INNOVATIVE AERATION DEVICE FOR REMOVING CARBON DIOXIDE FROM BORE WATER

M. W. Petrie
Opus International Consultants Ltd

ABSTRACT

Mosgiel's bores-sourced water supply has high levels of free carbon dioxide which is corrosive to metallic plumbing. Formerly treated by limited aeration and caustic soda dosing, alternatives to the caustic soda dosing were considered following three unrelated overdosing incidents. Options considered included aeration (at individual plants and at a single location) and full chemical dosing. Upgrade of the existing plants was severely limited by their location in residential areas and their very constrained site areas.

A vortex accelerator device manufactured in USA had great potential for Mosgiel. Although having a lower gas removal efficiency than aspirating type aerators the device required significantly less energy to operate and final carbon dioxide removal could be achieved by using the existing facilities to dose soda ash. Two of the devices within the existing aeration chamber would remove the bulk of the carbon dioxide. This met the noise and site area constraints and was the lowest cost option by a significant margin. Plant modifications have been completed and the system meets the project objectives.

Only two sizes of vortex accelerators are presently manufactured. The operating ranges and guidance on installation from experience gained during this project are covered in the paper.

KEYWORDS

Bore water aeration, carbon dioxide removal, aeration device, copper corrosion.

1 INTRODUCTION

The township of Mosgiel, with a population of 9,200, is located on the Taieri Plains, 13 kilometres (in a straight line) to the west of the metropolitan area of Dunedin. It is part of the greater Dunedin City. Mosgiel's water supply source is nine bores located throughout the township. These bores are categorised as "secure" in terms of the New Zealand Drinking Water Standards and are consented to supply a combined flow of up to 5,500 m^3 per day.

While of high quality bacteriologically the water, however, has high levels of free carbon dioxide which makes the water corrosive to copper piping, copper water heating cylinders, and pipe fittings. Four of the five small treatment plants had limited aeration and caustic soda dosing while the fifth used only caustic soda dosing.

Following three separate unrelated caustic soda overdosing incidents over a few years the Dunedin City Council stopped dosing and commissioned an options study to consider alternatives to the caustic soda dosing. As the treatment plants were located in residential areas and had very constrained sites any additional noise and any requirements for more land would be major issues.

2 OPTIONS STUDY

The options considered included:

- Deep Bores
- Chemical Dosing
  - Caustic soda using 1% solution concentration (the existing solution strength was 20%)
  - Sodium bicarbonate
  - Soda ash
  - Hydrated lime
- Aeration
  - At a single location
  - At individual plants

2.1 DEEP BORES

The possibility of obtaining high pH water from deep bores (similar to the Christchurch experience) and mixing it with the lower pH water from the existing bores was considered. A report from a Geohydrologist, MacTavish (2007), however, showed that the geology of the East Taieri Aquifer system (which supplies the Mosgiel water) is such that a pH of 8 was unlikely to occur naturally at any depth. In view of the costs and risks associated with such drilling, (only a 50% chance of a bore producing the same quantity and quality as the existing bores) and the fact that the water pH would not be above 8.0, this option was not considered any further.

2.2 CHEMICAL DOSING

Dosing a chemical solution to remove the free carbon dioxide had a number of issues. Hydrated lime is not very soluble and a 1% solution is the maximum practical strength. For soda ash a 6.5% solution strength is the maximum concentration that can be used without solidification of the stored solution occurring at the low temperatures that would be experienced. The solubility of sodium bicarbonate is a similar value at those low temperatures. Thus both soda ash and sodium bicarbonate were assessed using solution strengths of 6.5%.

The volumes of chemical solution required each day at the various treatment plants were determined and tabulated. Soda ash required the smallest volumes and this chemical was used for comparison of capital and operating costs for the chemical dosing options in the study. Soda ash dosing needed a building 10.5 metres by 5.5 metres. Unfortunately there was no such space available at the existing sites. Land purchase and Resource Consenting would therefore be problems.

