# Developing computer-integrated control system for reactor of nanocatalytic petroleum products refining

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**Summary.** The article deals with the automated control of the catalytic cracking process of vacuum gas oil. A functional scheme of automation is proposed, and a computer-integrated control system for the reactor of nanocatalytic petroleum products refining is developed.

Key words: catalytic cracking, aerosol nanocatalysis, reactor, mnemonic scheme, control.

## INTRODUCTION

Currently, catalytic cracking is the most prospective and important process of oil refining. Implementation of catalytic cracking using the aerosol nanocatalysis technology (AnC) with a vibrofluidized bed is a promising area of petroleum products refining. One of the major challenges facing each production is steadily improving product quality, increasing its efficiency and reducing costs. It can be solved by improving the existing and developing new control systems, creating appropriate mathematical models that allow implementation of modern methods of optimal control [1-5].

Thus, the purpose of this article is to develop a computer-integrated control system for the reactor of nanocatalytic petroleum products refining.

## THE ANALYSIS OF RECENT RESEARCHES AND PUBLICATIONS

Cracking reactor according to the AnC technology, being considered in this work, can be attributed to units with a vibrofluidized bed. The feature of such units, as well as reactors with mechanical mixing, barbotage units and reactors with a pseudofluidized bed, is stochastic movement of discrete phase in the unit volume and intensive fluctuations of different types [6-9].

Vacuum gas oil and a catalyst are driven to the catalytic cracking reactor using the technology of aerosol nanocatalysis. The catalyst undergoes continuous mechanochemical activation in situ by forced mechanical oscillations of inert dispersing material. There is constant grinding of flocculated catalyst particles to nanoscale and maintenance of their high activity during indefinite time [10]. Created particle serves as an acid catalyst for vacuum gas oil cracking, as a result of which high-octane gasoline fraction as well as diesel and gas fractions and coke are obtained. Reaction products and the catalyst are derived from the mechanochemical activation zone, the catalyst is separated and directed to regeneration and recirculation, and reaction products are directed to rectification.

According to numerous studies, there has been found out that characteristics of the catalytic cracking process, including the process speed and chemical transformations mechanism can be changed by varying the frequency of mechanochemical activation. It technically allows increasing selectivity of targeted reactions by changing processes of energy exchanges and force interactions at the microlevel [11]. In fact, hydromechanical processes in the vibrofluidized bed determine effectiveness of the chemical-engineering process as a whole to some extent. Mathematical modelling of such processes was carried out with the aim of their optimizing and using to build an automatic control system [12-15].

Absence of a carrier for the catalytically active substance is the difference of the aerosol nanocatalysis technology [10]. The catalytic system includes dispersing material – glass beads – which serves for mechanochemical activation of catalyst particles that are in the volume of the reactor, and mixture of reagents. Original size of catalyst particles is 200 microns. Work size is 8-100 nm under continuous mechanochemical activation. Absence of the carrier and high activity of a large number of nanoparticles of the catalytically active component causes absence of diffusion braking and $10^4$-$10^6$ increase in the cracking reactions speed (for different catalysts and modes) per weight of the catalyst. Thus, in terms of the AnC technology there are additional factors of the catalyst activity control (starting catalyst concentration, dispersing material size, intensity of mechanochemical activation, etc.), which are included in the speed constant in processes of heterogeneous catalysis owing to impossibility of their rapid change, or because of complete absence of similar factor in the process.

Research of catalytic cracking [16] of vacuum gas oil in terms of the AnC technology has showed the possibility of up to a 10-time increase in the reaction speed per reaction volume, causing corresponding decrease in the equipment size. Under these terms the required amount of the catalyst is 2 g/m$^3$ of the reactor against 300-700 kg/m$^3$ in heterogeneous catalysis causes a 2000-time decrease in the volume required for regeneration of the catalyst. Thus, if in industrial heterogeneous processes of catalytic cracking the ratio reactor: regenerator is 1: 1.2-1.5, then it the AnC technology it changes to 1: 0.001. In addition, coke deposit on the catalystsurface, deactivating it in industrial processes after 1-2 s of work, does not take place in the AnC technology due to constant mechanochemical activation. Coke moves parallely to catalyst nanoparticles along the cycle "reactor-regenerator". But at output from the reactor there is still a need for oxidation of coke in

order to separate it from the catalyst and get the heat required for the course of the cracking reaction in the reactor. All these factors require an original approach to the control process of the reactor of nanocatalytic petroleum products refining.

