Technical Letter: On turbidity from DrinTec™ limestone contactors.

S-6.7.1; April 2024

1. INTRODUCTION

Turbidity (NTU) is a measure of the cloudiness of water.

In water quality guidelines and standards, NTU it is used as a basis for validation of disinfection systems or the presence of sedimentary material in water runoff.

In surface waters, higher turbidity levels are often associated with higher levels of disease-causing microorganisms such as viruses, parasites, and some bacteria.

Legislation and guidelines are written, in this regard, for the outlet of drinking water treatment plants in general, but not specifically for the outlet of RO desalination plants.

Remineralisation of RO plants increases turbidity of the treated permeate, due to carryover of small calcite particles and impurities of less than 100 µm in diameter.

However, taken into consideration that the increase in turbidity from the remineralisation process is not due to the presence of disease causing micro-organisms or toxic sediments, the question arises: what maximum turbidity value should be allowed in the outlet of RO plants?

In most international tenders < 1 NTU is required. However, some establish a maximum of 0.5 NTU. Recent projects have even requested <0.3 NTU for 95% of the samples. Transposing this way the standard applied to surface water treatment plants.

This technical letter discusses the issue of the turbidity only for upflow limestone contactor with continuos calcite feeding system, i.e. with DrinTec process.

2. LEGISLATION OVERVIEW

This section provides an overview of the level of turbidity considered in various guidelines and standards.

The WHO, establishes a maximum of 5 NTU in the distribution network.

A slight cloudiness can be detected, by eye, when water surpasses 2 NTU, by placing the sample in a transparent beaker against a light source. Therefore, turbidity of 5 NTU is easily detected. In most countries this level of turbidity is considered too high for drinking water distribution networks.

With the objective of controlling water quality and disinfection, the EU Directive 2020/2184, establishes a maximum of 0.8 NTU at the outlet of the water treatment plants or at the outlet of the main network distribution tank. In addition, it establishes the condition that 95% of the samples should be ≤ 0.3 NTU.

In Spain, RD 3/2023 has added a provision to this new directive for desalination plants. It indicates that the criterion of 95% samples having ≤ 0.3 NTU should be applied only at the outlet of the RO racks and before post-treatment. Turbidity of permeate from RO permeate is generally 0.16 ± 0.04 NTU and therefore there is no issue for RO plant to comply with this limit.

Federal US-EPA establishes a maximum of 1 NTU at the outlet of the water treatment plants and adds also the condition that 95% of the samples should be ≤ 0.3 NTU. Canada has similar criteria.

The Federal US-EPA establishes the following provision: "considering that practice lime softening may cause elevated turbidities due to carryover of lime from the softening processes. If this significantly affects filter effluent turbidities, public water supply systems may apply to the State for alternative exceedance levels, if they can demonstrate that higher turbidity levels in individual filters are due to lime carryover only and not due to degraded filter performance". Presumably, this provision would be applicable to desalination plants with lime or limestone remineralisation processes.

Australian Drinking Water Guidelines 6, 2011 Version 3.8. Updated September 2022 establishes <0,2 NTU as the target for effective filtration of protozoa Cryptosporidium and Giardia and <1 NTU as the target for effective disinfection. However in recent projects, water authorities have establish 0.5 NTU as a maximum NTU value at the outlet of RO plants.

3. TURBIDITY AND PARTICLE SIZE

Turbidity in upflow calcite contactors is caused, mainly, by entrainment of undissolved limestone particles of Ø < 100 μm. Also, insoluble clayish material of ≤ 2 μm may be another source of turbidity. However, in case limestone has purity > 98.5% $CaCO_3$, the source will be small.

Figure 3.1 depicts the relationship between upflow velocity and entrainment of particles based on Stockes' law. A much more detailed approach would be required, using advanced fluid dynamics formulas, to improve the accuracy of these values. However, for the purpose of explain the range of values involved in the process, it has been considered adequate.

