Journal of Physics: Conference Series

PAPER • OPEN ACCESS

Methodological aspects of fuel performance system analysis at raw hydrocarbon processing plants

To cite this article: A V Kulbjakina and I V Dolotovskij 2018 *J. Phys.: Conf. Ser.* **944** 012068

Methodological aspects of fuel performance system analysis at raw hydrocarbon processing plants

A V Kulbjakina[1] and I V Dolotovskij[1]

[1] Yuri Gagarin State Technical University of Saratov (SSTU), 77 Politechnicheskaya street, Saratov 410054, Russia

Abstract. The article discusses the methodological aspects of fuel performance system analysis at raw hydrocarbon (RH) processing plants. Modern RH processing facilities are the major consumers of energy resources (ER) for their own needs. To reduce ER, including fuel consumption, and to develop rational fuel system structure are complex and relevant scientific tasks that can only be done using system analysis and complex system synthesis. In accordance with the principles of system analysis, the hierarchical structure of the fuel system, the block scheme for the synthesis of the most efficient alternative of the fuel system using mathematical models and the set of performance criteria have been developed on the main stages of the study. The results from the introduction of specific engineering solutions to develop their own energy supply sources for RH processing facilities have been provided.

1. Introduction
Modern raw hydrocarbon processing plants (RHPP) - gas, gas condensate, oil - are the major consumers of all energy resources (ER) for their own needs. The energy component in the final product cost reaches 11-15% with a negative trend of increase in recent years. Primary ERs for RHPP are fuel (liquid and gaseous), electric and thermal energy. On average, fuel consumption accounts for up to 60%, and electrical energy up to 40%. This distribution of primary ER consumption is related to the large amount of thermal energy produced in its own power engineering plants, thereby replacing consumption from a third-party source. The consumption of ER occurs in the technological system (TS) and the energy complex (EC) of the facility. The technological system is the basis for the formation of the EC and its subsystems, the bases of which are the heat technological, electrotechnological and fuel. The fuel system is characterized by the largest number of linkages with TS and external power supply systems.

2. Statement of problem
The solution of the problems of improving the efficiency of the RHPP fuel system and the synthesis of its optimal structure, taking into account all in-plant and external factors: *technological, operational, economic, environmental, climatic, organizational,* etc. can be only based on the system approach to study complex systems. The fuel system analysis is carried out in stages, including the development of a mathematical link between the original state of the system and its subsystems, as well as EC, TS, external energy systems at all levels of the hierarchy. The analysis also includes the efficiency assessment of the RHPP fuel structure, its comparing to alternatives.

3. Theory

3.1. The characteristics of the RHPP fuel systems
The main fuel users at RHPP are: fire engineering equipment, thermal waste treatment plants, flaring systems, boilers. To provide liquid or gaseous fuels, at the factories processing RH there is a fuel-handling facility, including fuel preparation shops, fuel loopback pipes with continuously circulating liquid fuel, with laid lines for separate technical facilities. There is also heat exchange equipment for the preheating of fuel before it is fed to the furnace burner. The principle scheme for generating and

consuming gas and liquid flows in the most general form for gas treatment plants (GTP) is shown in figure 1, for oil refinery plants (ORP) in figure 2.

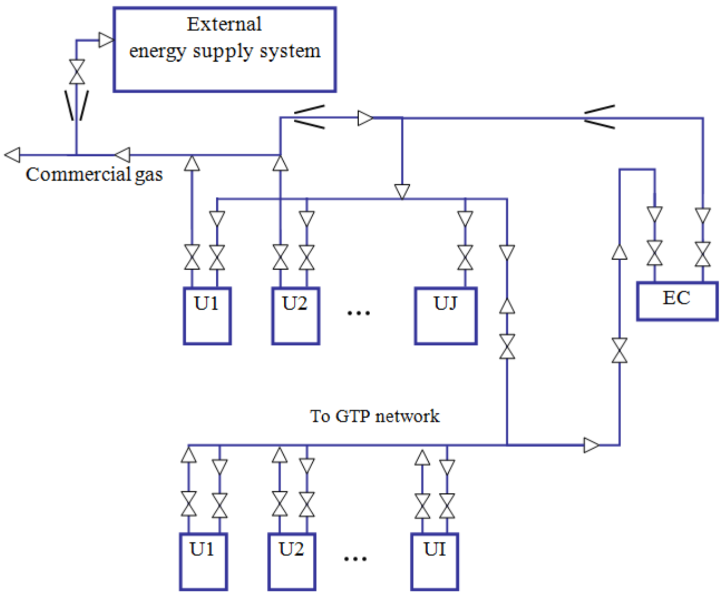

Figure 1. The principle scheme for generating and consuming gas flows at GTP: У1–УJ - gas plants; У1–УJ - gas condensate plants.

