# Theoretical substantiation of the design and dimensions of the impeller of the plant for the preparation of liquid feed mixtures

*Pavel* Solonshickov*, *Irina* Tolstoukhova, and *Artem* Shevchenko

Vyatka State Agrotechnological University, Kirov, Russia

**Abstract.** The article is devoted to a theoretical study to substantiate the design parameters of the impeller, an installation for the preparation of liquid feed mixtures created on the basis of a paddle pump. In the study of the pump, the indicator of the supply of liquid feed mixtures was taken as a basis. When calculating and determining the parameters, the theory of vane pumps was used, based on the laws and provisions of the hydromechanics of an ideal and viscous practically incompressible fluid. The proposed installation is universal and can be used both as a mixer and as a pump. Theoretical experiments were also carried out using the theory of experiment planning, as a result, regression equations were obtained.

## 1 Introduction

In animal husbandry, in the field of processing agricultural products, centrifugal pumps (vane type) are widely used. The design and development of mixing plants based on paddle pumps is relevant, since the simple design of the pump is justified by many studies. Justification of the parameters (dimensions) of the design of such a working body as an impeller is an important step. At the same time, it is known that the design of the impeller with curved blades is the most preferable, but in the conditions of farms and small enterprises, it is most simple and economical to make the blades straight or radial.

An overview of installations for mixing dry components with liquid allows us to identify certain boundaries, that is, technical characteristics that will be the initial data for design, but we should not forget about zootechnical requirements when it comes to the preparation of liquid feed mixtures. And therefore, an important parameter is the feed, which allows you to reduce labor costs and the cost of production as a whole, on which the time of preparation of the mixture also depends, and its further transportation. At the same time, this indicator is decisive when choosing the size and design of the installation based on a centrifugal pump, since the subsequent parameters and dimensions of the remaining elements will depend on it [1,2,3].

* Corresponding author: solon-pavel@yandex.ru

## 2 Methods

The theory of vane pumps, which is based on the laws and provisions of the hydromechanics of an ideal and viscous practically incompressible fluid, is used as the basis for calculating and determining the parameters. It is based on two main properties of a liquid medium: continuity and continuous change of flow parameters in the volume under consideration. Therefore, for the calculation, we use a methodology for determining the size of the impeller and the inlet diameter, in relation to the installation for the preparation of liquid feed mixtures [4,5].

In the practice of pump engineering, the most widespread methods of calculating impellers based on jet theory and using elements of similarity theory. Characteristic parameters and coefficients are widely used in both methods. Criteria for the similarity of pumps. The use of elements of similarity theory and dimensionless criteria of geometric, kinematic and dynamic similarity makes it possible to obtain similarity equations.

To determine which type of pumps can be attributed to the installation for the preparation of mixtures, it is necessary to use the coefficient of speed, which, due to historical circumstances, is widespread, and which is determined by the formula:

$$n_s = 3,65 \cdot \frac{n \cdot \sqrt{Q}}{\sqrt[4]{H^3}} \tag{1}$$

where H - pump head, m;
Q – pump flow, $m^3$/h.

In addition to using the laws and methods of a hydromechanic, we used the theory of experiment planning to find optimal parameters, since it is very convenient if there are problems with a set of boundary values, which sometimes allows us to narrow the search boundary. In this case, regression equations are obtained that allow describing the definition of design parameters.

## 3 Results and discussion

The installation is designed for the reasons that it can be universal as a mixer and as a pump. But at the same time, during operation, the question arises where and how to integrate a new machine into existing production without unnecessary costs. Of course, various adapters, flexible hoses and other seals can be used, but they can distort the operation of the installation as a whole, since the conditions for fluid entry into the impeller will be violated. According to the literature data, turbulence and premature cavitation are unacceptable, due to some violation of the fluid flow in the supply pipe [6,7].

Therefore, the design of the impeller was designed based on the following: the most common inlet diameter in pumps used for farms is the interval D0 = 30 ... 40 mm, and the supply Q = 5 ... 13 t / h (m3 / h). For mixers, the flow is Q= 2...20 t/h (m3/h).

The impeller of the installation is the following: windows 1 are made on the covering disk (Figure 1), located in relation to the blades in a staggered order. Schematically shows the working process of the impeller of the installation, where the arrows show the direction of movement of the fluid entering the center of the wheel, and then it enters the inter-blade channels. Loose or powdery material enters through windows 1 into another part of the inter-blade channels.

