TECHNICAL BRIEF
2 March 2023

Te Mato Vai Water Treatment Plants

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TECHNICAL BRIEF

1.0 Abstract

The Te Mato Vai Water Treatment Plants (WTP's) are facing a number of challenges in its ability to achieve and maintain system sustainability, with regards to water that is aesthetically and/or hygienically fit to be consumed directly, thus calling for some means of improved treatment.

As a consequence, the water supply infrastructure may cause health problems and, therefore, the drinking water thus should be:

- Free from pathogenic (disease causing) organisms
- Clear (i.e., low turbidity, little colour)
- Not saline (salty)
- Free from offensive taste or smell
- Free from compounds that may have adverse effects on human health (harmful in the long run)

The availability of potable drinking water is a fundamental requirement for public health.

The purpose of <u>water treatment</u> is to reduce or eliminate contamination or **unwanted characteristics of water**. It consists of a series of physical, chemical and sometimes biological processes that **remove contaminants from the water**. The aim is to give the water the right characteristics for the desired use. As a result, some of the existing water treatment processes will have to vary and or dramatically improved depending on its properties at the outset and also its ultimate use.

The main surface water treatment objectives for TVV's WTP 's are to improve its bacteriological quality, which at this stage are not compliant. Drinking water should not contain any pathogenic organisms, which are often difficult to detect analytically. Therefore,

the bacteriological water quality is analysed for faecal indicators. The bacteria used for such analysis are faecal coliforms, Escherichia coli and faecal streptococci present in large concentrations.

Analytical tests clearly show that water in the distribution system does not comply with the bacterial compliance criteria and regularly test positive for E. coli. See attached sheet on page 3.

A raw water treatment system is a system made up of several individual technologies (unit processes) that address the specific raw water treatment needs.
Treating raw water is rarely a static process, and a raw water treatment system that is engineered to accommodate fluctuations in treatment needs will go a long way in avoiding costly replacements/upgrades down the line.

An efficient and well-designed raw water treatment system should be able to handle:

- Seasonal variations in turbidity and flow.
- Variations in water chemistry needs and required chemical volumes adjustments. (See comment below)
- Changes in water quality requirements due to changing legislation over the life span of the WTP.

The Te Mato Vai Water Treatment Plants (WTP's) are lacking the ability of proportional flow dosing adjustments, i.e., to achieve the same ratio of chemical (coagulant) to water, regardless of flow variations.

The specific unit processes that need further attention include chemical coagulation, flocculation and filtration for reason's explained in this technical brief.

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Water Sample Run Sheet

North Reticulation

Weather/Site Condition(s): Fine

No.	Reticulation Sample Points	Tests	Time	NTU	Temp	pH	TC	EC	Comments
1	Takuvaine Bunker Tap	QT	9:35	0.25	28.4	6.6	165.0	4.1	
2	Tupapa Ground Rd Side Tap	QT	9:54	0.65	27.0	7.0	78.4	8.6	
3	Clubraro Bus Stop Tap	QT	10:00	0.79	27.4	6.9	22.8	1.0	
4	Tupapa backroad Side Tap (100m from intake rd)	QT	10:10	0.63	26.2	7.2	68.3	8.7	
5	Chestnut tree bckrd side Tap (opposite 'Inland Home' sign)	QT	10:15	0.44	25.9	7.1	66.3	12.1	
6	Matavera Puna Outside Tap (next door to Gibeona WS)	QT	10:25	0.39	27.9	7.0	7.4	1.0	
7	Turangi Back Rd Side Tap (100m from Turangi intake Junction)	QT	10:33	0.4	24.7	7.1	10.8	<1	
8	Avana Outlook Beach Side Tap	QT	10:44	0.61	36.3	6.7	41.4	19.9	
9	Rua Drive Rd Side Tap, Muri (Rd Opposite Convinience Store Muri)	QT	10:51	0.47	26.4	7.1	93.3	41.4	
10	Papa Ben store side Tap (opposite cemetary)	QT	11:00	0.32	30.5	7.0	162.4	29.5	
11	Papa'aroa Hall Tap	QT	11:08	0.51	29.2	7.0	17.3	1.0	
12	Vaimaanga Main Rd, Opposite Puna's RD	QT	11:21	0.59	27.3	7.2	547.5	127.4	
13	Ian's Beach Batch Accomodation	QT	11:32	0.57	30.0	7.1	40.8	15.6	
14	LDS Cemetry Tap, Betela, Arorangi	QT	11:49	5.21	29.1	7.2	49.6	9.6	
15	Social Centre Tap	QT	11:55	0.6	31.2	7.2	40.4	7.5	

Chain of Custody:

Date of Sample:	16.02.2023	Sample Receiver:	Stella/Steve
Sampler:	Steve	Lab Staff:	Stella
Recorder:	Stella	Date processed:	16.02.2023
Time Received:	12:15	Time processed:	2:00

Temp Control:
Time:

Lab Control:
Time:

Other Observations:

A separate bacterial compliance criterion for water leaving the treatment plant has to my knowledge not yet been established.

It was observed that the most widely encountered deficiencies in TVV's WTP's was the application of coagulants to raw water, facing operational problems with the coagulation-flocculation and its subsequent sedimentation and filtration processes.

A site visit, which commenced on Tuesday, 31st of January 2023 revealed that inadequate doses and inappropriate dosing were the most common mistakes.

Difficulties were also experienced with the flocculation step. Uncontrolled energy inputs resulted in fluffy flocs of low settleability. See attached picture on page 5.

This led to floc too light and large being flushed through the sedimentation tank and did not settle before the next step; i.e., filtration overloading the subsequent filters.

These in turn could not be backwashed properly and often produced filtered water at an unacceptable upper level of turbidity. **Turbidity** is the clarity of water and it is an important factor in water quality.

Turbidity, which is caused by suspended chemical and biological particles, can have both water safety and aesthetic implications for drinking-water supplies. Turbidity itself does not always represent a direct risk to public health; however, it can indicate the presence of pathogenic microorganisms and be an effective indicator of hazardous events throughout the water supply system, from catchment to point of use. For example, high turbidity in source waters can harbour microbial pathogens, which can be attached to particles and impair disinfection; high turbidity in filtered water can indicate poor removal of pathogens.

The described difficulties encountered with the Te Mato Vai WTP's often resulted in the production of water of erratic quality which is often unsafe for consumption.

Objectiveness at this point demands that it appears that the selection of the treatment technology, the appropriateness and the economy of the technology was an integral part of the selection process, i.e., the design and applied unit processes at the Te Mato Vai WTP's are considered a most appropriate water treatment technology.
Example, rectangular sedimentation tanks, baffle type flocculators and AVG filtration (which backwash automatically by siphoning).

2.0 Introduction

This technical brief, is divided in two parts, presents technical developments to improve/enhance the existing critical water treatment facilities and describes processes for solid matter separation.

Part 1 Focuses on the general aspects of coagulation/flocculation and the AVG filtration units and will also provide a glimpse of the different challenges posed by these treatment technologies.

Part 2 A view of the pre-treatment processes applied to solid matter separation and a description of the application of this technology

Part 1

General Aspects of AVG filter Application

The choice of a treatment process for potable water production is strongly influenced by the raw water quality, desired final water quantity, physical location and the availability of resources for operation and maintenance. The complexity of the treatment process required to treat raw water to potable standard is not significantly affected by the capacity of the plant.

When conventional type “small-scale plants” are operated by central authorities, operating costs are driven up primarily by traveling time to and from the plant, as swell as the wide range of specialised skills that are required to operate the processes from a central base.

These circumstances place restrictions on the designer of these water supply schemes to provide low cost, low maintenance plants without compromising the performance and quality of water produced. Processes that are inherently self-regulating and simple have an obvious advantage in that they will require fewer skilled operator visits to the plant at less frequent intervals. This allows many of the operating and maintenance task to be delegated to community level and reduces the reliance of the plant on specialised skills. An example of these processes includes the autonomous valveless gravity filter, (AVGF).

Experienced operational difficulties with the AVG filters have to be mentioned at this point.

Against the advantages, the AVGF filter has a relatively high capital cost due to its robust construction. Furthermore, the design may not be ideal for certain applications, and under some conditions the filter may fail. None-the-less the filter has the potential to operate for extended periods with only a low degree of intervention by a semi-skilled operator, provided that an appropriately skilled supervisor is available to deal with non-routine events.

The critical design parameters for the AVGF are the filtration rate, the head loss at which backwash is initiated (terminal head loss), the head and volume of water available for backwash and the resulting backwash velocity versus time profiles.

The objective of this part is to:

- Propose where necessary, design modifications aimed at improving the reliability, and
- Propose specific operating rules by which the unit should be operated and maintained and to prescribe minimum levels of operator supervision

Adequate AVG Filter operation is only possible with clarified water of low turbidity; i.e., virtually free of solid matter. Pre-treatment in the form of coagulation and flocculation is therefore necessary.

1 Coagulant dosing

In general coagulant is required to achieve acceptable filtered water turbidity's. Hence the filter performance will only be as reliable as the dosing system.

Coagulant chemicals with charges opposite those of the suspended solids are added to the water to neutralize the negative charges on non-settleable solids (such as clay and colour-producing organic substances). Once the charge is neutralized, the small suspended particle's are capable of sticking together. These slightly larger particles are called micro flocs, and are not visible to the naked eye. Water surrounding the newly formed micro flocs should be clear. If not, coagulation and some of the particle's charge have not been neutralized. More coagulant chemicals may need to be added. A high-energy, rapid-mix to properly disperse coagulant and promote particle collisions is needed to achieve good coagulation. Over-mixing does not affect coagulation, but insufficient mixing will leave this step incomplete. Contact time in the rapid-mix chamber is typically 1 to 3 minutes.

One of the major water treatment processes is coagulation and flocculation. Appropriate coagulation can aggregate particles to form larger sizes that can be easily separated from water. Determining the coagulant dose is a challenging issue in water treatment facilities. Determining the coagulant dosage is a nonlinear, time consuming, and multifactor process, also is a complex chemical process. This complexity is not only regarding raw water turbidity, raw water flow rate, temperature, pH value, and organic content of water, but also can be affected by the rapid mixing, the hydraulic factors of coagulation tank, and surrounding environment condition(s).

If coagulation is incomplete, flocculation step will be unsuccessful, and if flocculation is incomplete, sedimentation will be unsuccessful.

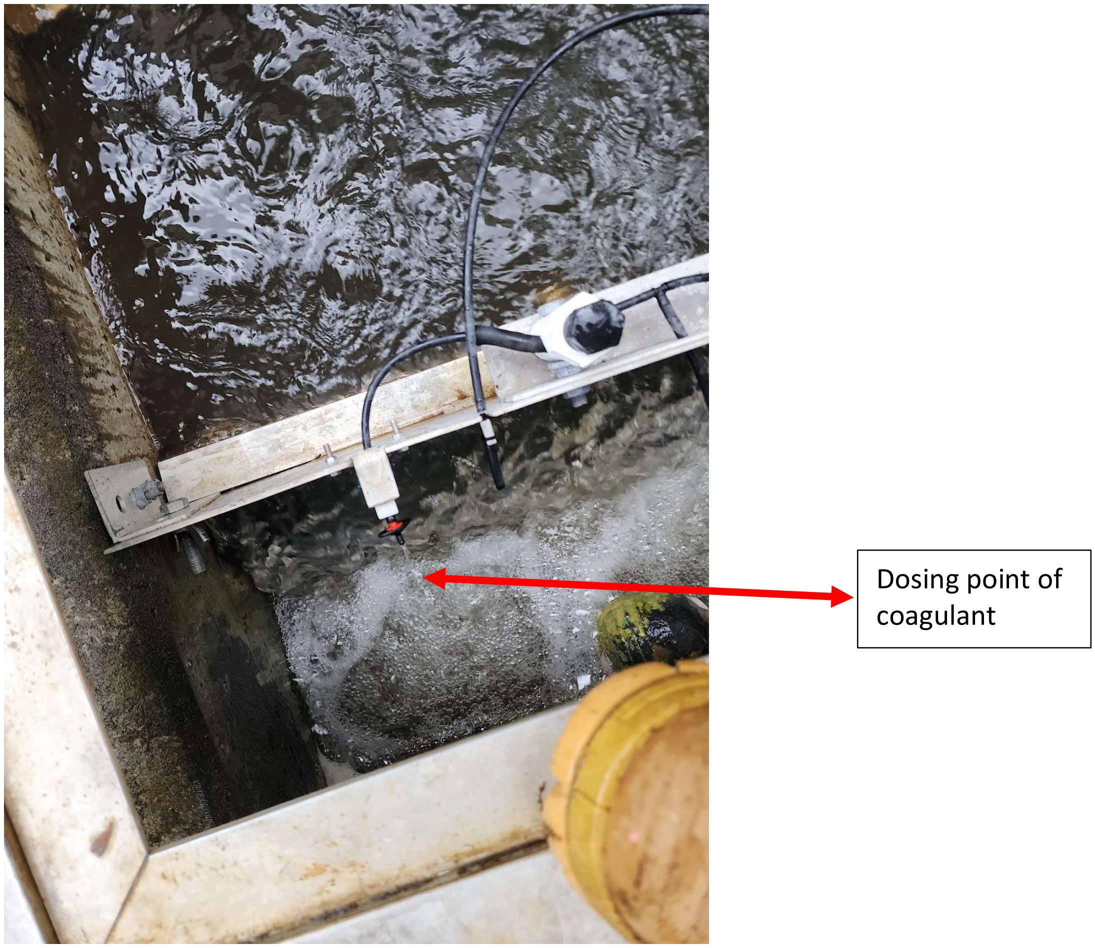
1.1 Rapid Mixing

The mechanism of rapid mixing and coagulation:

The purpose of rapid mixing is to disperse coagulant chemicals uniformly throughout the raw water as rapidly as possible in order to destabilize the colloidal particles (i.e., neutralize the negative charges around the colloid surface) present in the raw water.

Theoretical and experimental studies have shown that the contact between coagulant and colloidal particles should occur before the hydrolysis reaction with alkalinity is completed.

