Reduced energy consumption when feeding raw materials to the reactor for the production of carbon black

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Abstract. This article describes possible ways to reduce the energy consumption of pumps that supply liquid hydrocarbon feed to the nozzles of reactors for the production of carbon black. For achieving this goal, it is proposed to separate the functions performed by the pumps. Some pumps provide circulation, heating, dehydration of raw materials, and supply them to the reactor compartment. Other pumps increase the pressure of the liquid directly in front of the nozzles of the reactors. It is advisable to use piston pumps with pulsation smoothing pumps to increase the pressure.

1. Introduction
Carbon black is a nanotechnological carbon product of the pyrolysis of liquid hydrocarbons that proceeds in the gas phase at a temperature of at least 1000 °C [1, 2]. For obtaining a finely dispersed product, it is necessary to provide fine atomization of the liquid entering the high-temperature flow of fuel combustion products [3]. For this, high pressure is required – from 0.5 to 3 MPa, depending on the technical regulations and the types of nozzles used [4]. Before being fed into the reactor, the raw material from the tank passes through several filters, a heat exchanger, a moisture evaporator, and is supplied to a considerable distance of the reactor compartment.

2. Materials and methods
It is known that in the production of carbon black hydrocarbon raw materials are subjected to preliminary preparation to obtain the necessary component composition and to free from undesirable impurities – water, mechanical particles.

First, the required amount of various components of the raw material mixture is pumped into the tank. Then the raw material is circulated until a homogeneous mixture is formed by low-pressure centrifugal pumps with a high flow rate. After the mixture is prepared, the raw materials are fed through similar coarse and fine filters to the steam heat exchanger, where it is heated to a temperature of 105-110 °C. Heated raw materials are fed to the plates of the moisture evaporator, where emulsified water evaporates from it. From the lower part of the desiccant, dehydrated raw materials are fed into the reactor compartment by multistage centrifugal pumps.

The dehydrated feed is reheated before being fed to the reactor in a heat exchanger to improve atomization and evaporation in the nozzles of the reactor. Besides, spraying agents (air, steam, gas) are used for spraying raw materials upon receipt of active carbon black grades in order to increase the dispersion of raw materials and reduce coking on nozzles [5].
As an example, consider the technological scheme for the preparation of raw materials for carbon black used at the production site of Tuymazytekhuglerod OJSC in Tuymazy (Figure 1). The prepared raw material mixture from tank 1 through a receiving pipe about 200 m long is fed through a coarse filter 2 to inlet pipe of a multistage pump 3 (TsNSN-38-220, flow rate up to 38 m$^3$/h, head up to 280 m, engine power 75 kW). The pump feeds the raw materials to the track heater 4, where it is heated to 80 °C, then to the steam heat exchanger 5. From the heat exchanger, the raw materials at 105 °C are fed to the moisture evaporator 6, where they are partially freed from emulsified water by evaporation at atmospheric pressure. The raw material from the moisture evaporator is supplied by a similar multistage pump 7 to the fine filter 8, then to another steam heat exchanger 9. Some of the raw materials are fed to the reactor 10, and some are returned to the tank.

Figure 1. The technological scheme for the preparation of raw materials of Tuimazytekhuglerod OJSC

3. The study of energy efficiency of various schemes for the supply of raw materials

In the considered flow diagram, a typical layout of the raw material pumps is seen, when one multistage raw material pump feeds the raw mix to several reactors. Part of the raw materials used is returned to the tank or the moisture evaporator, providing additional heating and homogenization of the raw material mixture [6]. Thus, the pump simultaneously performs several functions in the raw material scheme. Pumps 3 and 7 are installed in the same model in order to ensure interchangeability and duplication of equipment in the technological scheme, if necessary. However, the hydraulic characteristic of the centrifugal pump does not allow achieving high pressures (up to 2-3 MPa) with the low flow even in the case of multistage pumps with a large number of impellers installed in series.

The productivity of a single reactor for raw materials for the production of carbon black in modern plants in the furnace production reaches 6 tons per hour, which with an average density of raw materials of about 1030 kg/m$^3$, corresponds to 6 m$^3$/h. In the technological scheme under consideration, up to 3 tons of the raw material mixture is delivered to a vertical reactor for the production of inactive carbon black.

To reduce the total power consumption of the used pump units, we propose to install an additional pump in front of each reactor, providing a flow of no more than 3 m$^3$/h at a pressure of up to 3 MPa. Such hydraulic characteristics are achievable using piston or plunger pumps. The resulting pressure pulsations are compensated by sequentially installed air hoods or other devices for damping pressure after volumetric pumps [8, 9].

