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Heating Systems in a Crude Oil Pumping Station. Case Study

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Abstract

The procedure used to crude oil transportation is pumping his after preheating at temperatures up to 70 ºC using low pressure saturated steam. This paper proposes as the heating system with low pressure saturated steam at 4 bar and 150 ºC to be replaced with a recirculated heating agent, namely hot gas oil. Heating with gas oil is more advantageous whereas it increases the logarithmic average temperature difference between crude oil and hot gas oil, which lead to decreases the heat transfer area required and to an increase of the overall heat transfer coefficient.

Keywords: *crude oil transportation, stream flow, heating agent, gas oil, pumping system*

Introduction

Petroleum products prices are depend on world market prices for crude oil, transportation, refining, distribution costs and different fees and taxes [6].

The national transport system of crude oil includes pipelines with diameter range between 4 and 14 inch. Also, the transportation crude oil country subsystem have pumping system, loading/unloading ramps and tank parks for reception and/or transition.

In present, the procedure used to crude oil transportation is pumping his after preheating at low temperature, up to 70 °C to avoid the light fractions loss from crude oil. The atmospheric temperature influences the crude oil temperature pumping into pipelines. The heat flow received by the crude oil in pumping station must assure him a higher temperature than the freezing temperature.

The heating crude oil for transportation is one of the important processes of the crude oil deposits; taking into account the high viscosity of crude oils creates serious problems for transport over the pipeline, especially in winter. On the one side, problems occur at low ambient temperatures (soil for the buried pipeline and air for the over ground pipeline), and on the other side because the high pressures required to pumping [2, 6, 8, 11].

As crude oil crosses the pipeline, it tends to cool due to heat losses to the ground. If the crude oil is transported on a longer distance than the distance until the temperature of oil drops to a minimum accepted value, then reheat stations are being mounted [4, 10].

Heating oil before pumping is realized in isolated tanks with a coil where steam is circulating. The steam is produced in boilers using fossil fuel as a primary source of energy.

Using the heat pump for heating viscous oil is an ecologic process which reduces by 65 % the consumption of fossil fuels. At the same time pollutants and greenhouse gases effect is diminished [1, 5].

Whereas the ambient temperature is lower than the inside pipeline temperature in transportation time, the crude oil transfers its heat, gradually cooling. For this reason, its necessary determination of heat transfer crude oil that must to store it in the pumping station, because at any moment the temperature of transportation does not fall below its freezing temperature.

In this paper it is analysed the heating system of a crude oil pumping station from Romania. It calculates the heat transfer coefficients for the actual variant and it is proposed an alternative variant.

Actual and Proposed Heating Systems in Crude Oil Pumping Station

In the actual heating system, the crude oil is heated with low saturated steam at 4 bar and 150 ºC [7]. This saturated steam is obtained into a battery of boilers. Steam boiler system presents a low yield and the condensate obtained is discharge to canal.

The justification of the proposal to use another heating agent such the gas oil type, derive from some disadvantages of steam like heating agent, at the pumping station:

- Additional expenses requires with groundwater pumping from 12 m depth and treating it to the salts, because the condensate is not recirculated;
- Relatively low yield for the steam boilers because the low saturated steam temperature;
- The steam circulates inside the coil and the crude oil circulates outside the coil. The heat transfer coefficient on inside coil (α_i) is substantially higher for steam condensate (1000 - 10000 W/(m^2·ºC)) than for cooling the heating liquid agent (1000 - 3000 W/(m^2·ºC)). The heat transfer coefficient on outside coil (α_e) has very small values by comparison with α_i. From the overall heat transfer coefficient (k_{ed}) expression results the inequality k_{ed} < minimum (α_i, α_e), thus a bigger value for α_i (i.e. steam condensation) cannot be justified if α_e has a small value [3].

Choosing a heating liquid agent allow a better heat transfer since can be obtained a higher temperature difference between fluids. In proposed variant for the heating system, the heat transfer coefficient on inside surface of coil is bigger when used hot gas oil than for steam, and this fact lead to a higher overall heat transfer coefficient. The new path which circulates the heating agent for the heating system proposed for the pumping station, it is shown in Figure 1.

