Research into the fish-friendly screw pumps

Report: VA2009_19

On behalf of:
FishFlow Innovations
August 2009

by:

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English translation of Axial pump sections on behalf of Aquatic Control Engineering Ltd

1. Introduction

Various studies have shown that large numbers of fish are injured and/or killed when passing through conventional pumping station pumps. FishFlow Innovations has developed two pump designs where the aim of the design is to allow fish to pass through without injury. The first design relates to a fish-friendly axial pump. FishFlow Innovations developed this axial pump in collaboration with Nijhuis Pompen. The second design relates to a fish-friendly Archimedean screw pump.

FishFlow Innovations wished to have the fish-friendliness of the pump designs established independently. This report describes the pump tests. While the pump tests were being conducted an independent observer from VisAdvies BV was present to record and report the results.

The statistical analysis was carried out by Onno Van Tongeren of the Data Analyse Ecologie (DATANECO) service in collaboration with Tim Vriese.

2. Description of the pump

2.2 Screw pumps

A screw pump, also known as the screw of Archimedes, consists of 1 or more windings rotated around the central axis over the length of the screw. The beginning of the windings pass through the water causing the water to be picked up. Due to the rotation of the screw, the water is gradually conveyed upwards.

Conventional screw pumps
With conventional screw pumps, the helix runs across the full width of the screw to the tip of the screw. Because of that the start of the windings consists of straight surfaces which hit the water with every rotation. A hit of these first windings can seriously injure the fish.
Most Dutch screw pumps are carried out as open screws. The screw rotates in a concrete or metal drain, the trough. Although for an optimal return the screw should connect to the trough as much as possible, there is always water declining between the screw and trough. Figure 2.1 shows an conventional screw pump, even as a detail of the start of a winding.

Figure 2.1 Example of a conventional screw pump with on the right side a detail of the winding

The FishFlow Innovations screw pump
Fishflow Innovations has made several adjustments to prevent injuries to fish. The first adjustment is that the screw is encased over the entire length (‘the tube’). This casing is integral with the screw and thus rotates with it. Therefore fish can no longer become stuck between the screw and trough.
The second adjustment concerns the design of the screw ribbons. In the screw pump, the width of the screw ribbons decrease gradually over the last windings. Because of that the blades run back to the

Daardoor lopen de bladen terug naar de
buitenkant van de vijzel tot ze uiteindelijk op lijken te gaan in de buis rond de vijzel.

Figure 2.2 Screw pump of FishFlow Innovations

3 Method used in the practical tests

3.1 Test animals

Coarse fish and eels were used when conducting the tests.

The coarse fish were caught in Medemblik harbour during seine net fishing. The fish caught were then loaded into the hold of a holding-tank ship using a crane. During fishing it appeared there were too few fish present. The catch therefore comprised a relatively small number of fish of various types and lengths.

The eels were procured from a professional fisherman. These eels were stored in an aerated tank.

Permission to use the test animals was obtained from the Dierexperimentencommissie (DEC) of the Central Veterinary Institute in Wageningen UR (letter dated 29 May 2009, see Appendix II). The animal testing was carried by *ir.* F.T. Vriese of Visadvies BV (authorized officer in accordance with Article 9 WOD {Dutch Experiments on Animals Act}) supervised by *drs.* P.S. Kroon of the Central Veterinary Institute (authorized officer in accordance with Article 14 WOD) in the presence of *dr.* G. Kruitwagen of FishFlow Innovations (likewise authorized officer in accordance with Article 9 WOD).

3.2 Set up

Screw pump

A tweegangige screw with a width of 700 mm and a capacity of 35m^3 per hour has been use for conducting the test. During the test the screw was rotating with 57 revolutions per minute.
The test with the screw pump was conducted on the shore of a city canal in Medemblik. The screw pump was positioned in such a way that the suction mouth (aanzuigmond) of the screw was above the central axis of the water of the canal. A laminated wooden container was placed below the outflow side of the screw that returned the uitgemalen water to the city canal.

