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Concept Selection: An Improved Clog Resistance Testing Methodology for Wastewater Pump Using Pugh Decision Model

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Abstract

Decision making is a systematic process and is an integral part of design function. This paper discusses the application of Pugh's decision matrices in concept selection within wastewater pump clog resistance testing methodology. Two individual concepts to test clog resistance testing in advanced wastewater pumps have been developed. A set of decision criteria were established and concept evaluation and selection have been carried out using Pugh's decision-making model. Combination of both concepts was used as datum while individual concepts were simultaneously compared against it and the outcome weighted. The recirculation concept showed a weighted total of 11 over the lifting device concept with 3. The datum was rotated and the recirculation concept showed a weighted total of 46 over the combination concept with 11. The recirculation concept has been selected and a standard two pump system with variable speed drive was further developed under this concept to assess upper volume clogging in wastewater pumps. 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 results achieved with this methodology validate its efficiency and show that Pugh's matrices if employed correctly can be a tool in decision making in engineering design.

1. Introduction

Municipal wastewater managers are no strangers to clogged pumps. Although the pumps themselves may sometimes be a cause of this problem due to design but they are not the only contributing factors. Other factors ranging from pump station design, improper pump selection and type of wastewater and its constituents contribute to this. Clogged pumps experience reduced capacity and consume more power leading to higher electricity bill: Continuous clogging can cause damage to pump parts and this may lead to premature failure of the pump and very costly unplanned service call-out [1, 2, 3]. Lessened pump efficiency and/or random stoppage can in turn result in leakage of wastewater to the environment [3]. The priority of most municipal wastewater managers to sustain a desired flow condition puts heavy demands on wastewater pumps. Wastewater pumps are required to handle the required flow at the specified head, pass solids without failing on a daily basis [4]. The goal for most pump manufacturers is to produce pumps that can offer unrestricted impeller passage capabilities for solid wastewater materials without causing clogging and compromising efficiency [5]. Although this is quite a hefty goal to attain, Xylem as a leading global provider of wastewater solutions has a team of committed design engineers and scientist who challenge themselves 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 within R&D [7]. Accounting for clogging in every part of the wastewater pumps hydraulic unit including gaps above the impeller under new and existing wastewater conditions is the goal when applying a clog testing methodology. In this paper, two concepts were developed and considered feasible to become an improved way to test wastewater pump clogging resistance which will account for the limitations of the methodology currently used in Xylem laboratory. In selecting the better of the two concepts to become a standard way to carry out testing that will not only be compatible with the goal the pump product seeks to attain, but also produce highly efficient results repeatedly and safely, critical design considerations and decisions have to be made. Decision making is an integral part of the design process in order to find the most optimal solutions to design problems. Scientific knowledge, experience and experiments or simulations generate the information required to make new decisions relating to product development. 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. Pugh's decision making model is a method that can facilitate a structured concept selection process [8]. This paper discusses the application and validation of efficiency of Pugh's model for the concept selection process during this study.

2. Methodology

2.1 Concept Development

A number of different concepts assumed to be able to promote upper volume clogging have been developed. The concepts were developed from ideas generated through brainstorming and from evaluating previous attempts towards the subject of clogging and upper volume clogging in wastewater pumps in general. The objective here is to develop as much concepts as possible without criticizing no matter unrealistic and out of context they seem. This ensured that no ideas were wasted.

2.1.1 Concept One–Impeller Lifting (using lifting mechanism)

This Concept also utilizes the idea that the adaptive impeller feature in some of these pumps could be advantageous in the process of inducing upper clogging. This involves designing a mechanism that can move the impeller upward and downward while the pump is running. The assumption in this idea is that the lifting mechanism creates a more open pathway for fibrous strands of materials to find their way up in the upper volume easily and faster. It is also of the assumption that it will create an avenue to manually control the movement of the impeller to determine whether or not and to what extent it contributes to clogging or cleaning of the upper volume.

2.1.2 Concept Two - Recirculation System

This concept 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.

