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Consumption of Irrigation Pumps Pumping Water with a High Content of Mechanical Impurities

Eduard Kan[1*], and *Nikolay* Vatin[2]

[1]"Tashkent institute of irrigation and agricultural mechanization engineers" National research university, Tashkent, Uzbekistan
[2] Peter the Great St.Petersburg Polytechnic University, Saint Petersburg, Russia

Abstract. The water pumped by reclamation stations of the Republic of Uzbekistan contains many mechanical impurities. This negatively affects the operation of pumping units. There is a decrease in the operating parameters of the pumping unit and the associated increase in electricity consumption. Analysis of the alluvial regime of the main water sources of large pumping stations shows that the sediment concentration can reach values of 15-20 kg/m^3 and, on average, up to 8-10 kg/m^3 (i.e., exceed the permissible values according to the technical requirements for centrifugal pumps by 2-3 times). Based on the consideration of a two-phase liquid model (pure water and mechanical impurities) and formulas for determining the useful power, a dependence is derived to determine the magnitude of the increase in power consumption. According to this dependence, a graph of the dependence of the increase in the value of the required useful power depending on the concentration of mechanical impurities in the pumped water is constructed, which can be applied in practice during the operation of irrigation pumping stations. The results of a quantitative analysis of the influence of the content of mechanical impurities in the pumped water on the value of the pump's useful power showed that with average turbidity of the pumped water of 10 kg/m^3, the overspending of electricity would be 1.75%. This is of great practical importance for the machine water lifting of the Republic of Uzbekistan (the main consumer of electricity in the agricultural sector), and the results can be used to develop an energy-saving strategy in the field of operation of irrigation pumping stations.

1 Introduction

The energy conservation issues in the context of global trends of increasing energy consumption and energy scarcity are becoming increasingly important. This issue is especially relevant for industries that consume a large amount of energy. The main electricity consumer in agriculture of the Republic of Uzbekistan is the machine water intake [1]. The park of pumping stations has more than 1600 pumping stations for

* Corresponding author: Kan_E1969@mail.ru

reclamation purposes. Therefore, the effective functioning of hydraulic systems with pumping stations ensures energy saving requirements [2,3]. To solve the problems of energy saving at pumping stations, various methods and methods are used: the use of frequency converters [4,5,6], methods for choosing energy-efficient methods for regulating the operation of pumping units taking into account specific conditions [7], improving methods for calculating structures of structures [8], choosing equipment during reconstruction and modernization [9,10] and a rational control system of pumping stations [11,12,13]. Accurate energy consumption accounting is necessary to ensure the energy saving requirement and the application and implementation of the above methods and means [14,15]. Knowing the power consumption's real value during pumping units' operation, it is possible to compare different modes and choose the most optimal ones [7].

The specifics of the Central Asian region make it necessary to attribute the operating conditions of pumping equipment to very severe: high content of suspended solids in the pumped water and high ambient temperature. One of the main negative factors that significantly worsen the operating conditions of pumping equipment is the saturation of the pumped water with mechanical impurities. The technical and economic consequences of the presence of a significant content of mechanical impurities in the pumped water are expressed in the deterioration of the operating parameters of the pumping unit (pressure, supply, efficiency) and the associated increase in electricity consumption and in significant labor and material costs for repair work to eliminate the consequences of waterjet wear of the pump flow parts [1,4,5,7,10]. The presence of suspended sediments in the pumped water leads to overspending electricity spent on lifting water or undersupplying this water at a constant value of the amount of electricity consumed. Therefore, this issue is of particular relevance for the conditions of our region and must be taken into account both when determining the norms of electricity consumption for lifting water and when designing existing and reconstructed pumping stations when choosing the main equipment [7,9]. If such norms exist for pumps pumping pulp during hydraulic works, mining pumps [17,18], and sewage [19], then this factor is usually neglected when calculating the energy consumption of irrigation pumps.

Therefore, this article aims to assess the degree of influence of the concentration of mechanical impurities in the pumped water on the energy consumption of pumps. To achieve this goal, it is necessary to solve the following issues:

- To identify the degree of mechanical impurities in the pumped water;
- To carry out a quantitative assessment of the influence of the concentration of impurities on the amount of energy consumption;

2 Methods

The methodological foundations of the research are based on a systematic approach since the subject of the study is a complex process of movement of a two-phase fluid, which depends on various factors. To solve the tasks, the following theoretical and empirical research methods were used: collection, comparison, system analysis of materials on the alluvial regime of the main water sources of pumping stations of the Republic of Uzbekistan and the development of recommendations based on a two-phase model of the pumped liquid for their accounting when calculating energy consumption. The water source of most of the large and unique pumping stations of our Republic (cascade of KMK, ABMK, Amu-Zang, etc.) is the Amu Darya River (in the upper and middle reaches).