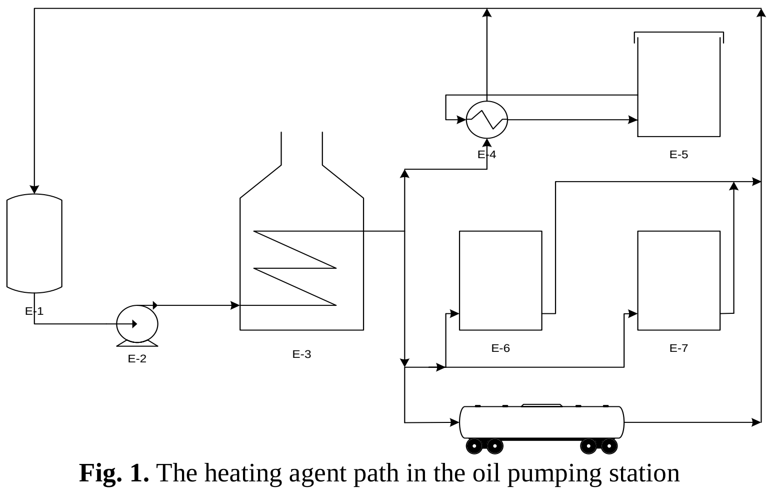

Fig. 1. The heating agent path in the oil pumping station
E-1 – vessel; E-2 – pump; E-3 – furnace; E-4 – heat exchanger; E-5, E-6, E-7 – closed tank

The gas oil is heated up to 300 °C in furnace, then it enters in a closed circuit: a ramp, petroleum tanks and a heat exchanger in which it is cooled with water. Hot water obtained provides the necessary heat of consumers (offices, housing, etc.). After the heat transfer is carried out, the gas oil is collected in a buffer vessel where it is drawn by a pump and recycled to the furnace. In Table 1, the input data are presented.

Table 1. Input data

Parameter	Symbol	Value
Tanks number	n_t	30
Tank capacity, t	D_{co}	38
Tank Length, m	-	8
Tank diameter, m	-	2.5
Initial temperature of crude oil, °C	$t_{c,i}$	-20
Final temperature of crude oil, °C	$t_{c,o}$	20
Coil length, m	L	84
Inner diameter of the coil, m	d_i	0.06
Outer diameter of the coil, m	d_e	0.07
Saturated steam temperature, °C	t_s	150
Saturated steam pressure, bar	p	4
Inlet gas oil temperature, °C	$t_{d,i}$	300
Outlet gas oil temperature, °C	$t_{d,o}$	150
Air temperature, °C	t_{air}	-26
Outside temperature of the tanks wall	t_w	-2
Density of crude oil	d_{15}^{15}	847
Watson factor of crude oil	K	11.7
Density of gas oil	d_{15}^{15}	835
Watson factor of gas oil	K	11

Determination of the Overall Heat Transfer Coefficient

The formula for the overall heat transfer coefficient is [3]:

$$k_{ed} = \frac{1}{\frac{d_e}{\alpha_i d_i} + R_{di}\frac{d_e}{d_i} + \frac{d_e}{2\lambda_o} ln\frac{d_e}{d_i} + R_{de} + \frac{1}{\alpha_e}} \tag{1}$$

where R_{di}, R_{de} represents thermal deposits resistances inside/outside surface of the coil and λ_m is thermal conductivity of the coil wall. If it neglects the fouling deposits and wall coil resistances, the expression of overall heat transfer coefficient becomes:

$$k_e = \frac{1}{\frac{d_e}{\alpha_i d_i} + \frac{1}{\alpha_e}} \tag{2}$$

The high value of α_i not favourably influences the heat transfer when α_e is small.

The formula of the Newton's law for the heat transfer achieved can be written as:

$$Q = k_e \cdot A \cdot \Delta t_{mlog} \tag{3}$$

$$A = \pi \cdot d_e \cdot L \tag{4}$$

where Q is the heat flow (W) and A is the heat transfer surface area (m^2).

An efficient heating agent ensures a higher mean difference temperature. Thus, it can be seen in the representation of figure 2 which are the differences temperature between the fluids at the ends, for a - steam - crude oil and b - gas oil - crude oil.

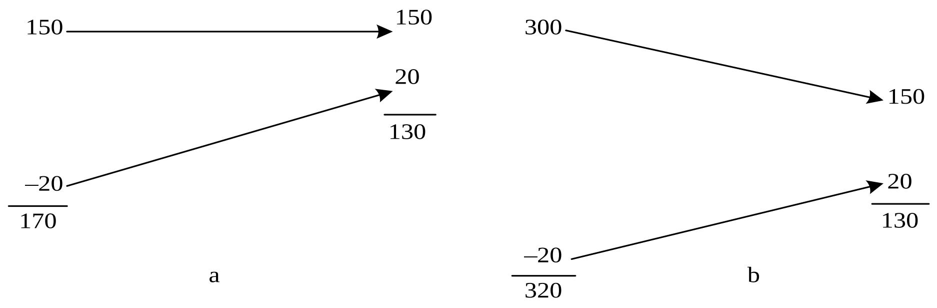

Fig. 2. Differences temperature between the fluids at the ends

It is calculated the logarithmic mean temperature difference, Δt_{mlog}, for co-current flow and values obtained are $\Delta t_{mlog\ steam}$ = 149,1 ºC for steam and $\Delta t_{mlog\ gas\ oil}$ = 210,9 ºC for gas oil. According to the obtained values, $\Delta t_{mlog\ gas\ oil}$ is greater with 41,6 % than $\Delta t_{mlog\ steam}$. The increase to the logarithmic mean difference temperature involve a decrease to the heat transfer area for the same necessary heat transfer flow, then an advantage to use an liquid heating agent.