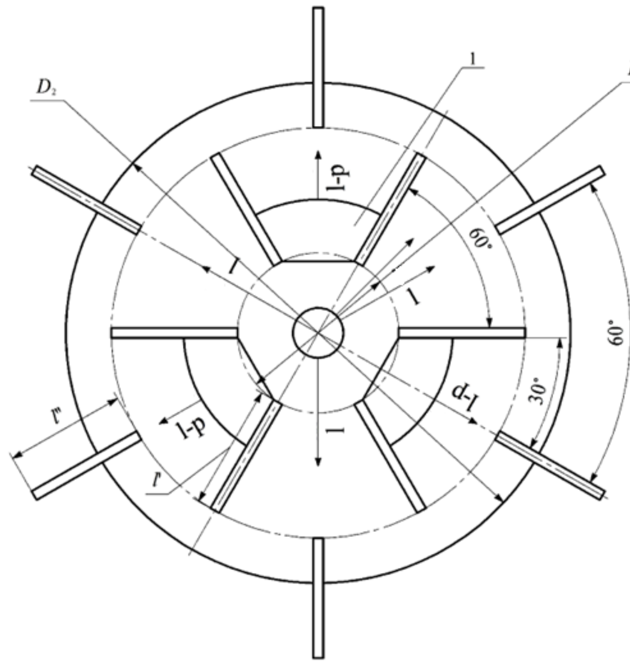


**Fig 1.** Scheme of the impeller of the plant for preparing mixtures: $\overrightarrow{1}$ - liquid, $\overrightarrow{1\text{-p}}$ - free-flowing or powdery component.

The design of the impeller is a closed wheel with two stages of blades. The input diameter is determined using the formula:

$$D_o = 4,5 \cdot \sqrt[3]{\frac{Q}{n}} \tag{2}$$

where n is the speed of rotation of the impeller, $min^{-1}$.

The diameter of the impeller $D_2$, can be determined from the corresponding ratio:

$$\frac{D_2}{D_0} = 2,5. \tag{3}$$

Or if we transform formula (3) to determine $D_2$, taking into account formula (1) we get:

$$D_o = 11,25 \cdot \sqrt[3]{\frac{Q}{n}}. \tag{4}$$

For calculations, we present Table 1 in which we enter parameters such as rotation speed n, feed Q. We will choose the rotation frequency based on the considerations that the drive is from an electric motor, that is, synchronous frequencies n = 500, 750, 1000, 1500 and 3000 $min^{-1}$. We will choose the feed in such a way that the minimum value will be $Q_{min}$ = 2 m3/h, and the maximum $Q_{max}$ = 20 $m^3/h$ (step 4.5 $m^3/h$). The feed is selected based on the recommendations and technical characteristics of the mixers:

$$Q_d = Q \cdot \left(\frac{n_t}{n}\right), \tag{5}$$

where $n_t$ is the speed of rotation of the impeller specified in the technical specification, min-1.

This will also be true for the dimensions of the inlet and impeller diameters:

To determine the parameters $D_0$ and $D_1$, we use a nomogram that allows us to determine the dimensions for different parameters of the rotation speed n and the feed Q. Do not forget that the refinement is carried out according to the similarity forms.

As an example, a pump of the G2-OPB brand was chosen, which is the basis for creating an installation for the preparation of liquid lump mixtures, which has Q = 10 m3/h. Following the arrows, we get the following: $D_0$ = 0.042 m, $D_1$ = 0.11 m at n = 3000 $min^{-1}$, but considering that $n_t$ = 2900 $min^{-1}$, taking into account the recalculation by similarity formulas (5...7), we get that $D_0^{'}$ = 0.4 m, $D_1^{'}$ = 0.106 m, which corresponds to the technical characteristic the pump.

**Table 1.** Initial data and results of calculations by formulas (1) and (2).

| **Flow rate, $m^3/h$** | **Rotation frequency impeller, $min^{-1}$** | **Inlet diameter $D_0$, m** | **Impeller diameter $D_2$, m** |
|---|---|---|---|
| 2 | 500 | 0.047 | 0.117 |
| | 750 | 0.041 | 0.102 |
| | 1000 | 0.037 | 0.092 |
| | 1500 | 0.032 | 0.081 |
| | 3000 | 0.026 | 0.064 |
| 6.5 | 500 | 0.069 | 0.173 |
| | 750 | 0.060 | 0.151 |
| | 1000 | 0.055 | 0.137 |
| | 1500 | 0.048 | 0.120 |
| | 3000 | 0.038 | 0.095 |
| 11 | 500 | 0.082 | 0.206 |
| | 750 | 0.072 | 0.180 |
| | 1000 | 0.065 | 0.163 |
| | 1500 | 0.057 | 0.143 |
| | 3000 | 0.045 | 0.113 |
| 15.5 | 500 | 0.092 | 0.231 |
| | 750 | 0.081 | 0.201 |
| | 1000 | 0.073 | 0.183 |
| | 1500 | 0.064 | 0.160 |
| | 3000 | 0.051 | 0.127 |
| 20 | 500 | 0.100 | 0.251 |
| | 750 | 0.088 | 0.219 |
| | 1000 | 0.080 | 0.199 |
| | 1500 | 0.070 | 0.174 |
| | 3000 | 0.055 | 0.138 |

