Analysis of The Possibilities for Reducing Water Vapor Consumption in Oil Refineries by Improving the Condensate Separation System

Konstantin Kostov, Ivan Denev, and Dimitar Dinkov

***Abstract* - It is known that in oil refineries, water vapor is the most used heat carrier, which is transported to consumers through a steam transmission network and occupies a significant share in their energy balance. From this point of view, any organizational or technical measure leading to a reduction in steam consumption can be considered an economic and energy-efficient solution. Of significant interest is the consumption of steam, because there is the greatest potential for the implementation of energy-saving measures. The required steam parameters for each specific installation are different, but the main reason for using this technology is that refineries have one main source of thermal energy that must supply steam to consumers. The article discusses and analyses the factors related to the possibility of reducing water vapor consumption in oil refineries by improving the condensate separation system. The technical feasibility and economic expediency of the replacement of old and the integration of new energy-saving technological units from the steam-condensation plant of an oil refinery have been assessed. The goal is to achieve a reduced consumption of steam for energy, technological and auxiliary purposes, which are a prerequisite for realizing energy savings and reducing energy costs. The scientific novelty is demonstrated through the proposal of new ways of organizing the work of the steam-condensation economy, with the aim of achieving cleaner production and achieving high energy efficiency of the considered oil refinery.**

***Keywords* – Condensate separation system, oil refinery, reducing water vapor consumption, energy saving measures.**

INTRODUCTION

The effective transformation and use of energy, from national priority in the field of energy, is already considered as a fundamental prerequisite for sustainable economic growth by the management teams managing the oil refineries. For Bulgaria, as a country poor in primary energy resources, in particular oil, which is provided by imports, the effective functioning of the established oil refining industry, accompanied by an increase in the energy efficiency of the installations, can lead to the optimization of the costs of primary energy sources and improve the external trade balance of the country [1], [2], [3]. Increasing energy efficiency requires a complex solution of a set of technical, economic and organizational tasks while minimizing the costs incurred to achieve this goal [4], [5], [6]. The Directives of the European Parliament and of the Council, on energy efficiency, address the need to increase energy efficiency in the Union to achieve a reduction in final energy consumption of at least 11.7% in 2030 compared to energy consumption projections for 2030 made in 2020. The introduced legal framework aims to accelerate the development and dissemination of innovative technological solutions, with the aim of improving the competitiveness of industry in the European Union and environmental protection. The multiple technological units interconnected, the long production chain and facing the global and increasingly intense market competition, for the sustainable development of oil refineries, it is necessary to save energy as much as possible. Since refineries are vital not only in the oil and gas industry, but also in many other industries, the high value-added products they produce are essential to many sectors of the economy and end users. Faced with the challenges of responding to the significant transformation of market demand and increasingly stringent environmental regulations, the oil refining industry is committed to qualitatively exploring the associativity between material, energy and emission flows.

The modern structure of the energy economy of oil refineries is a complex conglomeration of interconnected facilities for the production, distribution and consumption of steam, fuels, electricity and hot water. Since they are located on a relatively large area, with a large and interconnected energy structure of long steam pipelines, the consumption of steam is of significant interest, because there is the greatest potential for the implementation of energy-saving projects - starting with the power part (the different power steam lines) and ended with condensate separation.

The purpose of this publication is, based on a review of the literature published so far and after analysing some of the studies, to identify several possible ways to improve the condensate separation system, leading to a redistribution of energy resources and serving to increase energy efficiency and economic profitability of the steam-condensation economy of oil refineries.

SUBSTANTIVE PART

The structure of the oil refineries is determined by the market demand of the various oil derivatives [7], [8], [9]. In general, the plant is a classic refinery, with the differences being in the specific set of installations depending on the depth of oil processing. The set of different technological installations, depending on the specific configuration, is

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organized in such a way that each oil refinery can produce different types of products and semi-finished products in certain ratios. In oil refineries, depending on the organization of the technological process, thermal engineering and power systems of different nature are used. The classic scheme is by using water vapor as a heat carrier, brought to the individual productions through a heat transfer network. For modern powerful oil refineries, it is most profitable and economically expedient to use thermal power plants (CHP) as a source of energy. The use of steam with increased parameters in front of the turbines contributes to a significant increase in the efficiency of combined heat and power plants.

