Energy consumption and performance of the pump with a mixer – experimental tests

A. Wilk\textsuperscript{1} & S. Wilk\textsuperscript{2}
\textsuperscript{1}Institute of Power Machinery, Silesian University of Technology, Poland
\textsuperscript{2}Mining Mechanisation Centre KOMAG, Poland

Abstract

Pumps with mixer placed at the inlet to the impeller may be used for loosening and mixing solid deposits left at the bottom of a tank followed by pumping them out. This article discusses tests, which purpose was to determine the pump performance with the use of various mixers. There were 6 mixers that differed in shapes and sizes. During the measurements taken on pure water the impact of various mixers on the pump performance characteristics was searched for. Measurements of the power consumed by the mixers were also taken. During the measurements taken on the mixture of water and sand, efficiency of pumping out the solids was determined by applying various mixers. The results of the testing include the value of volumetric concentration of impurities and the mass flow of impurities for various mixers. Calculations of the energy consumed to pump out the mass unit of the solids were made as well. The effect of the works carried out is that the mixer with the highest performance and the lowest energy consumption was determined.

1 Introduction

When carrying liquids with mechanical impurities, it is very often necessary to pump out such impurities left at the bottom of tanks. It can be done mechanically. However, there is a simpler and cheaper method. The sediments may be loosen and mixed with water and then pumped out. For this reason, a plunger pump with a mixer placed at the inlet to the impeller was designed. The pump may also be used to mix solids dosed into water. For the needs of this
testing, a few mixers were made, which differed in designs and sizes. The purpose of the testing carried out was to determine the following:

- impact of a mixer on the pump performance characteristics,
- volume of solid impurities pumped out,
- energy consumed by a mixer,
- energy consumption for the mass unit of impurities pumped out.

As a result of the testing carried out, performance of various mixers was determined.

2 Description of the pump design and the nominal operation parameters

The pump with a mixer is a single-stage centrifugal impeller pump with an open impeller, arranged vertically, with a spiral frame. The mixer is installed on the shaft before the impeller. The axial forces, which affect the impeller, and the weight of the pump’s centrifuging assembly and the motor was balanced through relieving the blades placed at the rear disc of the impeller. The pump is not equipped with a gland. The shaft is sealed with a gap. The section of the pump’s flow unit is shown in figure 1.

The pump is driven with a three-phase induction motor, housed in a flameproof case, with the shaft power of $P_s = 7.5$ kW and the efficiency of $\eta_p = 0.865$.

The nominal (design) operation parameters when pumping clear water ($\rho = 1000$ kg/m$^3$) out are as follows:

- efficiency: $Q_n = 400$ dm$^3$/min
- delivery head: $H = 20$ m
- rotational speed: $n = 1450$ 1/min

Actual performance characteristics depend on the mixer applied.

3 Measurements of the pump operation parameters

3.1 Determination of the pump performance characteristics

In order to determine the mixer’s impact on the pump operation parameters, these parameters were measured for both the pump with no mixer and the pump with a mixer installed. The measurements were taken for every mixer.

Measurements of the pump operation parameters were taken pursuant to the provisions of the norm PN-85/M-44005 concerning measurements in the
accurate class. The measurements to make out performance characteristics were taken within the whole range of the pump efficiency – beginning from its

Operation when the slide damper on the forcing unit is shut through the operation of the slide damper opened completely.

Operation characteristics were presented as charts showing the following interdependences:

- pump's delivery head and its efficiency $H = f(Q)$
- electric power consumed by the motor and the pump's efficiency $P_{el} = f(Q)$
- pumping unit's efficiency and the pump's efficiency $\eta_\text{p} = f(Q)$

Examples of the performance characteristics at the nominal rotational speed for pure water were shown in figures 2 and 3.

3.2 Determination of the ability to pump out solid sediments

In order to determine the ability to pump out solid sediments by the pump with a mixer, a comparative testing was made. It included determination of the weight of solid impurities sucked in and pumped out of the tank where the pump was placed in. Measurements were taken for both the pump with no mixer and the pump with a mixer in each of the variations.