This requires very rapid dispersion of coagulant in the mass of water within a few seconds. To facilitate the rapid dispersion, the water is agitated vigorously with the aid of mixing devices and the coagulant is added at the most turbulent zone.

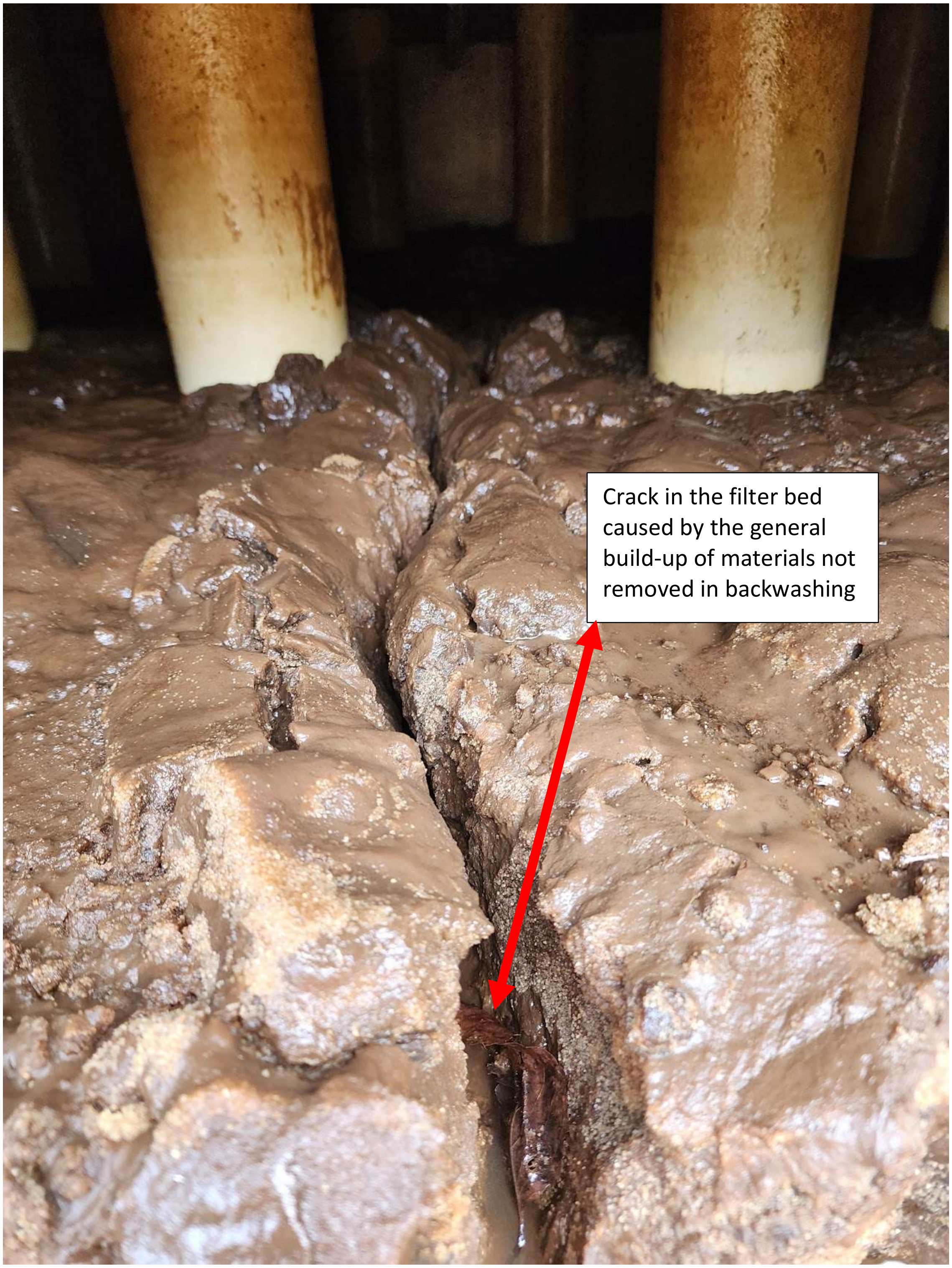


Referring to the coagulant mixing it is important to make the metallic coagulants rapidly disperse into the whole fluid bulk. Practically, it is not easy to disperse them in less than a second and consequently it is recommended in the literature to release this mass transfer operation as rapidly as possible (Hudson and Wolfner (1967), Vrale and Jorden (1971)). Moreover, due to the fact that the hydraulic mixing devices have not the potential to disperse metallic species during this short time, operators increase the coagulant dosage tested in the jar test by 30-40%. It leads to getting the required efficiency of coagulation just by increasing collision opportunities (Kawamura (2000)) between coagulant ions and colloids (Kurita (1999), Parsons and Jefferson (2006), Park et al. (2009), Li et al. (2009)).
In many of the conventional treatment plants, however, the coagulant mixing is typically performed in a concrete basin by hydraulic mixing

(weir mixers), and requires about 1—2 min of retention time. As mentioned earlier, hydraulic mixing with a longer retention time cannot guarantee an instantaneous and uniform coagulant dispersion (Kim and Lee (2006)).

As can be seen from the picture on page 9 the mixing did not result in the most efficient rapid mixing of the coagulant effecting the coagulation-flocculation performance in terms of solid matter removal. This is evidenced by the picture on page 11.

The degree of turbulence in hydraulic mixers is a function of flow, i.e., changes in flow will affect mixing efficiencies. Hydraulic rapid mixing is found to be more economical than mechanical rapid mixing due to the absence of moving parts and power requirements, but it is not as flexible as mechanical mixing. Mechanical mixing has been used extensively in both developed and developing countries, but hydraulic mixing is currently receiving increased attention due to recent research and field experiences.


Crack in the filter bed caused by the general build-up of materials not removed in backwashing

The mechanism of destabilization (removal of little or no tendency of colloids to aggregate) of colloids are classified in four types:

1. Sweep Coagulation
   Al $(OH)_3$ is formed when alum is added to water, is a shapeless and sticky precipitate in nature. These are heavier than water and settles down by gravity. This process is called sweep coagulation.

2. Ionic layer compression
   A high ion concentration compresses the layer composed of -ve charged ions towards the surface of the colloid. Once sufficient compression has occurred, Van Der Waal force of attraction will be predominant and thus particles grow in size and will be removed in a sedimentation tank. This kind of mechanism generally occurs in delta formation.

3. Adsorption and Charge Neutralization
   If alum is added in water, then it will form Al^{3+} and SO_4^{2-}. The Al^{3+} will react with water and form various aqua metallic cations like $Al(OH)^{2+}$ etc. These cations surround the clouds of -ve charged particles as they affinity for the surface, adsorbed on the surface.

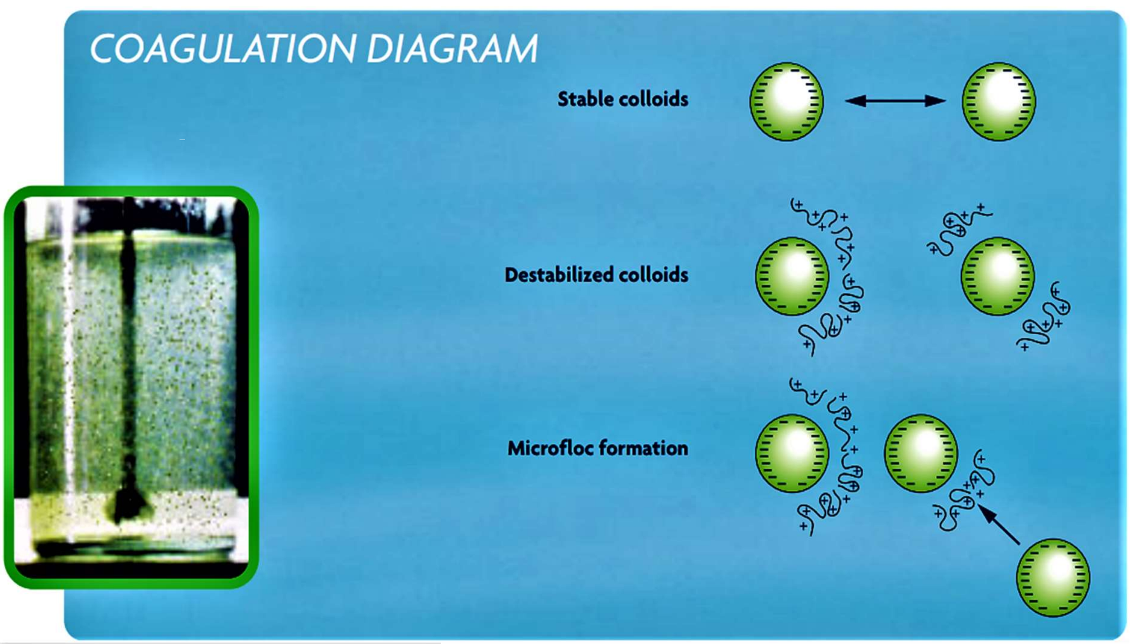
4. Inter-Particle Bridging
   Large molecules are formed when aluminium or ferric sulphate dissociate in water. Several colloids in water may get attached to these molecules and thus increase their size and settles down in the sedimentation tank.

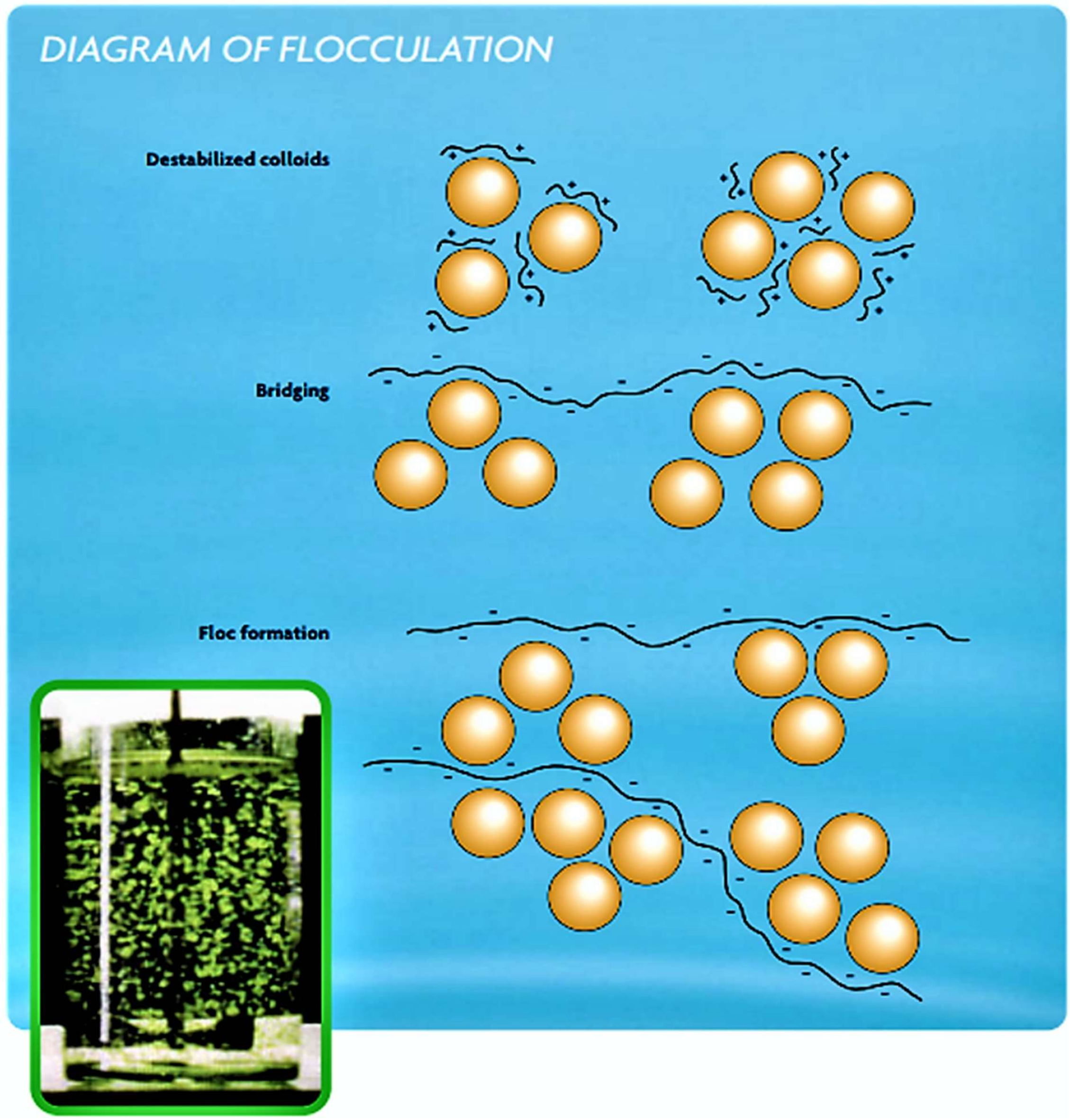
It is important to note of the advantages of adsorption and charge neutralization mechanism over sweep coagulation:

I. Higher colour and turbidity removal
II. Lower coagulant dosage
III. Lower sludge production
IV. Longer filtration cycle

It is argued that effective rapid mixing is a vital feature of design when employing any form of coagulation.

A rapid mixing device such as shown on page 16 could be deployed and build into the overflow weir, with the use of a simplified hydraulic ram supplying the pressure needed to rapidly mix and disperse the coagulant into the fluid bulk.