The energy economy of oil refineries is a complex conglomeration of interconnected facilities for the production, distribution and consumption of fuels, electricity and heat. fig. 1 shows a Sankey diagram of a classical oil refinery with a complex Nelson index of 8.9 [10].

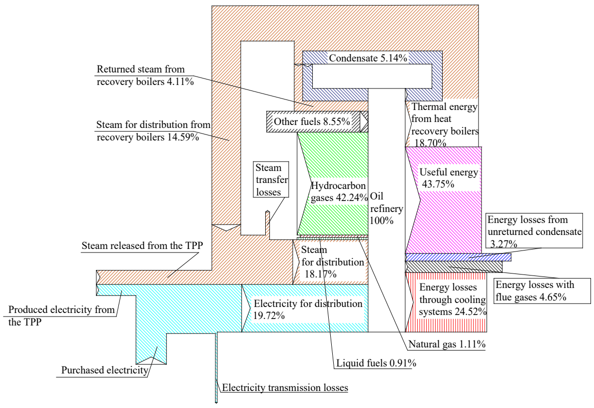

Fig. 1. Sankey diagram of a classical oil refinery

From the analysis of the diagram, the consumption of steam is of significant interest, because there is the greatest potential for the implementation of energy-saving projects - starting from the power part (the different power steam pipelines) and ending with the condensate separation. Steam is consumed everywhere for a wide variety of technological and auxiliary purposes. The main part is steam with a conditional pressure of 1.0 [MPa], which, if necessary, is throttled to lower parameters on site. For the higher temperature processes, it is provided by the thermal power plant, through the steam withdrawals of the steam turbines with a pressure of 1.5, 2.0 and rarely 4.0 [MPa]. Due to the large area, the steam highways are of considerable length and the heat losses during transmission are significant, especially in rainy weather [11].

A significant reserve for reducing heat consumption is possible by improving condensate separation in the drainage system and technological devices with subsequent collection and transportation of condensate to the thermal power plant [12], [13].

It must be said unequivocally that there are no universal condensate separators, that is, there is always an optimal solution for each technological scheme. In order to find, the existing options should be considered with their features. It is known that there are three fundamentally different types of condensate separators [14]:

- Thermostatic;
- Mechanical;
- Thermodynamic.

It is important to note that none of the mentioned constructions has absolute advantages over the others. The type and size of the condensate separator is selected by the specifics in which the heat exchange equipment works. In the considered oil refinery, all varieties are used to varying degrees. Mechanical condensate separators with inverse piston have prevailed. It should be noted that when the condensate separator is connected to a condensate drain line, it is very difficult to determine whether and to what extent it is working (fig. 2). In fig. 3 shows a scheme in which the fitting is difficult to access and is not connected to a condensation drain line. The analysis of whether the facility is working is carried out by a trained specialist with a stethoscope or by means of a thermal imaging camera. In the considered oil refinery, contrary to all theoretical recommendations, the practice is that the condensate compartments be installed by means of a tie to the condensate collection system. Thus, a certain amount of condensate is "sacrificed", but a reliable visual control of the operation of the condensate separator is guaranteed and the reliability of the steam supply is guaranteed. The main reasons for the occurrence of accidents in steam-condensate systems are related to inadmissible exceeding of the limit parameters of pressure and temperature, due to aging and used resource of time. Damages are usually associated with coolant breaks due to cracks, broken welds or failure of membranes, gaskets, springs in control and regulating valves, capsules and lever mechanisms in condensate pans.

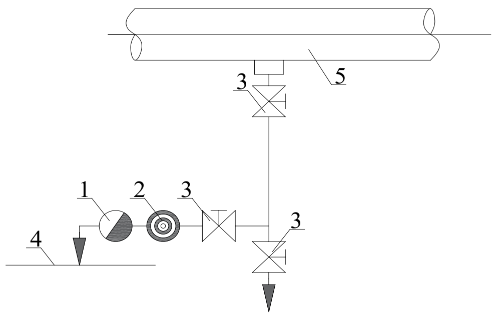

Fig. 2. Condensate separator connection diagram in the presence of a condensate pipe and access to the fittings; 1-condensate separator; 2-filter; 3-taps; 4-condensate line; 5-steam pipe.

The issue of efficient utilization of the heat of the steam is not reduced only to the condensation departments, but to the overall organization of the steam-condensation economy. It concerns the complex of technical facilities for steam supply and condensate collection [15], [16], [17].