2.3 AERATION

Full aeration would eliminate the need for chemical dosing and the various methods of bore water aeration were considered. An American firm (Venturi Aeration Inc.) was contacted for details of their venturi type aerator. In this device the water enters the unit at 140kPa and is accelerated to 16.5m/s through a nozzle. The vacuum created draws air through the aspirating zone and into the mixing zone. The air and water are mixed together under pressure in this zone and the hydraulic shear facilitates the release of the carbon dioxide from the water. The water and released carbon dioxide are discharged into the aeration tank. An exhaust fan keeps this tank under a slight vacuum and removes the carbon dioxide from the aeration tank. The detention time in the tank is 15 minutes and the treated water is then pumped to the reticulation system.

If required, the tank can be fitted with a recirculating flow in order to provide two or even three passes of the water, by using an additional aerator, until the targeted carbon dioxide concentration is attained.

The firm had developed a computer programme that predicts the resulting carbon dioxide concentration and pH values of the water following each pass through the unit. Information on the range of parameters for the Mosgiel bore waters was sent to the firm and the computer programme predicted that two passes of the water would reduce the carbon dioxide to non-corrosive levels.

While the writer was investigating the full aeration options the firm advised that it had also recently designed a new aeration device which they called a Vortex Accelerator. This was designed as a low cost unit to follow their venturi type aerator unit but which could also be used in a similar manner to those units.

The Vortex Accelerator dissociates entrained gases from a liquid. The device uses the kinetic energy of the fluid passing over a series of fixed geometrically-positioned internal elements to create a spinning vortex. This causes the less dense embedded carbon dioxide gas to move to the centre of the device and form a "gas core" while the denser water spins and adheres to the walls of the Vortex accelerator shell. The device is 325mm long, flanged at the inlet end, and is available in two diameter sizes.

The water flow through the 75mm diameter device is in the range 3.4m/s to 4.6m/s for satisfactory operation and the pressure drop across the device is 45kPa. Thus the Vortex Accelerator requires only a third of the energy input of the venturi type aerator device. However, the removal efficiency of the Vortex Accelerator at 60-65% is lower than that of the venturi unit at 75-80%.

At the temperatures of the Mosgiel bore waters the Vortex Accelerator was predicted to have an efficiency of 60% and the venturi aerator unit to be 75% efficient. The Vortex Accelerator appeared to have considerable potential as it could be fitted into the existing aeration chambers and the existing bore pumps could be used to provide the pressure for the first pass, as they appeared to have sufficient head capacity. This would be of considerable benefit as use of the existing plants would be severely limited by their being located in residential areas and having very constrained site areas.

The device was very new, however, and was still undergoing performance testing at a water treatment plant (in West Virginia, USA). It was, therefore, decided to trial a Vortex Accelerator at the Watt Street WTP to check the efficiency of the device and the effects on the bore pump operation.

2.4 TRIAL

A Vortex Accelerator was manufactured in New Hampshire, USA, for the trial and this was installed in the plant's aeration chamber along with the air extraction pipework in early August 2006. Pipework modifications were trialed to check the effects on the efficiency of carbon dioxide removal. A straightening piece was inserted after the water inlet bend and ahead of the Vortex Accelerator. This resulted in a better defined water exit pattern. The distance from the Vortex Accelerator outlet to the inlet of the air extraction pipe within the discharging water cone was varied and changes to the efficiency noted. The pipe diameter at the air extraction inlet end was also reduced. When the set-up was performing satisfactorily the noise attenuators and lid were replaced, and the fan installation and electrics made ready for permanent running.

By the beginning of September 2006 the plant was running with the Vortex Accelerator set-up as required. The Watt Street WTP was then run as "duty plant" to gather performance information with pumping for long and consistent periods. This was to check for performance drop off as the water level in the bore dropped.

Samples of bore water and aerated water were taken on a weekly basis during the period September to December and tested at a laboratory in Dunedin for carbon dioxide, alkalinity, pH, and temperature. On-site testing by the laboratory was also carried out over the trial period. The results showed that the 60% efficiency was attained.

2.5 AERATION OPTIONS ASSESSMENT

Carrying out aeration for full gas removal at one site appeared to have the advantages of requiring only one set of aeration devices and noise suppression equipment at only one site instead of five sites. However, finding a suitable site close to the bores was problematic because all land in those areas was built on.

