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Assessment of the Ballast Safe Filter Performance in Removing Quagga Mussels Veligers from the Raw Water of Lake Havasu

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EXECUTIVE SUMMARY

U.S.Bureau of Reclamation (USBR) is testing small pore self cleaning filter technology for the control of quagga mussels in cooling water systems. As part of this research project, USBR wished to evaluate if 80 micron nominal screen was adequate to prevent settlement-sized veligers from reaching cooling water piping or if a 40 micron nominal screen was required.

Ready to settle veligers are in the 250 to 450 size range. To provide protection for the downstream piping and components, the filters would need to remove all veligers greater than 250 microns. Both the 40 micron and 80 micron filters performed well.

Based on veligers of size greater than 200 microns, the 40 micron filter had 100% exclusion and the 80 micron filter achieved 95% exclusion.

Based on veligers of size greater than 100 microns, the 40 micron filter had 99.5% exclusion and the 80 micron filter had 73% exclusion.

A BallastSafe filter provided by the Sigma Design Company was purchased in April, 2008. The filter was sized to accommodate flow of 450 USGPM. The filter was equipped with interchangeable screens in the 40 micron (57 micron absolute) and 80 micron (120 micron absolute) size.

The filter and the screens were delivered to Parker Dam in May 2008. The filter, using the 40 micron screen, was installed and put in service on an eight inch domestic water line in December 2008.

Since the installation, the filter was in-service in unattended operation, without any system upsets. On February 2nd, 2009 a test team from RNT Consulting and USBR initiated the performance evaluation of the filter.

During initial sample collection, using the installed 40 micron screen, it became evident that there was leakage occurring from the non-filtered to the filtered side. Particles of size greater than the screen should allow through were being found in samples of filtered water.

The filter was taken out of service and the screen was removed. Careful examination of the filter screen revealed that the V shaped seal which separates the filtered water from the backwash chamber appeared to have been installed backwards. After consultation with the filter vendor, the seals on both screens (the 80 micron and the 40 micron) were reversed. The 80 micron screen was installed and the evaluation process was restarted. Two samples of 400L were collected. Subsequently the sample size was increased to 1,000L.

Ten samples of 1,000 liters (264 gallons) were collected just before and just after the filter (total of 20 samples). The samples were collected at the same time using dedicated 20 micron plankton nets. After collection, the samples were sent for microscopic examination which was carried out on site.

Once the10 samples were collected using the 80 micron mesh, the filter was stopped and the 80 micron mesh was replaced with the original 40 micron mesh with the seal in the correct position. The filter was returned to service and ten samples of 1,000 liters (264 gallons) were collected just before and just after the filter (total of 20 samples). Again, the samples were collected at the same time using dedicated nets. After collection, the samples were sent for microscopic examination.

Microscopic examination confirmed that with the seal in correct position, the 40 micron screen (57 microns absolute) only allowed veligers of less than 100 micron to pass through. Note that the shell of a veliger has some flexibility and the reason a veliger of 100 micron size can pass through a 40 micron opening is that when its body in an optimal position it can be squeezed through the mesh opening by the pressure differential across the filter pore.

The 80 micron screen (120 micron absolute) allowed some veligers of up to 220 microns to pass through the filter. It appeared to exclude all of the ready to settle individuals, (250 -450 micron size). Unfortunately there were very few individuals in the ready to settle size range in the incoming water.

It is important to note that small, live quagga mussel adults (5-20 individuals), as well as shell debris, were routinely found in the samples collected prior to the filter, despite the fact that this water had passed through a Hayward strainer. The live adults would represent a serious fouling threat to downstream piping if the filter had not been installed.

1.0 INTRODUCTION

Quagga mussels are present in significant numbers at the Parker Dam on Lake Havasu. Visual and remote camera inspection has confirmed that the Service Water system piping in the power plant has been colonized with mussels.

The mussels are growing in place and will reduce water flow. If mussels are not controlled, water flow in the system may be lost completely. If killed and left in place the mussels will shed shells. Shells will be transported into downstream equipment thereby impairing performance or causing blockages. Therefore, it is necessary to prevent shells and translocating adults from entering the piping and to prevent ready to settle mussel veligers from entering the system and establishing new colonies.

• Figure 1: Parker Dam

• Figure 2: Mussel densities are high at Parker. Photo shows a 1/2" rope infested after 1 season

A well documented technology for mussel control is filtration. When a self cleaning, small pore filter is installed downstream of a strainer, any piping downstream of the filter should be protected from ingress of adult shells, shell debris and ready to settle veligers. Small pore self cleaning filters have been available for at least two decades. However, during the last five years, several manufacturers have made substantial improvements to this technology as part of international ballast water control projects.

The filter installed at Parker Dam is such a filter. It is currently being tested for ballast water control (particle elimination) on board of a test marine vessel. The ability of this filter to perform under difficult circumstances while removing designated particles is fairly well documented.