The overall heat transfer coefficient for two fluids separated by a cylindrical surface it is determinate with the relation (1), where the heat transfer coefficient can be computed using criteria relations.

The heat transfer coefficient on the inside coil for gas oil was calculated from Sieder-Tate correlation [3]:

$$Nu = 0.027 \cdot Re^{0.8} \cdot Pr^{1/3} \tag{5}$$

where: *Nu* - Nusselt number, *Re* - Reynolds number, *Pr* - Prandtl number. The expressions of *Nu*, *Re* and *Pr* numbers are:

$$Nu = \frac{\alpha_i \cdot d_i}{\lambda} \tag{6}$$

$$Re = \frac{d_i \cdot w \cdot \rho}{\mu} \tag{7}$$

$$Pr = \frac{c_p \cdot \mu}{\lambda} \tag{8}$$

where: λ - thermal conductivity, W/(m·°C); w - linear average velocity, m/s; ρ - density, kg/m^3; μ - dynamic viscosity, kg/(m·s); c_p - specific heat, kJ/(kg·ºC).
In equations (6) - (8), all physical properties are at the average temperature of fluid from the coil between inlet and outlet.

For calculating the linear average velocity it is necessary the mass flow rate of the heating agent (D_{ha}, *kg/s*). The heating agent mass flow was calculated with following relation:

$$D_{ha} = \frac{Q_{platform}}{i_{ha}^{ti} - i_{ha}^{to}} \tag{9}$$

where: $Q_{platform}$ – heat flow for heating of discharged crude oil on the platform, kW, i_{ha}^{ti} – enthalpy of heating agent at the coil inlet temperature, kJ/kg, i_{ha}^{to} – enthalpy of heating agent at the coil outlet temperature, kJ/kg.

The heat flow necessary for heating crude oil is the heat flow yielded by steam.

$$Q_{platform} = Q_{steam} = D_{steam} \cdot r \tag{10}$$

In equation (10) Q_{steam} represents the heat flow yielded by steam (kJ/h), *r* is the latent heat of vaporization of steam (kJ/kg) and D_{steam} is the steam mass flow rate (kg/h). The heat flow is determined knowing the crude oil quantity witch is discharged, the initial and final crude oil temperatures, the crude oil specific heat and the mean heat transfer coefficient to tank from environment.

$$Q_{platform} = \frac{Q_{crude\ oil} + Q_{loss}}{\tau} \tag{11}$$

In equation (11) $Q_{crude\ oil}$ represents the necessary heat for increase the crude oil temperature and Q_{loss} is the loss heat to tank from environment.

$$Q_{crude\ oil} = D_{co} \cdot c_{pco} \cdot \left(t_{c,o} - t_{c,i}\right) \tag{12}$$

$$Q_{loss} = \alpha_{etank} \cdot A_{otank} \cdot (t_c - t_{air}) \cdot n_t \cdot \tau \tag{13}$$

where: D_{co} – quantity of crude oil, kg; $t_{c,o}$ – outlet temperature of crude oil, °C; $t_{c,I}$ – inlet temperature of crude oil, °C; c_{pco} - specific heat for crude oil, kJ/(kg·°C); τ – heating time of crude oil in hours; t_c - average temperature of crude oil between inlet and outlet by tank, °C; A_{otank} - heat transfer area on the external surface of the tank, m^2; α_{etank} - heat transfer coefficient for the tank wall - air heat exchange, W/(m^2·°C).