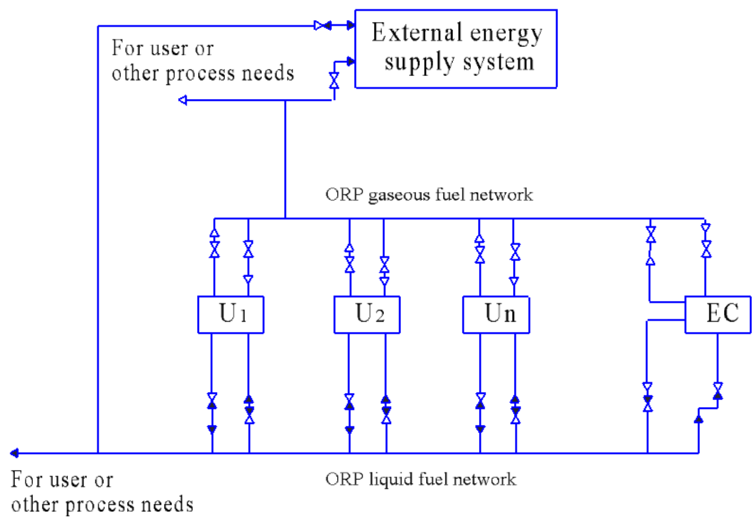

Figure 2. The principle scheme for generating and consuming gas and liquid flows at ORP: У1–Уn - oil refining units.

Despite the significant similarities in the process of GTP and ORP, their fuel supply systems have substantial differences. Thus, gas from the commercial gas network, as well as hydrocarbon gases obtained during the processing of raw materials, are the main fuel for GTP. The ORP has a large amount of own generation of liquid fuel, refinery gases, and the commercial gas is usually a third-party ER.
For the current domestic ORP, the percentage distribution of the fuel used in the main processes is shown in table 1.

Table 1. Percentage of fuel used in the ORP processes.

Technological process	Own gas,%	Natural gas,%	Fuel oil,%	Coke (conversed fuel),%
Primary distillation (crude vacuum unit)	75	15	10	-
Catalytic cracking	43	6	25	26
Hydrotreating	99.5	0.4	0.1	-
Thermal cracking	80	5	15	-

As it can be seen from the table, its own fuel (refinery gas, fuel oil and conversed fuel) accounts for a large share of the consumption, while the share of natural gas ranges from 0.5 to 20% for all technological processes. In this light, the scientific developments in maximizing the potential of combustible secondary energy resources (SER) that are in large quantities at RHPP are promising. They allow reducing the consumption of commercial or purchased fuel gas for the technological needs of the facility.

The analysis of ER consumption over the past few years reveals a trend of increasing specific consumption. This is due to objective factors such as: increasing RH processing yield, improving the quality of products produced; composition changing and increasing the volume of recycled RH; the introduction of secondary energy-intensive processes. On the other hand, there is a number of negative in-plant and external factors influencing on the absolute indexes and multiples of ER consumption. In-plant factors are: the outdated plant and the resulting low efficiency of energy-using and power generation equipment, the increased intensity of the processes; the low level of heat recovery and regeneration of the technological processes; ER losses. The most significant external factors can include the increased intensity in regional fuel and energy balances and the instability of electricity supply.

The improvement of RHPP fuel system efficiency and the synthesis of their optimum structures is possible with the integrated approach, based on the principles of system analysis. It makes internal and external connections between the facility, the systems and subsystems of RHPP, the external power systems in time variable dynamics, the most significant influencing factors.

3.2. The system analysis of RHPP fuel systems

The system analysis of the fuel system and its components involves the following stages: defining the structure of the object and its operating parameters: developing and calculating characteristics and efficiency factors; the identification of influential factors and their impact on modes of operation. The synthesis of the fuel system is primarily to define the principles underlying its operation, to develop a rational structure and the parameters of the fuel system; to model mathematically structure alternatives; to develop a set of engineering solutions to improve the efficiency of the fuel system.