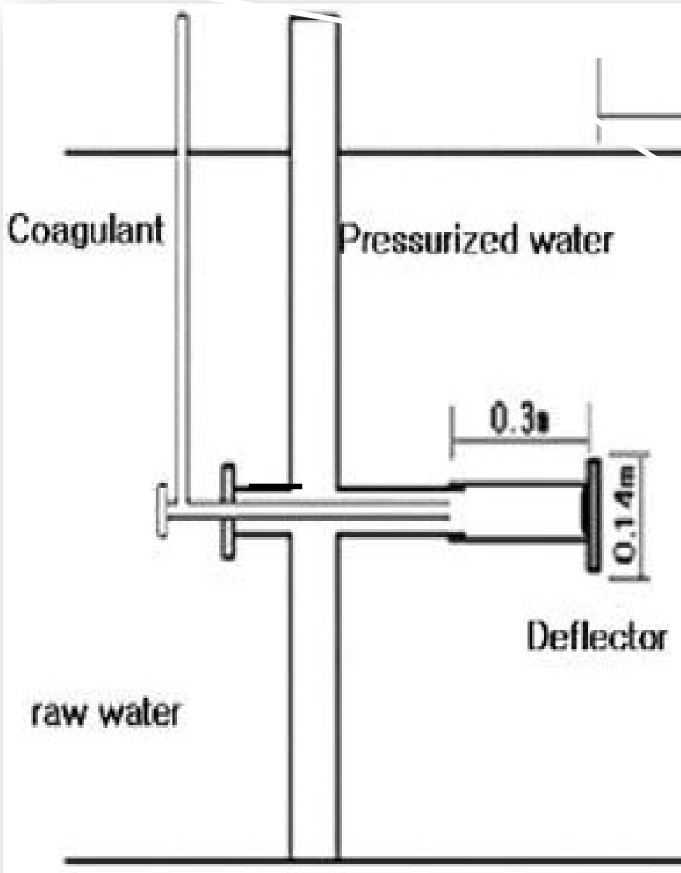


Conclusion:

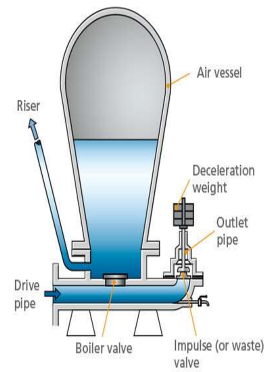
What makes the coagulation-flocculation unit processes so important is it represents the first treatment step; i.e., the separation of solid matter.

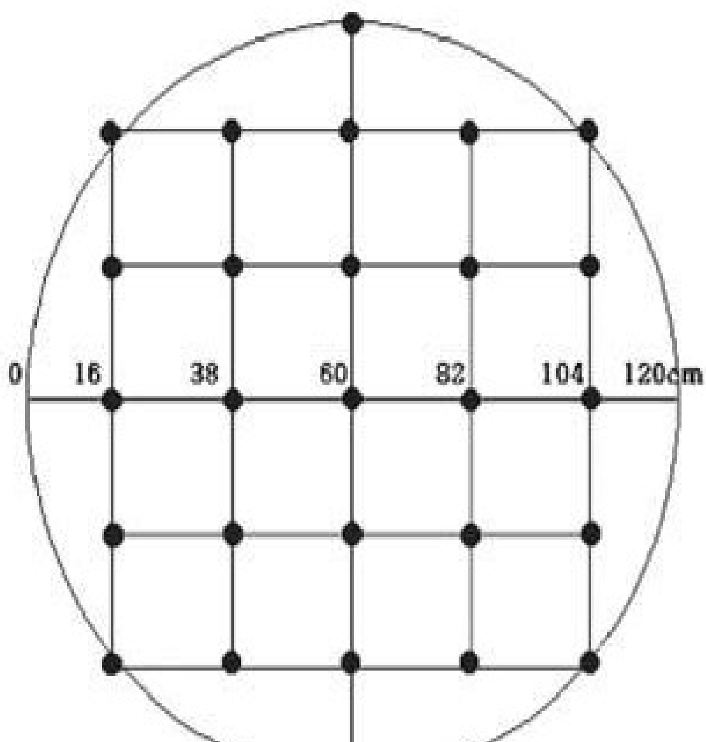
Hence, remedial action must be taken when being confronted with unsatisfactory effluent from the sedimentation tank(s), leading to solid matter overloading of the filters. **See pictures on pages 11 and 15.**

A clear example of mudballs in the media



Example of a hydraulic ram to provide the necessary pressure for rapid mixing and dispersing of the coagulant in the total body of raw water'





1.2 Dosing Proportional to Flow

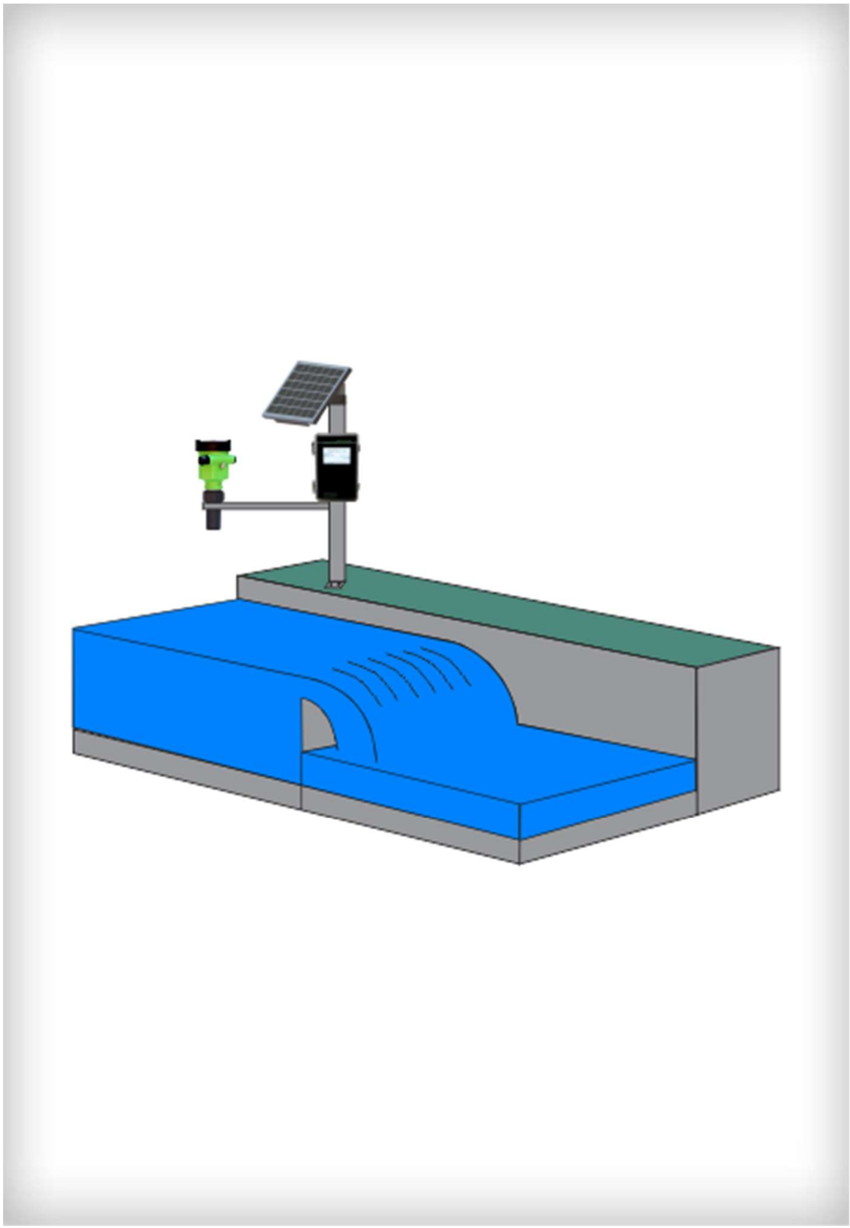
Removal of suspended and colloidal material from water requires the application of inorganic or organic coagulants for destabilization and subsequent flocculation and separation. To minimise the use of coagulants and to reduce the sludge volumes this unit operation requires optimized dosing control.

When looking at charge neutralization and sweep coagulation as the two main destabilization mechanisms, charge effects only play a minor role in the latter case. In many water treatment plants, however, charge neutralization can be considered the predominant process, especially if the coagulant dose has been optimized.

The use of a flow proportional dosing system consists of:

1. A metering device such as open channel ultrasonic flow meter
2. Pulsed input signal
3. Dosing pump proportional to 4-20mA input
4. Solar pannel to provide power to the flow meter and dosing pump in situations where no direct power from an electrical grid system is available
5. Associated pipe work

See an example of an open channel ultrasonic flow measurement that can provide a pulsed signal to a dosing pump powered by a solar pannel on page 18.



Open channel ultrasonic flow measurement set

These kind of flow meters enable the instantaneous flow and total flow to be obtained from the fluid level in conditioned channels (channels with flume/weir structure). It can be used in many flumes such as rectangular flume, U flume, Parshall flume, V-Notch and Cipolletti. An open channel ultrasonic flow measurement set consist of ultrasonic level sensor, flow control & recording device.

The following technical specifications for a flow proportional dosing system are recommended:

Measurement range	0,25...5 meters in liquids
Accuracy	±10 mm
Process connection	Threaded, G1½ A or 1½ NPT
Process pressure	-0,2 … 1 bar
Process temperature	-40...70 °C
Operating voltage	14…. 36 V DC (optional 220V AC)

Flow Measurement and Control Device

Language	English
Display	Touchscreen 4,3" TFT display
Data Record	SD card
Analog Input Signal	2 pcs. 4...20mA
Analog Output Signal	2 pcs. 4...20mA
Alarm Output	4 pcs. Relay (5A 250V)
Digital Input	1 pc. Pulse (12-30V DC)
Digital Output	2 pcs. Pulse (24V DC Max. 100mA)
Connection	RS485 MODBUS
Supply	12....30V DC
Power Consumption	Max.6W
Protection Class	IP67
Cable Input	PG11
Dimensions	160x240x53mm
Material	ABS
Seal	Silicone
Temperature	-20...60C
Humidity	<95%

2 Backwash efficiency-AVG Filter Hydraulics

2.1 Water-only backwash

Water-only backwash is likely to be insufficient to prevent the formation and accumulation of mudballs. However, for raw water turbidity's of < 5 NTU, partially mud-balled filters are able to operate for extended periods of time (studies have shown approximately for one year) without operator intervention (except coagulant dosing) and without any detectable decline in filter performance.

No valve adjustment is required to maintain a constant filtration rate. This is a significant advantage with respect to plant monitoring requirements. Backwash velocities are controlled by the head in the backwash tank and the head-losses in the pipes, nozzles and media. The maximum backwash rate is determined by the height of the backwash tank above the media compartment. Backwash rate (during backwashing) decreases relative to the level in the backwash tank and frictional losses in the pipes.

2.2 Media selection

It is imperative that the media selection is compatible with the available backwash rates for a given filter. Dual media filters have the advantage of longer run times with less risk of breakthrough at higher influent turbidity’s than mono-media sand filters. At low turbidity’s anthracite is more susceptible to mud-balling than sand, however the mud-balling is most likely entirely restricted to the anthracite layer in dual-media filters whereas the mudballs in the mono-media filters gradually move down towards the filter floor. Therefore, it may be easier to manage mudballs in dual-media filters. Increasing the fraction of sand in dual media filters delays turbidity breakthrough and shortens the run time.

2.3 Terminal head-loss

The AVGF hydraulic design usually sets the terminal head-loss for the initiation of backwash, at 1.5 m. See picture on page 21.

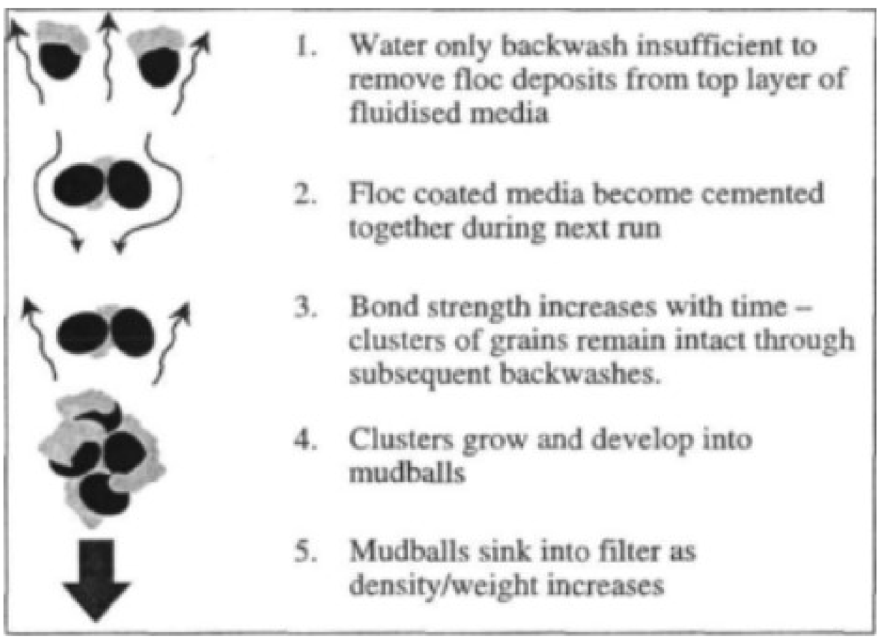
This fixed terminal head-loss can contribute to accumulation of solids in the filter, that may result in turbidity breakthrough for raw water turbidity's greater than 16 NTU. Under low raw water conditions, excessive long filter run times (>60 hours) can be experienced.

2.4 Backwash volumes

The actual backwash volume of one of the AVGF evaluated is 2,4 m^3/m^2 which is significantly less than the minimum recommended in the literature. Effective backwash volume, will range from 2,8 to 3,1 m^3/m^2 for mono media filters and 3.0 to 3,6 m^3/m^2 for dual media filters.

2.5 Mud-balling

Mud-balling is a common occurrence during the operation of the AVGF. The extent of mud-balling and their location in the filter depended, to a large extent, on the filter media (dual or mono media), coagulant type and dose (inorganic or organic).