The steam and water enthalpies to saturation they were taken from literature [3, 9], depending on pressure and temperature and the gas oil enthalpy (liquid heating agent) it is determined with an empirical relation [3]:

$$i_l^t = \left[\left(2{,}964 - 1{,}332 d_{15}^{15}\right)t + \left(0{,}003074 - 0{,}00115 d_{15}^{15}\right)t^2\right] \cdot (0{,}0538 \cdot K + 0{,}3544), \text{ kJ/kg} \tag{14}$$

The heat transfer coefficient on the inside coil for steam was calculated using the following relation [3, 7]:

$$\alpha_i = \left(3950 + 116 \cdot w\right)\left(\frac{1.21}{L}\right)^{1/3} \tag{15}$$

The heat transfer coefficient on the outside coil can be calculated by using the Lorenz correlation [3]:

$$\alpha_e = \frac{c \cdot \left(Gr \cdot Pr\right)^n \cdot \lambda}{d_e} \tag{16}$$

where *Gr* represents the Grashof number:

$$Gr = \frac{d_e^3 g \beta \Delta t}{\nu^2} \tag{17}$$

where: g - gravitational acceleration, m/s^2; ν - kinematical viscosity, m^2/s; Δt - difference temperature between crude oil and wall, °C; β - volumetric expansion coefficient, 1/°C, and [3]:

$$\beta = \frac{1}{2310 - 6340 d_4^{20} + 5965 (d_4^{20})^2 - t} \tag{18}$$

In equation (16) the physically properties are for the crude oil, and they take at average temperature between wall coil temperature and crude oil mean temperature.

Results and Discussions

In table 2 are presented the calculated values in the both situations, the actual situation and the proposed variant. They are necessary to justified the choice of the heating variant by technological point.

Table 2. Characteristics thermal values in actual and proposed variants

Characteristics	Value	Unit measure
Heat flow necessary for increase crude oil temperature	9141660	kJ/h
Heat flow necessary for loss compensation	1820808	kJ/h
Total heat flow necessary to platform	10962468	kJ/h
Saturated steam enthalpy at t_s	2742	kJ/kg
Condensate enthalpy at t_s	376	kJ/kg
Gas oil enthalpy at 300 ºC	755	kJ/kg
Gas oil enthalpy at 150 ºC	329	kJ/kg
Steam mass flow rate	4636	kg/h
Gas oil mass flow rate	25754	kg/h
α_{etank}	5.8	$W/(m^2 \cdot {}^oC)$
Overall heat transfer coefficient for the steam - crude oil heat exchange		
Re	1961034	-
Pr	0.976	-
Nu	2896	-
α_i	46725	$W/(m^2 \cdot {}^oC)$
Exterior wall temperature of coil	120	ºC
Mean crude oil temperature into tank	0	ºC
Mean temperature wall - crude oil	60	ºC
Crude oil density at 60ºC	790	kg/m^3
Dynamic viscosity crude oil at 60ºC	$1.98 \cdot 10^{-3}$	kg/(m·s)
Volumetric expansion coefficient of crude oil	0.000972	1/ºC
Gr	62479053	-
Pr	31.2	-
Nu	113.5	-
α_e	206	$W/(m^2 \cdot {}^oC)$
k_{ed}	179	$W/(m^2 \cdot {}^oC)$
Overall heat transfer coefficient for the gas oil - crude oil heat exchange		
Re	65159	-
Pr	68.43	-
Nu	772	-
α_i	757	$W/(m^2 \cdot {}^oC)$
Exterior wall temperature of coil	225	ºC
Mean crude oil temperature in tank	0	ºC
Mean temperature wall-crude oil	113	ºC
Crude oil density at 113 ºC	740	kg/m^3
Dynamic viscosity crude oil at 113 ºC	$1.27 \cdot 10^{-3}$	kg/(m·s)
Volumetric expansion coefficient of crude oil	0.00102	1/ºC
Gr	133015542	-
Pr	20	-
Nu	214.3	-
α_e	389	$W/(m^2 \cdot {}^oC)$
k_{ed}	243	$W/(m^2 \cdot {}^oC)$

Conclusions

The proposed variant for heating systems in crude oil pumping station using gas oil is more advantageous than heating system with low pressure saturated steam. The gas oil flow rate is very higher than steam flow rate in proposed variant. Using the gas oil heating system leads to the decrease of the heat transfer area, to the increase the logarithmic mean temperature difference between crude oil and heating gas oil and to the increase the overall heat transfer coefficient. Also, the proposed variant is advantageous because the gas oil is recirculated and in actual case the condensate is discharged into channel.

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Sisteme de încălzire într-o staţie de pompare a ţiţeiului. Studiu de caz

Rezumat

Procedura utilizată pentru transportul ţiţeiului este pomparea acestuia după preîncălzire la o temperaturi de până la 70 ºC cu abur de joasă presiune. În această lucrare se propune înlocuirea sistemului actual de preîncălzire a ţiţeiului, într-o staţie de pompare,cu abur saturat de 4 bar şi 150 ºC cu un agent termic recirculat şi anume motorină caldă. Încălzirea cu motorină este mult mai avantajoasă întrucât se obţine o creştere a temperaturii medii între ţiţei şi motorină, ceea ce conduce la o reducere a ariei de transfer de căldură necesare şi la creştere a coeficientului global de transfer de căldură.