As part of the research project at Parker Dam, USBR wished to evaluate if an 80 micron screen was adequate to prevent settlement sized veligers from reaching cooling water piping or if a 40 micron screen was required.

The filter began operating in mid-December 2008 using the 40 micron mesh. The density of quagga mussel veligers is very low in Lake Havasu during December and

January when water temperatures reach their minimum. Veliger counts increase in February. This is also the time when new mussel settlement is detected. February was judged to be the earliest time the filter efficacy could be tested after the installation. February 2nd, 2009 RNT Consulting arrived at Parker Dam to carry out the filter efficacy test. The test was overseen by members of the USBR Ecological Research and Application Group in the Technical Services Centre. Parker Dam staff provided technical support.

2.0 ASSESSMENT PROCESS and METHOD

2.1: The Raw Water System Description

Raw water enters the plant via an 8” supply pipe originating at the dam fore bay face. The inlet at the dam face is covered with a metal grille which is heavily fouled by mussels. The supply pipe travels from the face of the dam and through the dam wall for a distance of approximately 300 feet before it subsequently enters the plant. Immediately after entering the plant the pipe passes through a self-cleaning Hayward strainer.

The discharge from the Hayward strainer enters a supply header which delivers water to the fire protection system and plant service water. The header is connected to each of the unit cooling water lines via branch lines isolated by normally closed valves.

• Figure 3: Existing Hayward strainer upstream of BallastSafe Filter

The service water is sent to a treatment plant where it is filtered and chlorinated.

The screen openings in the Hayward strainer are approximately 3/16 wide. The strainer will allow mussel veligers to pass and enter into the piping downstream of the strainer. The strainer self-cleaning system incorporates a wiper mechanism that scrapes across the screen surface during backwash. The wiper appears to crush mussel shells that are lodged in the screen openings and some shell debris is therefore passing through the strainer. In addition, small live adult quagga mussels are able to pass through the mesh openings in the strainer. The source of the shells and live adults is the 8” piping and header, including the portion embedded in the dam. These areas are heavily fouled by settled mussels.

To protect the system piping downstream of the Hayward strainer, a self-cleaning small-pore filter was installed. The filter mesh size was chosen to exclude both the small shell debris as well as the mussel veligers that would be of a size that is ready to settle.

2.2: Description of the Filter

Most conventional industrial strainers have openings which will prevent some translocators and most shells from fouling the raw water system, but they will allow larval stages to penetrate the facility.

Advances in filtration technology have allowed several manufacturers to design filters capable of removing all particles greater than 40 microns from large volumes of water while experiencing a minimal pressure drop on the system. In addition, these filters are capable of automatically removing filtered debris that accumulates on the filter screen while the filter continues to perform its filtration function.

These types of automatic filters are using filter mesh which is woven, with very uniform square openings. This type of screen is sometimes referred to as WEAVE WIRE. This screen design is highly suitable for removal of organic matter.

More common industrial filters using slot-shaped filter media, referred to as WEDGE WIRE, have been found to be incapable or preventing larval stages of dreissenid mussels from entering cooling water systems. This is due to the fact that wedge wire type screen filters are designed to remove inorganic matter such as quartz or metal shavings but they have difficulty in stopping organic matter from passing through the screen. This is due to the flexible nature of the organic matter which tends to “sneak through” the wedges of the screen.

The Ballast Safe filter uses a four layer, sintered mesh screen of the square weave wire design. Two sizes of the mesh were purchased by the Bureau for the test. One mesh was nominal 40 micron size and the second was nominal 80 micron size.

• Figure 4: Ballast Safe Filter installed at Parker

For a specific flow capacity of a filter, the area of filter mesh required to pass the flow increases as the mesh size decreases. Therefore, to achieve a specific flow objective, the largest mesh size that will perform acceptable filtration will result in the smallest and therefore most cost effective equipment. The purpose of evaluating 2 mesh sizes was to determine how well each mesh size performed and provide USBR facilities the opportunity to choose the filter size that best meets their specific needs.

The terms “nominal mesh size” and “absolute mesh size” require some explanation. Nominal value is a somewhat arbitrary term generally corresponding to removal of 98 percent of all incident particles larger than this size. Various methods are used to determine the nominal rating and the reproducibility among different laboratories is extremely poor. It is used primarily for comparison purposes as some suppliers only state this value without indicating whether their figures are nominal or absolute.

Absolute value represents the diameter of the largest, hard spherical particle, which can pass the filter medium under steady flow conditions. The absolute rating is determined by the bubble point test according to SAE/ARP 901.

This is the test which has been used on the filter mesh used in the Ballast Safe filter.

