Use of centrifugal pumps with canned asynchronous motors in irrigation systems

A G Chernykh

Irkutsk State Agricultural University named after A.A. Ezhevsky, Molodezhny, Irkutsk district, Irkutsk region, 664038, Russia

E-mail: kandida2006@yandex.ru

Abstract. In most cases, taking into account the local geology and hydrology, water entering the system of humidified mobile irrigation from underground sources, such as from the depth of artesian wells, has an initial temperature below 12 degrees. Low temperature of irrigation water adversely affects the growth and absorption activity of plant roots, and the life of microorganisms, impairing the supply of plants with nutrients, mainly nitrogen. As a result, the use of water from aquifers in irrigation systems requires its preliminary settling in barrels or special storage ponds. Given that the water from the well rises to the surface using a pump (group of pumps), the choice of the type of pumping unit has a significant impact on the structure and composition of the equipment of the irrigation plant. The paper shows the features of using special-shaped centrifugal pumps in terms of increasing the water temperature at the outlet of the pumping unit due to its indirect heating in the design elements of the pump drive motor. Using the heat balance equation for the secondary conductive shells of the pump motor, the interval values of the water temperature at its outlet are calculated, proving the possibility of its further use for its intended purpose in the irrigation system without additional technical water treatment.

1. Introduction and Objectives
A number of people included in agricultural production as main economic activity are much larger than that of other productions. The share of agricultural production in total world water consumption is about 67% and is the highest in comparison with that of industry (25%) and households (8%).

The main task of agricultural production is to provide sufficient food and raw materials for humanity, which indicates the importance of correctly using and applying the full range of innovations in agriculture, including innovations in soil drainage and irrigation. The determining natural factors in agricultural production are water, light, temperature and soil.

The main source of available water in the soil is precipitation-rain. The annual precipitation distribution is largely inconsistent with the needs of crops. Therefore, agricultural measures that artificially give water to plants are required. One of the technical measures that provide artificial soil moisture in order to increase productivity is irrigation.

The world irrigates 250 million hectares of acreage, which is about 18% of the world's arable land. At the same time, almost 40% of the world's food is produced on irrigated land.

Natural sources for irrigated areas are ground water, surface water, and non-traditional water sources.

According to the data on the area equipped for irrigation with groundwater (AEI GW), with surface water (AEI SW) or with water derived from non-conventional sources (AEI NC) and on area actually irrigated with groundwater (AAI GW), with surface water (AAI SW) or with water from non-
conventional sources (AAI NC), the territory of the Russian Federation belongs to regions with possible irrigation of areas from ground water [1, 2].

Figure 1 shows a mainland map showing areas that are equipped with irrigation systems, are actually irrigated, or are set aside for groundwater irrigation.

![Figure 1. Irrigation fields on the mainland map: 1 - areas without irrigation; 2 - areas equipped with irrigation systems using ground water (AEI GW); 3 - areas actually irrigated with ground water (AAI GW); 4 - areas designated for irrigation with possible use of ground water (IWWD GW); 5 - areas equipped with irrigation systems using surface water.](image)

The advantages of using ground water for irrigation are getting water on site without building expensive water intake and conducting structures. However, ground water is not always suitable for irrigation due to the low flow rate and high mineralization. Water with a well flow rate of at least 15 liters per second is suitable for irrigation.

In general, groundwater irrigation has a number of features, such as low flow rate of wells; there are no sediments in the water; the water temperature is below 12°C; the water source is located next to the irrigated area, the area of which is usually 15...100 hectares.

The low temperature of the extracted ground water does not allow it to be used directly for its intended purpose. In this case, as a rule, technical measures are used to increase the temperature to the required values for irrigation conditions in storage electric water heaters.

For irrigation of 1 ha, 400-500 kW/h of electric energy is spent when lifting water from wells from a depth of 30 meters and 1500-1600 kW/h when lifting 100 meters. When the water is further heated to the set temperature values, additional energy is consumed. As a result, the low initial temperature of the extracted ground water during its heating during water treatment has an indirect effect on the operating costs of the irrigation process in the direction of increase.

