An experimental study on pump clogging

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Abstract. For sewage pump that various foreign substance is flowed into, anti-clogging performance is a factor as important as pump efficiency in order to avoid clogging trouble by foreign substance. Many investigations about pump inner flow and pump efficiency estimation have been carried out conventionally in order to realize coexistence with anti-clogging performance and pump performance. And these results have been reflected in construction of the running water section design method. As a index of anti-clogging performance, “impeller passage diameter” which is diameter of spherical solid that can pass through the pump is used widely. And there are various type of the sewage pump which have large impeller passage diameter. However real cause of clog is not a solid, and it is fibrous material such as towel and clothes, vinyl and paper diaper. In most case these material accumulate in the pump, so that clog is occurred. In this study, for the purpose of quantification of anti-clogging performance against fibrous materials, the factor that affect to clogging of pump was investigated by pump model test using a string. The test is done based on Taguchi method. In this test, type of the pump model, diameter of the string, material of the string, length of the string and flow rate are selected for the factor, and the effect that they have on the clogging of the pump was investigated. As a result of this test, it was made clear that length of the string has a strong influence on the clogging of the pump. And from the result of this test, evaluation method of anti-clogging performance of the pump against fibrous material by using string was considered. According to the result of above test based on Taguchi method, it was assumed that quantification of anti-clogging performance against fibrous materials is possible by flowing plural strings into the pump and calculating the probability of passing. Plurality sewage pumps of different types were evaluated based on this assumption. And it was confirmed that it is possible to compare anti clogging performance of the pump against fibrous materials quantitatively. And the specification of the string was selected according to the result of the test based on Taguchi method. By this method, one of the evaluation method on anti-clogging performance against fibrous materials was established.
1. Introduction
Sewage systems collect wastewater containing various foreign substances discharged from households and parks. They use a multitude of pumps for sewage transfer, which may fail due to clogging by such substances, resulting in lavatory failure or other serious problems. To prevent these problems, sewage pumps are required to resist clogging by foreign substances, i.e., to be anti-clogging, in addition to pump efficiency \[^1\]. Sewage pumps have been extensively studied regarding internal flow and performance estimation to maximize both anti-clogging performance and pump efficiency \[^2\] - \[^6\]. The results of these studies have been incorporated in the design of flow passage geometries. As low head hydropower turbine technology is drawing attention in connection with the effective use of renewable energy, studies on different aspects of clogging by foreign substances in river water are also underway \[^7\].

The anti-clogging performance of sewage pumps is often represented by the “impeller passage diameter”, which shows the size of spherical solids able to physically pass through the pump impeller. \[^2\] A wide variety of pump types with large impeller passage diameters are available; typical sewage pump types are shown in Figure 1.

In most cases, however, pump clogging is caused by accumulation of fibrous material, including towels, clothes, and paper diapers, not solids.

To quantify the anti-clogging performance of pumps against fibrous material, this study has identified factors affecting pump clogging through pump model testing using string as a typical example of fibrous material.

The test results have been used to develop an evaluation method for the anti-clogging performance of pumps against fibrous material.

| Type  | Configuration | Features                                      |
|-------|---------------|-----------------------------------------------|
| Non clog | ![Diagram](image) | Securing a passage area between vanes by reducing the number of vanes |
| One vane | ![Diagram](image) | Securing a passage area by using a single spiral vane |
| Vortex  | ![Diagram](image) | Securing a large passage area by providing a large space between the front side of vanes and the casing |

Fig. 1 Sewage pump types

2. Identification of factors affecting clogging based on experimental design
To identify factors affecting pump clogging by fibrous material, a test based on an experimental design was conducted using actual pumps to determine whether string could pass through the pumps.