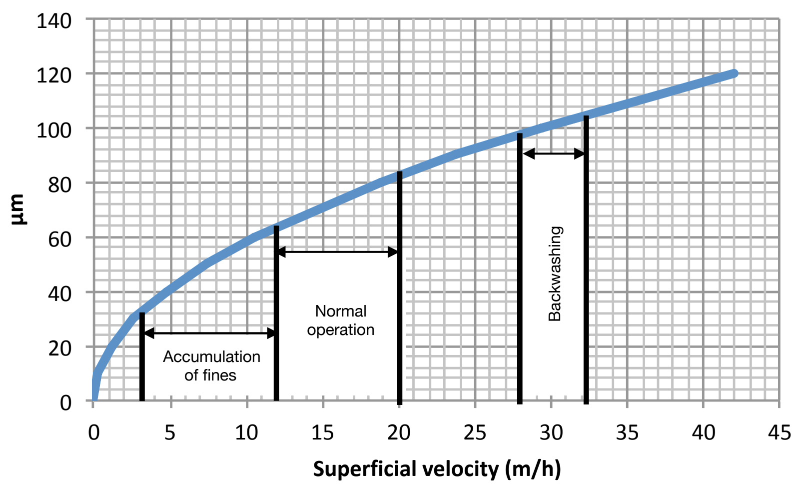

Fig. 3.1: Estimation of entrainment of calcite particles as related to superficial velocity (V_{sup}) using Stockes' formula.

According to Figure 3.1, accumulation of fines, i.e Ø < 60 µm, starts to occurs when V_{sup} < 12 m/h. Consistent with this statement, it has been observed in field projects and experiments that when working below 12 m/h of Vsup the plants are very sensitive to small increases in flow.

Normal operating conditions for upflow reactors are between 12 and 20 m/h. Within this range reactors are less sensitive to sudden increases in flow as beds remain clean of fines.

Recommended backwashing Vsup is 32 ± 2 m/h. At that Vsup bed has not been shown to expand but particles of Ø < 100 µm are dragged out of the bed via the pore channels. As a complementary note, it should be added that air sponging at ≈ 80 Nm^3/h and m^2 helps to fluff bed and turn particles around, making backwashing more effective. It should be noticed that air and water should not be run together as elutriation of larger particles can easily occur.

An experiment was carried to study how the settling of calcite particles of different sizes affects turbidity. For this, 1 g $CaCO_3$ (98.5%) of five different size ranges were mixed in 1 litre distilled water. $CaCO_3$ has a solubility of 0.013 g/L at 25°C. The distilled water had pH 6.3 and 0.36 NTU. Temperature through the duration of the experiment was 21 ± 1 °C. The turbidity value of the distilled water has already been subtracted from the results presented in Table 3.1.

As can be seen turbidity remains around 0.15 NTU for the range of particles Ø < 50 µm even after 94 hours settling time. That is, particles of smaller size remain in suspension.

Figure 3.2 shows the relationship between particle size and approximate settling time to reach < 0.2 NTU, as inferred from Table 3.1.

Table 3.1: Settling time for different particle diameter ranges.

Size Range	Settling time in hours								
	0	3	6	24	38	64	72	88	94
500-1000 µm	2,54	0,2	0,21	0,01	0	0,04	0,08	0,09	0,06
200-500 µm	5,48	0,7	0,26	0,18	0,03	0,08	0,06	0,0	0,07
100-200 µm	11,64	5,92	0,18	0,16	0,14	0,09	0,25	0,11	0,07
50-100 µm	280	30	18	0,43	0,16	0,17	0,10	0,1	0,1
< 50 µm	439,64	71	43,6	5,7	1,11	0,27	0,25	0,15	0,15

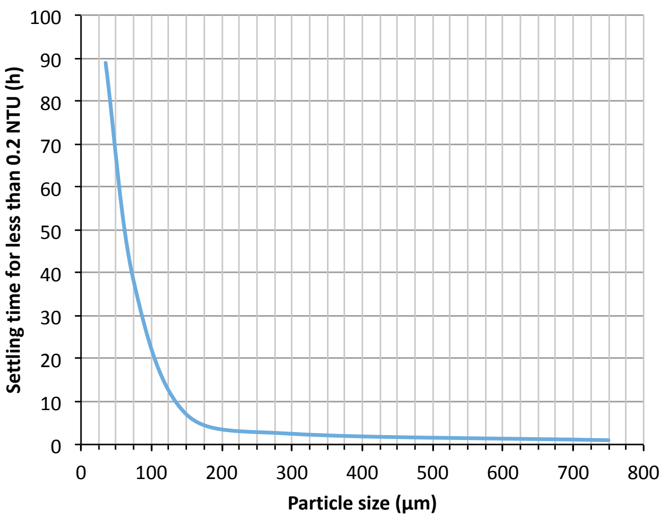

Fig. 3.2: Relationship between particle size and approximately settling time to reach < 0.24 NTU.(data inferred from Table 3.1).