For the purpose of the test, a net was placed in a square around the inflow opening of the screw. At the outflow side a meshed net was placed under the ending of the container. This net was strained over the full width of the city canal to give uitgemalen fish the opportunity to hold in relatively calm waters. Both nets had a mesh size of 22 mm intact mesh.
The test set up with the screw pump is shown in figure 3.1. Figure 3.2 gives an image of the net construction for the supply of fish to the screw pump. Figure 3.3 shows the net construction for the collection of uitgemalen fish.

Figure 3.1 Test set up with screw pump

Figure 3.2 Net construction for supply of fish to the screw pump

Figure 3.3 Netconstruction for collection uitgemalen fish

3.3 Conduct of the tests

The practical tests with the axial pump and Archimedean screw pump were conducted on 15 June 2009.

Screw pump

After conducting the test with the axial pump, the remaining coarse fish were scooped from the hold of the holding-tank ship and placed in a storage tank on a truck for transport to the location of the screw pump. The coarse fish and eels were scooped from the storage tank to a plastic barrel with a dip net and transferred to the net placed around the inflow opening of the screw pump.

Shortly after placing the fish the screw pump was started. After the set rotational speed was reached, during 5 minutes werd er gemalen. Subsequently/thereafter, the pump was switched off. The net behind the container was cleared, and the fish were placed with a dip net in a plastic barrel with water. One by one the fish were removed from the barrel whereafter the total length of each individual was measured and determined if there was any injury and/or death as a results of passing through the pump. After inspection the fish were placed in a second barrel with water. After measuring and viewing all fish, the fish were released into the water of the city canal.

4 Results

4.1 Screw pump

With the test with the screw pump, a total of 99 fish passed the screw, including 23 eels. All 99 fish were alive and intact after the passage.

Table 4.1. Fish passed through the screw pump and injuries

Fish specie	Length (cm)	No Injuries	Injured	Total number
Roach	13-24	33		33
Bream	10-50	33		33
Silver bream	15-32	5		5
Perch	15-18	3		3
Eel	55-82	23		23
Ruffe	13	1		1
Pike	44	1		1
		99	0	99