The Ballast Safe filter body is a cylindrical housing with a bolted cap at both ends. There are three inner chambers. There is one chamber for a strainer to pre-filter the water, the next chamber is for the filtration and the third chamber is for the backwash. The chambers are created by two annular metal rings inside the housing. The filter cartridge is also a cylindrical assembly with the strainer basket and the filter attached in line. The diameter of the filter cartridge is slightly smaller than the inner diameter of the two annular rings so that when the cartridge is inserted into the housing the three chambers are formed by rubber seals between the filter cartridge and the rings.

There are three flow ports. There is an inlet port at the pre-filter strainer chamber, an outlet port at the filter chamber and a smaller waste discharge port at the backwash chamber.

The online backwash is achieved by small nozzles that float on the inside surface of the filter mesh. The nozzles are connected to a discharge manifold by radial arms. The arms and discharge manifold rotate and translate during a backwash to vacuum the debris from the surface of the mesh. The backwash manifold is driven by an electric motor and worm drive.

The operation is controlled by a PLC that monitors pressure differential across the filter screen mesh and initiates a backwash at a predetermined pressure differential. The control logic also provides options for timed backwash and manual backwash.

The filter body incorporates a sampling port which allows for water withdrawal prior to filtration. During installation, a sampling port was incorporated in the piping past the filter itself. These ports were used for sampling of raw water, ahead of the filter and filtered water past the filter.

2.3: Description of the Test Process

The test began on February 2nd, 2009. Dedicated hoses were attached to the sampling ports provided just before and just after the filter. The valves on the sampling ports were opened and the volume of flow from each port was determined by running the water into graduated buckets. The valves on the sampling ports were adjusted until both ports were passing the same volume of flow. The time required to collect predetermined sample volume was calculated based on the volume of flow. The sample from each port was then collected by passing the water from each hose through dedicated 20 micron, brand new plankton nets. Both samples were collected at the same time.

• Figure 5 : Test sample 20 micron collection nets

Once the required collection time was achieved, the hoses were removed from the nets and the nets were taken to the sample collection table. The sample collection buckets at the bottom of the nets were removed and the sample from each bucket was transferred into a separate, labeled sample collection bottle. The label contained the date of collection, the micron size of the filter screen being used, the time of the collection and if the sample was collected before or after the filter. Extreme care was taken to prevent any cross contamination from non-filtered to filtered samples by using dedicated equipment for each sampling stream.

The sample bottles were taken to the microscope examination area and placed in a refrigerator.

The examination of the samples was done using an American Optical compound microscope with minimum magnification of 25x and maximum magnification of 100x. The microscope was equipped with polarized light option and an in-the-eyepiece micrometer.

The initial samples were examined immediately after the collection. The samples collected after the filter, were processed in the following manner. The sample bottle was shaken and 1ml of the sample was removed using a 10 ml pipette. The one ml sample was placed in a Sedgwick Rafter counting cell and examined under the microscope using polarized light to quickly find quagga veligers. Once a veliger was located, the polarized light was switched off and the veliger shell was measured. The size was taken from the umbone end of the veliger to the other end of the shell. In D-shaped veligers, the measurement taken was perpendicular to the straight side. The number and size of veligers was recorded.

Ten repetitions of the 1ml sample were examined in this manner. After that, 10ml of the remaining sample was withdrawn and placed in a Petri dish. The Petri dish was examined under the microscope and any veligers found were measured and recorded. This process was repeated until the sample bottle was empty. Using this technique the entire sample collected was examined and all veligers contained in the sample were measured and recorded.

The samples collected before the filter, were processed in a slightly different manner. The entire sample bottle was emptied into an ImHoff cone containing approximately 10ml of ethanol. The ethanol immobilized all plankton. The plankton was than allowed to settle to the bottom of the cone for one hour. At the end of the hour, 15ml sample was withdrawn from the bottom of the cone. This volume contained most of the plankton and all of the veligers from the entire sample. The 15mls were than examined 1ml at a time using a Sedgwick Rafter cell. All veligers found were measured and recorded.

The two different techniques yielded the same result, counting and measuring all of the veligers in the samples collected.