### THE MAIN RESULTS OF THE RESEARCH

One of the courses of development of the AnC technology is aerosol nanocatalysis in the vibrofluidized bed of the AnCVB catalyst, for which an industrial scheme has been proposed [17, 22]. In the proposed scheme, vacuum gas oil, heated in the furnace, gets into the reactor, which represents a vibromill. Reaction products get from the reactor into the cyclone, where they are separated from the catalyst dust and coke. The catalyst gets into the coke combustion bunker, after which it returns to the process again. Moreover, supply of the fresh catalyst is provided. Reaction products get into the rectifying column, from which a part of heavy distillate recirculates.

Experimental studies have shown that qualitative composition of feedstock of the catalytic cracking process of vacuum gas oil in terms of AnC is mainly influenced by both the catalyst type and the reactor oscillation frequency, affecting intensity of mechanochemical activation, and the temperature of the catalytic system in the reactor.

Existing control systems for liquid reactors [18-21] do not allow implementing all the features and benefits of catalytic cracking using the AnC technology to the full extent. In this regard, there has been offered a block scheme of the automatic control system for the catalytic cracking reactor by aerosol nanocatalysis [22].

The block scheme is not enough for complete representation of the process, so there has been built a functional automation scheme, which is shown in Fig. 1. The main parameters to be stabilized are oscillations frequency of the reactor and the temperature at which components are driven to the reactor.

Discharge of feedstock is regulated by changing discharge of the catalyst ACP streams ratio. The temperature is stabilized by changing fuel consumption, and the reactor oscillations frequency is stabilized using the circuit, which consists of a frequency sensor, frequency vector converter and asynchronous motor.

Based on researched calculations, there has been designed a mnemonic scheme of the reactor of nanocatalytic petroleum products refining, which is presented in Fig. 2. All modern SCADA-systems can create a graphic interface that facilitates a dialogue between the operator and the machine. Vector graphics is common in SCADA-systems. It allows creating separate graphic objects, fulfilling various operations on them, providing dynamic images with the help of zooming, moving, rotating, changing the colour of objects that form images.

Trace Mode software platform was used for development of the mnemonic scheme of the computer-integrated system for the reactor of nanocatalytic petroleum products refining.

Vacuum gas oil is heated firstly up to $180^{\circ}$C in the heat exchanger, and then up to $350^{\circ}$C in the furnace. Gas oil stream is divided into several streams, each of which is directed over the upper perforated grille of the construction. It is necessary to spray gas oil evenly throughout the construction.

The catalyst is parallely sprayed over the entire construction (microparticles $SiO_2$ / $ZrO_2$ – catalyst). Spaying is done by water vapour. Amount of the sprayed catalyst must be 1 g of the catalyst per every 1 normal $m^3$ of vacuum gas oil. The catalyst should be sprayed evenly.

Feedstock and the catalyst are going through structural elements, where the catalyst is dispersed by glass beads to nanoscale, and it is the moment when catalytic cracking of vacuum gas oil of aerosol nanocatalysis takes place.

Reaction products and the catalyst come out of the lower perforated grille of the construction and get to a dead tray (each construction in the unit is separated from each other by a dead tray). Products flow from the dead tray through pipe branches and merge into a stream with the temperature of about $340^{\circ}$C and then get into the heat exchanger where incoming gas oil is heated and directed to rectification.

The following streams get out from the rectification column:
- Gas into the heater,
- Gasoline fraction,
- Distillate,
- Gas oil cracking + the catalyst.

Aerosol catalytic reactor is a vertical cylindrical column-type unit. The reactor is equipped with special constructions instead of trays: the lower part of the construction is a perforated grille with 0.5 mm mesh size. It is enough to prevent disperse material from spilling (glass beads are 0.8-1.1 mm), but at the same time powder of the catalyst, feedstock and reaction products can get through freely. This grille is densely filled with metal pipe branches with the following dimensions: $D_{in}$ = 40mm $D_{out}$ = 43 mm. Height H is 40mm.