2.2 Concept Feasibility

Feasibility study was carried out to determine which of these concepts will be suitable for testing. Overall, the ultimate requirement for any feasible concept is their simplicity and ease of application. A number of interviews and discussions were carried out with fluid hydraulics and design expert engineers in xylem to examine and fault the feasibility of these concepts based the following criteria;

i. Technicality, ii. Skill, iii. Safety, iv. Objective related, v. Complexity, vi. Cost

At the end of the feasibility study, the lifting mechanism and the recirculation concept matched closely the most with the criteria above to be suitable concepts to proceed with for further testing and evaluation.

2.3 Concept Testing

Testing is carried out to investigate the assumed capabilities of these feasible concepts. A couple of pre-test demands are outlined so as to have an organized testing procedure for the concepts. These pre-test demands are structured aims that each test procedure seeks to identify. This is a way to avoid irregular deviation and maintain the purpose of the test. The pre-test demands are stated as;

i. The ability for the concept to induce upper clogging

ii. The time to accomplish substantial outcome

iii. The factors (both controllable and uncontrollable) that can affect the outcome of the test.

2.3.1 Reference Pump Specification

Table 1 Reference Pump Specification.

<table>
<tr><td>Model</td><td colspan="2">N3085SH</td><td>Frequency</td><td>50Hz</td></tr>
<tr><td>Impeller Diameter</td><td colspan="2">Φ 135mm</td><td>Phases</td><td>3</td></tr>
<tr><td rowspan="2">Rated Power</td><td rowspan="2">P1:2.94kW</td><td rowspan="2">P2:2.37kW</td><td>Voltage</td><td>415v</td></tr>
<tr><td>Rev</td><td>11</td></tr>
<tr><td>Rated current</td><td colspan="2">4.8A</td><td>Poles</td><td>2</td></tr>
<tr><td>Outlet diameter</td><td colspan="2">100mm</td><td></td><td></td></tr>
<tr><td>Weight</td><td colspan="2">68kg</td><td></td><td></td></tr>
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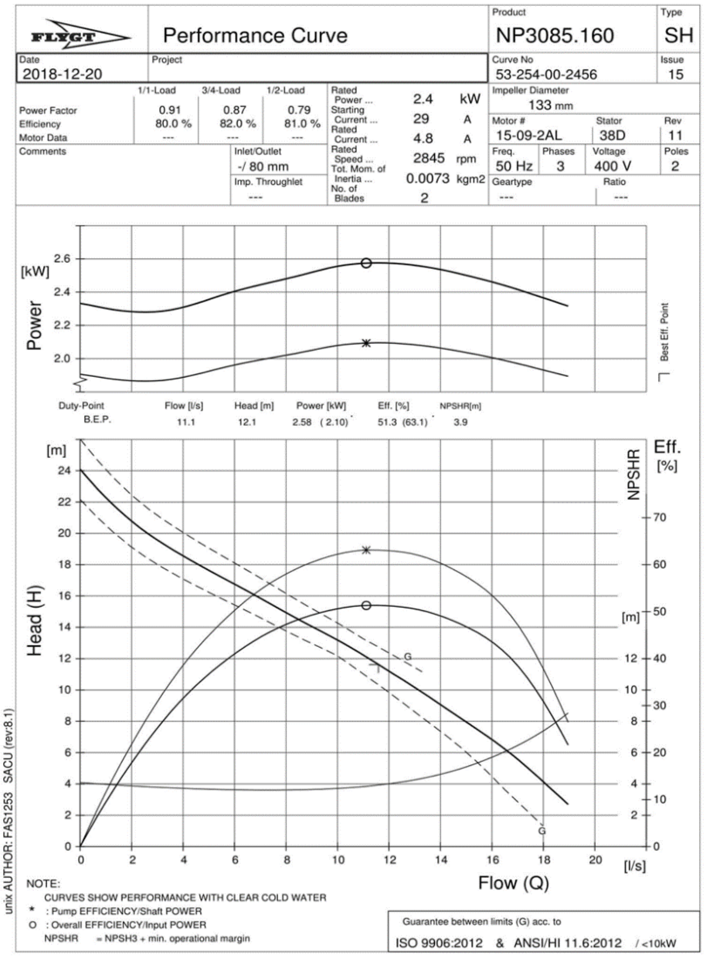

Fig. 1 Performance curve for reference pump

2.4 Impeller Lifting (Using Lifting Mechanism) Concept Test

The control test rig (CTR) in Xylem Laboratory in Sundbyberg is used for this test. The test is carried out on the reference pump (Flygt N3085SH) in a water medium at 40°C and fibrous material (textile) is used as the test object to induce clogging. Since the mechanism has not been design at this point, textile material of size *200x200mm* is used to control the lifting of the N-adaptive impeller during the test.

