Efficiency improvement of oil and gas facilities power supply systems

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Abstract. Oil and gas refineries have a significant impact on the environment. The paper considers the main harmful substances formed as a result of the manufacturing processes occurring at the enterprises of the given industry and having a negative impact on the atmosphere, hydrosphere and lithosphere. The most significant sources of contaminants have been identified. The paper presents the most promising approaches described by both domestic and foreign authors for developing environmentally friendly, low-waste productions through the complex use of all the components of raw materials, energy resources and industrial wastes to ensure the required processing conditions. The authors developed and proposed the scheme of the power plant comprising the integrated waste disposal in oil and gas refineries, aimed at combining the processes of the thermal utilization of industrial wastes (combustible gases, effluents) with the processes of gasification and energy production (electricity, thermal energy, synthesis gas, water supply), reducing the specific consumption of the fuel gas for the energy resources production and waste disposal, improving the environmental safety and reliability of the facility.

Keywords: environmental safety, oil and gas industry, thermal neutralization, cogeneration, gasification.

1. Introduction
Currently, one of the priority areas for the oil and gas refineries development is environmental safety, technological and energy reliability of facilities. Environmental safety considered as a matter of great importance is assessed primarily in terms of the absence of harm to the population and ecological environment, which is relevant especially for the hydrocarbon processing plants usually located in the urban areas, in close proximity to rivers and large water bodies. These facilities are the sources of the environmental impact caused by the influence of wastes of various hazard classes on the atmosphere, hydrosphere and lithosphere.

The main harmful substances entering the atmosphere at the oil refineries, gas processing plants and petrochemical plants are saturated hydrocarbons, carbon and nitrogen oxides, sulphur compounds, phenol, ammonia and a large number of carcinogens. Table 1 shows the harmful substances entering the atmosphere and their main sources [1, 2, 3, 4].
Table 1. Atmospheric emissions from oil refineries.

| Atmospheric contamination sources                        | Discharged substances                                      |
|-----------------------------------------------------------|------------------------------------------------------------|
| Tank farm                                                 | Hydrocarbons, hydrogen sulphide                             |
| Oil cargo piers                                           | Hydrocarbons, hydrogen sulphide                             |
| Cooling towers and oil separation plants                  | Hydrocarbons, hydrogen sulphide                             |
| Treatment facilities                                     | Hydrocarbons, hydrogen sulphide                             |
| Exhaust stack                                            | Carbon, nitrogen and sulphur oxides                         |
| Flare systems                                             | Hydrocarbons, carbon, nitrogen and sulphur oxides           |
| Leakages, seal failures                                   | Hydrocarbons                                               |
| Emissions from facilities:                                |                                                            |
| – CDU                                                     | Hydrocarbons, hydrogen sulphide                             |
| – Catalytic cracking                                      | Carbons, carbon and sulphur oxides, fine particles of catalyst |
| – Sulphuric acid treatment of paraffins and oils           | Sulphur compounds                                          |
| – Bitumen production                                      | Hydrocarbons, carbon oxides, water, carcinogenic substances |

The bulk of emissions contain hydrocarbons 68-72%, sulphur oxides 12-16%, nitrogen oxides 1-2.5%, carbon oxides 12-18%. Based on the atmospheric analysis data, these substances cause the increased environmental pollution in the area of the hydrocarbon processing plant location.

The nature of the oil refineries wastewater pollution depends on a number of the processing factors which primarily include the processed raw materials composition, the type of the enterprise, the production structure, the processing equipment condition, the units connection and treatment facilities operation optimality.

The sewage system at the operating oil refineries provides for:

- the open drain system for the oil contaminated wastewater disposal and treatment;
- the system for the discharge and treatment of the emulsion and chemicals-contaminated wastewater.

The specific amount of the wastewater per 1 ton of the processed raw materials ($m^3/t$ of oil) generated at the enterprises varies depending on their type: fuel enterprises (the first system is from 0.23 to 0.25, the second system is from 0.1 to 0.2); fuel and oil enterprises (the first system is from 0.4 to 1.5, the second system is from 0.1 to 0.25); petrochemical enterprises (the first system is from 2 to 3, the second system is from 1.2 to 2.0) [5, 6]. The main part of the polluted substances entering the surface water bodies in wastewater is chlorides and sulphates, and a significant proportion is typical for the oil effluents. The atmospheric emissions adsorption and solid wastes disposal also affect the soil contamination [7, 8].

In addition to the impact on the environment, the negative factors of the Russian oil refineries operation include a relatively large percentage (on average 1%) of irretrievable losses of oil and petroleum products. Losses due to evaporation (oil and petroleum products storage tanks and reservoirs, liquid surfaces in oil separators, handling works, equipment leakages, other leaks), flares losses, losses when burning coke with a catalyst, leaks to the ground, CDU low-potential gases losses, bitumen plants losses, waste water losses.

A serious environmental impact combined with losses influencing the efficiency of oil refinery facilities sets an objective of a comprehensive problems solution based on the innovative approaches and technologies.