Testing was conducted at the testing station. Its diagram is shown in figure 4. The pump 4 tested was placed at the bottom of the lower tank 1 with the square basis 1 x 1 m and 1 m high. Over the lower tank there was an upper tank 2 equipped with the volumetric pitch 3 and a draining valve 7. Behind
the pump's pressure connector pipe there was a rigid cable with impulse holes used to measure the forcing pressure, followed by a slide damper used to regulate the forcing pressure. The rigid cable with the slide damper was connected to the upper tank with a pipe with inside diameter of 50 mm. To catch the impurities pumped over, a woven sieve with the mesh size of 0.188 mm was used. Depending on its value, the forcing pressure was measured with a precise spring-type pressure gauge, class 0.6 with the measuring range of 0.6 MPa, or a precise spring-type pressure gauge with the measuring range of 0.25 MPa. The time necessary to pump the liquid from the lower tank into the upper tank was measured with a stopwatch. The weight of the sand caught on the sieve was weighed on the tangent balance with the measurement range of 25 kg and the accuracy of reading (pitch size) 20 g. The rotational speed of the pump was measured with a fast digital rotational speed meter.

4 Types of tested mixers

Testing the ability to pump out the sediments was carried out with the use of mixers made as welded, which differed from one another in their designs and sizes. The testing was also carried out with the use of the pump with no mixer (instead a nut with the same shape and sizes as the hub of the mixers 1 to 5 was used).

The following mixers were used in the testing:
1. Mixer with three radial blades - external diameter 110 mm (variation I)
2. Mixer with three radial blades - external diameter 85 mm (variation II)
3. Mixer with three radial blades - external diameter 155 mm (variation III)
4. Mixer with two helical blades - left ones (which make the liquid flow outwards the impeller inlet) - external diameter 110 mm (variation IV)
5. Mixer with two helical blades - right ones (which make the liquid flow towards the impeller inlet) - external diameter 110 mm (variation V)

The sense of the pump rotations, when looking from the drive side, was to the left (anticlockwise). The direction of "winding" (coils) of the helical mixer blades was determined when looking at the mixer from the inlet side.

Thickness of the blades in variations 4 and 5 was 4 mm while the spiral lead was 60 mm. Variation 4 differed from variation 5 in the blade screw line winding direction.
6. Mixer with three radial blades and cylindrical hub finished spherically with the blade’s inside diameter 110 mm (variation VI)

Shapes and main sizes of the mixers are shown in figure 5.

Figure 5: The main dimensions of various mixer variations (wyk.).

5 Measurements of energy consumption by a mixer

In order to determine the power consumed by a mixer it was assumed that the power consumed was the difference between the power consumed by the pump with a mixer and the power consumed by the pump with no mixer (instead a nut was screwed on the shaft), both pumps operating with the same efficiency. However, as it was found out when the measurements were taken that in case of using various mixers for the same delivery head the powers differed, the power consumed by the pump with a mixer was adjusted to the delivery head and the
delivery head obtained by the pump with no mixer, according to the formula (1), was used.

\[ P_{elK} = P_{elm} \frac{H}{H_m} \]  

(1)

Thus, the power drawn by a mixer was determined according to the following formula:

\[ \Delta P_{el} = P_{elK} - P_{el} \]  

(2)

where:

- \( P_{elK} \) - power drawn from the mains adjusted to the delivery head, kW
- \( P_{elm} \) - power drawn by the pump with a mixer from the mains, KW
- \( P_{el} \) - power drawn by the pump with no mixer from the mains, kW
- \( H \) - delivery head obtained by the pump with no mixer, m
- \( H_m \) - delivery head obtained by the pump with a mixer, m

As it results from the measurements and calculations carried out, the power consumed by a mixer depends on its design. The results of the calculations of the power consumed by a mixer at the nominal rotational speed for various variants of mixers are specified in table 1.

<table>
<thead>
<tr>
<th>Mixer</th>
<th>var. I</th>
<th>var. II</th>
<th>var. III</th>
<th>var. IV</th>
<th>var. V</th>
<th>var. VI</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Delta P_{el} ) [kW]</td>
<td>1,278</td>
<td>0,497</td>
<td>4,185</td>
<td>0,202</td>
<td>0,120</td>
<td>1,854</td>
</tr>
</tbody>
</table>

The measurements of the power consumed by a mixer taken after the impeller had been disassembled from the pump and a mixer or a nut itself had been left on the shaft, provided results similar to those specified in table 1.