The water flow of the Amu Darya River, as is known, transports a large amount of sediment [20,21,22]. The bulk of the sediment of the river moves in a suspended state, and a small part of the sediment - the largest fractions move into the bottom layer [22,23]. The water intake of large pumping stations is damless, so the sediment concentration in the pumped water is almost the same as in the water source [24]. The alluvial regime will be considered according to the data of the hydrometeorological service at the Kerka gate. The Kerki formation is located 1061 km higher from the mouth of the Amu Darya River and characterizes the alluvial regime of the middle current. The greatest average-decadal turbidity of the water of the Amu Darya River near Kerka was observed in the first decade of May 1934 and amounted to 10.2 kg/m^3. The lowest turbidity is observed during the winter and autumn and is 0.6-0.7 kg/ m^3. The greatest turbidity of the flood stream is 18-20 kg/m^3. The average annual turbidity varies within large limits. For the high-water year 1958, the average annual turbidity equals p= 5.35 kg/m3. The annual volume of sediment runoff of the Amu Darya River near Kerki is 270 million tons. [25,26,27]. During spring floods, the turbidity of the flow is greatest due to intense basin erosion. The subsequent increase in flood runoff occurs due to the melting of high-altitude snowfields and glaciers in areas of weak development of erosion activity. Accordingly, during this period, the flow of sediments into the basin decreases, and their content in the river depends on the size of the deformation [28]. When the flood subsides, the turbidity of the stream becomes less than when the flood rises. As a result, turbidity is distributed unevenly throughout the year: with large amounts of summer flood water flow, the turbidity of the flow is less than during spring floods. Usually, during the flood period (April-September), up to 80-90% of the annual sediment runoff is transported by the river [27,29].

The sediments of the Amu Darya River have a fine fractional composition. The largest fractions of suspended sediments are particles with a diameter of more than 0.25 mm (hydraulic size 0.3 m/s), and the bulk of suspended sediments consists of particles with a diameter of 0.1-0.05 mm (w = 0.2-0.7 m/s). The granulometric composition of suspended sediments varies in different periods. The number of small fractions of particles d = 0.01 m is approximately constant in all seasons and ranges from 10 to 20%, sediments larger than 0.05 mm in high water are up to 30%, and in the inter-ice period increases to 50%. Sediments with a size of 0.05-0.1 mm prevail in high water and range from 10 to 20%. The average hydraulic size of sediments in the area of Kerki station is w = 3.27 cm/s, which corresponds to d_{aver} = 0.3 mm. The specific gravity varies between 2.62-2.88 t/m^3, on average γ = 2.7 t/m^3.The volume weight varies between 1.4-1.7 g/m^3. [28,29,30,31]

3 Results and discussions

To identify the nature of the change in the value of the useful power required to lift a two-phase liquid, we will conduct a simple analysis. We will consider the water pumped by pumps as a two-phase flow, i.e., as a moving medium consisting of liquid and solid phases. The volumetric flow rate of the two-phase flow (hydraulic mixture) in this case will be equal to:

$$Q_{mixture}=Q_{solid}+Q_{liquid} \quad (1)$$

Where Q_{solid} is the volumetric flow rate of the solid phase;
Q_{liquid} is the volumetric flow rate of the liquid phase (water).
Volumetric turbidity (concentration) of two-phase flow:

$$S=Q_{solid}/Q_{mixture} \quad (2)$$

In view of the relatively lower content of the solid phase

$$S=Q_{solid}/Q_{mixture}\approx Q_{solid}/Q_{water} \quad (3)$$

and

$$Q_{solid}=Q_{mixture}S \quad (4)$$

The useful power supplied by the liquid pump to lift it to the required height H_{geom} will be equal to:

$$N=\rho gQH \qquad (5)$$

Accordingly, to raise the two-phase liquid, the pump must develop useful power:

$$N_{mixture}=(\rho_{solid}Q_{solid}+\rho_{water}Q_{water})gH \qquad (6)$$

Taking into account the expression (3), we obtain

$$N_{mixture}=(\rho_{solid}Q_{mixture}S+\rho_{water}Q_{water})gH \qquad (6)$$

Then the increase in useful power with a two-phase liquid, depending on the concentration of pumps, will have the form:

$$\frac{N_{\text{mixture}}}{N}=\frac{(\rho_{solid}Q_{solid}+\rho_{water}Q_{water})gH}{\rho_{water}Q_{mixture}gH}=\frac{\rho_{solid}S+\rho_{water}(1-S)Q_{mixture}}{\rho_{water}Q_{mixture}}=\frac{\rho_{solid}S+\rho_{water}(1-S)}{\rho_{water}} \qquad (7)$$

Thus, the increase in the amount of useful power required to lift a two-phase liquid will depend only on the concentration of pumps and density:

$$\frac{N_{mixture}}{N}=\frac{\rho_{solid}S+\rho_{water}(1-S)}{\rho_{water}}=1+S\left(\frac{\rho_{solid}}{\rho_{water}}-1\right) \qquad (8)$$

To demonstrate more clearly the degree of influence of the presence of impurities in the pumped water, a graphical diagram is constructed (Fig.1). When plotting the graph, the density of pumps was assumed to be equal to the average for the Kerk alignment according to [27] $\rho_{solid}=2{,}75\kappa g/m^3$.