• Figure 6: Filter cartridge being prepared for change-out

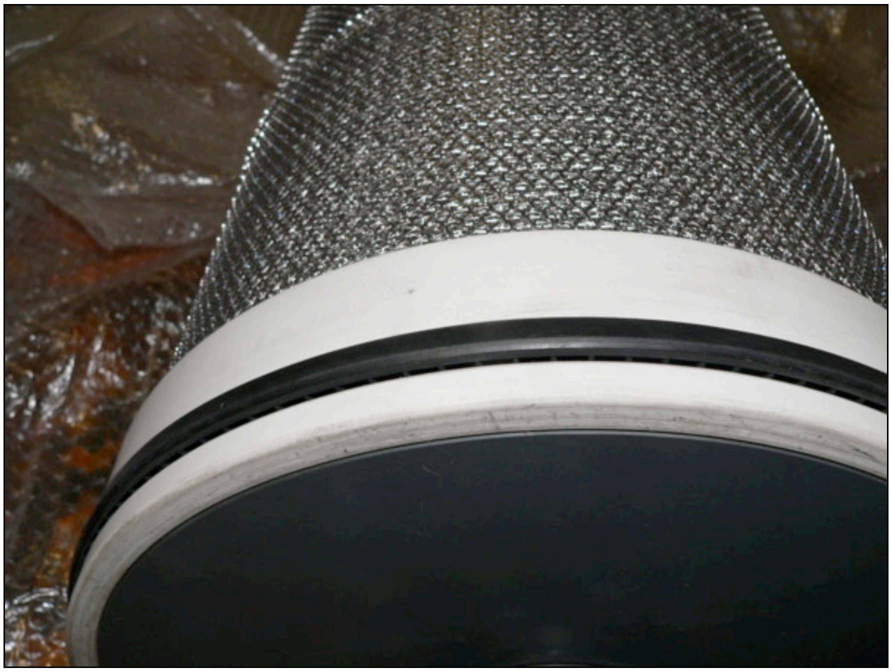
3.0 RESULTS

The sample collection started on Monday, February 2, 2009. Initially samples of 200L were collected before and after the filter using the installed 40 micron screen. During the first day of sampling two issues became evident. First, the samples collected did not contain sufficient number of veligers. Secondly, the after filter samples contained plankton considered too large to have passed through a 57 micron screen. Improper sealing was suspected in the filter. The test was stopped, the filter was disassembled and the seals were examined. The filter supplier concluded that the seal between the filtered water chamber and the backwash chamber was improperly installed by the factory. The seal was reversed on both the 40 micron seal and the 80 micron seal by Parker Dam staff.

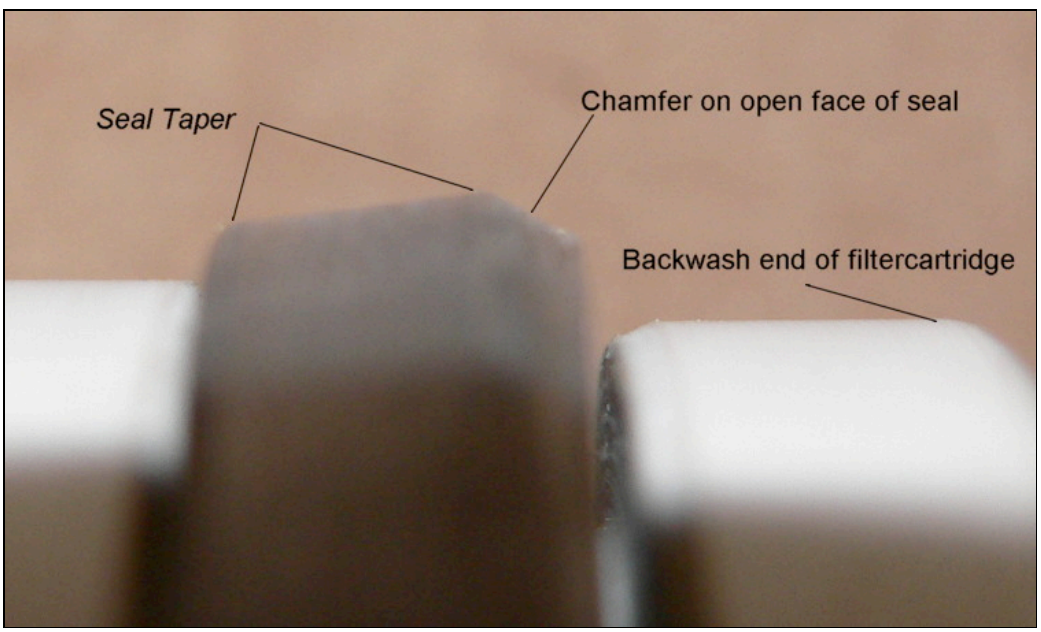
Once the seal problem was identified and diagnosed, the filter was returned to service with the 80 micron screen and the sample collection resumed. As we found that the initial sample volume of 200L collected low number of veligers, the sample size was increased to 400 L. Two samples were collected on February 3 and examined immediately. As it appeared that the study would benefit from even greater sample size, the next 10 samples on February 4 consisted of 1,000L both before and after the filter.

• Figure 7: Opening the filter housing to change the filter cartridge

The screen was changed to 40 microns in the evening of February 4, and on February 5, 10 samples before and after the filter of 1,000L each were collected.