The first point of RHPP fuel system analysis is to design its structure on the basis of block-hierarchical approach with complex deterministic relationships with ER and TS (figure 3). The analysis of the developed structure indicates that the fuel system is characterized by a large number of relationships with the TS and the heat engineering subsystem in a dynamic continuous ER consumption and generating process.

A formal description of the structure of the RHPP power engineering balance (figure 3), to solve the problems of improving the efficiency of the fuel system, represents the aggregation of multiple structure models:

N TS processing

$$P_{TS} = \left\{ P_{TS}^{1} ... P_{TS}^{N} \right\}; \tag{1}$$

M is EC subsystems

$$P_{EC} = \left\{ P_{EC}^{1} \ldots P_{EC}^{M} \right\}; \tag{2}$$

RHPP as a whole

$$RHPP = P_{TS} \cup P_{EC} \tag{3}$$

where $P_{TS}^{1} \ldots P_{TS}^{N}$ is the mathematical description of the structure of RH preparation and processing, waste recycling, conditioning and storage of intermediate and final technological flows, transportation of products;

$P_{EC}^{1} \ldots P_{EC}^{M}$ is the mathematical description of the structure of the EC subsystems that generate, transform, transport fuel, electricity, thermal energy, water, in-plant energy supplies.

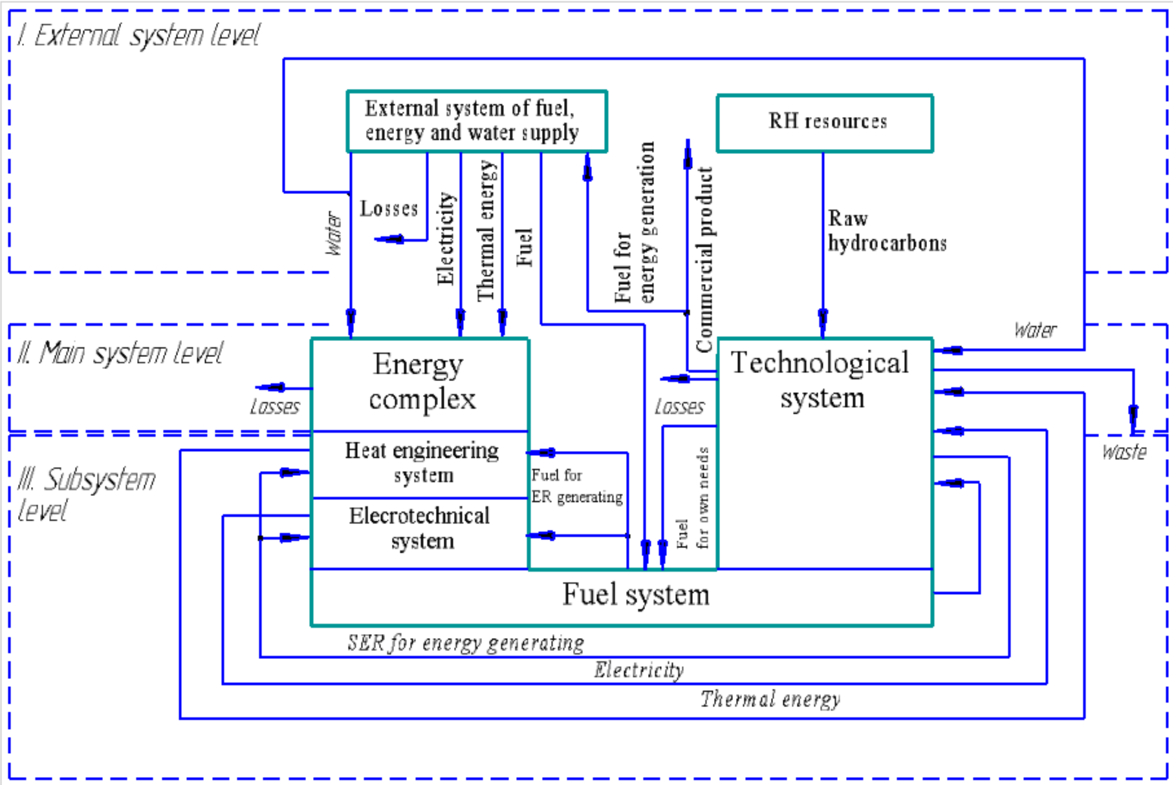

Figure 3. The scheme of RHPP power engineering balance at the hierarchical level of the external systems, the main plant systems and the subsystems.

