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Improved Clog Resistance Testing Methodology for Wastewater Pumps with Flygt Adaptive Impeller Design

Roy Emetitiri[1]*, Godfrey Ariavie[2], Elkin Martinez[3], Stefan Ramström[4] and Mats Karlen[5]

[1,2]Mechanical Engineering Department, University of Benin, Benin City, Nigeria
[3,4,5]Xylem Water Solution AB, Stockholm, Sweden
E-mail address: [1*]royemetitiri@gmail.com,[2]ariaviefe@uniben.edu, [3]elkin.martinez@xyleminc.com, [4]stefan.ramström@xyleminc.com,
[5]mats.karlen@xyleminc.com
*corresponding author (Phone Number: +46-76-936-2631, +234-803-817-2020)

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Abstract

Existing methodology for testing and comparing the clogging resistance of advanced wastewater pumps in Xylem laboratory was assessed in relation to how it accommodates evolving modern wastewater materials and their limitations. Recirculation design was tested and evaluated against a set of decision criteria using Pugh's decision-making model. The recirculation design was modeled in this study as the final methodology to assess upper volume clogging resistance. Experiments were designed for this methodology and validation tests were carried out using Flygt N3085SH (standard and Upgraded version) and N3069SH pumps with a combination of parts from the small product range. The outcome from experiment indicates an average weight of the residual outcome for the upgraded version of the N3085SH to be 93.85% less than the standard version, making it a better version. Full size (diameter Ø140mm) N3069SH impeller showed better upper volume clogging resistance compared to impellers with Ø122mm with a dish and Ø115mm without a dish. The results achieved with this methodology validate its efficiency.

1. Introduction

Clogging of a pump can firstly lead to reduced capacity/efficiency as well as increased power consumption (i.e. higher electrical bill): If the clogging continues it can lead to a stop of the pump and/or damages to its parts [1] [2]. This will lead to a very costly unplanned service call-out. Reduced capacity and/or an unplanned stop can in turn result in leakage of wastewater to the environment [3]. Clogging can cause wear which can result in premature failure of the pump. Maintaining a steady and smooth flow is a priority for municipal wastewater managers and this can be quite demanding as pumps are required to handle the required flow at the specified head, pass solids without failing on a daily basis [4]. Offering unrestricted impeller passage capabilities for solid wastewater materials without causing clogging and compromising efficiency is quite a goal to attain [5]. Xylem as a leading global provider of wastewater solutions has a team of design engineers and scientist who work constantly to develop more advanced and cost-effective design solutions for this problem. Several designs have been developed and tested which are currently used in practice today and have proven themselves worthy with outstanding performances. One of these designs unique for Xylem is the patented Flygt Adaptive N impeller design. This impeller has a unique self-cleaning operating capability in creating a clog free pumping for solid waste during wastewater transportation and also maintains very high efficiencies throughout the operation [6]. This is a huge leap in the advancement of wastewater pump technologies. Finding the most optimal solutions to customer's needs and challenges is the main objective with R&D [7] .In order to find the most optimal solutions and designs, scientific knowledge as well as experience is essential. Experiments and/or simulations generate the information required to make new decisions relating to product design. Efficiency in generating such information is needed to guide these decisions in order to meet market windows, keep development and manufacturing cost low, and to have high-quality products. It is a continuous challenge to design high-quality pumps with high clogging resistance and high efficiency under new and existing wastewater conditions[8] [9]. Testing is an integral part of the design process, and developing a standard test methodology to meet this challenge can be tasking. Clogging in every part of the wastewater pumps hydraulic unit including gaps above the impeller, needs to be accounted for in wastewater pump design [10] [11].The current methodology used in Xylem laboratory to evaluate clog resistance on specific pumps does not fully produce relevant data to evaluate and compare different types of impellers to the present day composition of sewage material. This method also only provides information about clogging resistance to certain extents in specific regions of the pump hydraulic unit and it is not aimed at providing relevant information to the outcome of debris winding up above the impeller, around the shaft and leading to accumulation of fibers and sewage material on the upper volume. This study is focus on improving clog resistance testing methodology for Xylem small and midrange wastewater pumps. This will enable Xylem to perform a standard test and obtain more robust data for analysis and comparison in terms of clog resistance abilities at the upper part of the impeller for the series of small and midrange pumps.