2.1 Test method
As shown in Table 1, control factors and levels were arranged in an L27 orthogonal array. The specifications and appearance of each string type used in the test are shown in Table 2 and Figure 2, respectively. Three impeller types used in the test are shown in Figure 3. The pumps under test have a capacity of 0.2 to 1.3 m\(^3\)/min and a head of 5 to 21 m. Using the open-loop test apparatus shown in Figure 4, 20 pieces of string were introduced one by one into each running pump through its inlet. The introduction of all string pieces into the pump was followed by continuous pump operation for one minute. Then, the number of string pieces that passed through the pump was counted to obtain the probability of passing. When the motor current increased to or beyond twice the value at the start of pump operation and/or abnormal vibration occurred during string feed, the string feed process was stopped; then, the number of string pieces that passed through the pump was counted one minute later.
### Table 1 Control factors and levels arranged in the L27 orthogonal array

| Level | Control factor (Diameter of the pump outlet) | A | B | C | F | D |
|-------|---------------------------------------------|---|---|---|---|---|
| 1     | Two Vanes Semi-Open (80mm)                  |   | ø4 mm | Vinylon | Qbep × 50% | Diameter of the pump outlet × 1 |
| 2     | Single Vane Semi-Open (80mm)                |   | ø9 mm | Polyethylene | Qbep | Diameter of the pump outlet × 2 |
| 3     | Semi-Vortex (65mm)                          |   | ø12 mm | Polyester | Qbep × 125% | Diameter of the pump outlet × 5 |

### Table 2 String materials used in the test

| String material | Braiding | JIS (Japanese Industrial Standards) | ISO | Property (reference) |
|-----------------|----------|-------------------------------------|-----|-----------------------|
|                 |          |                                     |     | Specific gravity      | Water absorption | Elongation |
| Vinylon         | Three strand | JIS L 2703                          | -   | 1.26 to 1.3           | Present          | 18 to 22   |
| Polyethylene    | Three strand | JIS L 2705                          | ISO 1969 1990 | 0.94 to 0.96 | Absent          | 22 to 26   |
| Polyester       | Three strand | JIS L 2707                          | ISO 1141 1990 | 1.38             | Absent          | 15 to 22   |

2.2 Test results

Table 3 shows the test results, and Figure 5 shows a response graph based on the results.

The response graph reveals that the probability of passing varies according to the impeller type, suggesting that a test method using the probability of passing as an index can compare different impeller types in terms of how easily string can pass through a pump. The graph also shows that the length of string significantly affects and correlates with the probability of passing; longer string pieces...
were more likely to lodge in the pumps. For the string diameter, thicker string pieces were more likely
to lodge in the pumps. The flow rate has been found to be less influential on the probability of passing.

Figure 6 shows typical examples of string lodging in the pumps during the test.

Some pieces of string lodging in the pumps were caught on the leading edges of the vanes or
wrapped around the impellers. Some pieces other than those wrapped around the impellers were
entangled with each other and aggregated in the casing.

Longer pieces of string may come into contact with the leading edges of vanes more frequently as
they pass the edges, resulting in a higher likelihood of being caught on the edges. Even after passing
through the impeller flow passage, they tend to wrap around the periphery of the impeller before going
out of the casing or entangle and aggregate in the casing.

Fiber breakage was often observed in the polyester or polyethylene string lodging in the pumps.

The response graph is used to examine a method to quantitatively evaluate the difference in anti-
clogging performance according to the impeller type.

Table 3 Test results

| No. | Probability of passing (%) (First test) | Probability of passing (%) (Second test) |
|-----|----------------------------------------|-----------------------------------------|
| 1   | 95                                     | 100                                     |
| 2   | 95                                     | 95                                      |
| 3   | 25                                     | 15                                      |
| 4   | 0                                      | 0                                       |
| 5   | 90                                     | 100                                     |
| 6   | 90                                     | 80                                      |
| 7   | 45                                     | 65                                      |
| 8   | 79                                     | 46                                      |
| 9   | 95                                     | 95                                      |
| 10  | 95                                     | 95                                      |
| 11  | 95                                     | 55                                      |
| 12  | 30                                     | 5                                       |
| 13  | 0                                      | 9                                       |
| 14  | 100                                    | 100                                     |
| 15  | 50                                     | 55                                      |
| 16  | 95                                     | 90                                      |
| 17  | 0                                      | 0                                       |
| 18  | 95                                     | 5                                       |
| 19  | 100                                    | 100                                     |
| 20  | 100                                    | 100                                     |
| 21  | 15                                     | 10                                      |
| 22  | 0                                      | 0                                       |
| 23  | 100                                    | 100                                     |
| 24  | 7                                      | 0                                       |
| 25  | 15                                     | 14                                      |
| 26  | 0                                      | 0                                       |
| 27  | 85                                     | 85                                      |
3. Examination of anti-clogging performance evaluation method

The test results described above have revealed the following two findings.