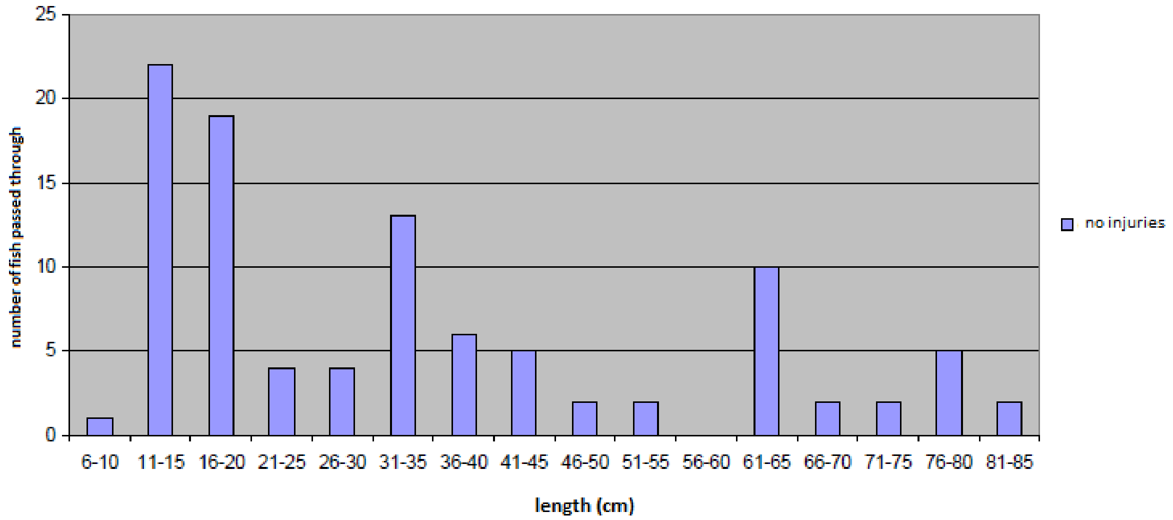

Figure 4.1 Fish passed through the screw pump by length and injuries

5 Statistical evaluation

5.1 Methods

On the one hand the results of the experiment with the two fish-friendly pumps can be regarded as simple observations, from which one can derive the probability of fish injury when such pumps are used under comparable conditions, and on the other hand it is possible to compare the results of this experiment with observations at pumping stations. In the latter case, providing the conditions relating to comparability (lift, capacity, pump diameter etc.) are met, then statistical methods can be used to conclude whether or not the fish-friendly pumps actually do result in fewer injuries.

From the results it is not only possible to make an estimate of the probability of fish being injured, but it is also possible to estimate the limits between which this probability lies, the so-called confidence interval. The estimated probability of certain type of injury is equal to the number of injured fish divided by the total number of fish that passed through the pump. The variance in the number of injured fish is then estimated with:

$$s^2(n) = N\hat{p}(1-\hat{p})$$

where $s_2(n)$ is the estimated variance in the number of injured fish, n and the number of injured fish, N is the total number of fish and the estimated probability of injury.

A rough estimate of the 95% confidence interval for the number of injured fish is given by n ± 2s(n). Dividing these values by the number of observations gives us the confidence interval of the probability.

The confidence interval can be determined more accurately, where the most conservative result is achieved with the so-called exact method, which makes direct use of the properties of the binomial distribution (Wikipedia). The confidence interval
in the results section are calculated using a confidence interval calculator on the Internet: (http://statpages.org/confint.html#Binomial)

Comparisons between various pumping stations and the fish-friendly pumps have been made using the Chi-squared test for r*k tables. The value of Chi-squared is calculated from the observed and the expected values for the number of fish injured or killed. The null hypothesis is that there is no difference between the various pump types. The expected number of fish killed or injured for every type of pump is thus equal to the total number of fish killed or injured (calculated across all pumps) divided by the total number of fish that passed through the pumps and then multiplied by the number of fish that passed through the pump concerned. Chi-squared is then calculated as the sum of the squared differences between observed numbers and expected numbers divided by the expected numbers. The larger the found value for Chi-squared the smaller the probability that there is no difference between the pumps. This probability is found by evaluating the found Chi-squared against the number of degrees of freedom (in this case the number of pumps or pump types minus 1)

5.2 Results

Table 5.1 below shows a summary of the evaluations from previous reports about fish injury in pumping stations that are more or less comparable with the lift works used for this experiment (Kunst *et al.*, 2008). Here, two comments bear making. The pumping stations concerned with which the comparison was made relate to conventional pumping stations, i.e. pumping stations that were not designed from the starting point of fish-friendliness. In addition, the tests mentioned related partly to natural migration of fish through pumping stations and partly to the forced exposure of fish to lift works. Also, the method of characterizing the fish injuries that occurred in the tests was different, where various injury categories were used (superficial injury, incisions, decapitation etc.). For the comparison in this research the data about injuries to the fish were divided into injuries that would eventually lead to the death of the fish and superficial injuries which the fish would probably survive.

Table 5.1 Fish injuries in a selection of pumping stations

	Referention	Name	Cap (m^3/h)	Head (m)	Fish specie	Length (cm)	N	N-n alive	n dead	% dead
	Screw pumps									
1	Denayer & Belpaire, 1992	De Seine	35	3.6	Div. cyprinids	6-15	138	103	35	25
					Eels	27-45	52	33	19	37
2	Germonpré et al., 1994	Sint Karelsmolen	30	2.9	Div. cyprinids	6-32	517	300	217	42
					Eels	15-37	57	49	8	14
3	Lange & Merkx, 2005	Snelrewaard	100	2	Div. coarse fish	3-29	1009	868	141	14

Table 5.2 below shows that there was no mortality with fish-friendly pumps, and no scale damage.