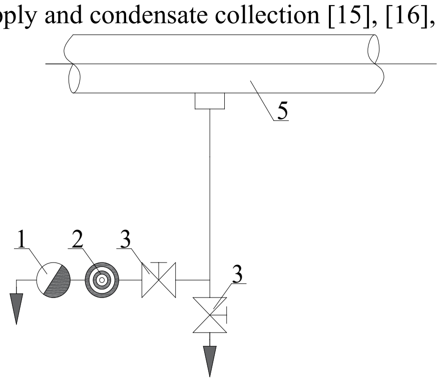

Fig. 3. Condensate separator connection diagram when the fittings are difficult to access; 1-condensate separator; 2-filter; 3-taps; 5-steam pipe.

A very painful issue is the dispersion of heat consumers over a very large area, which is why it is not economically expedient to build condensation collecting facilities separately. It makes economic sense for such an investment only if the users are grouped in one place. The reconstruction of the older installations is complicated, because in the process of designing them, energy efficiency issues were not so relevant.

There are also certain problems with the organization of steam companion on heavy oil products. In recent years, their replacement with companions electrically heated has begun. They are easy to operate and allow automatic maintenance of the set temperature, staff prefer them and their economic efficiency is comparable to that of steam passengers. Their main disadvantage is that when the insulation is repaired, their power goes out without being noticed and only in winter, when heating is most needed, it is noticed that there is a problem that is difficult to solve. According to the original construction concept of the oil refinery, the condensate was collected in four condensing stations operating at atmospheric pressure, from where it was individually returned to the thermal power plant. Since the final condensate temperature is the controlling parameter, the expansion of secondary steam is limited by cooling with desalinated water. Hourly laboratory control easily locates which station is contaminated and the specific pollutant is released to the drain.

RESULTS

Innovations are possible in the steam condensate system of the considered oil refinery, three of which, due to the significant economic effect, deserve serious attention and a thorough technical and economic analysis. It is envisaged to introduce cascade schemes to recover the heat of the high-pressure condensate through separators and release the separated steam at a lower pressure for re-use. In fig. 4 shows such a separator with the adjacent fittings, and in fig. 5 scheme of binding it with users.

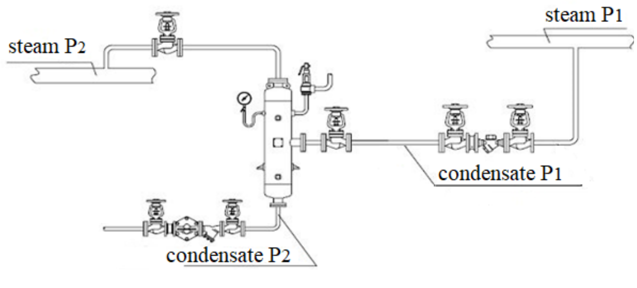

Fig. 4. Separator with adjacent fittings

The proposed scheme allows maximum use of the heat from the condensate with high steam parameters (P1=1.5 MPa) and the use of self-generated secondary boiling steam with fixed pressure and temperature values. The stopping, regulating, measuring and safety fittings of the system are standard products with the corresponding accuracy class and connection size, the steam pipes are made of steel seamless pipes with thermal insulation, and the separator is a steel cylinder with epileptic bottoms. Energy flows are clearly structured and directed. In case of a shortage of steam, the system will automatically receive the missing quantity from the inter-shop collector with a steam pressure of P=0.35 MPa. On the condensate side, the circuit prevents condensate from entering the steam branch, thereby minimizing the possibility of water hammer. After the implementation of the proposed solutions, the adjustment of heat exchange equipment during start-up and in the process of changing technological modes is significantly simplified.

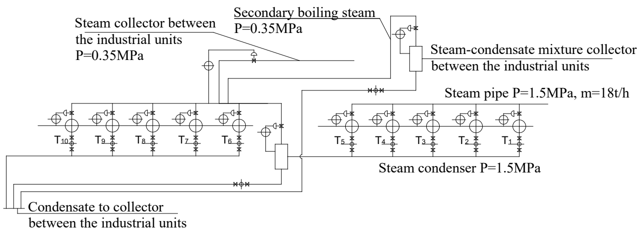

Fig. 5. Connection diagram of a separator with steam consumers

The separator can be modelled mathematically by making mass and energy balances as follows:

$$m_1 - m_2 - m_s = 0 \quad (1)$$

$$m_1 . h_1 - m_2 . h_2 - m_s . h_s = 0 \quad (2)$$

where are: m_1, *[kg/s]* is the condensate mass flow rate at the separator inlet; m_2, *[kg/s]* is the condensate mass flow rate at the separator outlet; m_s, *[kg/s]* is the mass flow rate of the steam produced in the separator; h_1, *[KJ/Kg]* is the condensate enthalpy at the separator inlet; h_2, *[KJ/Kg]* is the condensate enthalpy at the outlet of the separator; h_s *[KJ/Kg]* is the enthalpy of the separated secondary steam.