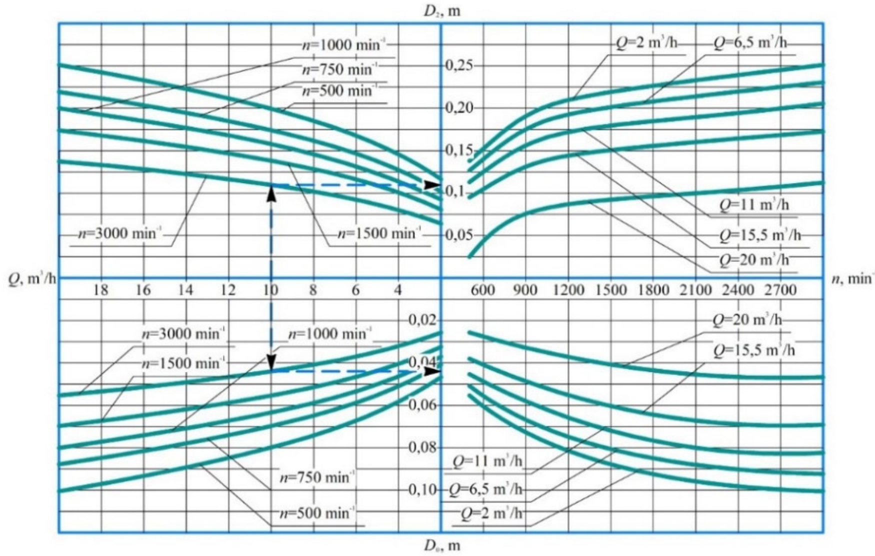


**Fig. 2.** Nomogram for determining the parameters of the inlet diameter $D_0$ and the impeller diameter $D_1$ when changing the impeller speed $n$ and flow rate $Q$.

The nomogram shows that all parameters change according to the same law. And the parameters of the impeller can be changed in a large range. Therefore, for convenience, we will use the theory of experiment planning to solve a compromise problem. To do this, we will use a 2nd-order plan with which we can obtain a mathematical model in the form of a 2nd-order polynomial, that is, in the general case when the number of variable factors is k, the model has the form:

$$\hat{y} = b_0 + \sum_{i=1}^{k} b_i \cdot x_i + \sum_{i=1}^{k} b_{ii} \cdot x_i^2 + \sum_{\substack{i<j \\ i.j=1}}^{k} b_{ij} \cdot x_i \cdot x_j . \tag{6}$$

The number of regression coefficients of such a plan will be equal to:

$$p = 1 + 2 \cdot k + \frac{k \cdot (k-1)}{2}. \tag{7}$$

Table 2 shows the experimental plan for 2 variable factors, so it will be an integral part of the complete factor experiment . And the second part is the so-called "star points". Obviously, with the number of factors k, there are 2k star points, so the total number of experiments will be equal to:

$$N = 2^k + 2 \cdot k. \tag{8}$$

**Table 2.** Factors and levels of variation.

| **Factors** | **Normalized** | **Natural** | **Variation levels** | | |
|---|---|---|---|---|---|
| | | | **(–1) lower** | **(0) main** | **(+1) upper** |
| Flow rate, $m^3$/h | $x_1$ | $Q$ | 2 | 12 | 20 |
| Rotation frequency impeller, $min^{-1}$ | $x_2$ | $n$ | 500 | 1750 | 3000 |

The planning matrix and the results of the experiments are shown in Table 3.

After the implementation of the experiments according to the plan and the processing of experimental data, a mathematical model of the workflow was obtained:

$$y_1 = 0{,}05 - 0{,}01 \cdot x_1 + 0{,}02 \cdot x_2 + 0{,}008 \cdot x_1^2 - 0{,}006 \cdot x_1 \cdot x_2 - 0{,}006 \cdot x_2^2, \quad (9)$$
$$y_2 = 0{,}13 - 0{,}04 \cdot x_1 + 0{,}05 \cdot x_2 + 0{,}02 \cdot x_1^2 - 0{,}015 \cdot x_1 \cdot x_2 - 0{,}016 \cdot x_2^2. \quad (10)$$

Analysis of the mathematical model (9) allows us to conclude that the size of the inlet diameter $D_0$ is most influenced by the rotation frequency ($b_2$=0.02) with its increase, the size increases. An increase in the feed ($b_1$=0.01) and leads to a decrease in the $D_o$ size. The situation is similar for the diameter of the impeller $D_2$, according to the mathematical model (10).