These pipe branches are an element of the aerosol catalysis reactor researched in laboratory conditions for which kinetics is studied, and optimal conditions of the process are known exactly. Thus, the entire structure is a set of parallely working homogeneous elements.

Pipe branches are filled with disperse material in amount necessary for a 20-millimetre height; the construction is closed by another perforated grille.

Such a construction along with other similar ones is fixed to a shaft. The shaft moves in the vertical plane with frequency and amplitude identified in the course of laboratory studies. The entire construction moves with the shaft. The body is motionless.

The furnace refers to control objects with high explosive and fire risk. Therefore, to ensure its trouble-free operation automatic locking systems are used.

Blocking is carried out by three factors: presence of flame in the furnace, availability of draft in the furnace and availability of the heating product in the heat exchanger. If one of these parameters is beyond the acceptable values, the disabling element covers the supply of fuel to the furnace. At the same time the scheme providing trouble-free operation of the furnace fully opens the air supply valve to the furnace for its cooling and rapid exit of the fuel-air mixture to the fume stack.
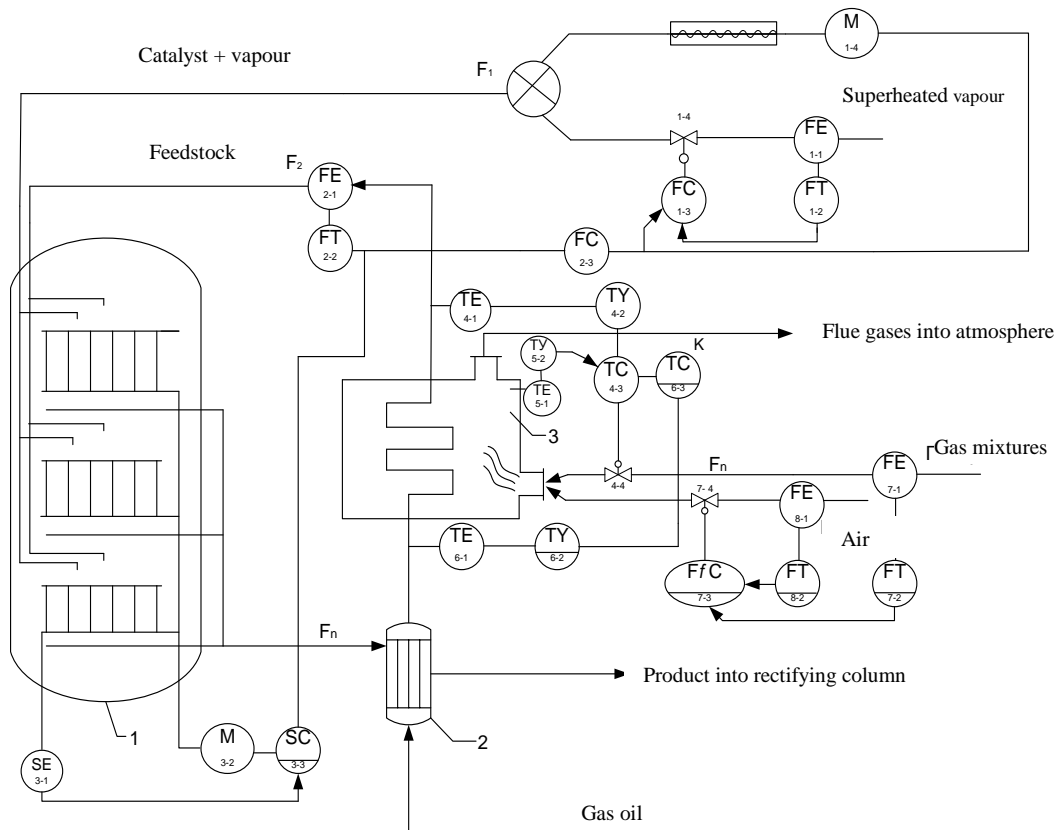
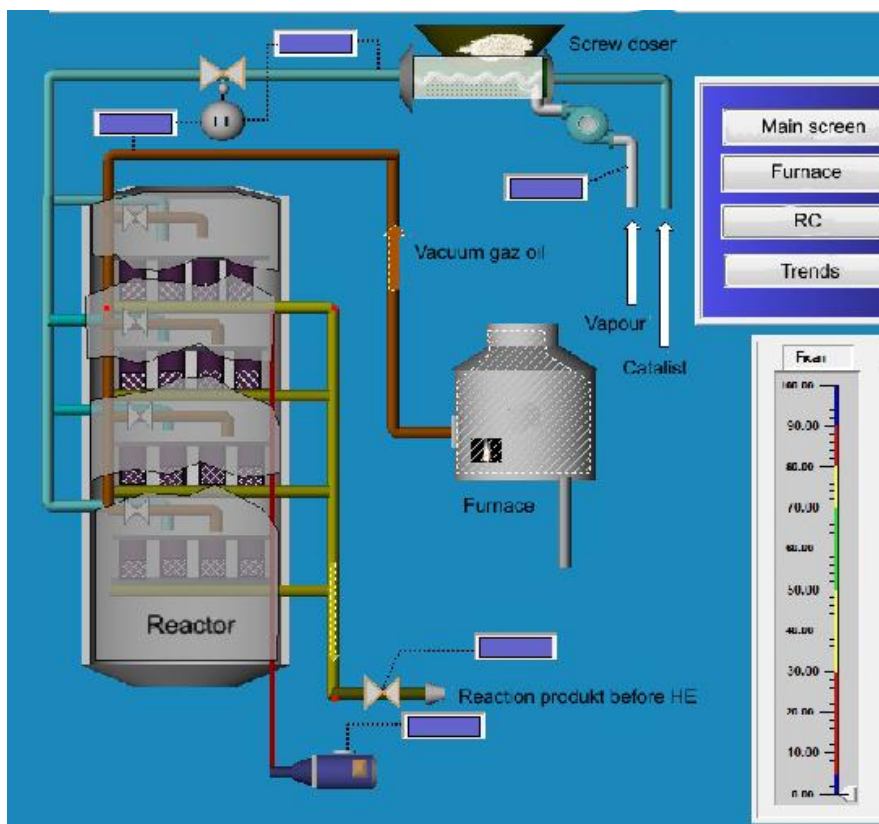**Fig. 1.** Functional Scheme of Nanocatalysis Reactor