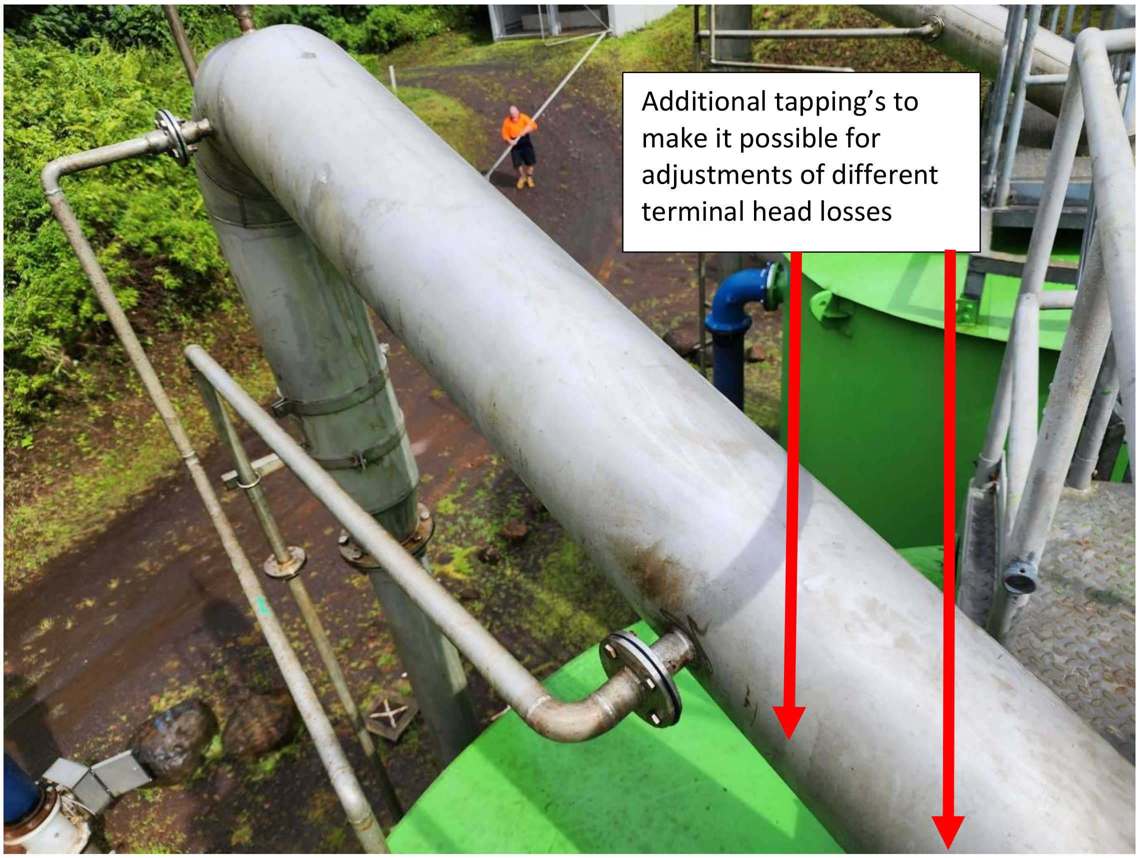
Mechanism of mudball formation

3.0 Design considerations

After analysing the components and dimensions of the AVGF some modification to the design and other considerations for design are suggested. Implementation of these suggestions will be influenced by cost and other factors like raw water variability, infrastructure, readily available technically competent operators.

Here, the more practical recommendations are presented:

- It is possible to provide facilities for manual auxiliary backwash and air scour.
- Additional tapping's on the backwash pipe for adjustments to the terminal head-loss.



- Dual media provides more protection against premature turbidity breakthrough at high raw water turbidity's (> 15NTU) than mono-media filters.
- The volume of backwash water required is at least 3. 1 m^3/m^2 for mono-media filters and 3.6 m^3/m^2 for dual media (anthracite/sand) filters.
- Filter nozzle density should be at least 50 nozzles/m^2.
- Greater emphasis should be placed on ensuring that the material of construction of the filter should be corrosion resistant. This is most critical to the internals of the filter, where rust and scale deposits contaminate the final water and may also block the nozzles. Although mild steel may be preferred for its strength

and cost, suitable coating of the insides with a corrosion resistant material should be considered.

- Due the inherent inadequacy of the 'water only' backwashing system, mudball formation and associated operating problems, will require more frequent access to the filter media. Filter media handling during loading of fresh media, inspection and removal of spent media can be significantly improved by increasing the size of the manholes. A thicker and more durable rubber gasket should be used to provide a better seal without damaging the nuts and bolts through excessive tightening.
- To increase the efficiency of backwashing and thus reduce mud-balling, the use of air scour is recommended. See Appendix 1.

4.0 Technical/Operational considerations:

Extensive experience in the USA has shown that high-rate water wash alone is generally successful in filters which remove iron from groundwater or remove colour from otherwise high-quality waters (Martin, 1998). However, it is generally inadequate for filters removing large amounts of suspended solids or using polymers. Kawamura (2001) states that water backwash without auxiliary wash cannot maintain filter beds in a reasonably clean condition for longer than several months if coagulants are used. Water only backwash without some form of auxiliary backwash is now seldom if ever employed in modern treatment plants (Haarhoff, 1997).

Note: According to information supplied by the operators the media at one of the Te Mato Vai Water Treatment Plant AVG filters had to be replaced after 8 months of use due to the excessive amount of solid matter (mud balls) in the media.

4.1 Up-flow water wash with air scour

Air scour systems supply air to the full area of the filter from orifices under the filter medium (Cleasby, 1990). Air scour has been used alone (consecutive air and water wash) or together with low-rate water backwash in an unexpanded or slightly expanded bed (simultaneous air and water wash). Both types of air scour have been found to be very effective in preventing filter mud-balling (Martin, 1998). When consecutive air and water is used, most of the scouring occurs near the bed surface. Agitation deeper in the bed is only observed in the first minute or so while discrete air bubbles move through the mixture of water and sand in the bed. Gradual displacement of water from the pore spaces results in compaction of the bed and the formation of fixed channels through which air travels directly to the bed surface (Haarhoff and Mai an, 1983). As a result, the system is not very effective in cleaning the lower sections of the filter bed and there have been a few cases of significant mud accumulation in the lower regions of filters using air scour (Kawamura, 2001). By contrast, simultaneous air and water flows in the correct ratios results in the formation and collapse of pockets of air throughout the filter bed, or "collapse pulsing" of the filter bed (Amirtharajah, 1993). This has been established as the most effective filter cleaning method as it produces the greatest amount of abrasion between the media grains throughout the depth of the bed. Air scour alone followed by low-rate water wash is typically used in mono-media filters with 0.6 to 1.2 mm effective size media (Martin, 1998). Air scour alone followed by high-rate water backwash is used in dual and multimedia filters. Simultaneous air and water wash is usually reserved for deep bed coarse grained filters (effective size 1 - 2 mm)

4.2 Criteria for initiating a backwash

Filters should be backwashed as soon as any of the following occur (Haarhoff, 1997) 21

1. terminal head-loss is reached.

2. filtrate turbidity deteriorates beyond an acceptable limit.

3. filter run length exceeds an acceptable limit.

For the AVGF, backwash on terminal head-loss is built into the design but the need to comply with the other criteria must also be taken into account.

4.3 Problems resulting from inadequate filter washing

Mud-balling is a common filter problem associated with inadequate backwash. Mudballs are composed of filter grains and solids removed by the filter compacted together. See mechanism of mudball formation on page 22. Inadequate cleaning leaves a thin layer of compressible mud around each media grain (Cleasby, 1990). As the pressure drop in the filter increases during filtration, the coated grains are squeezed together, sometimes resulting in cracks in the bed surface, usually close to the walls. This can result in short circuiting of the treated water and deterioration of the filtrate quality (Martin, 1998). Each time the filter is washed the particles of mud become more compact and build up in the filter bed forming greater masses (Baylis, 1954). According to Cleasby (1990), mudballs are formed when heavier deposits of solids near the surface of the sand breaks into pieces during backwashing. These can range in size from pea size to 2.5 - 5 cm or more. Baylis (1954) reported that mudballs when newly formed tend to remain at or near the surface of the bed after washing. Eventually they attain a specific gravity great enough to cause them to sink to the bottom of the sand bed during washing or to the sand - anthracite interface in dual media filters (Martin, 1998). The presence of the impermeable sub-surface regions increases the filtration rate through the remaining active portion of the filter bed with potential detriment to filtered water quality. They may also result in higher rates of head-loss development (Cleasby, 1990). Mudball problems are more like to occur when polymers are used as coagulants or filter aids which increase the attachment forces between filter grains and deposited floc (Cleasby, 1990). Finer media also appears to more prone to mud-balling than coarser media. Kawamura (1975a) found that ten times as much mud accumulated in 0.45 mm effective size filters compared to 0.72 mm sand filters over a period of 4 years. The two sets of filters were operated under the same conditions and backwashed at the same rates over the study period. The sand grains encapsulated in mudballs found in the upper regions of the filters were found to be mostly much smaller than the effective size of the sand bed. Kawamura therefore suggested that the fine fraction of filter media forms the core of small mudballs which gradually grow into much larger masses if backwash is inadequate. Air scour and surface wash can prevent the formation of mudballs, but previously formed mudballs have to be removed by hand or broken down by soaking in acidic solution (Martin, 1998)

4.4 Assessing the efficiency of backwash

Most plant operators evaluate filter performance based on the quality of the filtered water and filter run length under certain operating conditions. This method does not provide a complete picture of filter conditions (Kawamura, 2001).

Visual inspections and core sampling are difficult for many package plant type filters including pressure filters and AVGF's where the filter media is contained in a pressurized shell. Regular inspection may be possible, but often the media has to be completely removed and replaced with clean media if adverse plant operation is observed. The efficiency of wash water usage can be assessed by measuring the backwash turbidity profile (backwash turbidity as a function of backwash time). A relatively low, flat backwash turbidity profile is indicative of ineffective backwashing while a high, sharp turbidity peak indicates is characteristic of effective washing (Kawamura, 2000). Kawamura recommends termination of backwash when the turbidity drops to 15 to 10 NTU as further washing will waste water and can also negatively impact filtrate quality at the beginning of the next run by leaving the filter media too clean; the so-called ripening process.

5.0 Autonomous valveless gravity filters

Valveless filters are generally proprietary designs and there is very little information about their design criteria in the literature. The designers and suppliers of AVGF's claim the following advantages:

- regular backwash of the sand filters on terminal head loss,
- backwash pumps and electronic control systems for filter control are not required,

• operator intervention is not required (to initiate or control backwash),

• the declining backwash rate results in good re-stratification of the media,

• turbidity breakthrough is unlikely due to the low head loss permitted, and

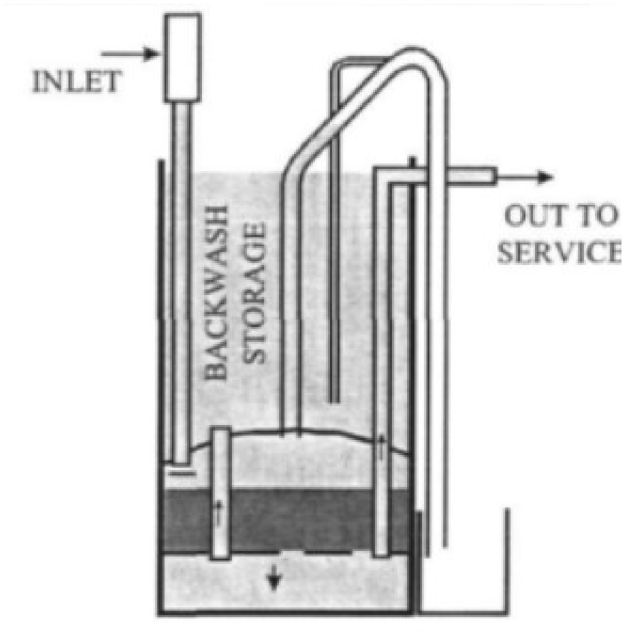
• after a backwash, the initial volume of poor-quality filtrate goes to the backwash reservoir rather than to service (i.e., built-in filter to waste).

The major disadvantages of AVGF's are that backwashing of sand filters using water alone is a relatively weak cleaning process (as discussed before) and that, as with other rapid filters, coagulant is generally required to achieve filtered turbidity's of < 1 NTU

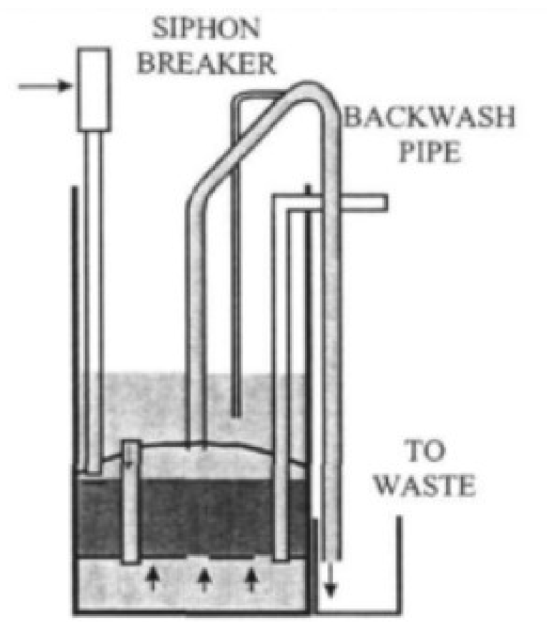
The "Autonomous valveless gravity filter" (AVGF), has the potential to ensure more reliable operation with less operator intervention than many other types of filters. The AVGF is unique in that backwash is initiated automatically without instrumentation, valves or electronic controls once a specific head loss across the media has been reached.

6.0 Operation

The raw water enters the filter-bed compartment just above the bed. It flows downward through the sand and filter nozzles into the collector chamber and upward through the effluent duct and out to service. See picture page 29.