Field data show that output of DrinTec remineralisation plants normally have <2 mg/L of total suspended solids (TSS).

Field data from DrinTec vertical tanks of < 5 m² of bed surface and operating at V_{sup} between 10 and 18 m/h, have been shown to add 0.24 ± 0.03 NTU to RO permeate when operating at conditions of constant flow.

Data from larger contactor cells, i.e. 12 to 32 m², suggest sightly higher input of turbidity from the contactors and in the order of 0.30 to 0.55 NTU, depending again on calcite purity and fines content.

From this information and considering RO permeate has normally a turbidity of 0.16 ± 0.04 NTU, remineralised water with < 0.5 NTU can only be achieved with good quality limestone and constant flow or by blending the remineralised water with a certain proportion of untreated permeate.

For the same reasons, to produce water with ≤ 0.3 NTU at the outlet of an RO plant it is necessary to blend remineralised and permeate water. See below Paragraph 6 for more detailed information.

Finally it can be deduced, considering the points discussed above, that DrinTec contactors can produce water with < 0.8 NTU even without blending, if the operating conditions and quality of the calcite meet specifications.

4. SOURCES OF TURBIDITY

Dragging of very fine calcite particles and clayish impurities is inevitable in upflow calcite contactors. However, different conditions may cause excessive amount of turbidity, either continuously or sporadically.

The following conditions have been identified:

- Feeding powdered calcite;
- Presence of clayish impurities;
- Effect of stops and starts of flow;
- Air from the RO plant;
- Overdosing of NaOH.

4.1 Feeding powdered calcite

It has been shown that after a period of bed maturing, which normally takes several months, finer particles accumulate at the bottom of the bed and above the underdrain. There, CO_2 concentration and dissolution of particles is highest.

On the contrary, at the top of the bed the water is practically saturated and therefore particles almost no longer dissolve. Thus, the fines that are present in the upper part of the bed come mostly from the material that descends continuously through the dosing system.

Figure 4.1 shows a schematic representation particle size distribution inside Drintec contactor after 8 months operation based on field observations.

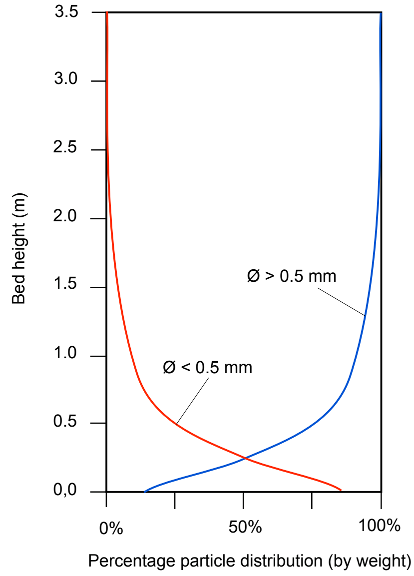

Fig. 4.1.1: Schematic representation of particle size distribution in a DrinTec contactor after 8 months operation at 12 m/h and with 24 mg CO_2/L.

Feeding calcite with 2% - 3% by weight of particles of Ø < 100 µm, i.e. powdered material, has been shown to generate a constant turbidity of 1.1 to 1.5 NTU in remineralisation plants.

Also, it has been noticed that during truck transportation, the material at the bottom of big-bags appears crushed and turned into powder.

Calcite has a hardness of 3 mhos. However, there are small differences as experience shows that when rubbing the granulated material between hands, some calcites are slightly softer and generate dust more easily than others.

Most granulated calcite is delivered in 1-3 mm or 2-5 mm grade. Using dust blowing system during sieving operation it may not be sufficiently effective and fine material remains adhered to larger particles.

Some calcite suppliers consider that the best way to guarantee fines-free limestone is to pre-wash it at the quarry and consequently have adapted their installation to offer pre-washed product.

Fig. 4.1.2: Appearance of the water at the outlet of a calcite cell during the initial stages. of the backwash process (left) and after completion

4.2 Presence of clayish impurities

Calcite, being a sedimentary rock, frequently contains embedded clayish material. This material is insoluble and has a diameter of less than 5 µm. Consequently it accumulates inside the contactor at low superficial velocities or is constantly being washed away with the treated water, causing turbidity.