For the purposes of the study two sites were assessed: a Council-owned yard and a site on agricultural land. Both sites were at the outer limits of the township. The latter site would have had to be designated and the fact that the site was flood-prone was another disadvantage. The major disadvantage of the single site aeration option, however, was the cost of pipelines from the existing treatment plants to the site and back to the plants. These pipeline costs completely ruled out full aeration at a single site as can be seen in Table 1 below.

Carrying out full aeration with the venturi type aerators at the existing water treatment plant sites also had a number of problems; mitigation of noise from the pumps and fans, and the available space being the major issues. The 15 minute detention period required would necessitate a new tank structure at each site as the existing aeration chamber and reticulation pump well were not large enough. The existing aeration chambers, however, could be modified and used as the pump wells for feeding the stage-one device. This lack of space was a major constraint as the footprint for an aeration tank at one plant was twice the footprint of the existing building.

The inadequate space available at the existing water treatment plants made venturi aeration a very unlikely option.

Aeration for full gas removal with the Vortex Accelerators at the existing water treatment plant sites was not possible because of their lower gas removal efficiencies. However, the device had great potential for Mosgiel as it required significantly less energy to operate (thus the existing bore pump could be used), a second “pass” could be carried out in the existing aeration chamber by installing a submersible pump, and the final carbon dioxide removal could be achieved by using the existing facilities to dose soda ash. Use of Vortex Accelerators at the existing plants would therefore mean that all site constraints were likely to be overcome. This carbon dioxide removal method was the lowest cost option by a significant margin and was the study’s recommended option.

Table 1 Summary of estimated costs for options

Option	Capital Costs ($)	Operating Costs ($)	Nett Present Value* Costs ($)
Alternative chemical dosing	1,637,000	94,000	2,550,000
Full Aeration at Single Site (Carlyle Rd.)	12,299,000	70,400	12,983,000
Full Aeration at Single Site (Silverstream.)	7,339,000	50,700	7,831,000
Full Aeration at Individual sites	1,972,000	50,200	2,460,000
Aeration plus chemical dosing	556,000	50,700	1,048,000

Notes Costs exclude GST

* i = 6%, N = 15 years

2.6 CHEMICAL OVERDOSE RISK TO CONSUMERS

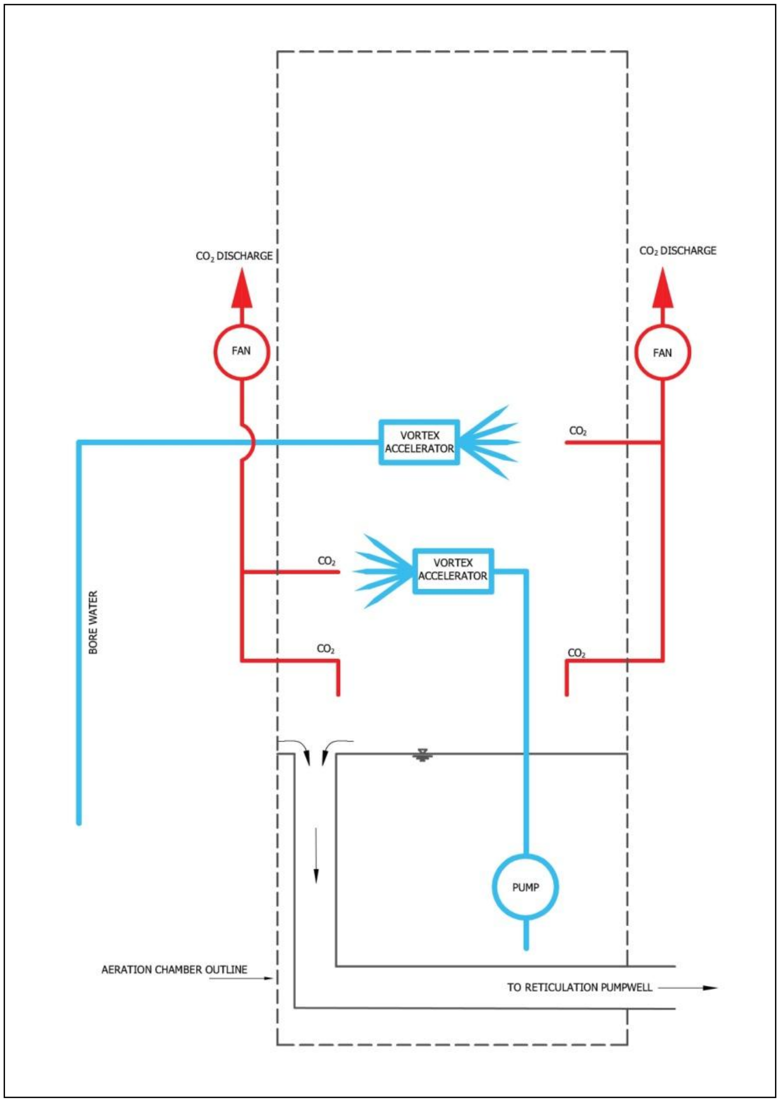
The options study had been instigated to avoid the risk to consumers from the adverse affects of caustic soda overdosing. As the use of the new device still required some chemical dosing the National Poisons Centre was contacted concerning the effects of chemical overdosing. It was established that overdosed water below a pH of 11.5 would be an irritant only and not cause any burning of internal tissue. Above a pH of 11.8 significant effects would be noticed and above pH 12.0 to 12.5 severe burning would occur.