2.4.1 Test Procedure

i. Install the reference pump in the CTR

ii. Run the pump and set the operating point (0.5QBEP, QBEP, 1.25QBEP). QBEP (reference pump) is 12.4 l/s

iii. Cut the materials into small bits and pour into the CTR

Fig **2** Shred materials for test

iv. Feed the pump with *200x200mm size* materials at preferred interval to control the adaptive mechanism.

Fig. 3 Standard size material

v. Run the test for 10minutes and 20minutes These are the standard test durations that have been adopted for this study

2.5. Recirculation Concept Testing

2.5.1. Equipment:

i. Tank , ii. Discharge Hose Φ100mm, iii. Pressure Gauge, iv. Installation

Fig 4a Tank for test

Fig 4b Clamp Valve and Hose

2.5.2 Test Procedure:

Duty Point: QBEP 12.4(l/s), Head: 12.6m = 1.23bar, Duration: 10 and 20 minutes

The discharge hose was connected to the outlet of the pump. The pump was installed in the tank using an S-installation type while the discharge end of the hose was put back into the tank. The tank was filled with water until a partially submersed level of the pump was reached. The pump was run at best efficiency points for the experiment and this was achieved by using a pair of clamps to create a flow resistance on the passage way (hose) at the discharge end of the pump. Small bits of textile materials were fed into the system and the experiment was timed.

2.6 Concept Evaluation

The implication of this evaluation is comparison and decision making. This process tested the completeness and understanding of requirements and identified which of the concepts possessed the greater potential of becoming a standard methodology for upper volume clog resistance testing. The evaluation was made using Pugh's decision making model. With this model, comparison was made against a set of established criteria, task left for each concepts and time to complete the task.

Logically, both concepts if combined together will make a more dynamic and robust methodology to test upper volume clog resistance. Although both concepts have their own individual advantages in a stand-alone situation and can still help us reach the goal, we believe would be a more robust and advantageous methodology if both concepts are combined together. For the purpose of this paper, one of these two concepts was selected to further development and we have also considered the combination of both concepts as a third concept in the selection process only for comparison purpose.

2.6.1 Pugh's Decision-making Model

This is an iterative decision-making process effective for comparing alternative concepts using a set of established requirements in a decision matrix. The method has been applied and broken down into the following steps.

Step 1: Establish criteria for comparison

This is the basis on which the concepts are compared. The criteria for evaluation were developed from the objectives of the thesis work, design and manufacturing task and also keeping in mind time scope to complete tasks. The resulting list is described in Table 2.

Step 2: Relative importance weightings

The importance of the criteria for comparison is reevaluated by allocating 100 points amongst them. Compromise values from several interviews and meetings with Xylem experts form the result which is shown in the decision matrix.

Step 3: Selecting Alternatives to be compared

The three alternatives considered are the Lifting mechanism, the Recirculation concept and the combination of the lifting mechanism and recirculation concepts.

Table 2 Definition of criteria

SN	**Criteria**	**Description**
1	Measurable	The method identifies and characterizes critical parameters, both quantitatively and qualitatively that can provide knowledge about the degree and nature of clogging
2	Adaptive Understanding	The method provides information about the pump's impeller adaptive feature involvement in upper volume clogging
3	Time constrain	The method of experiment can be to performed and measured in a short time. (10-20mins)
4	Repeatable	The method is suitable to be done again
5	Descriptive	The method is able to describe experimental set up, materials (type, size, combination, frequency of administration) and suitable volume of water
6	Safety	The method is within acceptable minimum or no risk levels
7	Ease of set up and Application	The method is easy to set up, use and can be applied to other pump types and sizes within the project scope for comparison
8	Design and Manufacture	The method is easy to design and manufacture within the limits of the time left for the project