2. Methodology

2.1. Recirculation Design

This design is based on the idea that fibers need to be tiny enough to be able to find their way up to the upper volume. Therefore recirculating a pool of fibers in a system to be re-pumped over again by the pump, allows the testing system to be self-sufficient over a period with a steady amount of test materials (fibers from wastewater materials) that can cause upper volume clogging and also that is required for the test. To get this design working, the equipment set-up to make the method fully functional is fully designed. The equipment setup includes the following;

i. A Tank,
ii. Piping system,
iii. Flow sensor
iv. Flow controller and

2.1.1. Tank Design

A tank with a much smaller dimension than that of the existing test rig (CTR) is most efficient for this design. The tanks used throughout this work have been chosen from among the available tanks in the Xylem laboratory. The tank selected at the initial testing phase has a cylindrical top and self-cleaning conical sump designed to improve flow over the sump floor during pumping. The sump base is designed to increase turbulence and cause re-suspension of settled solids and entrainment of floating debris. It is based on these desired flow characteristics that the tank finally adopted for this work was selected as shown in Fig 3.

Tank Dimension: Initial testing.

Cylindrical section: *Top diameter, D = 100cm, Height, H = 100cm*

Conical Section: *Sump base diameter, d = 30cm, Cone height, h = 50cm*

Fig. 1: Tank employed during initial testing phase

2.1.2. Piping System

A simple configuration which involves a hose with one end connected from the outlet of the test pump and the other end positioned in a manner that it directs flow back into the tank as shown in Fig. 2a-b was used to test this design in the beginning of the testing phase. As the testing phase continued, several modifications were made and a more convenient piping configuration was adopted as shown in Fig. 3. The dimensions of the pipes and hoses were dependent on, and also in direct proportion to the size of the outlet diameter of the test pumps which ranged from 50mm to 100mm.

Fig. 2a: Pump outlet connected hose

Fig. 2b: Pump submersed, Hose bent to recirculate flow

Fig. 2c: Clamp valve and hose

2.1.3. Flow Sensor

A standard analogue type pressure gauge with Bourdon tube per EN 837-1, welded to diaphragm seal available in Xylem Laboratory is used throughout this work to determine the operating point for the tests.

Pressure gauge specification:

Nominal size (NS) = 100mm

Accuracy class = 1.0

Scale range = 0 ... 6 bar

2.1.4 Flow Controller

One major concern with this design was the need to achieve a standard way of controlling the flow to attain operating along the performance curve of the test pump. Already established standards says that pumps operate best at the best efficiency points (BEP) and other points to the left (0.5BEP) and right (1.25BEP) of the pump performance curve. Therefore, this design must function and produce results at these points. A simple flow controller (clamp configuration) as shown in Fig. 2c used during the design testing phase produced results from multiple experiments at BEP and 1.25BEP, but it had its limitation when applied to test the pumps at the left side of the pump performance curve with much higher head and reduced flow (0.5BEP) than the other standard operating points. To achieve the 0.5BEP operating point, the clamp valve must be much tighter across the hose. This tightness creates a limited pathway for the water-fiber mixture to recirculate hence accumulating fibers and creating a clogging site at the valve end of the hose and disrupting the experiment. To extend the flexibility of the recirculation design along all standard points of the pump performance curve, several possible solutions were attempted. The different approaches identified and tested are listed below:

i. Standard Larox valve
ii. Hollow disk
iii. Flow reducer
iv. Standard two pump system with VFD

A maximum of 20 minutes per test at 0.5BEP is used to verify the suitability of these approaches. The approach with the ability to sustain the experiment for 20 minutes or more and produce a result is considered most suitable.

i. Standard Larox Valve

Conducting the experiment with the standard Larox valve and attempting to achieve operating point to the left side of the pump performance curve (0.5QBEP) was quite difficult to attain without having the valve almost completely closed. Although there was a chance in the beginning of the experiment for water-fiber mixture to go through the valve, after just a little amount of time (2minutes), the water-fiber mixture began to accumulate quickly to cause a blockage at the valve end of the system and then suddenly stopped the pump in less than 3 minutes into the experiment after three (3) attempts. The outcome was quite the same as the clamp configuration.