The synthesis of a rational structure and definition of the operating modes of the RHPP fuel system on the basis of the system performance vector test:

$$\overline{U} = \sum_{i=1}^{n} \gamma_i \cdot \overline{u_i} \tag{4}$$

where $\overline{u_i}$ is the value of i efficiency criterion u_i assigned to its extreme value u_{extr} in the technical solution alternatives; $\overline{u_i} = u_i / u_{extr}$;

n is the number of partial performance criteria of solutions being developed to increase fuel energy efficiency;

γ_i are the vector elements of partial criteria relative importance (rank) factors.

The priority vector $W = (\gamma_1, \gamma_2, ..., \gamma_n)$ is determined by calculating the geometric mean of each matrix row.

$$\gamma_i^{/} = \sqrt[n]{\prod_{j=1}^{n} g_{ij}} \quad (5)$$

where g_{ij} is the element of *i* row in *j* column in the matrix of pairwise comparisons of private criteria. The elements of the priority vector are obtained by dividing by the sum of the geometric means

$$\gamma_i = \gamma_i^{/} \Big/ \sum_{i=1}^{n} \gamma_i^{/} \quad (6)$$

The criteria for the rationalization of balances as well as technical and economical for efficiency have been taken as partial one.
Mathematical models for calculating and optimizing the balances of the fuel system have been established on the basis of the developed fuel system structure, the set of performance indicators.

3.3. Mathematical modelling of RHPP fuel systems
In general terms, the mathematical model of the fuel system, depending on the influencing factors can be written:

$$\overline{Y} = \overline{F}(\overline{X}, T, \overline{D}, \overline{P}, \overline{O}, \tau), \quad (7)$$

where $\overline{Y}, \overline{X}$ is the vector of output and input variables, respectively;
$\overline{F}$ - the vector function of vector arguments $\overline{X}, \overline{D}, \overline{P}, \overline{O}$ and scalar argument τ (time); T - process topology; $\overline{D}$ - the vector of structural parameters; $\overline{P}$ - the vector of the technological parameters; $\overline{O}$ - the parameter vector of the element process mode.

The mathematical model of the fuel system efficiency, which is a quality indicator of its operation, is written in general terms as follows:

$$k = k(T, \overline{D}, \overline{P}, \overline{O}, \overline{S}, \tau), \quad (8)$$

where k is the efficiency coefficient, $\overline{S}$ is the vector of system properties;

The use of mathematical modelling, the strategy for applying the principles and methods of system analysis, synthesis and optimization to solve the problems of synthesizing the optimum structure of the fuel system are based on the mathematical models of the fuel system (7, 8) (Figure 4). The use of mathematical models with specified vector of input parameters X and chosen efficiency criteria with required accuracy allows defining output variables Y, evaluating the system properties and values of the fuel system efficiency.
Thus, the task of synthesizing the optimum fuel system is a boundary value problem that will determine the process topology of the system, the parameters of its elements, the optimum parameters for its functioning in accordance with selected efficiency factors.

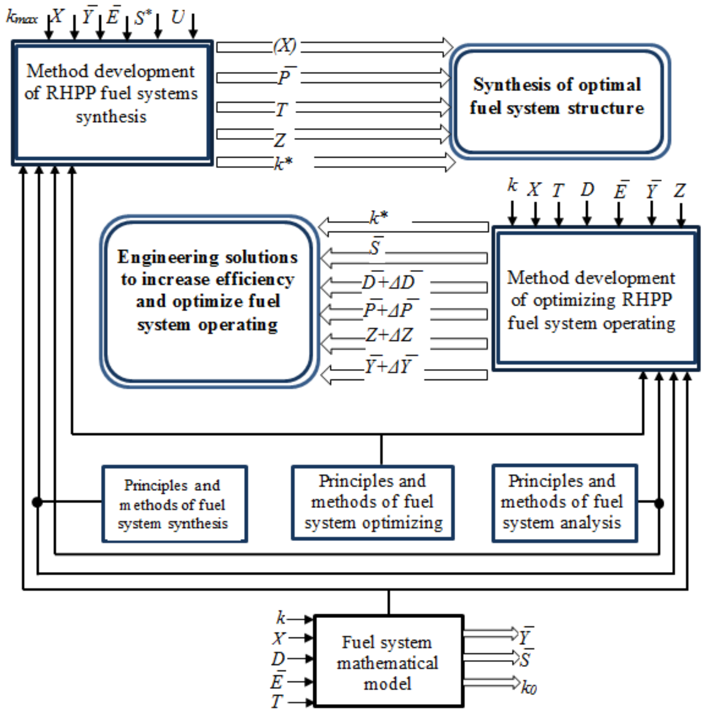

Figure 4. Block diagram of the synthesis of the fuel structure using mathematical modelling.