**Table 3.** Matrix of the full factorial experiment 32 and the obtained values of the optimization criterion.

| Experime nts | Factors | | Optimization criteria | |
|---|---|---|---|---|
| | **Flow rate, m$^3$/h** | **Rotation frequency impeller, min$^{-1}$** | **Inlet diameter $D_0$, m** | **Impeller diameter $D_2$, m** |
| | $x_1$ | $x_2$ | $y_1$ | $y_2$ |
| 1 | –1 | –1 | 0.05 | 0,12 |
| 2 | 0 | –1 | 0.03 | 0.08 |
| 3 | 1 | –1 | 0.03 | 0.06 |
| 4 | –1 | 0 | 0.08 | 0.21 |
| 5 | 0 | 0 | 0.05 | 0.14 |
| 6 | 1 | 0 | 0.05 | 0.11 |
| 7 | –1 | +1 | 0.10 | 0.25 |
| 8 | 0 | +1 | 0.07 | 0.17 |

For clarity of the results obtained, two-dimensional sections were constructed (Figure 3) the response surfaces, for which two factors were left in the original equation.

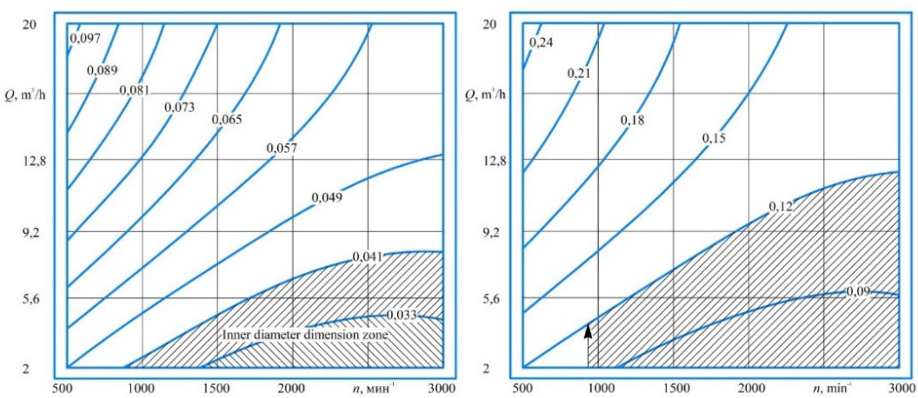


**Fig 3.** Two-dimensional sections of the response surface, characterizing the inlet diameter $D_0$ (a) and the diameter of the impeller $D_1$ (b), depending on the feed $Q$ and the speed $n$.

The analysis of two-dimensional sections (Figure 3, a) in the coordinates of the speed of rotation of the impeller and the feed at the following values n =850...3000 min$^{-1}$, and Q=2...8 m$^3$ / h, shows the diameter zone of the inlet to the impeller $D_0$= 0.030 ...0.041 m, which advises the size of the pumps, the most common in agricultural production and processing industry. As for the parameters of the mixers, the difference in flow is approximately 12 m$^3$/h.

If we take the results of the rotation speed range n =850...3000 min$^{-1}$ and the feed Q=2...12.6 m$^3$/h for a two-dimensional section (Figure 2, b), we get the impeller diameter zone $D_1$ =0.09...0.12 m.

Thus, it can be concluded that the design and justification of the parameters of the impeller of the installation for the preparation of liquid feed mixtures should have a flow within Q= 2...8 $m^3$/h, at a rotation speed of n =850 ... 3000 $min^{-1}$, but since the mixers are designed with such a bias that thewhose organ should occupy the maximum space in the mixing chamber, it is necessary to take this into account. Accordingly, we take the dimensions of the input diameter $D_0$ = 0.032 m, and $D_1$ = 0.1 m, then the range n = 1500... 3000 min is 1, and Q= 2...8 $m^3$/h.

## 4 Conclusion

Based on the theoretical studies of the plant for the preparation of liquid feed mixtures, the following conclusions are made:

1. As a result of the theoretical studies carried out, it was revealed that the determining indicator for substantiating the design of the plant for the preparation of liquid feed mixtures is such primates as the feed and the speed of rotation of the impeller, which in turn make it possible to determine the dimensions of the stroke dimeter and the diameter of the impeller, using the design theory of vane (centrifugal pumps).
2. A nomogram was obtained to determine the parameters of the installation in operation mode as a pump. Its further use will make it possible to predict real data that are obtained experimentally.
3. Theoretical experiments were carried out using the theory of experimental planning, as a result, regression equations (9) and (10) were obtained.
4. The main design parameters were determined, namely, the dimensions of the input diameter $D_0$= 0.032 m and the diameter of the impeller $D_1$=0.1 m, then the range n =1500...3000 $min^{-1}$, and Q=2...8 $m^3$/h.

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