Step 4: Evaluate the alternatives

In this step, a concept which is considered as the best concept that is yet to be developed, is chosen as the datum concept which all other concepts are compared against. This is measured by each of the criteria for comparison (Table 2) already developed. The concept to be evaluated is judged using a scale as shown below to be either

" better ***than****"* given a *'+' score*

" about ***the same as****"* given a *'0' score*

" worse ***than****"* given a *'–' score*

For this thesis we have chosen the combination of the lifting mechanism and recirculation concept as the ideal concept and hence the datum. For further evaluation, we also repeated the comparison process by rotating the datum. Here we replaced the ideal concept with either of the other two concepts as the datum one at a time. This is illustrated in the decision matrices.

Step 5: Compute the satisfaction

Four scores are generated from comparing concepts with datum for each criterion. They are;

a. The number of Plus (+) Scores, b. The number of Minus (-) Scores, c. The Overall Total, d. The weighted total

The difference between the number of plus scores and the number of minus scores is considered as the overall total. This gave an estimate of our level of satisfaction with the alternatives. The weighted total is calculated by multiplying each score by the importance weightings and summing altogether. A plus score is counted as +1, while a minus score is counted as -1 in the computing process. Concepts with high + total score were examined further to know what strengths they exhibited.

3 Results and Discussion

3.1 Outcome of Test (Lifting Mechanism Concept)

The test lasted for less than 4mins due to impeller hard clogging. The interaction between the chopped materials and the large materials (***200x200mm***) which act to stimulate the adaptive mechanism of the impeller causes the impeller to clog and the pump to shut off. The outcome at the upper volume and on the impeller is seen Fig 4a and Fig 4b.

Fig**. 5**a Outcome on the shaft

Fig. **5**b Outcome on the impeller

Although not too substantial amount of clogging can be seen from the outcome with the duration of the experiment, but this concept gives an insight into its ability to induce upper clogging.

3.2 Outcome of test (Recirculation Concept)

1. Clogging at the upper volume with fibers formed 30mm thick, 103mm wide (about the same as the diameter of the top part of the impeller)
2. No clogging on the impeller
3. Clogging around top of the pump housing (between the pump housing and the stationary part)
    a. 650mm long 10mm thick after 20 minutes
    b. 480mm long 10mm thick after 10 minutes
4. Thick mass of clogging at the tongue of the pump housing.