6 Testing efficiency to pump out solid sediments by the pump with a mixer

6.1 Purpose and conditions of the testing

The purpose of the testing was to determine the performance when pumping out solid sediments left in the tank where the pump with a mixer was installed in. Various mixers were used in this testing. Measurements for the pumps with no mixer were also taken.

For the needs of the testing, rinsed quartz sand was used as solid impurities. The sand density was determined and its sieve analysis was carried out. The sand characteristics were as follows:

- heaped density under dry conditions: \( \rho_s = 1,61 \text{ kg/dm}^3 \),
- heaped density under wet conditions: \( \rho_m = 2,10 \text{ kg/dm}^3 \),
6.2 Method of the measurements

When the measurements were taken for various mixers, it was tried to secure identical conditions for testing taken for every mixer and to obtain repeatability of the measured values. During the initial measurements it was found out that:

- with low liquid speeds in the pressure conduit, the sand is precipitated and deposited on a partially closed slide damper,
- as it is necessary for the pump to operate with high productivity, it is impossible to catch the impurities as they come,
- volume of the sand in the lower tank cannot be too high because the pump cannot be activated when the mixer is immersed completely in the sand.

For the above-mentioned reasons the measurements could not be conducted with constant operation of the pump.

In this case the measurements were taken in the following way:
1. After replacement of any mixer, the pump was reinstalled in the same place in the tank.
2. For every measurement, the tank was filled with the same volume of sand and the same volume of water.
3. The slide damper installed on the pump pressing unit was opened entirely, while the draining valve in the upper tank was closed.
4. The pump was activated and its working time was measured until the water was pumped out and the air was sucked in, then the pump was switched off.
5. The sand pumped with water was caught on the sieve and collected in the upper tank.
6. The sand was weighed when wet.

Measurements for the same mixer were taken several times.

6.3 Results of testing

The average results of the measurements are specified in table 2.

<table>
<thead>
<tr>
<th>Mixer</th>
<th>var. I</th>
<th>var. II</th>
<th>var. III</th>
<th>var. IV</th>
<th>var. V</th>
<th>var. VI</th>
<th>nut</th>
</tr>
</thead>
<tbody>
<tr>
<td>rotat. speed n [1/min]</td>
<td>1482</td>
<td>1482</td>
<td>1416</td>
<td>1482</td>
<td>1482</td>
<td>1480</td>
<td>1482</td>
</tr>
<tr>
<td>sand mass m [kg]</td>
<td>22,30</td>
<td>18,94</td>
<td>34,83</td>
<td>2,79</td>
<td>2,36</td>
<td>24,3</td>
<td>2,37</td>
</tr>
<tr>
<td>efficiency Q [dm³/min]</td>
<td>769</td>
<td>729</td>
<td>787</td>
<td>775</td>
<td>776</td>
<td>764</td>
<td>776</td>
</tr>
<tr>
<td>working time t [s]</td>
<td>24,19</td>
<td>25,53</td>
<td>23,39</td>
<td>24,05</td>
<td>23,84</td>
<td>24,65</td>
<td>23,94</td>
</tr>
</tbody>
</table>
7 Comparison of the ability to pump out solid sediments by the pump with various mixers

In order to compare and select the best mixer, the following criteria were assumed:

1) the highest volumetric concentration of impurities,
2) the highest mass flow rate of impurities,
3) the lowest unit energy consumption.

7.1 Evaluation as regards obtained volumetric concentration and mass flow rate of impurities

The volumetric concentration of impurities was determined as the ratio of the weight of the impurities pumped out and the volume of the liquid, which the impurities were pumped out with:

\[ k_v = \frac{m}{V} \quad [\text{kg/m}^3] \quad (3) \]

Mass flow rate of impurities was determined as the ratio of the weight of the impurities pumped out and the time the impurities were pumped out within:

\[ k_t = \frac{m}{t} \quad [\text{kg/s}] \quad (4) \]

where:

- \( m \) – sand mass, kg
- \( V \) – volume, dm³
- \( t \) – time, s

The obtained values concerning the volumetric concentration and the mass flow rate of impurities for different variations of mixers are specified in table 3 and on chart in figure 6.