**Fig. 2.** Mnemonic Scheme of Reactor of Nanocatalytic Petroleum Products Refining

Each of stabilization systems of the reactor of nanocatalytic petroleum products refining is connected with the automatic control system of catalytic cracking by aerosol nanocatalysis on the base of industrial PC. Connection between the PC and stabilization circuits

is carried out by using the interface converter IC (e.g., RS485/RS232).

## CONCLUSIONS

1. The functional scheme of automation system of catalytic cracking reactor with aerosol nanocatalysis to stabilize oscillation frequency and temperature in the reactor is developed.

2. The proposed computer-integrated control system for the reactor of nanocatalytic petroleum products refining will give an opportunity to accurately maintain the required qualitative composition of feedstock of catalytic cracking and reduce coolant discharge and electricity consumption using advanced automation means and SCADA-systems Trace Mode.

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## РАЗРАБОТКА КОМПЬЮТЕРНО-ИНТЕГРИРОВАННОЙ СИСТЕМЫ УПРАВЛЕНИЯ РЕАКТОРОМ НАНОКАТАЛИТИЧЕСКОЙ ПЕРЕРАБОТКИ НЕФТЕПРОДУКТОВ

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Аннотация. В статье рассматривается автоматизированное управление процессом каталитического крекинга вакуумного газойля. Предложена функциональная схема автоматизации и разработаны компьютерно-интегрированная система управления реактором нанокаталитическои переработки нефтепродуктов.

Ключевые слова: каталитический крекинг, аэрозольный нанокатализ, реактор, мнемосхема, управление.