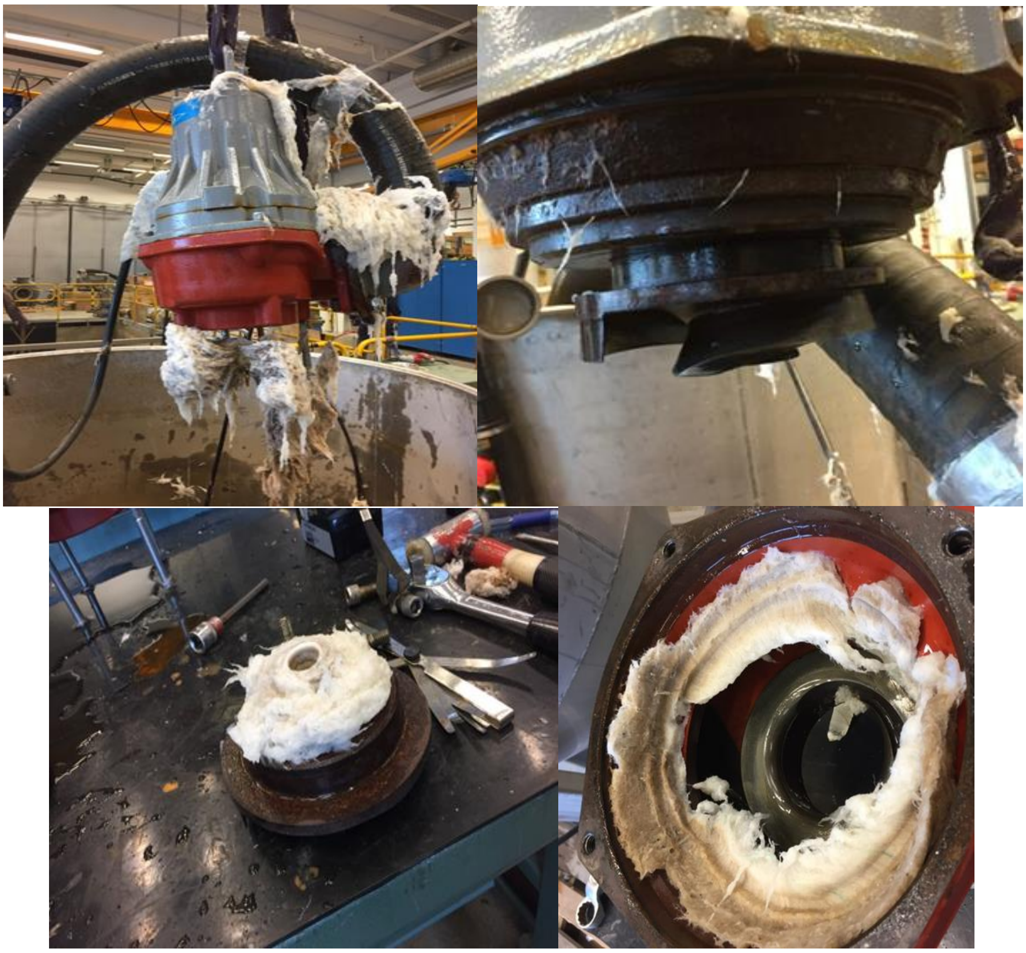

Fig **6**a Outcome after 20 minutes

Fig **6**b Test outcome after 10 minutes

3.3 Test Observation for both Concepts

1. Both concepts meet pre-test demands. (2.3)
2. A real lifting mechanism will improve the impeller lifting concept.
3. The size and geometry of the tank is a major factor for both concepts. A big tank requires more water to be able to submerse the pump either partially or fully. The outcome of this is a clean pump with little or no clogging after the experiment. In order to achieve substantial clogging with a big tank, more materials needs to be added to the system and the experiment will need to run for a longer time other than the adopted standard time for this study. Flat sump geometry does not contribute much turbulence that can cause the re-suspension of settled solids and entrainment of floating debris to the system.
4. Size of material affects the duration of the experiment. Smaller sized materials were observed to be more suitable for the experiment. They form fibers easily that are required to cause upper volume clogging and build up gradually at the upper gap of the pump. Larger sized materials cause the impeller to clog after a short time into the experiment and hardly produced any upper volume clogging.
5. Volume of water is a major factor for the concepts especially the recirculation concept. Water to material ratio is seen to be an important factor. More water and less material produced a clean pump after experiment while less water more material caused the pump to clog almost instantly.
6. Installation type affects the experiment by promoting impeller clogging. Materials tend to tangle around the installation elements. This is observed to form a twine with one end of the twine around the pump installation element and the other end being sucked in by the pump. This causes the impeller to clog as tension is being created along the twine. This slows down the impeller and builds up enough to cause the pump to shut down. This is observed with the S-type installation.
7. Air enters the system and causes the flow to be highly unsteady for the recirculation concept

3.4 Decision matrix results

The decision-making process and results are shown in the decision matrices of Fig 7a, Fig 7b, and Fig 7c.

	Criteria	Importance	Recircu-lation	Lifting Device	Recirculation & Lifting Device Mix
1	Measurable	16	0	0	
2	Adaptive Understanding	14	-	0	D
3	Time constrain	13	-	-	A
4	Repeatable	10	0	0	T
5	Descriptive	9	0	0	U
6	Safety	20	+	0	M
7	Ease of set up and Application	8	+	0	
8	Design and Manufacture	10	+	+	
		Total +	3	1	
		Total -	2	1	
		Overall Total	1	0	
		Weighted Total	11	-3	

Fig 7 a Decision matrix (Concept mix datum)