2. Problem statement

A widespread approach traditionally used at the domestic oil and gas refineries to reduce the environmental pollution is the treatment facilities construction. This approach can be considered relatively appropriate only for the majority of the existing industry facilities to adapt them to
constantly increasing environmental requirements, as it involves the significant capital and operating costs, while insufficiently reducing the tangible indicators of wastes. The current priority of solving the problem of environmental safety and efficient use of energy resources (ER) including the secondary energy resources (SER) should be considered the development of the environmentally friendly, low-waste productions through the complex use of all the components of raw materials, ER and industrial wastes to ensure the required processing conditions. Domestic and foreign authors identify the following approaches to achieve this goal [9-14]:

- the integrated use and advanced processing of raw materials implementing the resource-saving technologies and reducing the specific consumption of raw materials, ER, reagents per unit of production;
- the optimization of the fuel and energy resources (FER) utilization through the increased capacity, energy and technological integration, the continuous processing implementation;
- the design and implementation of the low-waste processing; the design and implementation of the closed-loop water systems; providing the high operational reliability at all stages of the object's life cycle; ensuring a high quality of commodity products;
- the application of the alternative sources of raw materials and energy.

In accordance with the identified issues facing the industry facilities based on the data of the studies and engineering solutions conducted by the authors [15, 16], the power plant scheme comprising the integrated waste disposal in oil and gas refineries [17], which implements a broad range of the mentioned above approaches to the environmental cleanliness of the industry facilities, was developed and patented.

3. Theory

The developed scheme [17] belongs to the field of the cogeneration of the heat and electric energy, water supply, industrial waste disposal and can be used at the oil and gas refineries to improve their efficiency and environmental safety. Figure 1 shows the schematic diagram. The engineering problem which should be solved by implementing the developed scheme is improving the energy efficiency and environmental safety of the power plant of the oil and gas refinery.

![Schematic diagram of the power plant comprising the integrated waste disposal in oil and gas refineries.](image)
Heavy oil residues, compressed air (oxygen) and blow steam are fed to the gasification unit (the installed gas generator). The resulting high-temperature synthesis gas is sent to the waste-heat steam boiler 1, where it is cooled by giving heat for producing vapour and overheating the water vapour followed by feeding into the neutralization unit as fuel gas.

Preheated liquid wastes (industrial effluents, household wastes, drains) as well as gaseous wastes (low-potential hydrocarbon gases), and if needed fuel gas are supplied to the neutralization unit for thermal neutralization. Due to the high temperatures and optimal design of the neutralization unit, a complete thermal treatment of harmful substances contained in wastes occurs. The resulting solid residue refers to a low class of hazard.

The flue gas flow containing water vapour from the neutralized effluents and from the hydrocarbon fuel combustion after a neutralization furnace passes through the gas conduit into the waste-heat boiler 2. Then the cooled flue gas flow is sent into the chimney. Besides, a reagent input device is provided for absorbing the sulphur oxides from the flue gas flows. A nozzle for supplying the cooled condensate water is placed in the chimney to humidify and cool flue gases and to condensate water vapour out of them. Condensed water is fed to the water supply unit, where is subject to the necessary stages of purification and cooling. The resulting condensate does not contain mineral impurities and salts and is sent to fill and feed the water path of waste boilers and heat supply network without additional purification. Moreover, the water quality makes it possible to supply it to the drinking water treatment plant.

The heat of the flue gas flows and synthesis gas is recovered in the waste-heat boilers, which allows to produce the superheated water vapour used in the cogeneration turbines of the STP unit, while part of the steam is utilized for the processing requirements.

The proposed plant can improve the energy efficiency and environmental safety of generating heat, electricity and water supply, and can be integrated into the energy mix (EM) of oil and gas refineries and combined with various manufacturing processes.

Using the combustible gaseous and liquid-phase wastes, synthesis gas produced in the gasification unit as fuel in the neutralization unit contributes to reducing the fuel gas specific consumption for the cogeneration and wastes disposal processes. The scheme energy efficiency improvement is also provided by the flue gases heat recovery and through the use of the high-temperature synthesis gas flow heat.

Thermal neutralization of gaseous wastes, industrial effluents, flushing water, drainage (in this case the lithosphere and hydrosphere pollution during underground storage is avoided) determines the environmental safety of the scheme. Furthermore, the reagent input device placed in the neutralization furnace chimney makes it possible to almost completely avoid atmospheric pollution caused by sulphur oxides during thermal treatment of gaseous wastes and household effluents.

The reliability improvement by extending the continuous operation life of the proposed scheme is provided by the highly reliable, steam supply independent sources of the cogeneration turbines with two waste-heat boilers consuming heat energy from various sources. Thus, the technical result of implementing the proposed scheme is combining the manufacturing processes of the thermal utilization of industrial wastes (combustible gases, effluents) with the processes of gasification and energy production (electricity, thermal energy, synthesis gas, water supply), reducing the specific consumption of the fuel gas for the energy resources production and wastes disposal, improving the environmental safety and reliability of the scheme.