ii. Hollow Disk

In Xylem Laboratory, a set of hollow disk have been designed to achieve pump operating points for wear test purposes. One of these disks among the sets with the smallest diameter was chosen on the assumption that it may meet the desired operating point for the experiment on the reference test pump for this work. The disk was incorporated into the existing pipe configuration in the tank and tested. The disk produces almost the exact operating point at 0.5QBEP for the reference pump with just a slight difference. This seemed like a much better solution to the valve clogging problem than the Larox valve and the clamp configuration, but there still exists a problem of fiber accumulation around the hollow part of the disk which inhibits the experiment. Although several experiments with this configuration lasts a little over 10 minutes at this duty point, the problem of fiber accumulation makes this solution still unsuitable to apply.

iii. Conical Reducer

This approach is a sequel to the hollow disk configuration. This configuration is developed in order to go around the complication of the clogging accumulation limiting the hollow disk configuration. In this case, a trial-and-error approach is applied to design and model a conical hollow extension that will acts as a flow reducer. This hollow cone is 3D printed and fitted into a metal (hollow cylindrical) extension. One end of the conical reducer is dimensioned with the diameter of the hollow disk to give the operating point for the experiment and the other end with the same dimension as the metal extension pipe connected to the main pipe leading from the pump outlet. The conical extension is modeled with a spline curve on its inner surface with no specific detailed design consideration. This curve on the inner surface is to provide a more streamlined pathway for the water-fiber mixture. This was a successful approach and the problem of pipe clogging was completely eliminated with several experiments sustained for up to 20 minutes hence suitable for application.

iv. Standard Two Pump System with VFD

As with other approaches, some kind of system pressure is created by constriction in the discharge pipes but in this approach, we attempt to create a system pressure or operating point without any constriction whatsoever. Two pumps each are installed with a P-type installation in the tank. One of the pumps which we have considered as the system pump works directly against the other pump (test Pump) to produce the maximum system pressure attainable from the combination. The total system pressure is controlled using a VFD connected to the system pump by altering its speed to the level that eventually produces the required operating point for the test. Proper pump selection is carried out for this approach. Selection is made based on the kind of flow properties the intending system pump can offer. Initial consideration for system pump selection was geared towards pumps with the following flow/performance properties in Table 1.

Table 1: Performance properties for system pumps

Pump Designation	Flow Property	Max Head (m)	Max flow (l/s)	Specification
NP3069.160SH	High head / High flow	26.5	17	2.4kW-5.1A 50Hz, 400V, 2 poles Ø140
DXG turbo	High head /Low flow	43.5	3	
FP3068.180 LT	low head/low flow	14	9.5	2.4kW-5.1A 50Hz, 400V 2 poles Ø102

An appreciable amount of total system pressure suitable to ascertain the viability of the standard two pump system approach could not be attained with these selections. Singularly and in combination with the test pump, the maximum pressure attained in the system was less than 5m of head. A different selection approach was applied and in this case, selection is based on how much head the system pump can create at maximum flow rate. What is required here is that the minimum amount of head produced by the pump at maximum flow rate should be appreciable high. A pump with a D-impeller (vortex) matched the requirements and was eventually selected to fit into this application. Performance properties for the selected system pump are presented in Table 2.

Table 2: Performance properties for selected system pump

Pump Designation	Flow Property	Min Head (m)	Max flow (l/s)	Specification
DP3085.183HT	high min. Head /max flow	15,5	5.8	2.4kW-4.5A 50Hz, 415V-2poles 6blades

The pressure produced by the system pump combined with that produced by the test pump creates a high total system pressure which is about 21m of head. However, asides using the system pump (vortex) to create the system pressure, it was also applied as the discharge end of the system for recirculation. The design and geometry of the vortex impeller and pump housing is seen to be a technical match for this discharge duty. A trial test with sewage material and water is carried out with the standard two pump system approach. The following were observed:

i. Experiment can be sustained for more than 20minutes
ii. No pipe clogging
iii. Upper volume clogging achieved
iv. Experiment can be tested at any point along the pump performance curve

These observations show that the standard two pump system approach is better suited for the recirculation design and for the aim of this work than the others. Hence, it is adopted for further real time experiments and comparison for pumps within the scope of this work.

2.2. Adopted Model (Recirculation Design)

The adopted model for the recirculation design now consists of a tank with pipes fitted into it to accommodate two P-type installations. One of the installations serves to hold the system pump, while the other holds the test pump. This configuration also consists of a pressure measurement point connected to a pressure gauge via a tiny hose where the pressure/flow condition of the system can be measured. The tank is filled with water to a certain volume after installation of the pumps. The test pump and the system pump run against each other to create a total system pressure which is controlled to the required operating point for the test using a variable speed drive (VFD) connected to the system pump. The tank is filled afterwards with calculated amount of sewage material. For this model, a measured amount of materials are chopped into bits before pouring into the tank. This is carried out to eliminate impeller clogging and target more upper volume clogging. After completing an experiment with this model, the tank is cleaned, and the process is repeated for another experiment.