Filtering



Backwashing

As the filter-bed collects dirt during the filter run, the head loss increases, and the water level slowly rises in the inlet pipe and in the backwash pipe. Just before the water reaches the top of the U bend, water flows through a subsidiary pipe and discharges through a venturi into the effluent tank. This creates a suction which evacuates the air from the large downward leg of the backwash pipe. This action draws the water over the U bend, initiating backwash. The backwash pipe carries approximately four times as much water as the inlet pipe. The siphoning effect causes the water to be drawn from the backwash storage chamber down through the ducts into the collection chamber, from whence it rises upwards through the strainers or nozzles, the sand bed, and the filter compartment into the backwash pipe. (Figure backwashing). The backwash action continues until the level of the water in the backwash storage space drops below the end of the siphon breaker. This admits air to the top of the backwash pipe, and backwashing stops. The inlet water resumes its downward gravity flow automatically, flushing some of the remaining detached floc out of the media and into the underdrain. Consequently, the filtrate quality directly after backwashing is typically poor compared to the rest of the run and may not meet finished water turbidity standards. In the AVGF, the filtrate cannot go out to service until the backwash tank is full which means that the initial volume of poor-quality water is diverted to and stored in the backwash tank for use in the next backwash. Hence, a filter-to-waste period equivalent to the volume of the backwash tank is inherent in the design of the AVGF.

Backwash can also be initiated manually by running water directly from the backwash tank into the venturi. The suction generated evacuates the air from the backwash pipe to establish the siphon between the filter compartment and the effluent tank.

Note: It may be possible that the process of filtering to waste can be extended by increasing the height of the filtrate outlet, thereby artificially increasing the volume of the backwash water storage.

7.0 Proposed modifications for viewing backwashing

- A window/sight glass could be installed in the side of filter bed so that the state of the filter bed could be viewed during backwashing. This allows for, the height of the bed and the point at which it began to expand during backwashing can be viewed.
- A calibrated sight glass on the backwash tank allows for the measurement of the rate at which the level drops during backwash. These measurements can be used to calculate the backwash rates.

- A filter head loss site tube could be installed which will indicate the amount of increase in head loss over time.

8.0 Filter nozzles

It is important to investigate the number of nozzles per m^2.

At least 50 nozzles per m^2 is recommended in its design as poor flow distribution and dead zones between nozzles may promote mud balling.

It is possible that the original nozzles used in the AVGF are quite large which would to some extent compensate for the low number density.

Note: When replacing the existing nozzles particular care is needed to compensate for possible head loss across the underdrain to match the original nozzles (taken into account the increase in number of nozzles).

8.1 Media specification

The use of media needs to be compatible with the available backwash rates in the AVGF.

Design considerations for mono and dual media filters are summarised in the table below and next page.

	Pilot-scale filters				AVGF
	0,5 mm sand	0,7 mm sand	0,7 mm sand with sand added	0,8 mm sand	0,8 - 0,9 mm sand
Mass of media	22,5 kg	22,5 kg	27,5 kg	22,5 kg	800 – 1000 kg
Bed height	0,51 m	0,52 m	0,64 m	0,54 m	~0,6 m
Minimum fluidisation velocity, Vmf (20 °C)	21 m/h	31 m/h	31 m/h	53 m/h	53 m/h*
Fluidised bed headloss, Δh_{media}	0,42 m	0,42 m	0,51 m	0,51 m	0,46 m (assumed)
Contactor area, ΣA (**Equ 2.6**) m^2/m^2	2405	2065	2523	1561	
l/d, (**Section 2.1.2**)	962	722	882	635	

Mono Media Filter Bed Specification

		Pilot-scale filters				AVGF
		DM#1	DM#2	DM#3	DM#4	Dual Media
Media sizes	Sand Anthracite	0,5 mm 1,1 mm		0,5 mm 0,9 mm		
Media mass	Sand Anthracite	17,5 kg 5,1 kg	22,5 kg 1,9 kg	17 kg 3,1 kg	17 kg 3,1 kg	600 kg 110 kg
Bed height	Sand Anthracite	0,39 m 0,23 m	0,51 m 0,08 m	0,41 m 0,12 m		
Minimum fluidisation velocity, Vmf (20°C)						
Fluidised bed headloss, Δh_{media}		0,37 m	0,46 m	0,34 m		
Contactor area, ΣA (**Eqn 2.7**) m^2/m^2		2359	2597	2204		
l/d_e (**Section 2.1.2**)		943	1034	905		

Dual Media Filter Bed Specification

9.0 Autonomous valves gravity filter hydraulics

The initiation, intensity and duration of backwashing in the AVGF is completely dependent on its hydraulic design. Failure or improper specification of any of the hydraulic components will severely compromise the filter operation. **Backwash velocities have to be adequate to achieve fluidisation of the filter media.** A detailed investigation into the filter hydraulics with emphasis on backwash is strongly recommended. This will provide a number of important insights into the operation of the filter and its limitations, and will most likely lead to a number of recommendations for the design and operation of the existing AVGF's. A hydraulic model could be developed in the course of this investigation which will make it possible to predict the effect of various design changes on the filter operation.

Note: If the AVGF cannot operate indefinitely without intervention to restore the filter bed to an acceptable state then the feasibility of this process may depend on the nature and frequency of the intervention required to maintain satisfactory performance.

9.1 Backwashing

Cleaning of the filter during backwashing can be conceptually broken up into two steps:

1. Detachment of floc from the media, and
2. Flushing of the detached material out of the filter and transport to the backwash trough or backwash pipe.

Ideally, the floc should be instantaneously detached as backwash is initiated and the resulting mobilised sludge be washed out in plug flow. In practice the volume of water required for effective cleaning is increased by a number of factors:

- Most detachment of floc occurs within the first few seconds of backwash at properly designed backwash rates; however, it is not entirely instantaneous. The lower the backwash rate, the slower the breakdown of the floc-media composite.
- Uneven velocity distribution within the media and the freeboard below the backwash trough/pipe results in dispersion and back mixing.

The volume of wash water required to flush the bulk of the detached floc out of the bed is the fraction of the total wash water which is effectively cleaning the media. An additional volume increment is required to flush the floc into the backwash trough/pipe to ensure it is permanently removed from the filter.

If the backwash is stopped too soon, the media may still be dirty and detached floc, which has not yet been flushed out will settle back onto the bed as a layer of sludge which gels within minutes. Fluid shear above the media is much less than within the media and the sludge layer cannot be flushed out of the filter without auxiliary backwash to break it up. However, washing filters for too long, wastes wash water and tends to increase filtrate turbidity at the beginning of the next run and prolong filter ripening.

The optimum backwash volume can be determined by analysing the filter backwash turbidity as a function of backwash duration. Grab samples of backwash turbidity can be collected during backwashing. The raw water feed should be turned off during backwashing for these experiments. The results can be analysed to determine the efficiency of backwash water use in terms of both detaching floc from the media and flushing it out of the filter. Effective backwash can be assumed to have ceased when the backwash turbidity drops below 10 NTU. This is based on Kawamura's recommendations (Kawamura, 2000) for determining when to terminate backwash. It must be noted however, that low turbidity backwash effluent does not necessarily imply a clean filter bed. In particular, the declining backwash rate means that the last remaining filter deposits, which are obviously the most difficult to remove, will face declining shear forces resulting in declining detachment rates. Kawamura's recommendations for optimum backwash rates are based on a theoretical analysis of the maximum cleaning action on the average grain size (d^). However, the bulk of floc removal during filtration occurs in the upper layers of the filter bed where the finest grain sizes are found. Furthermore, studies have shown and others reported in the literature (Kawamura, 1975a) suggest that the finer grain sizes play a major role in mudball formation. Therefore, it is possible that backwash efficiency may not be significantly impacted if backwash velocity towards the end of backwashing drops below the optimum backwash rate or even the minimum fluidisation velocity for the average grain size provided that conditions remain close to optimal for the finest grain sizes.

Based on studies performed, the effective backwash volume appears to depend mainly on the amount and strength of (detachable) floc in the bed and the type of the filter bed.

The same studies observed that the maximum effective backwash volumes are estimated to be 3,1 m^3/m^2 for mono media and 3,6 $m^3/m^2$for dual media for higher influent turbidity's.

10.0 Recommended design parameters

10.1 Media selection

The use of dual media has significant advantages over the use of mono-media especially at influent turbidity's > 15 NTU.

10.2 Terminal head loss

The terminal head loss could be decreased.

For example, setting the terminal head loss at 1.0 m would decrease the risk of breakthrough in the filters. Decreasing the terminal head loss also reduces the run time. This would be an advantage at low alum doses and low coagulated water turbidity's.

In order to maintain filter performance over a broad range of raw water turbidity's and coagulant doses whilst ensuring that the filter backwashes regularly, it is desirable to be able to adjust the terminal head loss as required. The position at which the self-actuating primer system connects to the backwash pipe determines the head loss at which the filter backwashes. Multiple ports on the backwash pipe with individual isolation valves could be installed to provide this flexibility. Decisions to adjust the terminal head loss could only be made by skilled personnel and should be based on breakthrough and run time data collected on site.

10.3 Backwash rates and volume

It may be possible to increase the efficiency of backwashing by increasing the volume and rate of backwash **by extending the filtrate outlet**, i.e., increase the height of the outlet.

Design recommendations are for 3 m^3/m^2: to 4 m^3/m^2 of volume of backwash to be available for which the media in the filter is fluidised, as a function of the minimum fluidisation velocity. The rate of backwash is governed by the head available for backwashing, which is determined by the instantaneous level in the backwash tank, the friction losses in the pipes, nozzles and filter media as well as the head required for acceleration of the fluid and the media.

Most of the head loss during backwashing occurs in the pipes and appurtenances and in particular in the backwash pipe itself. The backwash rates can therefore be increased by either increasing the available head or decreasing the head losses in the backwash pipe (by increasing the pipe diameter).

Note: A potentially serious disadvantage, is that the wash rates towards the end of backwash are too low to affect solids removal and some portion of the wash water is essentially wasted. Increasing the minimum backwash rate would, however, require an increase in available head which implies extending the height of the filtrate outlet or failing that a larger and more expensive filter.

10.4 Options for auxiliary backwash

Using occasional auxiliary backwash to supplement routine autonomous backwash may slow down the deterioration of the filter bed due to mud balling although it may not be able to breakdown existing mudballs (Martin, 1998). Air scour can be introduced in the system. This arrangement will make it necessary to install air distributing piping on top of the filter floor between the nozzles. See Appendix 1 for some more explanation.

Any auxiliary backwash procedures will have to be carried out by skilled personnel on a fixed schedule e.g., once a week or once a month. The frequency of auxiliary backwash required to arrest deterioration of the filter bed needs investigation. The cost of such a strategy would have to be compared to other cleaning options e.g., chemical cleaning or more frequent media replacement.

11.0 Technical guidelines

11.1 Backwash cycle

When the maximum head loss is reached, the filter backwash is initiated automatically.

It is recommended that a visual inspection immediately after a backwash be performed, through a site glass which should be installed on the filter.

This is important to indicate whether there is a presence of sludge on the surface of the media.

As the backwash is initiated by the terminal head loss, fixed by the design, the operator has no control in setting the backwash frequency. However, the operator can manually initiate a backwash by opening a valve on a pipe connecting the backwash tank to the venturi. The length of time it takes to initiate manual backwash depends on how far the filter is from reaching terminal head loss. A visual indication that the filter is close to terminal head loss, is an increase in the water level in the effluent tank and the steady stream of bubbles from the venturi. Large air bubbles are periodically forced out from the backwash pipe due to the increasing water level in the pipe throughout the filter operation. This does not indicate imminent backwash.

11.2 Filter media

Studies showed that there is a significant difference in mudball distribution in the mono-media and the dual media. Mud balling does not generally extend beyond the sand/anthracite interface, while in mono media mud balling is likely to extend all the way down to the filter nozzles.

11.3 Variable raw water quality

One of the main challenges of the coagulation-flocculation process is coping with changing raw water turbidity's, namely solid matter. Overdosing with alum is more forgiving (with respect to filtered turbidity) than underdosing but in the long term, excess solids in the filter generated by high doses of alum, result in shorter run times and poor water recoveries.

Note: raw water turbidity greater than 15NTU is not suitable for treatment by the AVGF.

11.4 Coagulant type

The use of polymeric organic coagulants is not recommended and will more than likely result in rapid and irreversible solids accumulation in the filter media. The available backwash volume and rate provided is ineffective in removing the solids which will rapidly form into large mudballs at various sections at the bottom of the filter.

Inorganic coagulants, particularly alum will produce more favourable results than organic coagulants.

11.5 Coagulant dose control

For optimum operation of the filter, the coagulant dose will require frequent monitoring, especially during times of high variability in raw water turbidity. More importantly it needs a very efficient coagulation-flocculation process as described earlier in this technical brief.

12.0 Operating guidelines

- The dosing system should be regularly checked and cleaned to remove precipitates, grit etc.,
- Operators need to be trained to adjust the coagulant dose when the filtrate turbidity falls outside certain limits. If there is a substantial delay before a dose change is reflected in the filtrate quality, then jar tests should be conducted.
- The filtrate quality should be checked at least once daily and the operator should ensure that the filter backwashes once a day. He or she can easily check whether the filter has backwashed since their previous visit by sprinkling sand on the weir of the effluent tank. The sand will be washed away when the filter backwashes.
- If sedimentation is used, the plant should be operated to maintain a filter influent turbidity of well below <15NTU.
- Adjustments to the terminal head loss should only be made by skilled personnel. Local operators may be trained to conduct manual backwashes if the filters do not backwash at least once a day and should advise their supervisors when this occurs.
- The backwash rates and/or duration should be checked every few months. Low rates and prolonged backwash durations indicate potential blockages or other hydraulic problems.

13.0 Part 1 to be concluded

The most important quality criteria for drinking water are its bacteriological quality. However, improvement of TVV's produced bacteriological water quality is greatly depending on its efficiency of the pre-treatment processes, i.e., coagulation-flocculation as well as on its treatment units, which is sedimentation and filtration.

Properly operated backwash processes can significantly reduce the risk of disease-causing organisms (pathogens) passing through the filter and entering the distribution system.

Filtration is used as the final clarifying step in the treatment process and plays a key role for bacteriological water quality improvement. Hence, a failure of this system can cause a major deficiency in the overall multiple barrier water treatment concept.