Criteria	Importance	Recirc-ulation	Lifting Device	Recirculation & Lifting Device Mix
1 Measurable	16	D A T U M	0	0
2 Adaptive Understanding	14		+	+
3 Time constrain	13		-	+
4 Repeatable	10		0	0
5 Descriptive	9		-	0
6 Safety	20		-	0
7 Ease of set up and Application	8		-	-
8 Design and Manufacture	10		-	-
	Total +		1	2
	Total -		5	2
	Overall Total		-4	0
	Weighted Total		-46	9

Fig 7 b Decision matrix (Recirculation concept datum)

Criteria	Importance	Recirc-ulation	Lifting Device	Recirculation & Lifting Device Mix
1 Measurable	16	0	D A T U M	0
2 Adaptive Understanding	14	-		0
3 Time constrain	13	+		+
4 Repeatable	10	0		0
5 Descriptive	9	+		+
6 Safety	20	+		0
7 Ease of set up and Application	8	+		0
8 Design and Manufacture	10	+		-
	Total +	5		2
	Total -	1		1
	Overall Total	4		1
	Weighted Total	46		11

Fig 7 c Decision matrix (Lifting device datum)

3.5 Concept Selection

The recirculation concept has been selected with respect to the outcome from the evaluation in the decision matrices. The recirculation concept can be seen to show its strengths in safety, ease of set up and design.

The selection of this concept based on its strengths against others does not fault the adoptability of either of the other two concepts it was compared with in the decision matrix. The recirculation concept was also selected based the amount of task left to develop a complete model with respect to time left for this study. It has less task in comparison with others and so more likely to be completed within the time frame left for the study.

3.6 Recirculation Concept Model (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.

The final model for the recirculation concept now consists of a tank with pipes fitted in 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/frequency drive (VFD) connected to the system pump. The tank is filled afterwards with calculated amount material sewage material. For this model, a certain amount of materials are chopped into bits before pouring into the tank. This is carried to eliminate impeller clogging. After completing an experiment with this model, the tank is cleaned, and the process is repeated for another experiment.

Fig **8a** Standard Two pump system with VFD

Fig 8**b Analog pressure gauge**

Fig **8c VFD**

Proper pump selection is carried out for this approach. 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.

Table 3. Performance property 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

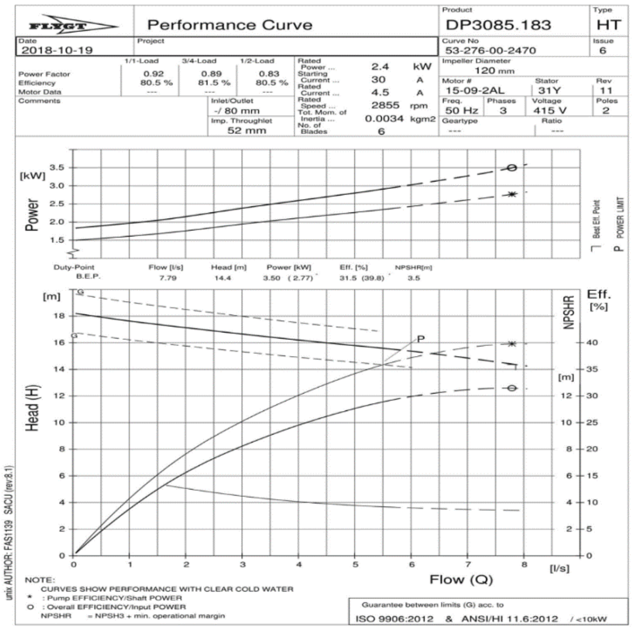

Fig 8d Performance curve for System Pump Vortex Impeller

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:

1. Experiment can be sustained for more than 20minutes
2. No pipe clogging
3. Upper volume clogging achieved

4. 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 concept and for the aim of this work than the others. Hence, it has been adopted for further real time experiments and comparison for pumps within the scope of this work.

4. Conclusion

In conclusion, the process in which the recirculation concept was selected to be developed into a methodology that can be applied as a standard way for testing upper volume clog resistance in wastewater pumps was very efficient. This proves that Pugh's decision model, if applied correctly can be a useful tool in concept selection or decision making in the engineering design process to achieve robust solutions.

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