To calculate the axial dimensions of inkjet devices for hydraulic transport of sand and gravel materials

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Abstract. The article presents the results of the dredger in a deep deposit of sand and gravel materials. It was found that when the diameter of the suction pipe exceeds the diameter of the inlet mixing chamber by 150 mm, the actual pressure from the ejector does not exceed one meter, and with an increase in the supply of the suction pump as a result of a sharp jump in hydraulic resistance, the vacuum is disrupted. It was also found that the effect on the calculated compression ratio of the jet apparatus increases with an increase in the injection coefficient and the input velocity of the injected stream.

1. Introduction
Jet devices are widespread in almost all branches of technology. Their principal feature is to increase the injected flow pressure without mechanical energy direct expenditure with an exceptionally simple design.

Jet apparatuses are devices in which the injection process, which consists of the one stream kinetic energy transfer to another stream by direct contact (mixing) is carried out. Mixed streams may be in the same phase (liquid, vapour, gas) or different phases (e.g., steam and liquid, gas and solid, etc.). In the mixing process, the mixed streams phase state may remain unchanged or change (e.g., steam may turn into liquid). The flow entering the mixing process at a higher velocity is called a working flow, at a lower velocity - the injected flow. As a rule, potential energy and heat are first converted into kinetic energy in jetting apparatuses. In the moving process through the jet apparatus flow-through part, the mixed flows velocities are equalized, and then the mixed flow kinetic energy is converted back to potential energy or heat. Usually, mixed flow pressure at the jet apparatus outlet is higher than injected flow pressure before the apparatus but lower than working flow pressure.

Jet apparatuses, in which the interacting streams one aggregate state changes completely, can be divided into two types. The first type includes apparatuses, in which the working medium is steam, and injected - liquid (steam-liquid injectors). The second type includes apparatuses, in which the working medium is liquid, and injected - steam (jet heaters) [1].

The processes occurring in jet apparatuses depend primarily on the interacting media aggregate state.

Jet devices operating conditions also depend on interacting media elastic properties. By elastic properties or compressibility is meant a significant change in the medium - specific volume when its pressure changes. In practice, jet apparatuses are used in which: a) both media (operating and injected) are elastic; b) the media one is elastic; c) both media are inelastic.

From these viewpoints, all-jet apparatuses can be divided into the following three groups: 1) apparatuses, in which the working and injected media aggregate state is the same; 2) apparatuses,
which the working and injected streams are in different aggregate states that do not change in the mixing these streams process; 3) apparatuses with media changing aggregate state. In these devices working and injected flows before mixing are in different phases, and after mixing - in one phase, i.e. in the flows changes one mixing the aggregate state process.

The first group includes gas jet compressors, ejectors and injectors as well as jet pumps.

The second group includes jet devices for pneumatic conveying, water-air ejectors and jet devices for hydraulic conveying. The third group includes steam-water injectors and jet heaters.

The all-jet apparatuses processes characteristic without exception are described by three laws [1]:

- conservation of energy

\[ h_p + uh_i = (1 + u)h_c, \]  

where \( h_p, h_i, h_c \) - are enthalpies of working and injected streams before apparatus and mixed flow after apparatus, kJ/kg; \( u = G_i / G_p \) - is injection coefficient, i.e. injected stream mass flow rate ratio to working stream mass flow rate;

- conservation of mass

\[ G_c = G_p + G_i, \]  

where \( G_c, G_p, G_i \) - are mass flows of working, injected and mixed flows, kg/sec;

- of momentum conservation, which for an arbitrarily shaped mixing chamber is written as

\[ I_p + I_i = \int_{f_3}^{f_1} pdf + I_{c_3}, \]  

where \( I_p, I_i \) - impulse of working and injected flows in the mixing chamber inlet section, n;
\( I_{c_3} \) - mixed-flow pulse in the mixing chamber outlet section, N;
\( \int_{f_3}^{f_1} pdf \) - is the momentum integral over the mixing chamber side surface between sections. In a cylindrical mixing chamber \( \int_{f_3}^{f_1} pdf = 0. \)

- flow momentum in any cross-section

\[ I=Gv+pf, \]  

where \( G \) - mass flow rate, kg/s; \( v \) - velocity, m/s; \( p \) - pressure, Pa (n/m²); \( f \) - cross-section, m².

It is known, that all soil pumps have a water column suction ability of 5-6 m restrictions. It allows at a deck arrangement of the pump on the dredger to develop an underwater pit to 10 m a depth at a slurry density no more than 1.1-1.15 t/m³. A bilge pump location on the dredger the pit development depth can be increased up to 12-13 m [1].