Table 5.2 Fish injuries in the FishFlow Innovations pumps

	Name	Cap. (m^3/h)	Head (m)	Fish specie	Length (cm)	N	Scale damage pump	Scale damage netting	% injury
2	Screw pump	35	1	Coarse fish		71	0	0	0
	Medemblik			Eels		23	0	0	0

Comparison between the fish injuries in pumping stations and fish injuries in the fishfriendly pumps in this experiment is only possible on the basis of mortality figures because of the absence of detailed information about injuries in the pumping stations. Many mutual comparisons are theoretically possible, but based on the numbers of observations of a few types of fish statistically reliable statements are only possible for a few (combinations of) fish types and pumping stations. Tables 5.3 and 5.4 show that in all cases the fish-friendly pumps perform better statistically in terms of limiting fish mortality as a result of passing through a pump. Apart from the results of the testing using the Chi-squared test the calculated confidence intervals of individual mortalities was tested also.

In the Archimedean screw pumping stations (Table 5.3) the mortalities vary between 14 and 42% for cyprinids while the upper limit of the 95% confidence interval for the Archimedean screw pump is only 5% mortality. The occurrence of injury was measured at 0 for both coarse fish and eels.

Div. cyprinids	Alive	Dead	Total	Mortality	95 % confidence interval
De Seine	103	35	138	0.25	0.18 – 0.33
Sint Karelsmolen	300	217	517	0.42	0.38 – 0.46
Snelrewaard	868	141	1009	0.14	0.12 – 0.16
Screw pump	71	0	71	0.00	0 – 0.05
Chi-squared	174.8931	Freedom degr.	3	p	<0.00001

Div. cyprinids	Alive	Dead	Total	Mortality	95 % confidence interval
Totaal gemalen	1271	393	1664	0.24	0.22 – 0.26

Screw pump	71	0	71	0.00	0 – 0.05
Chi-squared	21.67926	Freedom degr.	1	p	<0.00001

Eels	**Alive**	**Dead**	**Total**	**Mortality**	**95 % confidence interval**
De Seine	33	19	52	0.37	0.24 – 0.51
Sint Karelsmolen	49	8	57	0.14	0.06 – 0.26
Screw pump	23	0	23	0.00	0 – 0.15
Chi-squared	15.62559	Freedom degr.	2	p	<0.00001

Eels	**Alive**	**Dead**	**Total**	**Mortality**	**95 % confidence interval**
Totaal gemalen	82	27	109	0.25	0.17 – 0.34
Screw pump	23	0	23	0.00	0 – 0.15
Chi-squared	7.162254	Freedom degr.	1	p	0.0074

The conventional screw pumps (Table 5.4) show a comparable image, but the mortality is much higher (0.3 - 1.0) except in the case of the fish-friendly axial pump. Here 2 seriously injured fish were not counted as injured but were counted as dead because they probably would have died as a result of passing through the pump. The upper limit of the confidence interval for the axial pump is 11% for cyprinids and the upper limit of the confidence interval for eels is 14%. The occurrence of injury in cyprinids is very small, while it was 0 for eels.

In view of the fact that the data for these comparisons were not collected in a single experiment the result of the statistical analysis must be interpreted with the necessary caution. It is recommended that conditions are better standardized in a subsequent experiment and the fish-friendly pumps as set up such that lift and capacity are the same as those of the pumps they are being compared with.