• Figure 8: Seal at backwash end of filter as received



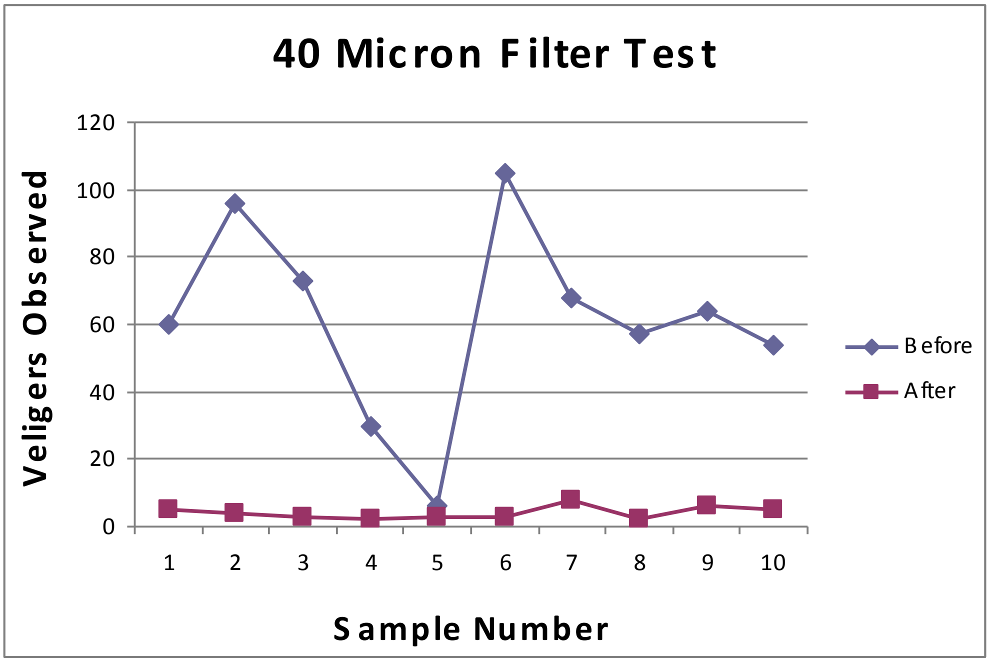
• Figure 9: Close-up of installed seal as received

• Figure 10: Inside of pre-strainer showing damaged mussels from Hayward strainer entering Ballast Safe filter.

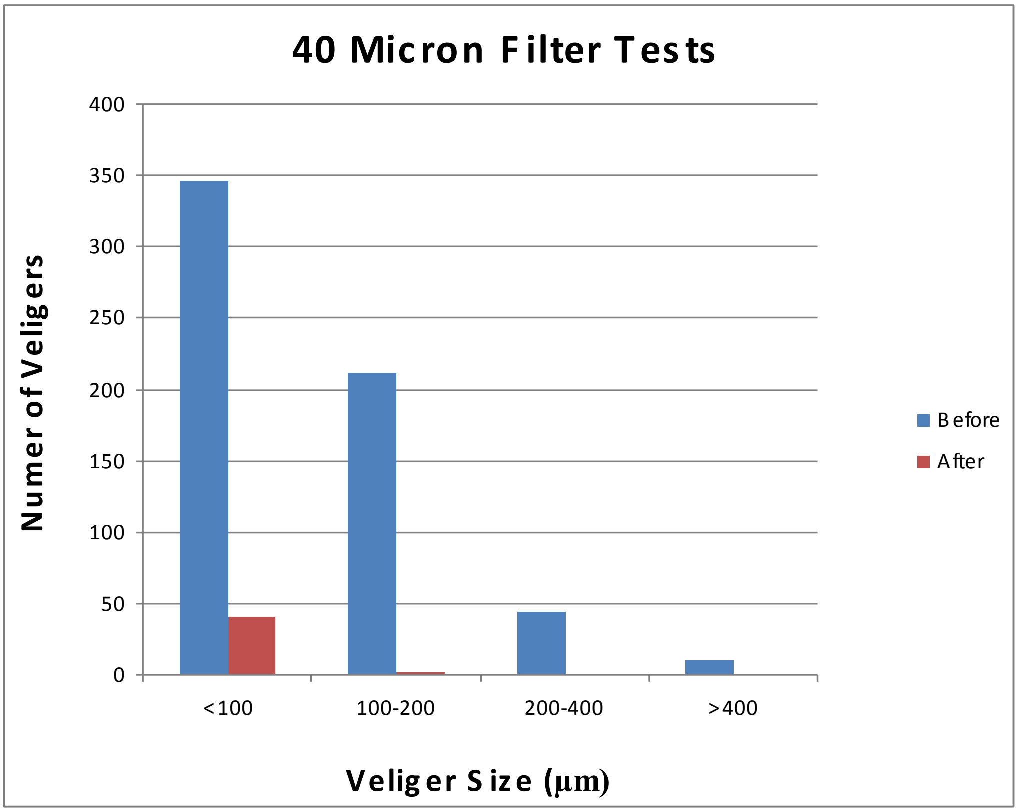
• Figure 11: Inside of backwash chamber showing typical debris removed from water stream

3.1: The 40 Micron Filter Screen Test Results

Below are graphs of the results obtained with the 40 micron filter mesh. The raw data is contained in a table in Appendix 1. The following graph shows the veligers removal across all veliger size ranges. In all samples, there was a significant difference between the numbers of veligers coming into the filter and numbers of veligers exiting.