Obtaining a priori information related to ground water temperature is a necessary multi-factor condition for conducting a feasibility study of a specific irrigation array.

Due to the lack of direct measurement, the temperature of shallow ground water is estimated by adding the offset to the average annual surface air temperatures [3]. Given that there are no hidden heat sources in the near-surface layer, such a layer can be considered a closed system. As a consequence, near-surface temperatures and shallow subsurface temperatures must be in equilibrium. However, when estimating the average annual ground water temperature (GWT), seasonal displacement factors and geographical coordinates of the ground water location must be taken into account. The GWT assessment, taking into account the specifics of practical application, is usually made for areas of the earth's surface South of 61° latitude.

The main source for estimating GWT is satellite data [4]. Although the near-surface layer can be considered as a closed system, there is a certain displacement between the GWT and the Earth's surface temperature (LST) in both hemispheres. The specified offset is caused by two factors. In the first case, it is necessary to take into account the seasonality factor, in particular the presence of snow
Snow cover isolates (screens) the warm temperatures of ground water from the cold temperatures of the outer cover. Thus, there is a certain gradient between the specified temperatures.

In the second case, regardless of the seasonality factor, it is necessary to take into account the error caused by the need to extrapolate weather data obtained by satellite and actual data of temperature fields in the place of groundwater occurrence.

Figure 2 shows global average annual groundwater temperatures (GWT) without seasonal bias.

![Figure 2](image-url)

**Figure 2.** The average annual temperature of continental groundwater at a depth of 60 meters.

Any mobile irrigation complex, including for ground water irrigation, consists of three main functional modules: water intake, water supply network and irrigation device. Elements of mobile irrigation equipment include: sprinklers, sprinklers, collapsible transport pipelines, and mobile pumping stations. Mobile pumping stations are designed to take water from a water source and supply it through a transport pipeline with the necessary head and flow rates to irrigation devices. Booster pumps are used to supply water through the transport pipeline.

Horizontal centrifugal pumps are most widely used in irrigation pipelines as booster pumps.

Before choosing a pump, you should know the following:

- the volume and maximum speed of water intake from the source feeding the system (this must be known before the design is completed);
- flow required for irrigation system;
- pressure required for system operation (total dynamic head), including all losses caused by friction from pipes, fittings and valves;
- location of the main water source - above or below the pump;
- energy source for powering the pump motor.

In the future, at the stage of choosing the brand and type of pump, it is necessary to follow the criteria of reliability, trouble-free operation and minimization of operating costs.

Air leaks in the elements of the irrigation system, including the pump seals, are one of the main reasons for disrupting the integrity of the entire system.

The non-oil seal design of the centrifugal pump makes it possible to completely eliminate the phenomenon of air leakage in the elements of its design and, as a result, solve a local technical problem associated with increasing the reliability of the pump unit.

2. Case Study

2.1. Energy sources of mobile pumping stations

Irrigation costs are determined by the amount of water being pumped and the cost of the irrigation complex. Factors that determine irrigation costs include those that are fixed for a given location and those that irrigators can influence. Pumping costs can be minimized if the issue related to the choice of the type of energy source used to power irrigation is investigated at the design stage of the complex
Electricity and diesel fuel are used to power irrigation systems in approximately 76% of cases. Natural gas and propane are used in about 20% and 4% of cases, respectively.

Table 1 shows the amount of work per unit of time produced by the pump, depending on the type of power source of the pump drive.