But in many fields, sand and gravel may lie well below the development possibility by conventional dredgers. For example, in the oil-bearing basin of Western Siberia sands lie at 20-30 m a depth, and to develop waterlogged fields it is necessary to raise the extraction sites and roads by 3-4 m sand embankment, which can be done only with the dredgers help.

Under these conditions, it was necessary to upgrade dredgers a number to develop soils up to 15-25 m by installing ejection devices. For this purpose, it was necessary to establish parameters a number.

One of the most important values is the working nozzle cross-sectional area ratio to the outlet cross-section area. At the ratio small value apparatuses are high-pressure. Such apparatuses develop a high compression ratio but are characterized by a low ejection ratio. If the ratio increases, the apparatus compression ratio decreases and the ejection coefficient increases.

The nozzle and diffuser coaxial are important for obtaining the optimal ejector characteristic. Experience shows that jet apparatus elements deviation from coaxiality can significantly reduce the ultimate backpressure and induction coefficient [2].
The ejector main axial dimension is the distance from the nozzle cut-off (the nozzle outlet section) to the diffuser cylindrical part entrance. This dimension is determined by the jet shape flowing out of the nozzle.

The nozzle removal from the mixing chamber significantly worsens the apparatus performance, because in this case, the free jet final cross-section diameter exceeds the mixing chamber inlet cross-section diameter. The free jet introduces more gas into the mixing chamber than the mixing chamber can pass, which causes reverse medium currents and increased energy losses.

Until recently quarrying by hydro mechanization means referred to as construction works, but now these works are referred by law to the mining works with higher requirements to works performance, including industrial sand and gravel reserves full excavation.

2. Research methodology

For jet devices, axial sizes parameters substantiation, industrial experiments on second group devices on one of sand-gravel materials deposits with the head reception purpose before a ground pump in 3-4 m water column for an increase in sand and gravel pitches development depth up to 20-30 m have been carried out.

As the basic premise for conducting research, the hypothesis was accepted, according to which in designing jet apparatuses the nozzle optimum distance from the mixing chamber is determined from the condition that at the injection calculated coefficient final cross-section of the free jet is equal to the mixing chamber inlet cross-section;

The site for the commercial experiment is confined to alluvial deposits of the 1st above the floodplain terrace of the Yenisei River and stands 1.5 km to the river bed south, rising 5-15 m above the water's edge. The deposit productive layer is composed of loose modern alluvial sediments, represented by dusty and fine sands. Underlying sediments are loamy and gravelly-pebble horizons interlayers, permafrost sands are host rocks and are not the productive sequence part. Semi-oxidized organic remains are ubiquitous.

The pay zone has a reservoir form, does not contain barren rocks interlayers and is composed of dusty, fine and medium water-saturated sands. Its thickness varies in general across the deposit from 5 m to 15.0 m, reaching 25 m. There is no overburden.

At the 25.0 m given open-cast minefield a useful maximum thickness, and also the high waters maximum level in a river bed to 5 m, pulp moving distance, and the connection points optimum and rational application minimum quantity as the mining equipment was accepted the type 300-40 dredger with the dredger 20P-11.

The quarry development is started with a dredger introduction into the pit at the beginning of July after the flood water recedes to 11.5 m or less a water level, which will allow the soil laying on non-watered areas. The open-pit is stripped with a pioneer cut trench sinking. The open-pit field is excavated to the scarp full height, i.e. a continuous scarp, to the pay zone full depth to the permafrost or underlying loam boundary, with subsequent stowing in the structure and the wastewater discharge to the process sump. The cut width was 40 m.

The continuous excavation process is carried out by the dredger coordinated transverse and translational working movements with the help of papillote rope devices, in which the dredger is held and moved in the face by papillote means winches (bow and stern, which steel ropes are equipped with river anchors and attached to the coastal anchor devices. As the bottom is worked out and the dredger moves forward, the anchors are shifted by floating cranes or boatage motorboats, as well as the transfer of coastal anchor devices. The soil intake process is decisive for ensuring the dredger effective operation. Poorly compacted sand-gravel soils underwater excavation at sections with thickness up to 25 m is advisable by suction with ejection and with the hydraulic rippers help to work according to hydro monitor principle. It is not possible to work out sections with such capacity by 300-40 dredgers without ejection. For the hydraulic ripper water supply, a D630-90 type pump is used.

The soil is to be excavated using a floating non-self-propelled dredger equipped with a hydraulic opener. The dredging tool is moved by rope papillote means by successive parallel cuttings.
Soil is transported to the laying site by floating, main and reclaimed slurry pipelines. Mineral resources are deposited in the structures (stacks). The sites for the facilities are located under the general plan.

Deposit development technological scheme is defined by open pit field experiment - development conditions by 25 m depth continuous scarp, hydro transportation by slurry pipeline, grounds laying.