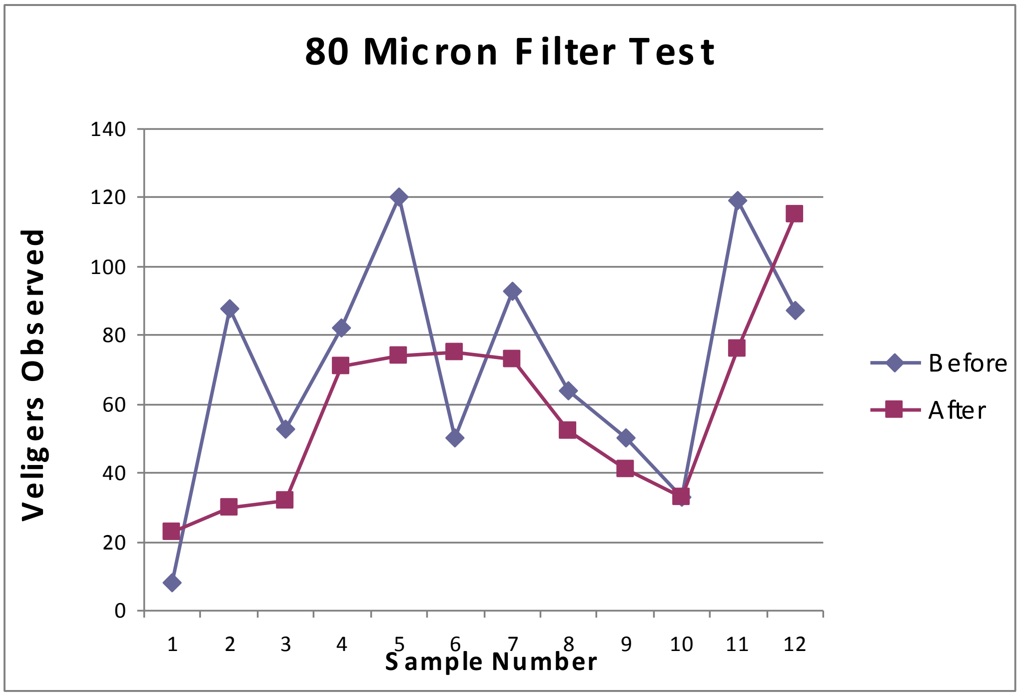


When examining the size distribution of veligers removed by the filter in the following graph, it is clear that the 40 micron nominal mesh removed all veligers greater than 100 micron. Even in the 0 to100 micron range, the filter achieved 89% removal. As the absolute mesh of the filter is 57 microns absolute it was evident during the microscopic analysis that some veligers greater than 57 microns were passing through the filter mesh. The veligers observed in the filtered samples, in some cases were demonstrably alive, displaying characteristic circular swimming motion.

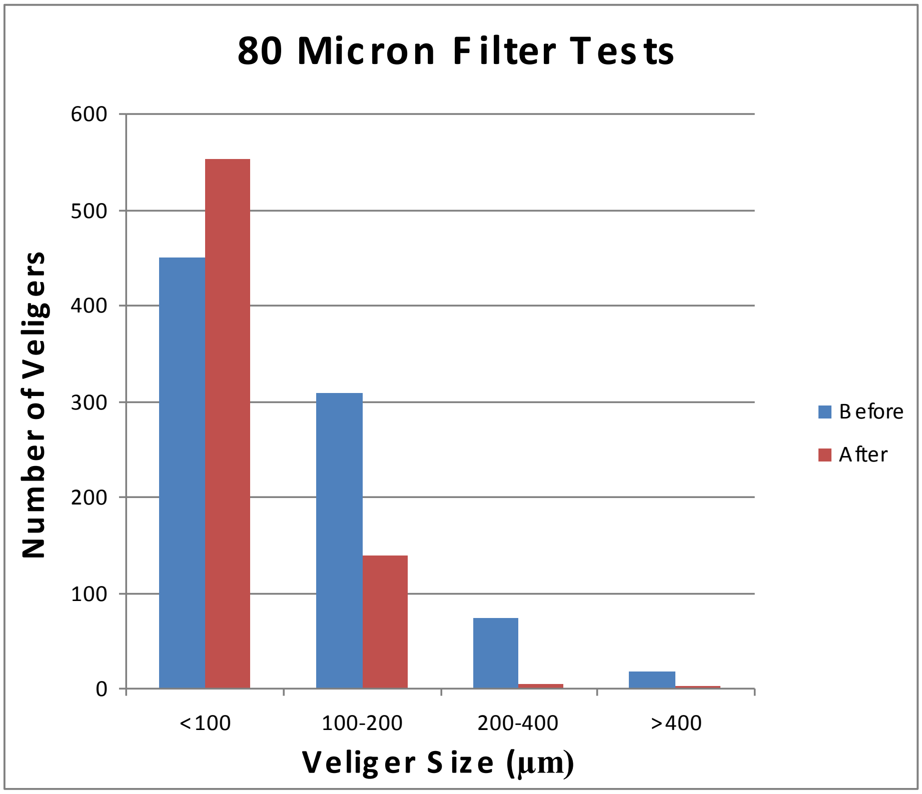


3.2: The 80 Micron Filter Screen Test Results

During the test with the 80 micron screen, a greater percentage of veligers were able to pass through the screen as seen in the graph below. In ten samples out of 12 there was some reduction in the total numbers, in two samples there were actually more veligers found after the filter than before.