### Table 1. Energy content of fuels for powering irrigation engines

| Energy source                      | Average energy content, kilowatt-hour | Engine or motor performance, kilowatt-hour | Pumping plant performance, kilowatt-hour | Engine or motor efficiency, % | Pumping plant conversion, % |
|-----------------------------------|--------------------------------------|--------------------------------------------|-----------------------------------------|-------------------------------|----------------------------|
| 1 gallon of diesel fuel           | 40.7                                 | 12.5                                       | 9.4                                     | 31                            | 23.2                       |
| 1 gallon of gasoline              | 36.6                                 | 8.6                                        | 6.5                                     | 23                            | 17.2                       |
| 1 gallon of liquefied petroleum gas| 28.0                                 | 6.9                                        | 5.2                                     | 25                            | 18.8                       |
| 1 thousand cubic foot of natural gas| 299.1                               | 61.3                                       | 46.0                                    | 21                            | 15.8                       |
| 1 therm of natural gas            | 29.3                                 | 6.0                                        | 4.5                                     | 21                            | 15.8                       |
| 1 gallon of ethanol               | 24.8                                 | 5.8                                        | 4.35                                    | 18.5                          | 13.9                       |
| 1 kilowatt-hour of electrical energy| 1.0                                 | 0.88                                       | 0.66                                    | 88                            | 66                         |

Analysis of table 1 data shows that the highest efficiency is provided by pumping units with an electric power source. Taking into account the fact of mobility of irrigation complexes accepted for consideration in this work, it is necessary to pay attention to autonomous sources that use photovoltaic energy [6]. This choice of energy source is confirmed by modern engineering solutions in the field of creating electrochemical energy storage systems using zinc-bromide and polysulfide-bromide flow batteries [7].

2.2. Booster pumps for irrigation pipelines

There are a significant number of pumps that differ in their operating principle, design, and so on. Depending on the principle of operation and design there are, 130 types of pumps and 22 types of pumping units, and according to the type of working chamber and its connection to the pump inlet and outlet, two groups: volumetric and dynamic.

One of the main reasons for failure of pumping equipment is the violation of mechanical seals in the main and peripheral equipment of the pump. The use of systems for direct hydraulic sealing of the pump shaft and the motor shaft does not provide reliable tightness for many technical and operational reasons.

Rotation of the impeller of a centrifugal pump can be practically carried out in one of the following ways:
- hydraulic input via a pipeline that supplies liquid to drive a hydraulic motor placed inside the pump;
- electric input that feeds the electric motor built into the pump;
- an electromagnetic drive using a magnetic field that penetrates through the walls of the pump and rotates a magnet or rotor placed inside the pump.

The third method of energy transfer – using the so-called electromagnetic drive, is based on the transfer of mechanical energy to the pump impeller due to the torque generated by the rotating magnetic field of the stator winding of a canned asynchronous motor (EAD) [8]. As an EAD rotor, a short-circuited or solid rotor, placed in a special sleeve made of a material with a magnetic permeability close to one, and with a high electrical resistance can be used. Since the sleeve is stationary and located in a rotating magnetic field, eddy currents, which counteract the penetration of
the magnetic field into the rotor, occur in the sleeve. Thus, eddy currents have a shielding effect. Similarly, if the material of the sleeve has a large magnetic permeability, then most of the magnetic flux will pass through the sleeve and less through the iron of the rotor. The sleeve will also shield the rotor. In order to reduce the effect of double shielding, a material with a high resistivity and low magnetic permeability is taken, which also reduces losses from eddy currents in the sleeve. In relation to the external environment, such a sleeve is a part of the device that can resist the pressure in it, i.e. it has a sufficiently high mechanical strength.

The electromagnetic drive makes it possible to carry out almost any speed of rotation of the shaft. It is applicable under certain conditions to work in an aggressive environment and can be used for devices operating at a pressure of more than 1000 ATM. and temperatures up to 500°C, as well as at high vacuum.

Unlike conventional drives equipped with standard electric motors, which are completely unsuited for transmitting mechanical energy to rotating parts of devices working under pressure, EADS are a component of devices that operate at almost any pressure and a significant speed of rotation of the working mechanism.