$\overline{E}$ - environmental vector; S^* - the extreme (favorable) values of system properties; U -modern-level hardware; k_0 - some value of the efficiency test; k^* - optimum value of the efficiency coefficient; $k_{\max}{}^*$ - the extreme optimum value of the efficiency coefficient of the existing fuel systems; Δ-variation of vector change.

4. Results of numerical experiments

The considered theoretical aspects of system analysis allowed developing a number of technical solutions for optimizing the fuel system structure as a part of RHPP EC. For RH production, processing and storage plants, the system of fuel, energy and water supply with maximum recycling of hot waste and effluents was proposed [1].

Also, options for the energy supply systems of individual units of the large RHPP with house set on the basis of combined cycle power plants have been developed [2, 3]. For example, for integrated oil refining unit GK-3 with productivity 3000000 t/y, gas turbine GTE-6u, KU-42 TKZ, *R-2.7-4.5/0.6 KTZ* was considered for energy supply:

Capacity, MW:	
• electric	9.2
• -thermal	14.2
Fuel consumption, ton of reference fuel/h	2.844
Profitability index rub/rub	1.963
Integral effect (for 10 years), mln. rub.	990
Payback period, years	no more than 5

Options for a refinery tankage with the units RBS -5000 located in the medium climatic zone have been proposed [4]. The feed capacity is 9.1 million t/y by *gas turbine power-plant* GTES-2.5.*Exhaust heat boiler* Г-250 *Drive condensing turbine* К-2,5-3,4П:

Capacity, MW:	
• electric	4.2
• thermal	8.0
Fuel consumption, ton of reference fuel/h.	1.393
Integral effect (for 10 years), mln. rub.	372.9
Payback period, years	~4,0

5. Result discussion

House set options were evaluated in accordance with developed set of efficiency criteria. The data analysis allows concluding about their use as part of RHPP EC, a variety of process topology. For individual processes in RHPP, the application of the proposed energy supply options with the optimization of the fuel system results in a significant economic impact and reduces the ER consumption, including fuel for its own needs. The synthesis of the fuel system structure as part of RHPP was carried out in accordance with the developed principles of the system approach and based on a block diagram, using mathematical modelling techniques.

6. Summary and conclusion

1. Methodological aspects for system analysis of raw hydrocarbon processing plants fuel systems have been defined including the development of the hierarchical structure for the fuel system, the set of performance criteria and the mathematical model of its elements.
2. The developed hierarchical structure of the fuel system has resulted in the identification of quantitative and qualitative relationships between the systems and subsystems of the raw hydrocarbon processing plants and the external energy supply systems.
3. The block scheme to synthesize the optimum structure of the fuel system has been developed on the basis of the set of efficiency criteria, the fuel system structure, the mathematical models of the elements using the principles of system analysis, synthesis and optimization.
4. The technical and economic indicators for the implementation of solutions to develop efficient fuel systems as part of energy complex at raw hydrocarbon processing plants have been given.

Acknowledgment
The work was supported by the grant of the Russian Science Foundation (project №17-79-10134).

Reference

[1] Dolotovskij I V, Larin E.A., Dolotovskaja N V and Kulbjakina (Lenkova) A V Pat. No. 134993 Russian Federation, IGC f01k 17/02. Energy-fuel-water supply apparatus B33
[2] Kulbjakina (Lenkova) A V, Larin E A and Dolotovskij I V 2016 Efficient energy supply system for combined oil units *The problems of improvement of fuel and energy complex* **8** 233-38
[3] Kulbjakina (Lenkova) A V and Dolotovskij I V 2013 A plant for absorbent regeneration utilizing fuel wastes *Chemical and Petroleum Engineering* **49** 517-521
[4] Dolotovskij I V, Larin E.A., Dolotovskaja N V and Kulbjakina (Lenkova) A V 2017 Increasing the Energy Efficiency of Heating and Cooling Systems for the Tank Farms of Oil and Gas Enterprises. *Chemical and Petroleum Engineering* **52** (11) 803-809

.