However, when examining the size distribution of the veligers passing through the screen, the most abundant size category, (0 to 100 microns) is passing right through while there is a 69% removal in the 100 – 200 micron size category. Virtually all veligers in the next size category were eliminated (200 to 300 microns). The three which were recorded as greater than 200 microns in the after filter samples were “just” greater than 200 microns. One individual was recorded in the after filter sample in the greater than 400 micron category. As this is the only individual of this size in 12 after filter samples, there is a possibility that this record was due to cross contamination of samples in the laboratory, despite all possible precautions..



3.3: Results From Backwash Sample Collected

Samples of full backwash from the filter were collected through a 50 micron plankton net when the filter was using the 80 micron screen and again when it was using the 40 micron screen. An attempt was made to estimate the amount of material collected in the backwash of the filter. However, the flow in the 8" raw water piping changes depending on demand. The backwash cycle was set for timed backwash at 2 hours but it could not be determined if the amount of flow during the 2 hour back wash was the same for the 80 micron filter as for the 40 micron filter. Therefore, the data collected was meaningless as we could not correlate sediment collected vs. total flow in the filter for either mesh size.

4.0 DISCUSSION

The number of veligers in the incoming water was highly variable. This observation is normal as veligers are not uniformly distributed in the main water body and, accordingly, will have variable population densities in the raw water intake. The numbers present in any one sample were not necessarily proportional to the volume of water collected. Despite collecting as large a volume of sample as practical, the total number of veligers found in any one sample was relatively small.

The vast majority of the veligers found in the samples were D shaped, in the <100 micron category. The number of individuals decreased with increasing size of individuals. This situation made the evaluation of the 80 micron mesh more difficult as there were only few individuals in the ready to settle size class (250 - 450 micron) in the incoming water. These ready to settle individuals were the target of the 80 micron mesh.

It would appear that both the 40 micron and the 80 micron mesh are allowing through veligers which are larger than the absolute openings in the mesh weave. For both mesh sizes it is important to remember that the shell of the veligers is flexible. Unlike glass spheres used for testing of the screen, veliger shells can be bent and pushed through openings smaller than anticipated.

The 40 micron mesh appears to provide complete protection against any veligers which could cause a concern to an industrial facility with water retention time measured in minutes, hours or even days.

The 80 micron mesh appears to eliminate the ready to settle size class of veligers. However, due to the low numbers of veligers in this size class, we would recommend repeating this experiment when ready to settle veligers are more plentiful.

The incoming raw water had very little sediment or algae present. The volume of water which was filtered never approached the designated rating of 450 USGPM. At most we had observed flow of 260 USGPM during the test. The combination of very clear water and less than designated flow meant that the filter, even with the 40 micron mesh, never developed noticeable differential pressure across the filter screen. The backwash was only performed because it was programmed to do so every two hours and not because there was differential pressure across the screen. Thus the there never was any substantial cake built-up on the filters screen. It is our understanding that the filter needs to be “seasoned” for optimal performance. This involves running the filter for break in period to allow minute particles to become embedded in the screen. The 80 micron screen did not have this break in period and may perform better after some running time.

5.0 RECOMMENDATION for FUTURE STUDIES

The efficacy study described in this report supports the filter as an effective barrier to incoming dreissenid veligers. We would recommend that additional efficacy study be done using the 80 micron mesh to verify the results we obtained. This study should be done when maximum density of veligers is expected to be present in the incoming water.

Based on our experience, we would recommend measuring each veliger in the 150 to 250 micron size range in the post filter samples, rather than assigning them to broad categories as we had done. This evaluation would give greater assurance that veligers in the ready to settle range (250 – 450micron) are consistently eliminated.

Further we would suggest an evaluation of the sediment volume which is removed by the backwash of the filter. A sediment removal test using 40 micron mesh and 80 micron mesh would help determine if there is an additional benefit of sediment removal using the finer mesh.

The performance of the filter under conditions of high TSS could not be evaluated due to exceptional clarity of the water. Evaluation under conditions of high suspended solids is recommended to establish the upper TSS limit for acceptable filter performance using both mesh sizes.