From the joint solution of equations (1) and (2), the amount of separated steam is obtained:

$$m_s = m_1 . (h_1 - h_2) / (h_s - h_2) \quad (3)$$

Depending on the parameters, the amount of separated steam is in the order of 6 – 10% of the mass flow rate of the condensate at the separator inlet, which at 8000 hours of annual usage gives a serious saving. The indicated hours of annual use are related to the uninterrupted operation of the facilities, with a time of the year for prevention and repair activities.

Another effective way to solve the problem of utilization of the low-potential heat of the steam and condensate is to increase the pressure and temperature of the waste steam and the steam from the secondary evaporation to technologically acceptable parameters by means of steam jet compressors. The steam jet compressor is essentially a steam ejector in which, through an injection process, kinetic energy is transferred from one steam stream to another, by way of their mixing. As a result, at the expense of a certain amount of high-potential steam, the temperature and pressure of the low-potential steam sucked in by the ejector are increased to the required values. The use of steam jet compressors has an advantage over other methods because it does not require special capital investments and significant changes in technological schemes. The processes in all devices of this type are described by three laws as follows:

1. Law of conservation of energy:

$$h_p + u . h_н = (1+u) h_c \quad (4)$$

Where are: h_p*,[kJ/ Kg]* is the enthalpy of the working steam; $h_н$*,[kJ/ Kg]* is the enthalpy of the injected steam; h_c*,[kJ/ Kg]* is the enthalpy of the mixed steam; $u = m_н / m_p$ – injection ratio.

2. Law of Conservation of Mass:

$$m_c = m_p + m_н \tag{5}$$

Where are: m_c, m_p *u* $m_н$ are the mass costs of the mixed, working, and injected streams.

3. Law of conservation of impulse:

$$I_{p1} + I_{н1} = \int pdf + I_{c3} \tag{6}$$

Where are: I_{p1} *and* $I_{н1}$ are the pulses of the working and injected flow in the inlet section of the mixing chamber; I_{c3} is the impulse of the mixed flow in the exit section of the mixing chamber; $\int pdf$ is the integral value of the impulse along the side surface of the mixing chamber between sections 1-1 and n-n (Fig. 6). In the case of a cylindrical chamber $\int pdf = 0$.

The impulse at any section is:

$$I = m.w + p.f \tag{7}$$

where are: *m, [kg/s]* – mass expenditure; *w, [m/s]* – speed; *P, [Pa]* – pressure; *f, [m²]* – section.

As a jet compressor suitable for the utilization of low-potential steam, ejectors having a high degree of expansion are suitable ($p_p/p_c \geq 2.5$) and a moderate degree of compression ($p_c/p_н = 1.2 \div 2.5$).

A typical scheme of using a jet compressor for vapor recovery above a condensate tank is shown in Figure 7. The effectiveness of the proposed scheme is possible in solving the problem using low-potential fuel and condensate. A scheme has been proposed that allows the temperature to be adjusted to the temperature of the exhaust steam and the evaporated steam to technologically acceptable parameters.