The danger of caustic soda is apparent when even 0.5% solution strength has a pH of 13.0. Soda ash is a more benign chemical. A 6.5% solution strength of soda ash has a pH of 11.2-11.3. Any overdosing is therefore likely to have the effect of being only an irritant.

3 TREATMENT PLANT MODIFICATIONS

Three of the treatment plants had a single Vortex Accelerator in each aeration stage while the fourth plant had two Vortex Accelerators per stage and used two submersible pumps for the second stage water discharge. The 75mm diameter Vortex Accelerator device was used throughout. The submersible pumps used were Grundfos SE1.80.100.22.4.50B and the air extraction fans were Fantech TD-250/100 Lo. Two fans were installed at the plants having a single accelerator per stage and three fans were used at the fourth plant. A process flow diagram for the system used at the three plants is shown in Figure 1.

Figure 1: Process Flow Diagram



The treatment plants were taken off-line one at a time for the modifications and the procedure at each plant was similar. The lid and noise attenuation baffles from the existing aeration chamber were removed first. The cascade trays in the aeration chamber were also removed. An epoxy coating was then applied to the walls and floor of the chamber to protect the concrete. Deflector plates fabricated from 0.9mm thick stainless steel sheet were fixed to the concrete wall for further protection from the accelerators' discharge. A raised level outlet pipe was fitted to the existing outlet to create a reservoir for the submersible pump. Installation of the air extraction piping, Vortex Accelerators, and submersible pump followed. The extraction fans were fitted outside the chamber and the electrical work completed. Commissioning of the Vortex Accelerators was undertaken and the chamber then disinfected. The noise attenuation baffles and lid were re-fitted and the treatment plant brought back into operation. Chemical dosing upgrades were also undertaken.