Appendix 1 – Raw Data

Date	Time	Location	Mesh size	Filtrate Amnt (L)	Sample Size (ml)	Total Sample Count	Size Distribution N<100	100 to 200	N>200	N>400	Average Density (N/l)	Tec
2-Feb	11:00	Before	40	200	40	23	0	21	2	0	0.12	Denise
2-Feb	11:00	After	40	200	41	1	0	1	0	0	0.01	Carolir
2-Feb	13:30	Before	40	200	91	14	0	12	2	0	0.07	Denise
2-Feb	13:30	After	40	200	42	2	1	1	0	0	0.01	Carolir
2-Feb	15:30	Before	40	200	79	19	2	12	3	2	0.10	Denise
2-Feb	15:30	After	40	200	72	4	0	4	0	0	0.02	Carolir
3-Feb	9:15	Before	40	200	15	10	9	1	0	0	0.05	Carolir
3-Feb	9:15	After	40	200	65	0	0	0	0	0	0.00	Carolir
3-Feb	15:30	Before	80	400	16	8	4	4	0	0	0.02	Carolir
3-Feb	15:30	After	80	400	83	23	8	14	1	0	0.06	Carolir
3-Feb	16:30	Before	80	400	62	88	3	58	17	10	0.22	Denise
3-Feb	16:30	After	80	400	73	30	17	13	0	0	0.08	Carolir
4-Feb	9:15	Before	80	1000	101	53	28	23	2	0	0.05	Carolir
4-Feb	9:15	After	80	1000		32	9	23	0	0	0.03	Carolir
4-Feb	10:00	Before	80	1000	57	82	6	59	13	4	0.08	Denise
4-Feb	10:00	After	80	1000	85	71	57	13	1	0	0.07	Carolir
4-Feb	10:50	Before	80	1000	20	120	60	35	25	0	0.12	Denise
4-Feb	10:50	After	80	1000	61	74	70	3	1	0	0.07	Carolir
4-Feb	11:30	Before	80	1000	134	50	30	16	3	1	0.05	
4-Feb	11:30	After	80	1000	87	75	66	9	0	0	0.08	Carolir
4-Feb	12:15	Before	80	1000		93	69	22	2	0	0.09	
4-Feb	12:15	After	80	1000	76	73	64	9	0	0	0.07	Carolir
4-Feb	14:10	Before	80	1000		64	42	20	2	0	0.06	
4-Feb	14:10	After	80	1000	89	52	47	4	0	1	0.05	Carolir

4-Feb	14:50	Before	80	1000		50	33	15	1	1	0.05	
4-Feb	14:50	After	80	1000	49	41	32	9	0	0	0.04	Carolir
4-Feb	15:30	Before	80	1000		33	20	10	3	0	0.03	
4-Feb	15:30	After	80	1000	125	33	17	16	0	0	0.03	Carolir
4-Feb	16:05	Before	80	1000		119	84	30	5	0	0.12	
4-Feb	16:05	After	80	1000	110	76	62	14	0	0	0.08	Carolir
4-Feb	16:40	Before	80	1000		87	71	16	0	0	0.09	
4-Feb	16:40	After	80	1000	114	115	104	11	0	0	0.12	Carolir
5-Feb	8:30	Before	40	1000	116	60	5	38	13	4	0.06	Denise
5-Feb	8:30	After	40	1000	62	5	5	0	0	0	0.01	Carolir
5-Feb	9:30	Before	40	1000	221	96	10	71	13	2	0.10	Denise
5-Feb	9:30	After	40	1000	83	4	4	0	0	0	0.00	Carolir
5-Feb	10:00	Before	40	1000	124	73	55	15	3	0	0.07	Denise
5-Feb	10:00	After	40	1000	101	3	3	0	0	0	0.00	Carolir
5-Feb	10:30	Before	40	1000	264	30	12	14	4	0	0.03	Carolir
5-Feb	10:30	After	40	1000	82	2	1	1	0	0	0.00	Carolir
5-Feb	11:00	Before	40	1000		6	1	0	3	2	0.01	Denise
5-Feb	11:00	After	40	1000	112	3	3	0	0	0	0.00	Carolir
5-Feb	11:30	Before	40	1000		105	88	15	1	1	0.11	Denise
5-Feb	11:30	After	40	1000	118	3	3	0	0	0	0.00	Carolir
5-Feb	13:40	Before	40	1000		68	51	15	1	1	0.07	Denise
5-Feb	13:40	After	40	1000	115	8	8	0	0	0	0.01	Carolir
5-Feb	14:10	Before	40	1000		57	47	9	1	0	0.06	Denise
5-Feb	14:10	After	40	1000	111	2	2	0	0	0	0.00	Carolir
5-Feb	14:45	Before	40	1000		64	43	19	2	0	0.06	Denise
5-Feb	14:45	After	40	1000	58	6	6	0	0	0	0.01	Carolir
5-Feb	15:15	Before	40	1000		54	35	16	3	0	0.05	Denise
	15:15	After	40	1000	75	5	5	0	0	0	0.01	Carolir