Pumps 3 and 7 in the diagram can be replaced with low-power pumps, for example, TsNSN-38-44. Table 1 shows comparative data on the characteristics of the pumps. The power consumption of a single unit is reduced to 18.5 kW, while the reduction in electricity consumption is 56.5 kW.

For installation on a reactor, it is proposed to use a dosing pump ND of the ARZ1 series. Pump specifications are given in Table 2.

It is known from industrial practice that up to 3 reactors are fed from one tank at a time. Therefore, the total power consumption, according to the traditional scheme, is 150 kW. When introducing the
proposed scheme for the use of pumps, three-piston pumps will be additionally installed, and the pumping capacity of the central pumping station will be reduced, which will lead to a reduction in power consumption to 40.3 kW, saving 73%. At the same time, the number of raw materials pumped by CNS pumps can be increased by lowering the required pressure and achieving the optimum operating point [10–14].

Table 1. Characteristics of CNSN oil pumps

| Pump       | Delivery, m³/h | Pressure, m | Rotation frequency, min⁻¹ | Mass of the pump, kg | Electric motor power, kW |
|------------|----------------|-------------|----------------------------|----------------------|--------------------------|
| CNSn 38-44 | 38             | 44          | 2950                       | 178                  | 18.5                     |
| CNSn38-220 | 38             | 220         | 2950                       | 341                  | 75.0                     |

Table 2. Characteristic of dosing pump ND

| Pump       | Delivery, m³/h | Pressure, m | Rotation frequency, min⁻¹ | Mass of the pump, kg | Electric motor power, kW |
|------------|----------------|-------------|----------------------------|----------------------|--------------------------|
| ND2,5      | 5              | 250         | 2950                       | 145                  | 1.1                      |
| 5000/1,5K14A|                |             |                            |                      |                          |

The physicochemical properties of carbon black (iodine number, specific surface area, absorption of dibutyl phthalate) mostly depend on the conditions of evaporation of the raw materials, which in turn depend on the size of the droplets of raw materials entering the reaction zone of the reactor [1, 9]. When using centrifugal mechanical nozzles, the dispersion of the sprayed raw materials depends on the difference in pressure before and after the nozzle, that is, on the pressure of the raw material in front of the nozzle.

The advantage of individual pumps for independent regulation of the pressure of raw materials at each reactor is either due to a change in the shaft speed or due to throttling using shut-off and control valves. Changing the shaft speed is the most preferred way to control the pressure at the outlet of the centrifugal pump; however, for volumetric pumps, changing the shaft speed leads to a proportional change inflow.

Autonomous pressure regulation on the raw material collector of each reactor in the case of piston pumps is complicated due to the non-trivial task of the joint operation of centrifugal and piston pumps on one line. For maintaining the raw material flow and pressure parameters specified in the technical regulations, it is necessary to provide synchronic control of the rotational speeds of the piston and centrifugal pump shafts. In this case, the piston pump motor must be controlled by a frequency converter with negative feedback from the pressure sensor in the damper device in front of the nozzle, and the circulation centrifugal pump monitors and maintains constant pressure at the inlet to all piston pumps.

If at the same time, there is an additional requirement to ensure the maximum supply of raw materials to the circulation of the raw material tank, the automatic control system is supplemented by control valves on the line from the reactor compartment to the raw stock. Here it will be necessary to ensure the maximum opening of the control valve while maintaining the set pressure in front of it, taking into account the fact that the power consumption of the centrifugal pump motor should not exceed a safe value [15, 16].

An additional advantage of the proposed scheme is that the working pressure of the raw material pipelines in the raw material preparation department will be reduced to 0.4-0.5 MPa, and the section of the pipeline with pressure above 2 MPa will be located only directly near the reactor, not directly after
the piston pump. This process reduces the cost of installation and operation of process pipelines, allows the use of cheaper shut-off valves, and reduces the requirements for the strength and tightness of track heaters and heat exchangers.

4. Conclusion
The separation of the functions of heating, pumping raw materials, and increasing pressure in front of the nozzles with the installation of additional piston pumps can reduce energy consumption by 73%. However, this process requires the installation of additional pumping equipment and complicates the pressure regulation scheme in the raw material collectors in front of the nozzles. At the same time, the costs of operating technological pipelines, the acquisition, and installation of pipe fittings and heat exchange equipment are also reduced.

The proposed feedstock supply scheme can be used if the same feed mixture is used in several reactors of sufficiently high productivity if part of the purified and heated feed from the reactor compartment is returned to the feed tank for additional homogenization and heating.

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