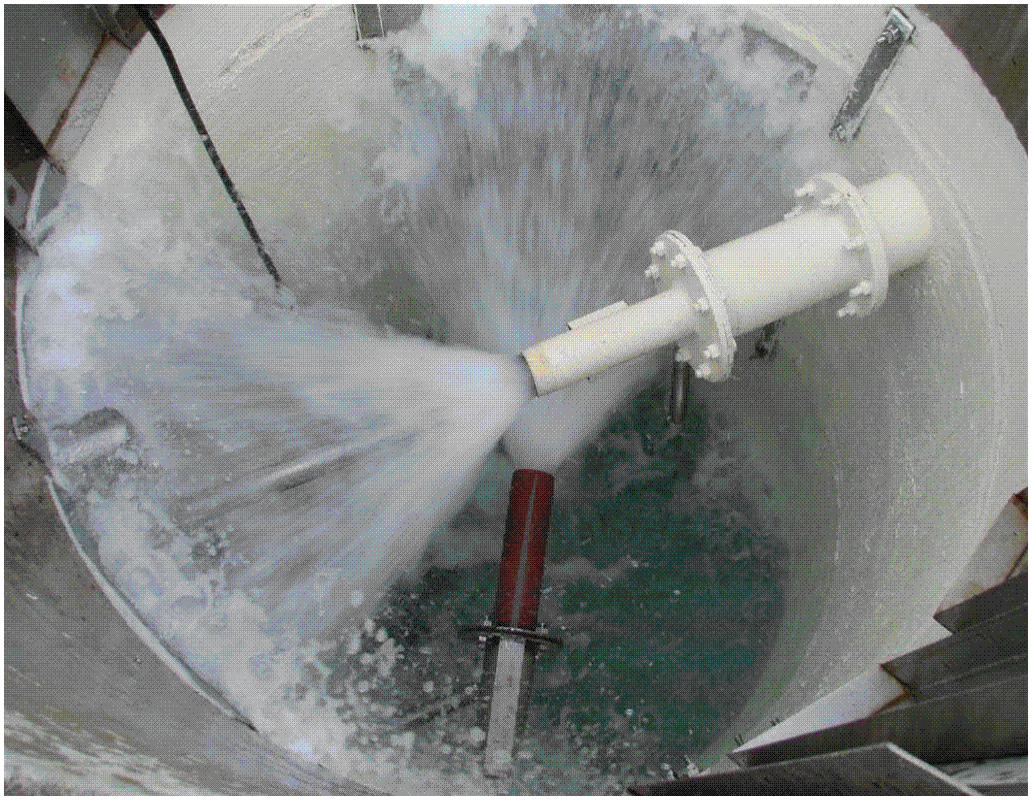
Photograph 1: Aeration chamber pipe work arrangement

Photograph 1 shows the pipe work arrangement in one of the aeration chambers. The stage one Vortex Accelerator which discharges the in-coming water from the bore pump is painted white. The stainless steel piping which extracts the carbon dioxide from within the discharge cone of the Vortex Accelerator is directly in line with the accelerator. The lower level extraction piping is also visible.

The submersible pump for the stage two aeration can be seen in the lower left of the photograph. The stage two Vortex Accelerator, painted brown, is located at a lower level than the stage one accelerator. The stainless steel piping for the stage two aeration is at centre top and the raised outlet pipe (creating a reservoir for the submersible pump) is at centre right.

The stainless steel fittings at the bottom right of the photograph are the supports for the noise attenuation baffles.

Photograph 2: Vortex Accelerators operating



Modifications to the first treatment plant commenced in May 2008 and commissioning of the vortex accelerators in the last of the plants was completed in December 2008. Commissioning of the soda ash dosing was completed in early July 2009. The project duration was extended beyond the programmed period as a result of delays caused by failure of existing pumps at duty plants and staff sickness at critical times. (Treatment plants could not be taken off line for modifications while duty plants had pumps out of commission and disinfection of the modified aeration chambers was carried out by DCC Water Services staff).

4 TESTING

The DCC water treatment technicians have measured pH of the bore water and aerated water at the plants and from these values and the long term testing results of the bores' water alkalinities the free carbon dioxide values have been calculated. Confirmation testing by the local IANZ certified laboratory has been carried out on-site at the treatment plants on two separate occasions. The tests included pH, alkalinity, free carbon dioxide, and temperature. Results are shown in Table 2.

Table 2 Typical Results of Testing

Treatment Plant	**Raw Water**				**Aerated Water**			
	Alkalinity (g/m^3)	Free CO_2 (g/m^3)	pH	Temp. (^oC)	Alkalinity (g/m^3)	Free CO_2 (g/m^3)	pH	**CO_2 Removed** (%)
Eden Street	33	47	6.15	11.2	33	13	6.70	72
Old Council Yard	77	64	6.38	12.5	77	19	6.91	71
Severn Street	60	35	6.54	11.6	60	12	7.01	66
Watt Street	43	40	6.35	12.2	44	14	6.82	65

The water flows and extracted air flows at the Mosgiel water treatment plants are shown in Table 3.