Fig 3: Adopted model (Interior and Exterior view with VFD)

2.3. Experiment Medium Design for Method

2.3.1. Volume of water

The volume of water is determined with respect to the test pump. The amount of materials and the volume of water required for the methodology were determined simultaneously. In this work we have determined the water level in three ways;

i. Volume of water at fully submersed level of the pump
ii. Volume of water at partially submersed level of the pump.
iii. Volume of water when the pump is excessively submersed.

2.3.2. Quantity of Materials

Formation of fibers is an important part of this methodology. To be able to access the worst-case scenario of upper clogging, a lot of fibers should be formed in the system. There must be a balance between water and fiber content in the method. Several experiments have been carried out with Shreds formed from textile material of size 585mm×465mm to determine how much material is suitable at different levels of water. One factor each between water level and quantity of material was kept constant while the other was varied during the process. First the level of water was kept constant while the amount of materials was varied and vice versa. A range of material quantity against water level suitable for this method has been determined as follows;

i. Shreds of 7-10 pcs for Partially Submersed
ii. Shreds of 11-14pcs for Fully Submersed
iii. Shreds of 15 pcs- above for Excessively Submersed

2.3.3. Operating Point for Test

Although the method is able to function at any point on the pump performance curve, Standard operating points have been adopted for this method. These operating points are relative to the best efficiency point (BEP) as follows;

i. Best efficiency point (BEP)
ii. 0.5BEP
iii. 1.25BEP

2.4. Validation Test

2.4.1. Flygt N3085SH Standard

This is the reference pump to which other validation test outcome are compared. It has been extensively used during the methodology design and experimental design stages for this work to determine the worst-case outcome of upper volume clogging for waste water pumps within the small range products. The design of the upper shroud of the impeller, the upper insert ring and the pump housing are shown below.

Fig. 4a: Upper shroud of the impeller(L) and insert ring(R)

Fig. 4b: Pump housing

2.4.2. Flygt N3085SH Upgrade

The upgraded version of the reference pump in Fig. 5a-b consists of unique design with cutting capabilities from the interaction between the upper shroud of the impeller and the upper insert ring of the pump. This upgrade has the same specification as the reference but has proven efficiency in the field in terms of upper volume clogging as no reported cases have been recorded since its introduction to the market. Therefore by comparing with the standard version, a considerable difference in the amount of upper volume clogging should be attained when this method is put to test on both versions. The upgrade also includes the pump housing where the geometry of the cut-water has been redefined for better performance.

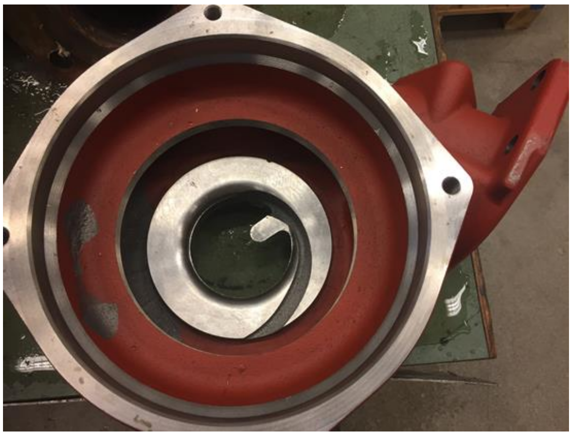

Fig. 5a: Upgrade impeller   Fig. 5b: Pump housing

To validate the workability and efficiency of this model for the methodology, three experiments each are carried out with a standard version and an upgraded version of the reference pump. Experiments were also carried out with a combination of the parts from both the standard and upgraded version in different manners to validate this model.

2.4.3. Flygt NP 3069 SH

This is a comparison pump within the small product range. It has been chosen as comparison pump for validation because a few cases of upper volume clogging have also been recorded for this product. A couple of different impeller designs for this product were tested to make comparison within itself and also to the reference pump. Comparison within itself provides information about which impeller design and size is best compatible with the product and also for further improvement. The pump specifications are presented in Table 3 while the pump sizes of the different impellers are shown in Table 4 and Fig. 6a-c.