<table>
<thead>
<tr>
<th>Mixer</th>
<th>var. I</th>
<th>var. II</th>
<th>var. III</th>
<th>var. IV</th>
<th>var. V</th>
<th>var. VI</th>
<th>nut</th>
</tr>
</thead>
<tbody>
<tr>
<td>( k_v ) [kg/dm³]</td>
<td>0.0719</td>
<td>0.0611</td>
<td>0.113</td>
<td>0.0090</td>
<td>0.0076</td>
<td>0.0775</td>
<td>0.0077</td>
</tr>
<tr>
<td>( k_t ) [kg/s]</td>
<td>0.992</td>
<td>0.742</td>
<td>1.489</td>
<td>0.116</td>
<td>0.099</td>
<td>0.986</td>
<td>0.099</td>
</tr>
</tbody>
</table>

During the testing, the pump’s flow rate and working time were very similar. Mixer variations are ranged in the same sequence as regards both the factors. The highest efficiency of loosing the sand left at the bottom of the tank
and pumping it out was obtained by the pump with mixer variation III, while the lowest – the pump with mixer variation V.

The pump with no mixer (with a nut) also pumped out a small quantity of sand. It may be explained that flowing into the impeller the liquid stream carries the sand grains away.

7.2 Evaluation as regards the lowest unit energy consumption

Testing the ability to pump out solid sediments (sand) was carried out under the conditions of unstable pump operation. The durations of measurements were short. For those reasons direct measurement of the power drawn from the mains was impossible. Thus calculation of the unit energy consumption was made for
average values with the use of the results of the measurements taken to draw up performance characteristics when pumping clear water.

As during testing various mixers their rotational speeds were different from the nominal rotational speed for which the pump performance characteristics were made, for the calculation purposes the average efficiencies were adjusted to the nominal rotational speed and then, upon determination of the power, it was adjusted to the rotational speed under the measurement conditions.

The unit energy consumption was determined as the ratio of the power consumed by the pump with a mixer and the mass flow rate of impurities:

\[ e = \frac{P_{el}}{k_1} \left[ \frac{kJ}{kg} \right] \text{ lub } \left[ \frac{J}{g} \right] \] (5)

The values concerning the unit energy consumption for various mixer variations are specified in table 4.

<table>
<thead>
<tr>
<th>Mixer</th>
<th>var. I</th>
<th>var. II</th>
<th>var. III</th>
<th>var. IV</th>
<th>var. V</th>
<th>var. VI</th>
<th>nut</th>
</tr>
</thead>
<tbody>
<tr>
<td>e [J/g]</td>
<td>10,318</td>
<td>11,360</td>
<td>7,594</td>
<td>72,440</td>
<td>84,051</td>
<td>10,211</td>
<td>82,758</td>
</tr>
</tbody>
</table>

The lowest unit energy consumption was obtained when the mixer variation III was used, while the highest – for the mixer variation V.

8 Summary

A pump with a mixer may be used to desludge sedimentation tanks filled with sediments or solids. It may be also used when it is necessary to mix solids dosed to liquids followed by pumping them out.

Measurements of the power consumptions by mixers with various designs and the performance characteristics were taken on clear water, while the measurements of the abilities to pump out solid sediments – on the mixture of water and quartz sand. Thus the results obtained are of comparative nature.

During the testing the measurements of the pump performance characteristics were taken for various mixers. Mixers installed at the inflow to the impeller make power consumed by the pump increase but, in principle, it does not affect the pump’s delivery head.

Measurements of the ability to pump out solid sediments by a pump with mixers of various designs were taken as well. The best results, i.e. the highest mass flow rate and the highest volumetric concentration of impurities, were obtained for the mixer variation III, i.e. a mixer with straight blades and the highest external diameter of the blades, while the helical mixers (both left-coiled and right-coiled) are not applicable to mixing and pumping out impurities.

Under the conditions of industrial application of the pumps with mixers, each time it is necessary to carry out an analysis of power consumption by the pump and a mixer in order to prevent the motor from being overloaded.