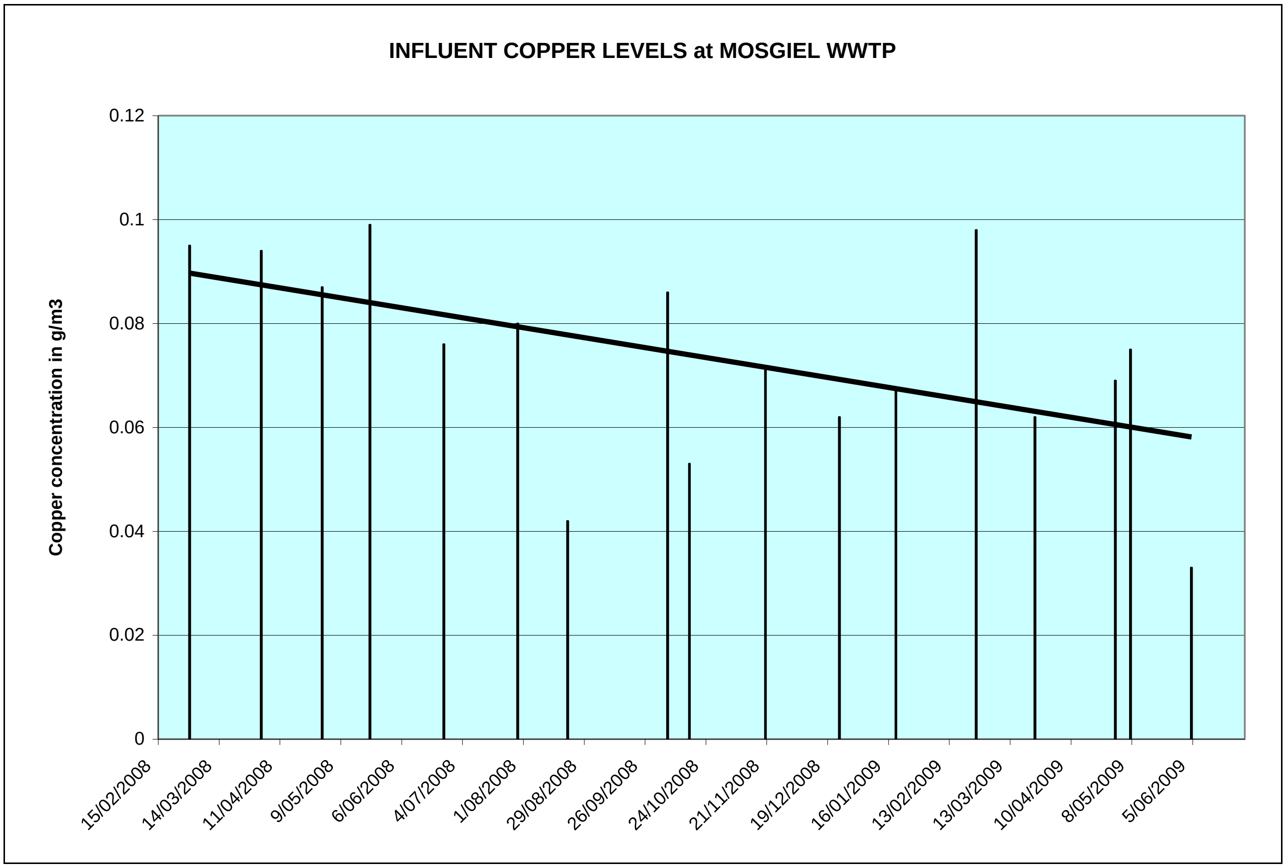
Table 3 Plant Flows

Treatment Plant	**Inlet Flow** (m^3/h)	**VA-1 Flow *** (m^3/h)	**VA-2 Flow **** (m^3/h)	**Air Flow ***** (m^3/h)
Eden Street	51.0	45.0	62.5	144.0
Old Council Yard	96.0	81.0	62.5	144.0
Severn Street	157.0	122.5	125.0	216.0
Watt Street	80.0	62.5	62.5	144.0

* Expected flow based on affect of Vortex Accelerator headloss on bore pump(s).
** Flow from submersible pump(s).
*** Total air flow from fans.