- A test method using the probability of passing as an index can compare different impeller types in terms of how easily string can pass through a pump.
- The length of string significantly affects the probability of passing.

These findings lead to an assumption that the anti-clogging performance of a pump can be quantitatively evaluated by introducing multiple pieces of string with different lengths into the pump and measuring the probability of passing.

An evaluation of different sewage pumps based on this assumption has determined that the anti-clogging performance of pumps against fibrous material can be quantitatively compared.
3.1 Test method
Changes in the probability of passing were determined by introducing multiple pieces of string with different lengths into the pumps shown in Figure 7.

As was the case with the test discussed in Section 2, the open-loop test apparatus shown in Figure 3 was used, and pieces of string were introduced one by one into each running pump through its inlet. The introduction of all string pieces into the pump was followed by continuous pump operation for one minute. Then, the number of string pieces that passed through the pump was counted to obtain the probability of passing. When the motor current increased to or beyond twice the value at the start of pump operation and/or abnormal vibration occurred during string feed, the string feed process was stopped; then, the number of string pieces that passed through the pump was counted one minute later.

The operating conditions, the specifications of the string under test, and the number of test runs are given below.

- Operating conditions: Best efficiency point
- Specifications of the string under test: Solid cord rope made of vinylon
  - Diameter: $\phi 4$, Length: About 1 to 5 times the diameter of the pump outlet
- Number of string pieces used per test run for each string length: 20
- Number of test runs for each string length: 6

The pumps under test shown in Figure 7 have a capacity of 0.4 to 1.3 m$^3$/min and a head of 11 to 18 m.

Based on the test results described in Section 2, vinylon rope was selected since it was resistant to breakage and allowed for easy verification of test results. Solid cord rope, which was more resistant to breakage than three strand rope, was used. Figure 8 shows the appearance of the solid cord rope.

Rope 4 mm in diameter was used to facilitate the evaluation of test results for small sized pumps. Considering the interaction of string pieces lodging in a pump as indicated by the test results described in Section 2, the number of string pieces used per test run for each string length was 20.

3.2 Test results
The test results are shown in Figure 9 in the form of the relationship between the string length and the probability of passing. The string length was made dimensionless by the diameter of the pump outlet so that the results could be compared regardless of the pump size. Each plot shows the results per test run for each string length; average curves are formed by connecting the mean values of six test runs for each string length.

Like the response graph obtained in Section 2, the probability of passing decreased as the string length increased for all pumps under test. While all short pieces of string passed through the pumps, the probability of passing declined and varied more significantly for longer string pieces. When the string length was further increased, the probability of passing varied less significantly and fell to almost zero.
Since there is variation in the results for each string length, it may be necessary to conduct multiple test runs for the string length. To validate the number of test runs, additional test runs were carried out for Two Vanes Semi-Open, which had the greatest variation in Figure 9. For additional test runs, a string length three times longer than the diameter of the pump outlet was used to determine the mean value of the probability of passing with changes in the number of test runs. The results are shown in Table 5.

Table 5 indicates that the mean value of the probability of passing with six test runs differs only about 5% from that with seven or more test runs. Thus, our number of test runs (six) may be proper.

A graph representing the mean value of the probability of passing shows that the probability of passing begins to fall at a certain string length and that the slope of the mean value depends on the impeller type. These facts suggest that an evaluation of anti-clogging performance based only on the probability of passing for a specific string length is insufficient.
Figure 10 shows the test results for Semi-Vortex as a representative. In this figure, Area A is an area with string lengths one to five times the diameter of the pump outlet and probabilities of passing of 0 to 100%. Area B is an area with string lengths one to five times the diameter of the pump outlet and the mean value of the probability of passing for each string length.