3. Results and discussion

As experimental studies show, the basic regularities obtained for a free jet in boundless space can also be used with sufficient accuracy for practical purposes to calculate the jet apparatuses axial dimensions with the working jet supercritical velocity.

When designing jet apparatuses, the nozzle optimum distance from the mixing chamber is determined from the condition that the free jet final cross-section is equal to the mixing chamber inlet cross-section at the induction calculated coefficient.

To select the working nozzle correct position, the free jet two dimensions must be calculated: the free jet length and the free jet diameter. If larger parameters are reached, cavitation develops in the ground pump with its operation consequent failure. These restrictions do not allow to development the soil pit to a greater depth and limit the dredger slurry and the productivity density [3, 4].

The nozzle approximation to the mixing chamber, in this case, leads to cylindrical mixing chamber working length reduction, as the free jet final cross-section moves closer to the compressor diffuser.

Removing the nozzle from the mixing chamber significantly degrades the apparatus performance. This leads to an increase in the free jet length. The free jet final cross-section increases, as it fits already into the mixing chamber inlet section, which diameter is larger than the cylindrical chamber diameter. Under these conditions, the free jet introduces more fluid into the mixing chamber than the apparatus can pass, so the fluid must flow back out of the mixing chamber into the receiving chamber. This results in reverse currents in the inlet section of the mixing chamber and the associated additional losses in the apparatus.

If the mixing chamber diameter is larger than the nozzle diameter, the working nozzle outlet section distance from the cylindrical mixing chamber inlet section should be taken equal to the mixing chamber inlet section length, at which the diameter changes.

If the distance between the nozzle and the mixing chamber is less than the calculated one, the flow rate of injected medium entrained by the free jet is also less than the calculated one. Approaching the nozzle to the mixing chamber, as well as removing it, worsens the apparatus performance in comparison with the calculation.

The effect of the inlet section profile of a jet compressor mixing chamber is accounted for by the injected flow velocity coefficient, which is the product of three velocity coefficients: mixing chamber, diffuser and inlet section.

The mixing chamber inlet section profile affects the velocity coefficient value. If the inlet velocity ratio decreases, the calculated injection coefficient decreases or, for a given injection coefficient, the jet unit calculated compression ratio decreases.

The velocity coefficient influence on the jet apparatus calculated compression ratio increases with an increase in the injection coefficient un the injected flow inlet velocity. When the injection coefficient decreases, the inlet section profile influence on the compression ratio weakens.

The jet apparatuses experimental study with mixing chamber inlet sections different profiles shows that the conical inlet section provides velocity with a sufficiently high coefficient.

The mixing chamber main purpose is to equalize the mixed flow velocity field before it enters the diffuser. Experience has shown that when a flow with an equalized velocity profile enters the diffuser, the kinetic energy conversion into potential energy occurs with the lowest losses.

The mixed flow velocity field alignment is ensured by the appropriate length.

Based on experimental data, the jet apparatuses cylindrical mixing chamber length is usually selected within the 5-8 mixing chamber diameters range:
4. Conclusion
In the conducted experiments course, it was found that when the distance between the nozzle and the mixing chamber is smaller than in the calculation, the injected medium flow rate entrained by the free jet is also smaller than in the calculation. Bringing the nozzle closer to the mixing chamber, as well as removing it, worsens the apparatus performance in comparison with the calculation. In the jet apparatus calculation, the nozzle optimum distance from the mixing chamber is determined from the condition that at the injection calculated coefficient the free jet final cross-section is equal to the mixing chamber inlet cross-section. It has been established, that at the suction pipeline diameter exceeding inlet mixing chamber diameter on 150 - 200 mm the actual head from the ejector does not exceed one meter, and an increase in the dredge feed as hydraulic resistance a sharp jump a result led to the vacuum failure. With the injected flow injection coefficient and the inlet velocity increase, the jet section profile influence the jet apparatus calculated compression ratio increases and, on the contrary, with the injection coefficient decrease, the inlet section profile influence the compression ratio weakens. A suction pipe diameter of 600 mm and inlet mixing chamber of 400 mm actual head from the ejector did not exceed one meter at design head of 4 - 5 m, and at increased ground pump flow the device turned to hydraulic resistance.

For this problem decision and device work stability increase, this device modernization on a dredger 300-40 has been made.

After mixing chamber replacement with a pipe from 400 mm to 600 mm the ejector design head was achieved, which allowed to work out sections with 25 m a depth. It was also found that the effect on the jet apparatus design compression ratio increases with an increase in the injected flow injection and the inlet velocity coefficient. When the injection coefficient decreases, the inlet section profile influence on the compression ratio is attenuated. Since in the nozzle, the working flow expansion degree exceeds the critical value, the working fluid mass flow rate is determined by the critical nozzle cross-section.

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