The objective of the work was to lessen the corrosiveness of the water caused by the high levels of free carbon dioxide. The effect of the corrosion had been monitored in the past by testing of the levels of copper arriving in the sewage at the Mosgiel wastewater plant. Testing by DCC Waste Services has shown that the copper levels have been trending down since the first plant had the Vortex Accelerators installed and recommenced operation. Figure 2 shows the trend.

Figure 2: Reduction in water corrosiveness



Modification of the first water treatment plant was completed at the end of May 2008. The last of the four modifications was completed in mid-November 2008. The Reid Avenue plant has no aeration and so no carbon dioxide was being removed from the water supplied by that plant. The treatment plants are also operated in a changing priority sequence. Which plant, and the number of plants operating at any time, depends on the water demand and the operating priority sequence. The test results are therefore affected by whether or not the Reid Avenue plant was operating and the length of time operating. The commissioning of the soda ash dosing was completed in early July 2009. The copper levels have already reduced to near the levels experienced during the previous caustic soda dosing and are expected to decrease further with the soda ash dosing.

5 DISCUSSION

Using the Vortex Accelerators in a double pass system and the extent of use of the Vortex Accelerators at Mosgiel is a world first. The trial of the device in the one pass set-up gave some confidence as to future success but the two pass arrangement resulted in two issues that lowered the expected performance.

Combining the two passes in one chamber instead of a separate chamber for each pass reduced the overall efficiency of the gas removal. Instead of the 84% reduction anticipated this was reduced to 75%. It was also found that as the level of free carbon dioxide is reduced the efficiency of removal of the second Vortex Accelerator decreases. The normal 60% removal efficiency can fall to 50% efficiency.

The advantage of having only one aeration chamber at the Mosgiel plants, however, significantly outweighed these losses in efficiency. The extra carbon dioxide remaining is neutralised by a slightly greater volume of the soda ash being dosed. An additional dosing storage tank has been installed within the bunded area at each plant.

Using the Vortex Accelerator devices to remove the free carbon dioxide from the bore water at Mosgiel was an extremely cost effective method which allowed the use of the existing treatment plant facilities and overcame the problems of restricted site area and noise issues.

There are constraints to the use of the devices, however, and the following section gives guidance on their use based on the experience with the Mosgiel installations.

6 GUIDELINES FOR USE OF VORTEX ACCELERATORS

Presently only two sizes of Vortex Accelerators are manufactured. The specifications for the two sizes are tabulated below.

Table 4 Vortex Accelerator specifications

Size	Parameter	Minimum	Normal	Maximum
75 mm	Flow	12.9 l/s	14.5 l/s	17.8 l/s
	Velocity	3.4 m/s	3.7 m/s	4.6 m/s
	Pressure Drop	34 kPa	37 kPa	45 kPa
100 mm	Flow	29.1 l/s	32.3 l/s	38.8 l/s
	Velocity	3.4 m/s	3.8 m/s	4.6 m/s
	Pressure Drop	48 kPa	59 kPa	85 kPa

Aspects to be considered during design are as follows:

- For a two pass system two separate aeration chambers give greater carbon dioxide removal than the two passes within one chamber.
- The gas removal efficiency of the Vortex Accelerator is lower when the concentration of the carbon dioxide in the water is low.
- A straight section of pipe immediately before the Vortex Accelerator reduces flow disturbance from upstream bends or fittings. This results in a better discharge cone from the accelerator.
- In the one aeration chamber system ensure that the second pass flow is equal to or greater than the first pass flow.
- In the one aeration chamber system reduce the possibility of short circuiting the aerated water flow. (Keep the water discharging from the first accelerator clear of the chamber outlet and close to the submersible pump).

- The air flow extracting the carbon dioxide from the aeration chamber should be greater than the total water flow.

7 CONCLUSION

The use of the new Vortex Accelerator aeration devices to remove the carbon dioxide from the bore water at Mosgiel was an extremely cost effective method which allowed the use of the existing treatment plant facilities and overcame the problems of restricted site area and noise issues.

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