6 Discussion and conclusions

The original test set up as was discussed with FFI differed in a number of aspects from the experiment now carried out. A choice was made for the forced passage of 50 specimens of eel in the length class 50-60 cm and 50 specimens of bream in the length class 20-30 cm. Because fewer coarse fish were available, the experiment was finally conducted with an assortment of coarse fish of various lengths where smaller numbers passed through the pump also. As far as the eels that passed through are concerned there was a misunderstanding about the number of animals available and as a result fewer animals were exposed to the pump than was originally intended. Although all of this has consequences for the calculated confidence intervals, it can, nevertheless, be concluded that the Archimedean screw pump and the axial pump perform considerably better in the fish-injury aspect than conventional Archimedean screw pumps and axial pumps.
Although on the basis of previous experiences it has already been observed that it was important to choose a large catch net (certainly for the axial pump due to the relatively large capacity) it appeared that while the experiment was being carried out scale damage still occurred in small roach and to a lesser degree in small bream as a result of contact with the net. Additionally this was probably not to blame on the size of the net but more that at the outlet from the axial pump the high delivery still 'blew' the fish along the netting. This is an important point for attention in future experiments with forced exposure of fish to lift works with a high capacity. There was no scale damage in the experiment with the Archimedean screw pump. Because of the lower delivery the fish landed in the catch net relatively 'calmly' without making contact with the netting.
In the experiment with the axial pump a cage structure was used where the fish were deposited prior to passage through the pump. With the Archimedean screw pump a net structure was used and the fish were led from this to the Archimedean screw. In an ideal situation the choice would have been to have the fish pass through the pump one by one, partly because this better resembles the natural passage through a lift works. Because it is possible that large numbers of fish were sucked into the pump simultaneously it is probable that there was maximization of injuries in the current experiment. Nevertheless, in practice there appeared to practically negligible injury in the axial pump and 0 in the Archimedean screw

Axial pump
During the test with the axial pump 91 fish in wide range of lengths passed through the pump. Of these, only 2 of the 66 coarse fish that passed through showed injuries that probably occurred during the passage through the pump. All 25 eels were uninjured.
For statistical evaluation it was decided to include the roach, bream and white bream types in the various cyprinids category. Any injury to these fish, given their relationship, is better comparable than injuries occurring in percids such as perch for example. The two perch that passed through were then not included in the analysis either. From the cyprinid group a total of 64 specimens passed through the pump, where 2 specimens suffered a possibly fatal injury. The calculated injury to cyprinids then comes to 3%. The confidence interval runs from 0 - 11%. In total 25 eels passed through the axial pump without any form of injury. The injuries were therefore determined to be 0%. The confidence interval runs from 0 - 14%. If more eels had passed through the pump (the expectation being without injury to eels) the upper limit of the confidence interval would have been even lower.
For both eels and cyprinids it can be noted that the axial pump performed significantly better in the fish-injury aspect than the conventional screw pumps against which they were compared (for cyprinids $p < 0.00001$ and for eels $p < 0.0001$).

Archimedean screw pump
In the test with the Archimedean screw pump all 99 fish passed through the pump without injury. The group of various cyprinids here comprised 71 specimens. All of these fish passed through without injury, and as a result the injuries were determined to be 0%. The confidence interval runs from 0 - 5%. Of the eel fish type 23 specimens passed through the Archimedean screw pump without any form of injury. As a result the injuries were determined to be 0%. The confidence interval runs from 0 - 15%. The same applies here too, if more eels had passed through the Archimedean screw pump, without injury as expected, the upper limit of the confidence interval would have been even lower.
For both eels and cyprinids it can be noted that the Archimedean screw pump performed significantly better in the fish-injury aspect than the conventional Archimedean screw pumps against which they were compared (for cyprinids $p < 0.00001$ and for eels $p < 0.0074$).

Closing remarks
The experiment did not examine delayed mortality in the fish that passed through. No founded statements can be made in this respect. The experiment observers did gain the impression that the 'condition' in which the fish left the lifting works was so good that no delayed mortality could be expected to occur.
An important comment on the results obtained is that the findings apply to the pumps used in the situations tested. Deviations from the specific conditions (different speeds or lifts for example) could lead to a different result.
It seems advisable that this kind of experiment is not carried out in the summer, but in the spring or autumn. In those periods the natural passage through lifting works is at its peak. In summer the fish are more vulnerable due to relatively higher temperatures and less oxygen.

7 Literature *(Dutch)*

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