4. Numerical experiments results
The conducted efficiency analysis of the alternative energy sources [18-22] and scheme [17] based on the proposed performance indicators system [23] including the energy, technical and economic performance indicators taking into account the influencing factors uncertainty [24, 25] made it possible to perform a comparative assessment of the scheme integration effectiveness with the EM of the operating domestic oil refinery producing fuel and oil with an average capacity of 6 million tons per year, compared with the conventional power supply scheme.

The energy efficiency indices \(I_{\text{eff}}\) used to assess the degree of the process efficiency and taking into account a complex engineering topology have been calculated according to the following formula:
\[ I_{ef} = \frac{\sum_{i=n} P_{i,j} \cdot E_{sp,j}^S}{\sum E_{sp}^A}, \]  

(1)

where \( E_{sp}^S \) is the standard indicator of the energy intensity of the process or unit under consideration; \( E_{sp}^A \) is the actual energy intensity indicator; \( P_{i,j} \) is the output of \( j \) products of \( i \) manufacturing process for the selected period; \( E_{sp,j} \) is the standard energy consumption of the \( j \) products.

The calculated energy efficiency indices \( (I_{ef}) \) of the most energy-intensive industrial processes in the base case before implementing the proposed scheme and after its integration with the energy mix of the facility are presented in Table 2.

**Table 2.** Energy efficiency index of the particular processes before and after implementing the power plants with integrated energy resources generation into the EM.

| The manufacturing process | The primary processing | Thermal cracking | Catalytic cracking |
|---------------------------|------------------------|------------------|-------------------|
| Energy efficiency index*  | \( I_f = \frac{0.65 - 0.89}{0.75 - 0.91} \) | \( I_f = \frac{0.8 - 0.98}{0.9 - 1.1} \) | \( I_f = \frac{0.75 - 0.83}{0.85 - 0.98} \) |

*The numerator value is before retrofitting, while the denominator value is after retrofitting.

Furthermore, the options of the energy supply systems for the particular production facilities of the enterprise based on the proposed scheme including the calculation of the performance indexes have been developed. Net present value (integral effect \( E_\Sigma \)) defined as the sum of the current effects for the analyzed period, presented to the initial step is:

\[ NPV = E_\Sigma = \sum_{t=0}^{T} (R_t - C_t^*) \cdot \alpha_t, \]  

(2)

where \( R_t \) is the results achieved at the \( t \)th step of the calculation; \( C_t^* \) are the costs at the same step; \( \alpha_t \) is the discount coefficient defined for the constant discount rate by the following equation:

\[ \alpha_t = (1 + E)^{-t}. \]  

(3)

The profitability index is the ratio of the net present effects sum to the amount of the capital investments:

\[ PI = K^{-1} \cdot \sum_{t=0}^{T} (R_t - C_t^*) \cdot \alpha_t. \]  

(4)

where \( K \) is the amount of the capital investments; \( C_t^* \) are the costs at the \( t \)th step (without capital investments).

Thus, a gas turbine GTE-6u, a waste-heat boiler KU-42 TKZ and a back pressure steam turbine P-2.7-4.5/0.6 KTZ have been considered as the basic energy supply option for the crude distillation unit with capacity of 3000 thousand tons per year:

- Power, MW:  
  - electric power .......................................................... 9.2  
  - heat power ............................................................. 14.2  
- Fuel consumption, toe t/h ........................................... 2.844  
- The profitability index dollar/dollar ................................ 1.286  
- Integral effect (over 10 years), USD million .................. 12.74
Power supply options of thermal cracking plants with a total raw material capacity of 1000 thousand tons per year based on a gas turbine power plant GTES-2.5 with a waste-heat boiler G-250 and a drive condensing turbine K-2.5-3.4 P have been proposed:

Power, MW:
- electric power .......................................................... 4.2
- heat power ................................................................. 8.0

Fuel consumption, toe t/h ................................................ 1.421
Integral effect (over 10 years), RUB million ........................ 4.66
Payback period, years ....................................................... no more than 5

In addition to the above data, according to the consolidated preliminary calculations, it was possible to define a specific consumption reduction of the fuel gas by 27-42% for the individual industries and minimization of the water consumption for the process needs.

5. Conclusions
1. The main harmful substances formed as a result of the manufacturing processes occurring at the oil refineries and having a negative impact on the atmosphere, hydrosphere and lithosphere have been considered. The most significant sources of contaminants have been identified.
2. The most promising approaches to improve the environmental safety and efficient use of energy resources at the industrial enterprises with practically closed manufacturing cycles are presented.
3. The developed innovative power plant scheme comprising the integrated waste disposal in oil and gas enterprises aimed at combining the processes of the thermal utilization of industrial wastes (combustible gases, effluents) with the processes of gasification and energy production (electricity, thermal energy, synthesis gas, water supply), reducing the specific consumption of the fuel gas for the energy resources production and waste disposal, improving the environmental safety and reliability of the facility was proposed.

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