_cost = Are the capital and the maintenance costs per 1 ton of recovered oil loss, respectively;
$F(i)$ = is the function dependent on the rate of discount value.

The rate of loss reduction and the costs of applied system usage must be determined to calculate the Ka-criterion. A computational experiment was conducted to determine the rate of loss reduction by means of gas-liquid ejector. Using the phase equilibrium theory, the residual amount of hydrocarbons in the AVM after the contact with the ejector's motive fluid was calculated. The calculation was performed for various values of pressure (P), temperature (T) and at different mix proportions (U). Consequently, the correlation between the recovery rate and the constitutive parameters was derived.

Then the analysis was performed to retrieve data on the actual efficiency range of different means of oil loss due to evaporation reduction. The Ka-criteria for baffles, tank pontoons and the ejector LFR system (Fig.3) were compared in this analysis. The following is the outcome of our analysis.

Given that the life service t_n=20 years and the rate of discount E=0.1, then for vertical oil storage tanks RVS-2000 and RVS-3000 the ELFR-3 system proves advantageous, at the turnover rate 15=n_{turn}=48 per year. But for the RVS-5000 and RVS-10000 tanks (when 8<n_{turn}=43 per year) the ELFR-2 system becomes more effective than ELFR-3. Such an effect occurs due to the electricity costs (when increasing the pressure in the main oil pipeline, for ELFR-3) exceeding those for the additional pump required for ELFR-2. Moreover, when it is impossible to increase the pressure in the main oil pipeline (to suit ELFR-3), it is advised that the ELFR-2 system be used for RVS-2000 and RVS-3000 tanks as well. For the RVS-20000 and RVS-50000 large capacity oil tanks, at the low turnover rates (less than 25 per year for RVS-20000 and less than 10 per year for RVS-50000), the use of LFR system is most advantageous. In this case the Ka-criteria values for ELFR-2 and ELFR-3 are almost equal. This means that both of them can be implemented. Still, at the higher turnover rates, there is no competition with the metal tank pontoons, as electricity costs for ejector operation become too high.

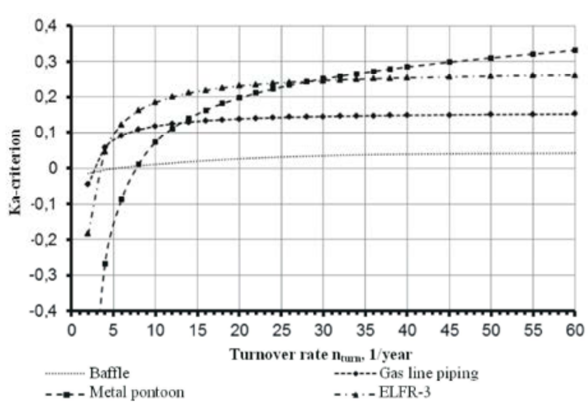

Fig. 5: Ka-criterion and turnover rate correlation for the RVS-10000 oil storage tank

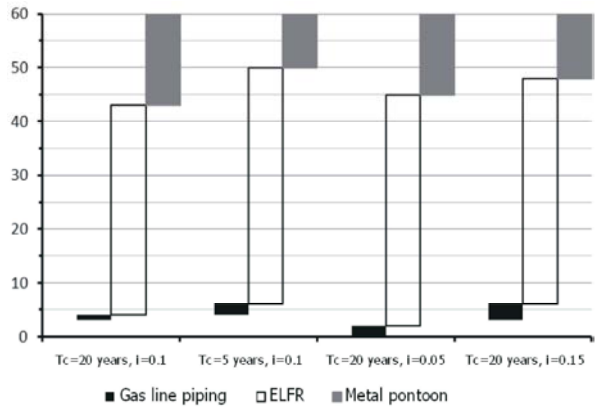

Fig. 6: Efficiency range of different loss reduction means for the RVS-10000 oil storage tank

As the rate of discount (E) is increased to 0.15 (when t_{π}=20 years) and the tank remaining life is decreased to 5 or 10 years (when E=0.1), the efficiency range of ejector LFR systems extends. For instance, the ELFR system retains efficiency up to the turnover rate n_{turn}=30 per year, for the RVS-20000 tank. Because of the tank's short service life in this case there is not enough time for metal pontoon to expire.

The results described show the complex interaction betwen the Ka-criterion value and several constitutive parameters acting at once.

The conclusions on the efficiency range of different oil loss reduction means are drawn as the evaluation. First of all, they were drawn using the set of simplifying assumptions. Secondly, the actual material and equipment costs are agreed in contract, so the Ka-criterion value has to be defined each time for the actual project.

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