By expressing the anti-clogging index (resistance to clogging) with the following formula, the anti-clogging performance of pumps can be evaluated regardless of the slope of the curve of the probability of passing in relation to the string length.

\[
\text{Anti-clogging index} = \frac{\text{Area B}}{\text{Area A}} \times 100 \text{ [%]} \quad (1)
\]

Table 6 shows the results of anti-clogging index calculation.

| Impeller type          | Anti-clogging index |
|------------------------|---------------------|
| Two Vanes Semi-Open    | 66.3 %               |
| Semi-Vortex            | 64.2 %               |
| One channel-Close      | 98.0 %               |

3.4 Pump evaluation using the anti-clogging index

To validate the evaluation method discussed above, a test similar to that in 3.3 was conducted using multiple pumps to evaluate their anti-clogging performance.

The test was carried out for the impeller types shown in Figure 7 and Single Channel Semi-Open shown in Figure 3. The pumps under test have a capacity of 0.2 to 1.3 m³/min and a head of 4 to 18 m.

The test results and anti-clogging index calculation results are shown in Figure 11 and Table 8, respectively. Single Vane Semi-Open, Semi Vortex, and One channel close are tested for several types.

For most pumps under test, Figure 11 indicates that the probability of passing is 50% or less at a string length five times the pump diameter. It also shows that no string five times longer than the pump diameter can pass through the pump depending on the impeller type.

With consideration given to the convenience of the test, these results suggest that the evaluation of anti-clogging performance using the anti-clogging index with up to a string length five times the pump diameter is proper for most pumps.
Table 7  Explanation notes of  Fig. 11

| Impeller type                          | Results per test run for each string length | Average curve |
|---------------------------------------|---------------------------------------------|---------------|
| Two Vanes Semi-open                   | ![Graph](image)                              |               |
| Semi-Vortex                           | ![Graph](image)                              |               |
| One channel-Close                      | ![Graph](image)                              |               |
| Single Channel Semi-Open I            | ![Graph](image)                              |               |
| Single Channel Semi-Open II           | ![Graph](image)                              |               |
| Semi-Vortex II                        | ![Graph](image)                              |               |
| Semi-Vortex III                       | ![Graph](image)                              |               |
| One channel-Close II                  | ![Graph](image)                              |               |
| One channel-Close III                 | ![Graph](image)                              |               |

Table 8  Evaluation of anti-clogging performance

| Impeller type                          | Anti-clogging index |
|---------------------------------------|---------------------|
| Two Vanes Semi-Open                   | 66.3 %              |
| Semi-Vortex                           | 64.2 %              |
| One channel-Close                      | 98.0 %              |
| Single Channel Semi-Open I            | 36.0 %              |
| Single Channel Semi-Open II           | 40.4 %              |
| Semi Vortex II                        | 38.3 %              |
| Semi Vortex III                       | 40.4 %              |
| One channel-Close II                  | 97.5 %              |
| One channel-Close III                 | 85.6 %              |
3.5 Additional test
For One channel-Close II, the anti-clogging index of which is almost 100% in Table 8, an additional test was conducted by further increasing the string length.

Fig. 12 shows the test results.
The figure indicates that the probability of passing decreases as the string length increases, as is the case with the other impeller types.

For a more detailed comparison of impeller types with an anti-clogging index of almost 100%, they can be quantitatively compared by extending the range of string lengths for evaluation with the method discussed in 3.3.

4. Conclusions
The results obtained from pump model testing conducted to quantify the anti-clogging performance of pumps against fibrous material are as follows.

- A test method using the probability of passing as an index can compare different impeller types in terms of how easily string can pass through a pump.
- The length of string significantly affects the probability of passing.
- The anti-clogging performance of a pump can be quantitatively evaluated based on the probability of passing for each string length by introducing multiple pieces of string one to five times longer than the diameter of the pump outlet into the pump.

These results have led to the development of a string-based evaluation method for the anti-clogging performance of pumps against fibrous material.
The correlation between this evaluation method and the actual foreign substances will be examined in the future.
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