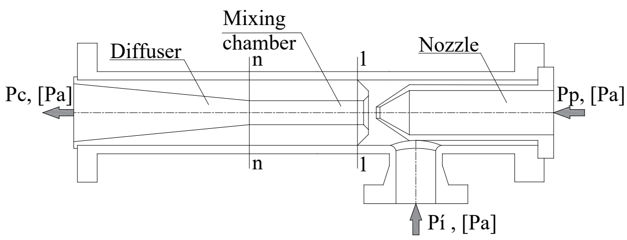

Fig. 6. Jet compressor

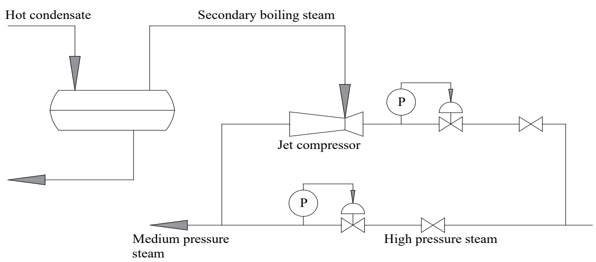

Fig. 7. Scheme of use of a jet compressor

Recently, developments from leading global companies in the field of steam-condensate economy have appeared on the market, enabling the utilization of condensate for remote single users [18]. It concerns local condensing stations with pumps with steam displacement of the condensate. There is no need for power supply with them, which is a big advantage. The high pressure with which the condensate is pushed out allows considerable distances to be overcome.

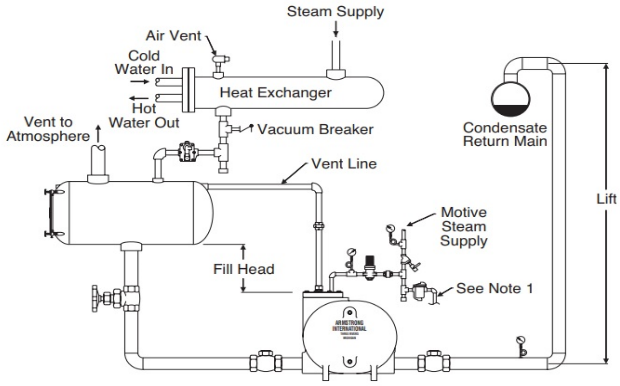

Fig. 8. Local condensate station with steam displacement of the condensate [18]

However, the need to build a new condensate pipeline remains and the question comes down to an economic assessment of the feasibility of the investment. It is an undoubted advantage if the situation allows the grouping of several local condensing stations in one condensing line, because the parallel operation of several such stations in one condensing line is possible if non-return valves are installed after each of them. Often on the field there are pipes for light oil products abandoned due to technological reasons, which can be cleaned by steaming and used to transfer the condensate along part of the route, thus reducing the investment. There is a positive practice in this regard in the oil refinery under consideration. Fig. 8 shows the appearance and flow chart of a local condensate station with steam displacement of the condensate.

A considerable amount of heat in oil refineries is used for technological needs of various installations. It concerns the stripping processes in some columns, the steam for the regeneration of the catalysts and in the special furnaces for the production of hydrogen. This steam consumption is a priority technology focus and is beyond the scope of this publication. As for the plant's heating and domestic water supply, there are also certain reserves and heat consumption that can be reduced. Renovation of the building stock, modernization of heating and domestic hot water installations are good examples that can be implemented. Controversial in economic terms is the question of which heat carrier to use for heating. The specificity of each oil refinery requires a specific solution. In principle, if the combine has its own thermal power plant, it is better to build water heating, powered by the steam extraction of the turbine. If the plant is located on a smaller area and does not have its own thermal power plant with electricity production, the use of steam as a heat carrier for domestic hot heat supply seems appropriate. Both heat carriers are used in the considered refinery. Most of the administrative and production buildings are heated with hot water provided by the boiler system of the TPP. Steam is used for heating single buildings further away from waterways. Condensate from these users is usually not returned because the construction of a condensate farm is unprofitable due to the small quantities and seasonal consumption.

CONCLUSION

The proposed alternative solutions depend on the operation of the steam condensing installation and their application is related to the correct choice and mode of operation of the equipment. This applies above all to the type of condensation compartments for the specific technological positions, to the operation of the drainage system of the main steam pipelines and to the condensation farm as a whole. The transition to cascading condensate heat recovery through separators and closed condensate return systems is a goal.

Steam pressurization systems using jet compressors increase the energy efficiency of heat supply in oil refineries, bringing low-potential steam to parameters acceptable for technological use. The emergence of new technological solutions for the return of condensate from remote consumers by means of local condensing stations with steam displacement of the condensate seems to be an attractive solution. Water vapor is the most used heat carrier in the refinery. From the Sankey diagram presented in Figure 1, it can be seen that steam occupies a significant share in the energy balance. At the same time, the cost of heat transferred by water vapor is constantly increasing. From this point of view, any organizational or technical measure leading to a reduction in steam consumption can be considered an economic and attractive solution.

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