Operational experience clearly indicates that inadequate operation of these processes and its inability in reducing turbidity peaks, with the consequences of supplying poor water quality to the AVGF filters are the main reasons for the problems and failures experienced at TVV's WTP's.

The result is the production of water of erratic quality which is often unsafe for consumption with regards to its bacteriological quality.

Coagulants are extensively used in TVV's conventional water treatment systems.

This process is dependent on careful implementation of the correct coagulation-flocculation process to produce settleable flocs. These flocs (solids) then settle under laminar flow conditions to the tank bottom of the sedimentation tank, and the clarified water is abstracted uniformly over the full width on the opposite side of the tank.

The flocculation/sedimentation process is an advanced treatment technique requiring qualified personnel and above all well-equipped facilities, i.e., the necessary means of flow control equipment. Flow control equipment proved to be not existent and as a consequence the treatment facilities were not able to adapt to the varying raw water quality. Hence, producing poor clarified water overloading the downstream AVGF filtration units during higher turbidity events.

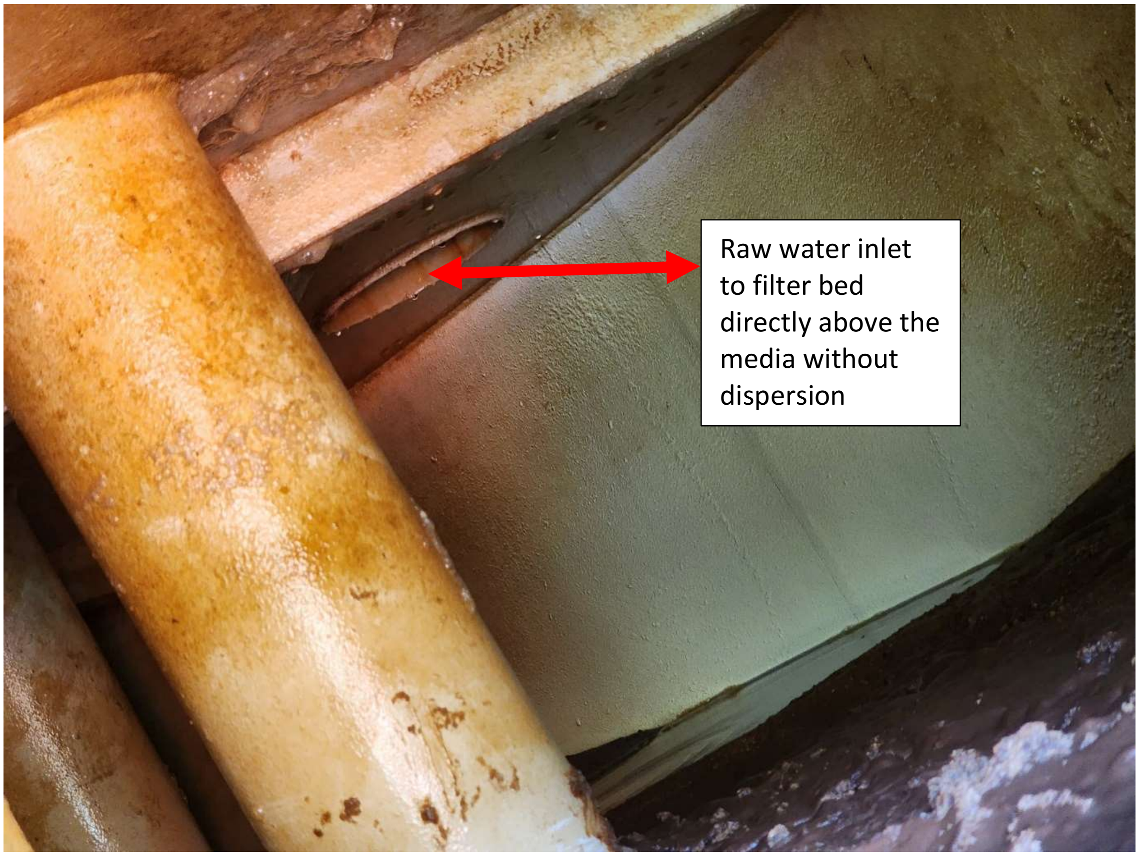
The filter media specification will also impact greatly on final water production and sustainable water quality. Also very important is the compatibility of the selected filter media with the available backwash rates, and volume. Operating experience indicates that AVGF requires air-assisted backwash on at least a weekly basis.

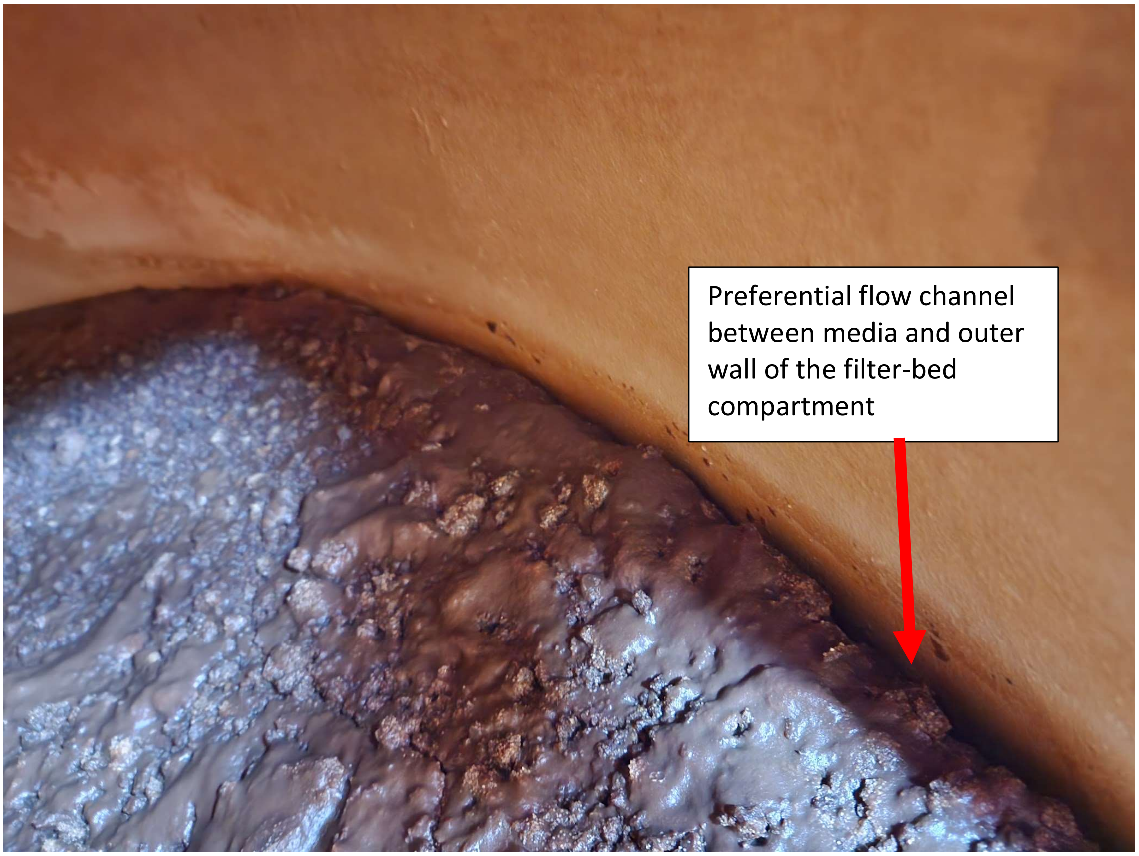
While the operator may not be expected to spend the whole day on site attending to the plant, he will need to ensure that chemical dosing and regular backwashing of the filter is taking place and that water quality and supply expectations are met through an appropriate monitoring programme.

Recommendations:

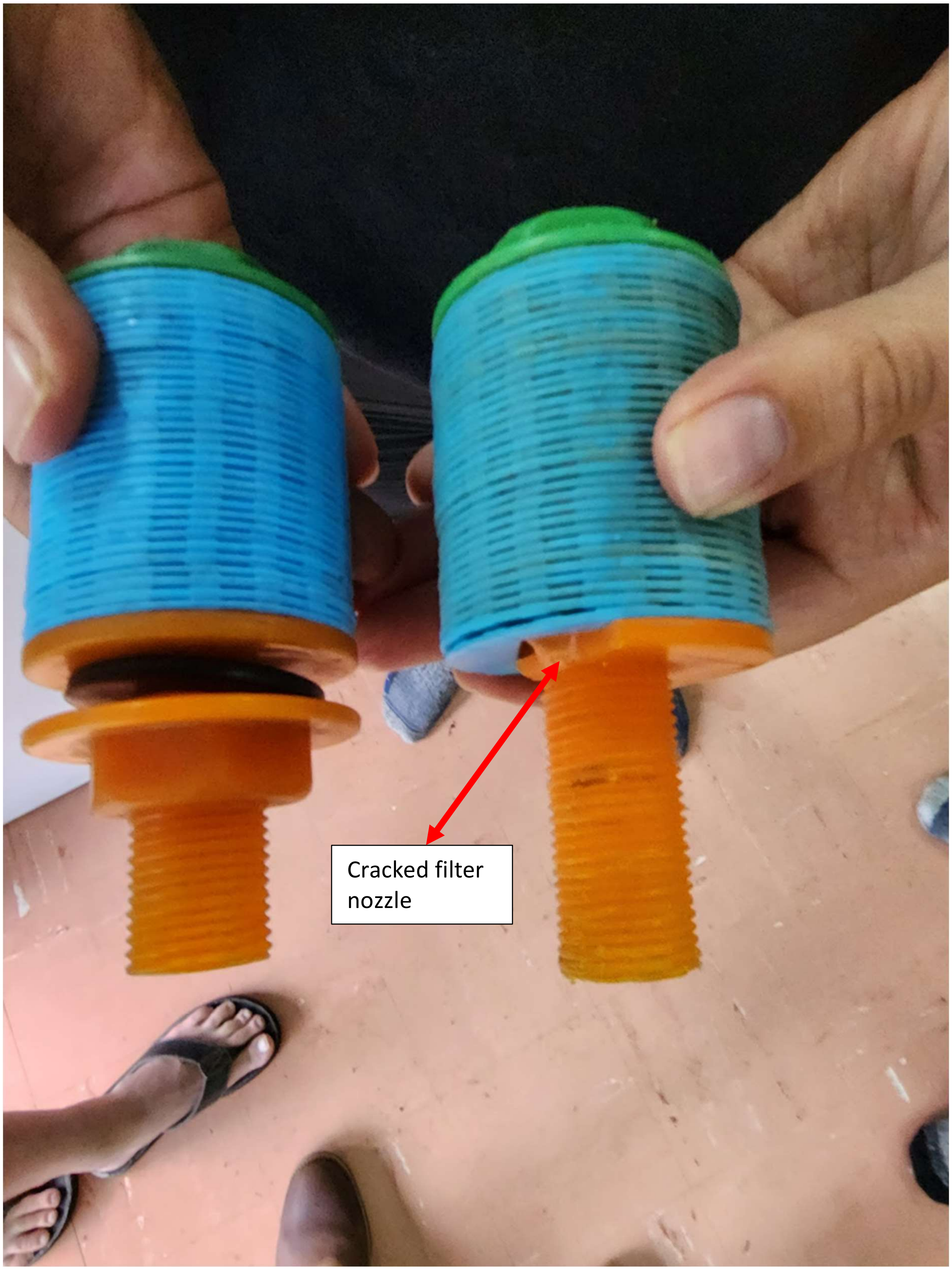
1. **Implement the ability of proportional flow dosing adjustments.**
2. **Implement the mechanism of rapid mixing of the coagulant.**
3. **Implement air-assisted backwash. Refer to Appendix 1. A full technical design brief is not part of this technical brief.**
4. **Reinstate vent to atmosphere on the head tank as per as build.**
5. **Implement additional tapping's (below the existing tapping) on the backwash water riser to be able to make adjustments for different terminal head loss backwashing. Say at 1- and 1.25m.**
6. **If feasible, implement the increase of backwash water storage volume'**
7. **Implement the installation of a deflector plate under the raw water inlet to the filter bed. Refer to picture on page 43.**

8. **If feasible, use the existing Bermad valve at the raw water inlet to the filter(s) as an inrush limiter, thereby creating a slow start procedure. See page 45.**
9. **Implement the installation of a "lip" along the circumference of the filter-bed compartment (well below the sand bed) to create an artificial grooved surface to prevent preferential flow along the filter bed and outer wall. Refer to picture on page 44.**
10. **Inspect and replace faulty nozzles of all filters and implement the right procedure of the installation of these nozzles. It appears that the right torque has not been applied while mounting the nozzles. Refer to picture on page 46.**
11. **Backwash velocities have to be adequate to achieve fluidisation of the filter media. At the time of the site visit this could not be established. This needs some further investigation.**
12. **Install a window/sight glass on the side of the filter bed.**
13. **Install a calibrated sight glass on the backwash tank.**
14. **Install a filter head loss site tube.**


Raw water inlet to filter bed directly above the media without dispersion


Preferential flow channel between media and outer wall of the filter-bed compartment


Bermad valve at inlet to the AVG Filter


Cracked filter
nozzle

Part 2

1.0 General Aspects of Solid Matter Separation

Chemical coagulation and flocculation in conjunction with sedimentation for solid matter separation is generally the first step applied as surface water treatment.
Flowing surface water as encountered in Rarotonga is often subjected to drastic quantitative and qualitative changes. The annual rainfall distribution influences the seasonal surface water fluctuation mainly with regard to turbidity and solids concentration. Flowing surface water will usually carry settleable solids at varying concentrations during different periods of time. **During the dry season, small upland streams/rivers are generally low in turbidity, however, they can exhibit *high short term* turbidity peaks during heavy rainfalls.** **See picture page 47 ,** **which shows the intake of one of the water supply schemes exhibiting just such a turbidity peak.**

The water quality of surface waters can be significantly improved during these short-term turbidity peaks when filtered through gravel and sand layers.