Table 3: Pump specifications

Model	N3069SH
No. of vanes	2
No. of poles	2
Frequency, voltage	50Hz 400v, 60Hz 440v

Table 4: 3069 Impeller sizes

Fig. 6	N3069SH Impellers for Validation Test	Description
	Diameter Ø (mm)	
A	140	Full size
B	122	with dish
C	115	without dish

Fig. 6a: N3069SH **Ø140 impeller**

Fig. 6b: N3069SH **Ø 122 impeller**

Fig. 6c: **N3069SH Ø115 impeller**

Note that all validation tests carried out with this methodology are with the same volume of water and quantity of sewage material for the same period. This is done to avoid variation and error while making comparison.

3. Results and Discussion

3.1. Validation test result for reference pump (standard)

The residual outcome of entangled fibers is seen to occupy the entire volume at the upper gap of the pump. It is observed to be tightly packed around the shaft area of the pump and freely packed as it spreads away from the center of the impeller. Some amount of clogging is observed at the cut water of the pump housing and around the area between the pump housing and the stationary part of the pump. The reference pump validation test results are presented in Table 5.

Table 5: Reference pump validation test result

N3085SH (standard) Reference Pump Results					
Exp. S/N	Duty Point	Duration (Minutes)	Water Level	Material Qty (pcs)	Weight of dry residue (g)
1	0.5QBEP	20	Partially submersed	7	29.8
2	0.5QBEP	20	Partially submersed	7	28.7
3	0.5QBEP	20	Partially submersed	7	28.3
				Average	28.93

3.2. Validation test result for N3085SH (Upgrade)

The outcome is just a small amount of fibers entangled not too tightly around the shaft behind the impeller. Some amounts of fibers are seen around the pump housing but not particularly cut water. Upgrade reference pump validation test results are presented in Table 6.

Table 6: Upgrade reference pump validation test result

N3085SH (Upgrade) Reference Pump Results					
Exp. S/N	Duty Point	Duration (Minutes)	Water Level	Material Qty (pcs)	Weight of dry residue (g)
1	0.5QBEP	20	Partially submersed	7	1.24
2	0.5QBEP	20	Partially submersed	7	1.54
3	0.5QBEP	20	Partially submersed	7	2.57
				Average	1.78

The outcome from the conical reducer test is seen to produce quite the same results as the standard two pump system model for both versions of the pump.

3.3. Validation test result for N3069SH

The full sized (**Ø** 140mm) impeller records no residual outcome at the upper volume. The **Ø** 122 mm shows little residual outcome at the upper volume around the shaft. The Ø115 impeller shows substantial amounts of residuals behind the impeller around the shaft. The various weights of the residuals for the different impellers are presented in Table 7.

Table 7: Comparison pump validation test result

N3069SH Comparison Pump Results						
Impeller Diameter (mm)	Description	Duty Point	Duration (Minutes)	Water Level	Material Qty (pcs)	Weight of dry residue (g)
140	full size	0.5QBEP	20	Partially submersed	7	0
122	with dish	0.5QBEP	20	Partially submersed	7	0.986
115	without dish	0.5QBEP	20	Partially submersed	7	8.413

3.4. Comparison of upgrade and standard version of pump

Shows the comparison of the average weight outcome between the upgrade and the standard impellers of the N3085SH is shown in Table 8. The average weight of the residual outcome for the upgraded version is 93.85% less than that of the standard version.

Table 8: Average weight for upgrade and standard N3085SH validation test result

	Standard pump	Upgrade Pump
Average weight (g)	28.93	1.78

3.5. Comparison of impellers for N3069SH

The full size impeller in Table 7 is the better of them all as no substantial material outcome could be recorded for comparison. After comparing the outcome for the **Ø122 with dish and Ø115 without dish,** the Ø122 with dish is seen to be better for applications at their respective 0.5QBEPs'. Outcome from test at QBEP for the Ø115 impeller without dish shows that Ø122 with dish is a much better design of the two.

4. Conclusion

Distinctions in the outcome of experiments between the reference pump for this work and the comparison pumps evidently show that this methodology can be applied as a standard way to assess upper volume clogging. The main constituent of upper volume clogging is fibers. Therefore, fiber initiation is very critical for this methodology. This method can be scaled up to assess upper volume clogging for bigger pumps than the ones used as reference in this work. The P-type installation is most suitable for this method.

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