The use of a structural sealing scheme in serial centrifugal pumps using asynchronous canned electric motors (EAD) allows you to exclude slotted and contact seals between the pump and the drive motor.

2.3. Calculation of electrical losses of a sealed centrifugal pump with a canned asynchronous motor

EAD design features associated with the presence of protective, made of non-magnetic material, conductive sleeves on the stator and rotor leads to the need to ensure a minimum flow of pumped water in the cavity between the stator and the motor rotor. Flowing through the space limited by a cylindrical gap between the stator and rotor sleeves, the pumped water washes them, providing them with a \( Q_{\text{min}} \) flow rate to cool them to the required operating temperature values. Thus, the water at the pump outlet will have a higher temperature than the water temperature at the pump inlet.

Ignoring the inductive resistance of the stator sleeve, the expression for calculating the loss \( P_1 \) in it will take the form:

\[
P_1 = \frac{\pi^3 l_1^2 B_1^2 D_1^3 \delta_1 \varepsilon}{2 \rho_1 p^2} \text{ [watt]},
\]

where, \( l_1 \) - the length of the steel package of the stator; \( \rho_1 \) - electrical resistivity of the sleeve of the stator (steel 1X18H9T), om-m; \( p \) - number of pole pairs; \( \delta_1 \) - the thickness of the sleeve of the stator, m; \( D_1 \) - is the diameter of the bore of the stator with a protective sleeve, m; \( B_1 \) - the average value of the induction in the space between the stator and rotor sleeves, Tesla; \( f_1 \) - frequency of the alternator output voltage, Hz; \( \varepsilon \) - the ratio of the overhang, depending on the geometric dimensions of the bore of the stator pack \( \gamma (\varepsilon = 0.62 \text{ when } \gamma = 1) \).

The increase in water temperature at the pump outlet will occur not only due to cooling of the stator and rotor sleeves, but also due to mechanical friction that occurs when the rotating rotor sleeve contacts the flowing water washing it. The power used to overcome the water friction of the rotating rotor consists of two components:

- \( P_2 \) - friction losses of the rotor end surfaces (disk losses);
- \( P_3 \) - friction losses of the cylindrical surface of the rotor on water (cylindrical losses).

\[
P_2 = 19.6 C_f \rho_2 R_2^5 \omega^3 \text{ [watt]},
\]

where, \( C_f \) - coefficient of liquid friction; \( \rho_2 \) - water density kg·sec\(^{-2}\)/m\(^4\); \( R_2 \) - outer diameter of the rotor with a protective sleeve, m; \( \omega \) - angular speed of rotation of the rotor along the outer diameter, sec\(^{-1}\).

\[
P_3 = \pi \lambda l_2 \rho_2 R_2^4 \omega^3 g \text{ [watt]},
\]
where, $l_2$ – length of the rotor steel package; $\lambda$ - coefficient of resistance for the cylindrical flow; $g$ – acceleration of gravity.

Taking into account the entered designations, the increment of the water temperature $\Delta \tau$ at the pump outlet can be determined with sufficient accuracy by the expression [9]:

$$\Delta \tau = \frac{(0.5P_1 + P_2 + P_3 + P_4) \cdot 1000}{2 \cdot Q \cdot \gamma_c} \text{[} ^\circ \text{C}],$$

where, $P_4$ - electrical losses in the short-circuited rotor of the EAD, watt; $Q$ - pump flow rate, kg/sec; $\gamma_c$ - specific heat content of water per unit volume ($\gamma_c = 4190 \text{ Joules/m}^3 \cdot \text{degree}$).