As can be seen from the picture above a small weir/dam has been installed in the water course and functions at one of the Te Mato Vai WTP's intake to raise the water depth and to reduce the flow velocity. The consequence of this weir/dam is that the upstream side of the dam is silting up by the easily settleable solids. Small pebbles or sand particles will undoubtedly settle in the artificially created still water zone in front of the dam.
The coarse floating matter is retained by a Johnson screen placed over the intake situated just past the dam. This fixed coarse screen is most commonly used to avoid blockage and excessive head losses. This course screen, however, does not prevent the retaining of fine particles/solids which are difficult to remove in treatment processes.

Intake- and dynamic filters are often used as first pre-treatment step in the form of prefiltration.

Prefiltration is not only a simple, efficient and chemical-free alternative treatment process applied mainly for solid matter separation, it also improves the microbiological water quality.

These kinds of “filters” are currently used extensively in water supply schemes in numerous developing countries and also in artificial groundwater recharge plants in industrialised countries. Practical experience shows that intake filters are capable of reducing the solid matter content by 50 -70 %.

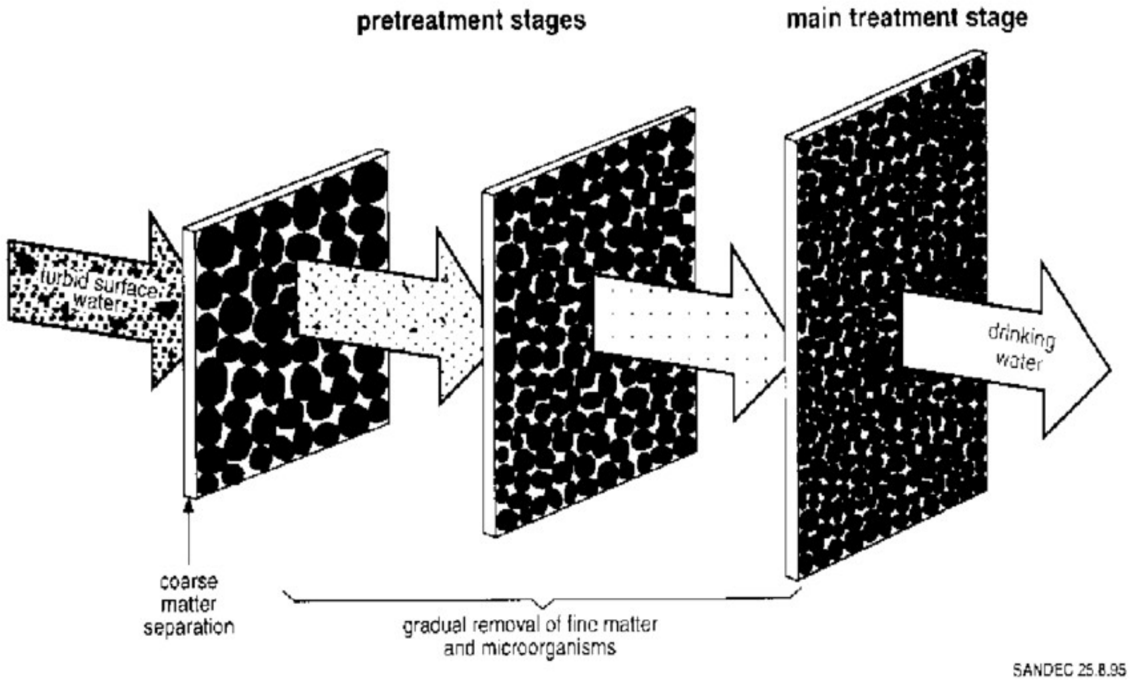
However, stable suspensions with a large amount of colloidal matter are difficult to treat with these kinds of filters and still require the addition of coagulation, flocculation, sedimentation and filtration process units.

Against this background I consider the choice of the Te Mato Vai water treatment process units as a sound treatment engineering solution as is earlier mentioned in the Abstract of this technical brief.

Study results shows that roughing filtration, intake filters or dynamic filters may be considered as efficient pre-treatment process in case surface water is used as water supply. Gravel and sand used as filter media are key components in natural treatment processes.
The filter material should have a large specific surface to enhance the sedimentation process taking place in these filters and high porosity to allow the accumulation of the separated solids. Generally speaking, any inert, clean and insoluble material can be used as filter medium. Filtration tests revealed that neither the roughness nor the shape or structure of the filter material have a great influence on filter efficiency. The following material could therefore be used as filter media:

a) Gravel from a river bed or from the ground.
b) Broken stones or rocks from a quarry.

c) Broken burnt clay bricks.

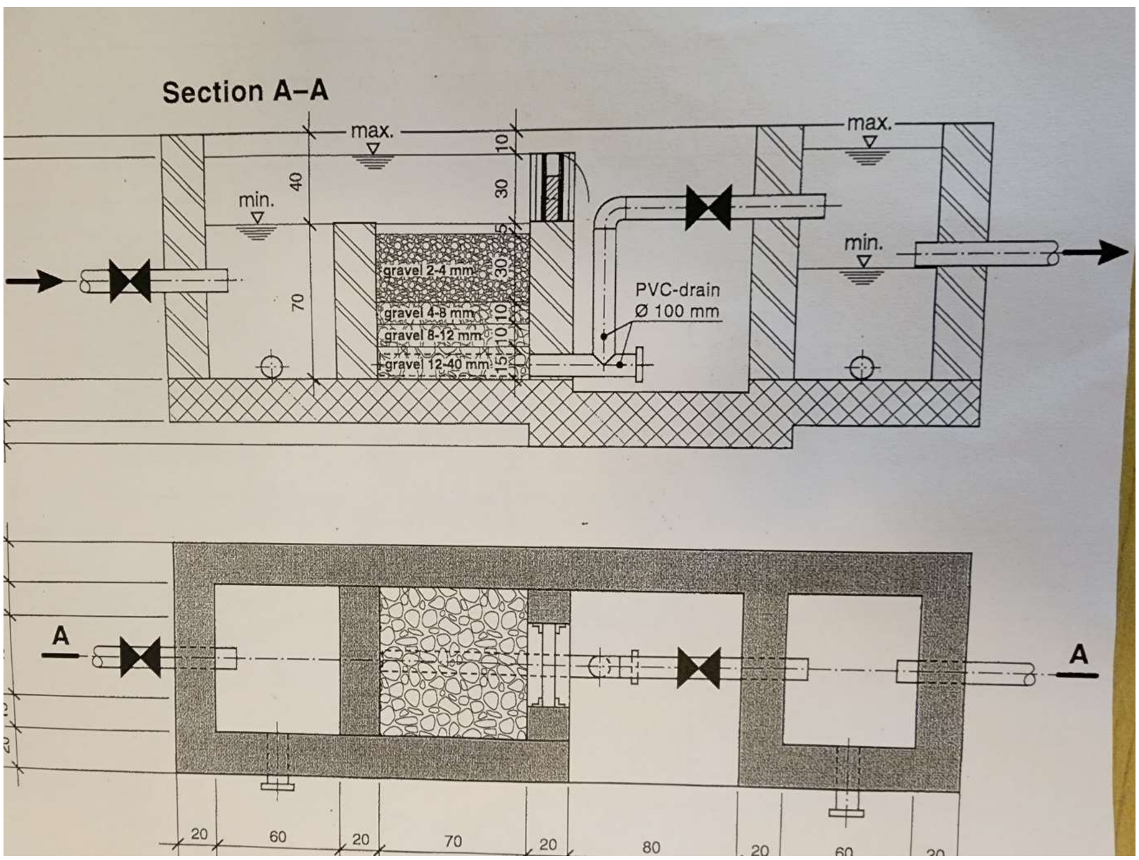


Multiple Barrier Water Treatment Concept

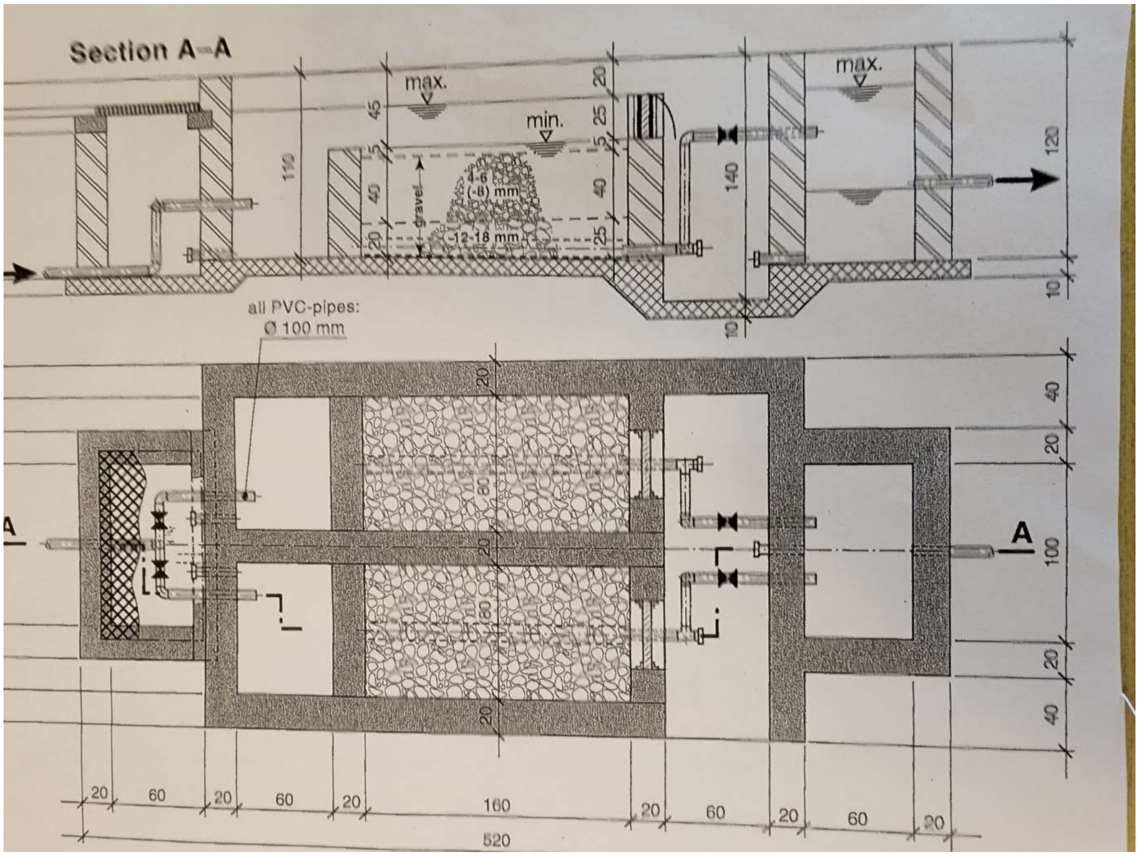
Water has to undergo a step-to-step treatment especially if it contains differently sized impurities. The first and easiest step in sound water treatment schemes is coarse solids separation. Finer particles are separated in a second pre-treatment step and finally, water treatment will end with the removal or destruction of small solids and microorganisms. These different pre-treatment steps will contribute to reducing the pathogenic microorganisms. The pathogens attached to the surface of suspended solids will get stranded when the solids are separated. Some of the microorganisms floating in the water might also get pushed to the surface of the treatment installations and adhere to biological films. Solid matter and microorganisms, therefore, face a multitude of treatment barriers. See multiple barrier water treatment concept above. Since treatment efficiency of each barrier increases in the direction of flow, it becomes increasingly difficult for the impurities to pass through each subsequent treatment barrier.

Flowing surface water as encountered in the streams of Rarotonga carries solids of different sizes, such as coarse sand and silt to fine clay.

Selecting an appropriate pre-treatment system in the form of an Intake- or Dynamic Filter will contribute significantly to reducing the levels of fine particles during higher turbidity events, which are difficult to remove in treatment processes. Particularly because the turbidity peaks encountered are generally of short duration e.g., hours rather than days.



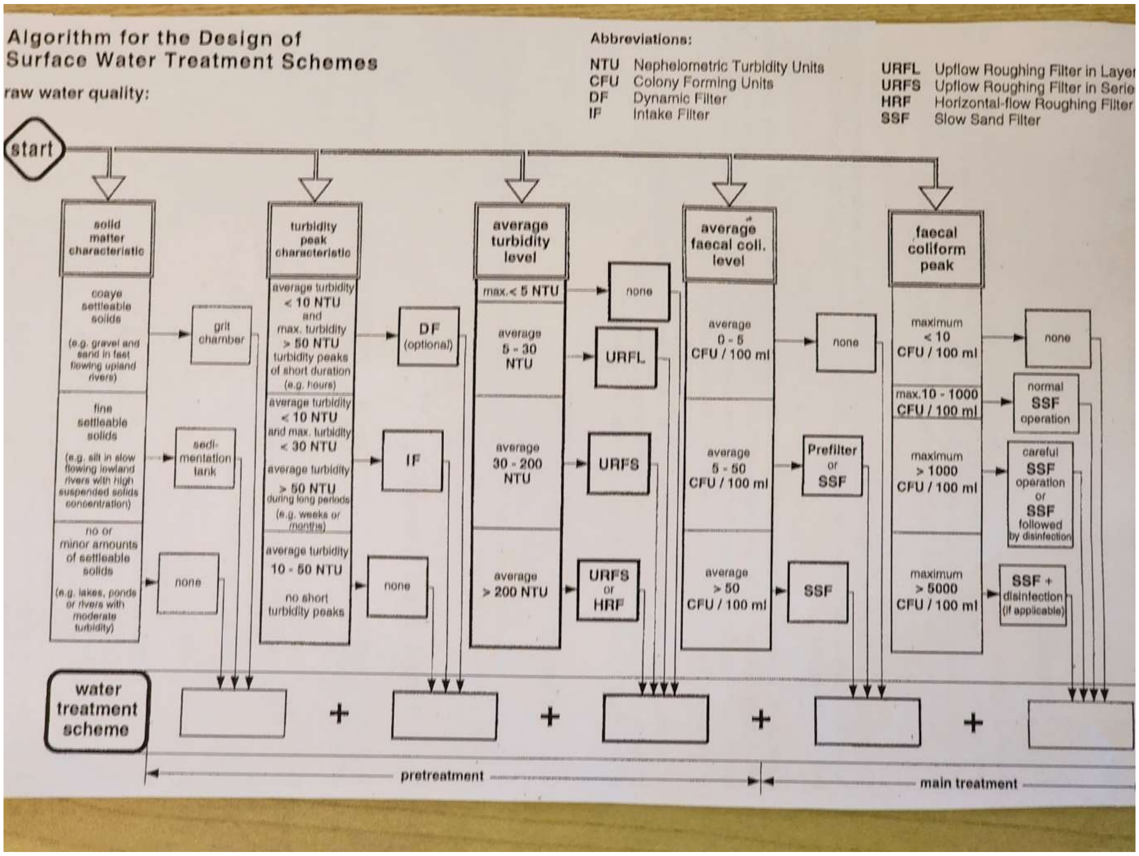
A general schematic of a design example of a Dynamic Filter



A general schematic of a design example of an Intake Filter

A choice of one of these pre-filtration units could be placed or build at the outer side of the stream bed beside the existing intake in order to reduce the abstraction of fine matter.