From the graph in Fig.1, it can be seen that at a concentration of mechanical impurities equal to the average turbidity value per hydrological post (g/ p) of the Kerki of 10.2 kg / m^3, which corresponds to a concentration of S= 1.02%, the value of the useful power required for lifting a two-phase liquid will increase by 1.75% (or) compared to the useful power needed to lift clean water. Accordingly, at a maximum concentration of S = 2.0%, the value of the useful power will increase by 3.5%. This means that at an average concentration of 1%, the pumping unit consumes an additional 1.75% of power (or raises less water). And taking into account the fact that pumping stations of our Republic annually spend up to 7-8 billion kWh on raising water, it is clear that the scale of additional energy costs is also huge.

Here we analyzed the change in useful power only. As you know, the power on the pump shaft (or the power received by the pump from the drive motor) is equal to:

$$N_{\text{shaft}}=N/\eta_{pump} \qquad (9)$$

where η_{pump} is the efficiency of the pump, which takes into account the hydraulic, volumetric, and mechanical losses arising from the transfer of energy of the pumped liquid:

$$\eta_{pump}=\eta_{hydraulic}\eta_{volumetric}\eta_{mechanical} \qquad (10)$$

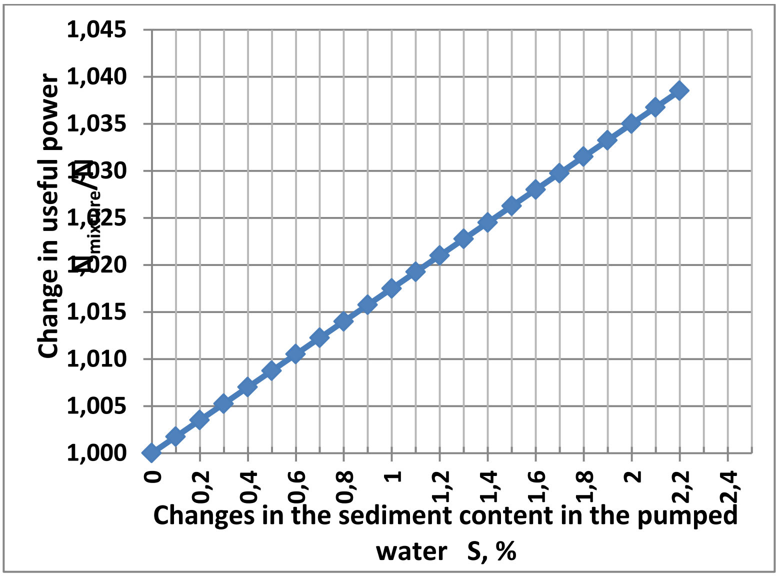

Fig. 1. Graph of the dependence of the increase in the value of the required useful power depending on the concentration of mechanical impurities in the pumped water

Naturally, the presence of mechanical impurities in the pumped water leads to a change in the values of losses. It is not possible to determine the nature of these changes analytically. The pump's efficiency primarily depends on the size of the pump, the shape of the flow part, the impeller and the design of the pump, and then on the properties of the pumped liquid [3,4,5]. Therefore, by conducting full-scale parametric tests of the pump using indirect measurement methods [32] for liquids with different sediment concentrations, it will be possible to identify the nature of the influence of the content of mechanical impurities in the pumped water on the change in parameters by comparing the obtained pump performance characteristics (pressure, power, efficiency, and cavitation) at different concentrations and mechanical size of sediments.

4 Conclusions

1. One of the main negative factors that significantly worsen the operating conditions of pumping equipment is the saturation of the pumped water with mechanical impurities. As a result of the presence of a significant content of mechanical impurities in the pumped water, there is a decrease in the operating parameters of the pumping unit (pressure, supply, efficiency) and the associated increase in electricity consumption and significant labor and material costs for repair work to eliminate the consequences of waterjet wear of the pump flow parts.

2. As a result of considering the pumped water as a two-phase flow consisting of liquid and solid phases, a dependence is obtained for calculating the increase in useful power with a two-phase liquid depending on the concentration of pumps. The obtained dependence can be used to estimate the energy consumption of irrigation pumps pumping water with high mechanical impurities. The results of a quantitative analysis of the influence of the content of mechanical impurities in the pumped water on the value of the pump's useful power showed that with average turbidity of the pumped water of 10 kg/m3, the overspending of electricity would be 1.75%.

3. A graph of the dependence of the increase in the value of the required useful power depending on the concentration of mechanical impurities in the pumped water is proposed, which can be applied in practice during the operation of irrigation pumping stations when developing an energy saving strategy.

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