Let's assume that the average specific flow rate of wells for upper aquifers ranges from 4.65 to 6.8 m$^3$/hour, with a water depth of about 30 meters in the well. If we take a decrease in the level when pumping a well of 6 meters, the flow rate of the well is equal to:

$$Q = \frac{4.65 + 5.8 + 6.8}{3} = \frac{34.5}{3} \text{ m}^3/\text{hour} = 34431 \text{ kg/hour} = 9.56 \text{ kg/second}.$$  

Taking the irrigation period of 10 days and the irrigation rate of 400-800 m$^3$ per 1 hectare, we will get, with the round-the-clock operation of the well, the area of irrigation from one well:

$$S = \frac{34.5 \cdot 24 \cdot 10}{600} = 13.85 \text{ hectare}.$$  

Taking into account the value $D$, the EAD power is equal to 7500 watts. It is calculated that in this case the total electrical losses in the EAD, taking into account the weight coefficients, are equal to 1325 watts [10]. Then, the increment of the water temperature at the pump outlet is determined by the expression:

$$\Delta \tau = \frac{1325 \cdot 1000}{2 \cdot 9.56 \cdot 4190} = 16.5 \text{ } ^\circ \text{C}.$$  

The temperature difference at the pump inlet and outlet is equal to an algebraic difference of the form:

$$\Delta = \Delta \tau - t = 16.5 - 12.0 = 4.5 \text{ } ^\circ \text{C}.$$  

The calculations prove that the use of hermetic centrifugal pumps with EAD as part of mobile irrigation systems allows you to exclude from the process of water treatment of water for irrigation, technical measures related to its preheating.

3. Experimental Study

The laboratory installation created at the University allows us to test in practice the advantages of design schemes for sealing serial centrifugal pumps with EAD operating in closed water and heat supply systems.

The principle of operation of the unit is based on reproducing the volume flow of the working fluid using a hydraulic system, and measuring the volume (mass), temperature, or volume flow of this liquid with reference measuring instruments.

The units operate in a closed cycle.

Figure 3 shows the main components of the installation.
The measuring section of the working table of the installation consists of a frame, a bath for draining water, clamping devices, shut-off valves, pressure gauges, thermal converters and special inserts. The pump motor control system allows reversing the water flow. Water circulation is provided by a centrifugal pump that supplies water from the storage tank to the work table via flow stabilization devices.

The storage tank (working capacity) is a tank with a volume of more than 6 m³/hour, which has a fill and drain taps, water level sensors (upper and lower).

The automated measuring system that is part of the installation allows you to make the necessary mathematical calculations, form measurement protocols and display them on a computer monitor.

The ambient and recirculating water temperature is controlled using platinum class a resistance thermometers with a measurement range from 0 to 150 °C.

Experiments carried out on the installation and experimental data obtained from their results confirm the theoretical calculations related to the calculated values of the coolant temperature at the pump outlet in relation to a closed network (cyclic pipeline).

4. Conclusions
When choosing pumping equipment in mobile irrigation complexes, first of all, it is necessary to follow the criteria of reliability, trouble-free operation and minimization of operating costs. The use of centrifugal pumps driven by shielded asynchronous motors in irrigation systems as pumps determines high performance in terms of reliability and trouble-free operation due to the design features of this type of pumps.

The use of an electric motor built into the pump with sealing along the inner contour and working with a wet rotor makes it possible to eliminate any leaks of the pumped liquid at the pump installation site and, as a result, by excluding the corresponding repairs, reduce the total operating costs of the irrigation complex.

The presence in the design of the pump motor of secondary non-magnetic current-conducting cylindrical shells located on a short-circuited rotor and a non-polar stator makes it possible to implement in practice additional features implemented by the pump associated with indirect heating of the pumped liquid.

In most cases, the heat transferred from the stator and rotor liners of the pumped liquid in the direct flow mode allows you to get a liquid at the pump outlet with a temperature that meets the technical
requirements for its further direct use. In particular, in relation to the moisture obtained from ground water, the paper presents a method for estimating the temperature of water at the pump outlet as a result of its indirect heating from secondary shells. A numerical example is used to calculate the value of the outlet water temperature for the accepted standard size of the pump. It is concluded that it can be further used for irrigation without additional water treatment.

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