Intake- and dynamic filters separate the solids mainly at the inlet zone of the filter and, thus, act as a surface filter. These filters are therefore manually cleaned by scouring the top of the filter bed with a shovel or rake. Well-operated intake- or dynamic filters should at least achieve more than 1 to 3 months of filter runs, depending on the surface water fluctuations mainly with regard to turbidity and solids concentration.
The term “filter run” is defined as the time between filter cleanings.



The above algorithm table for the Design of Surface Water Treatment Schemes illustrates that an Intake- or Dynamic Filter might be a prudent concept and will generally characterise smaller raw water quality fluctuations.

2.0 Part 2 to be concluded

The main challenge is the reduction of turbidity (to < 10 NTU) to protect fine sand filters, i.e., AVG filtration units from frequent clogging and to ensure effective operation. Operational experience shows that this cannot or is not being achieved by the conventional processes such as chemical coagulation, flocculation and sedimentation during turbidity peaks. Some treatment at the raw water intake may be necessary for very high-turbidity raw water in order reduce the suspended load to the above processes.

Importantly, careful withdrawal and disposal of the sludge must also be considered in this stage.

The choice of a treatment process for potable water production is strongly influenced by the raw water quality. With a clear treatment concept, including a reasonable appreciation of the raw water characteristics and seasonal variations of the raw water quality, logically combined with the most appropriate treatment processes, failures can be avoided.

Efficient pre-treatment of the surface water, such as for instance an Intake- or Dynamic filter, is necessary to avoid serious operational difficulties with the sedimentation and filtration units during high turbidity events.
The major advantages of the dynamic filter over the slow sand filter are its ability to tolerate high turbidity peaks, long filter runs and much simpler operation and maintenance requirements Thus, the dynamic filter is an alternative to the slow sand filter in those situations where there is adequate water for crossflow and the topography is suitable to divert water by gravity to a filter nearby.

Inadequate pre-treated raw water supplied to the sedimentation tank reduces the solid removal efficiency of this tank, resulting in “overloading” the downstream filtration units. Also, as important it reduces the production of sludge in the sedimentation tanks.

Premature, rapid AVGF filter clogging, frequent manual filter cleaning and unable to produce low turbidity water - which is not fit for consumption - are the resulting consequences.

2.1 Recommendations

Against this background it is believed that a form of pre-filtration in the form of an Intake- or Dynamic filter exhibits numerous advantages, and therefore further investigation in such a device is warranted.

APPENDIX 1

Implementation of an air-assisted backwash

In the case of AVGF filters, this involves the installation of a separate air scour system above the existing filter underdrain (between the nozzles) and gravel support. This will represent many challenges and therefore it is recommended to further investigate and to produce a separate technical brief for the implementation and logistics of this option. This was not part of the scope of this technical brief.

This will include a proposed backwash protocol, which will differ from the existing protocol, as well as a commissioning brief and the specifications of air-piping, associated valves, pressure regulator, flow meter, air scour drop pipe(s) and air distribution grid etc.

It will also have to include a Mechanical Performance Test sheet, stating the following:
Phase 1 - Optimise High-Rate Backwash Duration
Phase 2 – Optimise Air Scour Duration etc.
This list is by no means complete.

A preliminary design guide for such a system is given below.

Design Guide on Air-Assisted Backwash

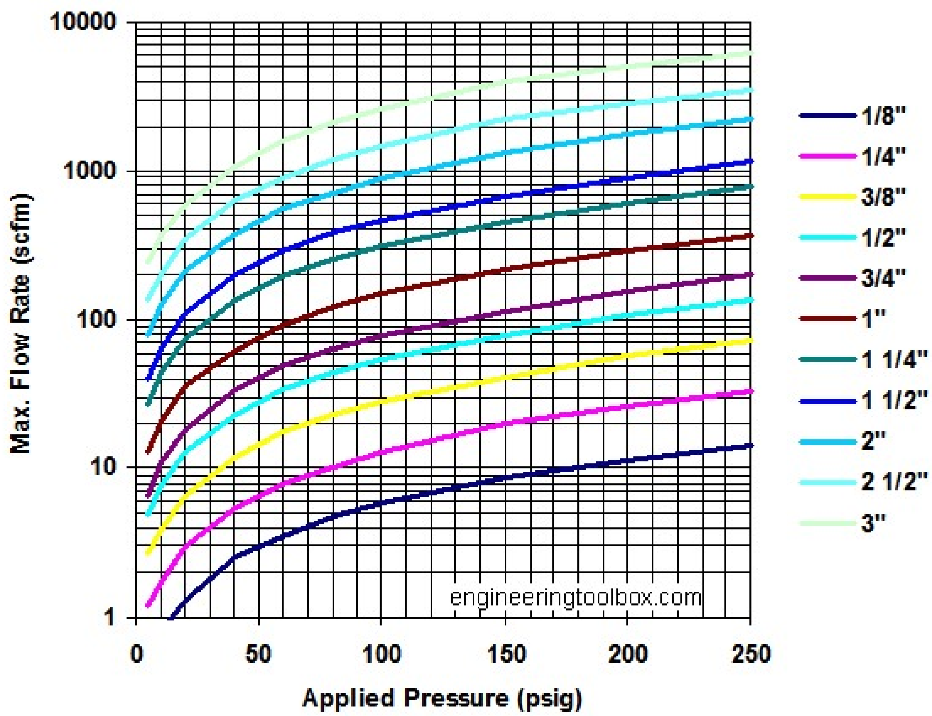
1. Air scouring controls must allow the operator to control the air flow rates and duration;
2. Air distributing piping on top of the filter floor between the nozzles is required;
3. The water filter gravel at the bottom of the water filter bed is not part of the filter media and it is merely providing a support for media above the underdrains and allowing an even

distribution of flow of water and air across the filter bed during filtering and backwashing.

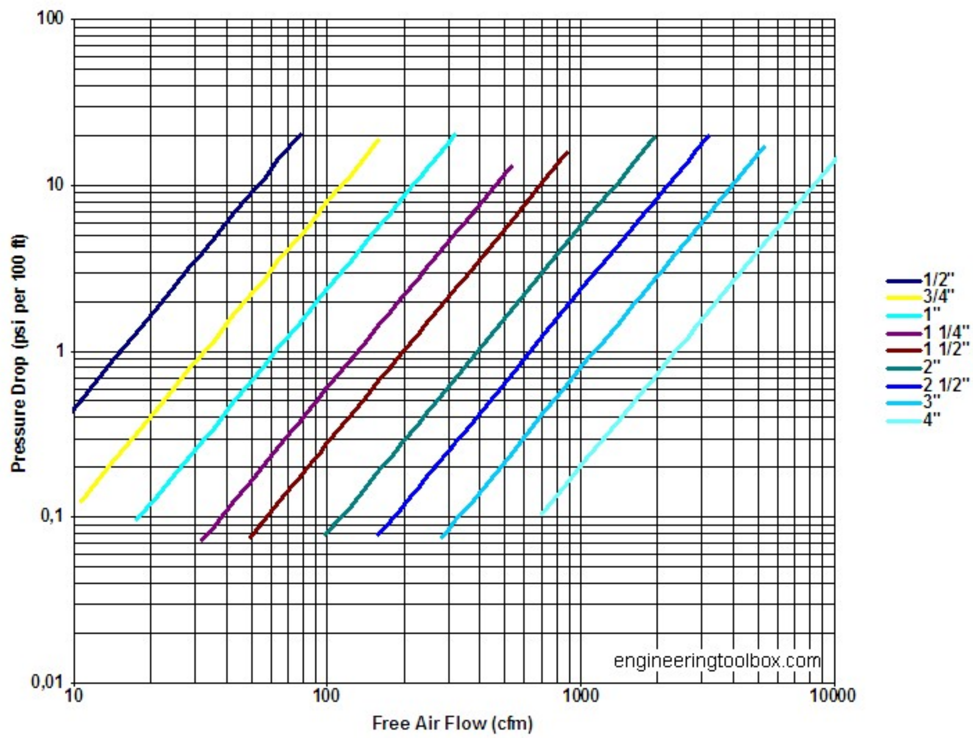
4. Air scouring must be initiated manually;
5. While literature specifies 0.085 – 0.14 m^3/min per m^2 of filter area it is recommended that a flow rate of 0.058 m^3/min per m^2 of filter area, with a maximum of 0.085, which has to correspond to an air flow dictated by the area of the filter flow, for about five minutes.
6. A lower air rate shall be used when the air scour distribution system is placed above the underdrains, say 0.08 m^3/min per m^2 of filter area;
7. Air scouring should be followed by a fluidization wash to re-stratify the media;
8. Air must be free from contamination;
9. Air scour distribution system should be placed at or below the media and supporting bed interface, the air scour nozzles shall be designed to prevent media from clogging the nozzles or entering the air distribution system;
10. Piping for the air distribution system shall not be flexible hose which may collapse when not under pressure and shall not be relatively soft material which may erode at the orifice opening with the passage of air at high velocity
11. Air delivery piping shall not pass down through the filter media unless a minimum of two (2) anti-seepage collars, 155 mm apart are provided

Table 6.8 Recommended Design Values for Various Backwash Methods (Adapted from Vigneswaran et al., 1983)

Parameter	High-rate water backwash	Low-rate water backwash: Air scour followed by low-rate water backwash	Low-rate water backwash: Simultaneous air and low-rate water backwash followed by low-rate water backwash	Water backwash with air auxiliary: Air scour followed by high-rate water backwash	Water backwash with air auxiliary: Simultaneous air and low-rate water backwash followed by high-rate water backwash	Water backwash with surface wash auxiliary
Backwash rate	37.5 $m^3/m^2 \cdot h$	18 $m^3/m^2 \cdot h$	15–18 $m^3/m^2 \cdot h$	>18 $m^3/m^2 \cdot h$	—	15–18 $m^3/m^2 \cdot h$
Backwash water pressure	2.5–5 kg/cm^2	2.5–5 kg/cm^2	2.5–5 kg/cm^2	2.5–5 kg/cm^2	2.5–5 kg/cm^2	0.25–0.5 kg/cm^2
Air scour rate	—	27 $m^3/m^2 \cdot h$	18–27 $m^3/m^2 \cdot h$	27 $m^3/m^2 \cdot h$	36–46 $m^3/m^2 \cdot h$	—
Surface wash rate	—	—	—	—	—	10–12 $m^3/m^2 \cdot h$
Pressure of surface scour water	—	—	—	—	—	1.5–4 kg/cm^2 This type of filter backwash is used when mud ball formation occurs on the top of filter bed
Porosity range during expansion	0.68–0.70	—	—	—	—	—
Expansion of medium	80–100%	Low	Low	Low	Low	—
Time of washing	3-6 min	3–6 min	2–3 min	3–4 min	2–3 min	—
Time of air scour application	—	3–6 min	2–3 min	3–4 min	2–3 min	—
Amount of wash water needed	High	Low	Low	High	High	High
Efficiency of cleaning action	Poor	Fair	Good	Good	Good	—
Applicability	Single and multimedia filters	Single media only	Single media only	Single and multimedia filters	Single and multimedia filters	Single media filters



Assuming air supply pressure of 100-110 psi (6.8-7.8 bar), the graph above indicates that a 1.5” (38mm) airline would be expected to be able to supply almost 500 scfm (235 l/s) of air.



Note: applied pressure = 100 psig = 6.9 bar

The following graph indicates that, even at a flow as high as 500 scfm (235 l/s), a pressure drop of less than 5 psi (0.35 bar) through one hundred feet of 1.5” (38mm) airline would be expected.

Air Wash System

In most cases the filter backwash rate will not be sufficient to break up the mass on the top of the filter. During filter backwash, the media expands upwards. If air is forced through the under-drains until the sand is thoroughly agitated, for a period of about five minutes the expansion of sand media and complete removal of the floes could be achieved. In the air wash system, compressed air is used to secure effective scrubbing action with a smaller volume of wash water. The air may be forced through the under drains before the wash-water is introduced or through a separate piping system placed between the gravel and the sand layer on top of the filter floor. The latter will be the case for the AVG filtration units. Though the former results in better washing, the gravel (see picture below) is likely to be disturbed. The cleaning of TVV's water treatment AVG filters with air agitation followed by backwash is a very efficient method but requires some kind of mobile compressed air pressure tank (see an example of this kind of tank below) or air blower to produce the air. The normal design of backwashing employing conjunctive air and water wash, air will be applied at 700 to 850 Lpm/ m2 of filter area (45 – 50 m/hr) and water at 200 to 250 Lpm/ m2 of filter area (12-15 m/hr). Hence, assuming an air-scour duration of at least 5 minutes the tank can be sized on the above figures.

Fig. Graded *Gravel*

The water filter gravel at the bottom of the water filter bed is not part of the filter media and it is merely providing a support for media above the filter floor and allowing an even distribution of flow of water or air across the filter bed during filtering and backwashing