More than 1% clayish material content has been shown to cause turbidity to exceed 1 NTU

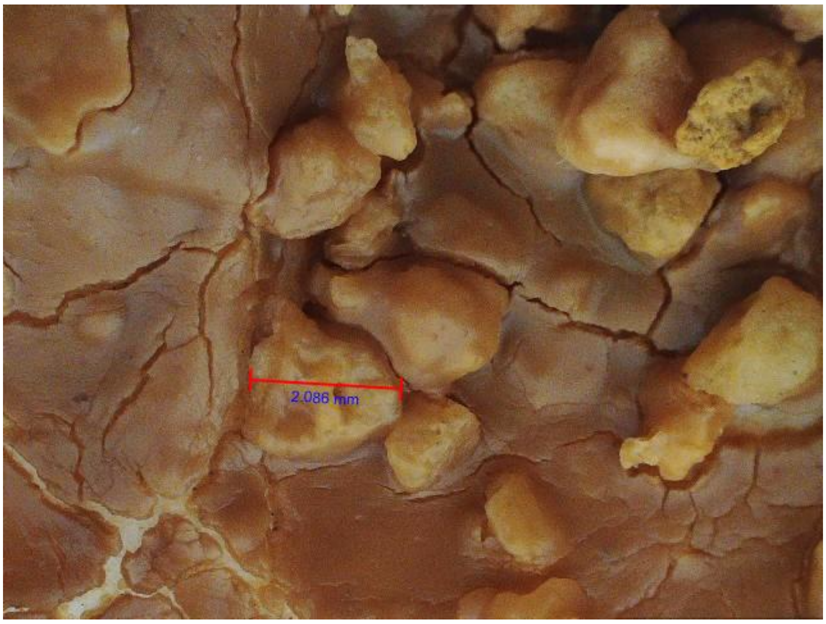

Fig. 4.2.1: Appearance of clayish impurities obtained from a calcite sample, together with some silica particles.

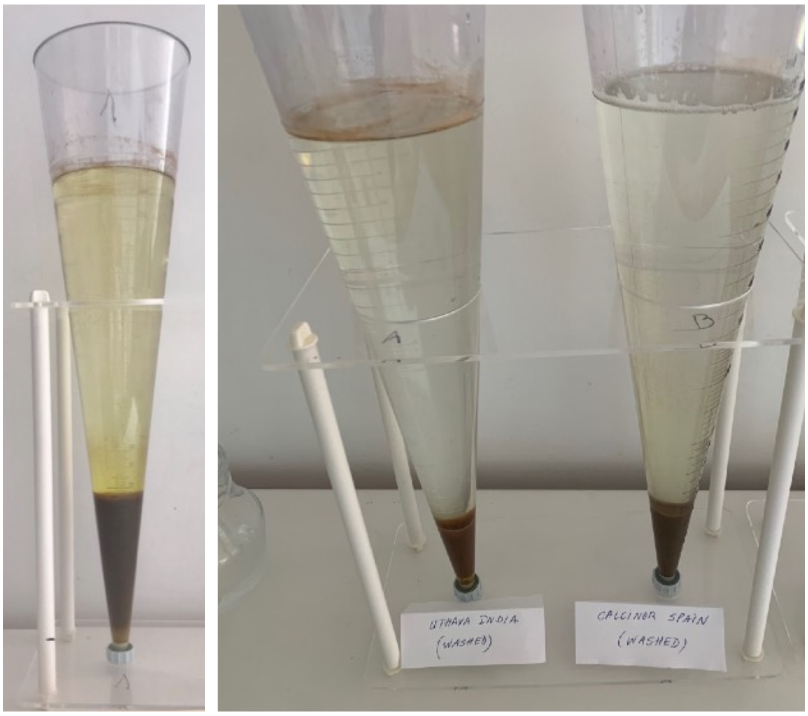

Fig. 4.2.2: Results of a settling test after 24 hours for samples having high clay content (left picture) and low clay content (the two samples on the right)

4.3 Effect of stops and starts of flow

Fine particles, either clayish impurities or calcite powder accumulate in the contactor, particularly when operating at low superficial velocities (Vsup <10 m/h). A sudden increase in Vsup or a stop - start event can cause a turbidity peak.

Figure 4.3.1 shows turbidity peaks appearing during pulses of flow rates at low superficial velocities in a pilot facility. The turbidity peaks diminish in size after fines where washed away. The tiny peaks in both curves are due to small amounts of undissolved air coming from the RO plant.

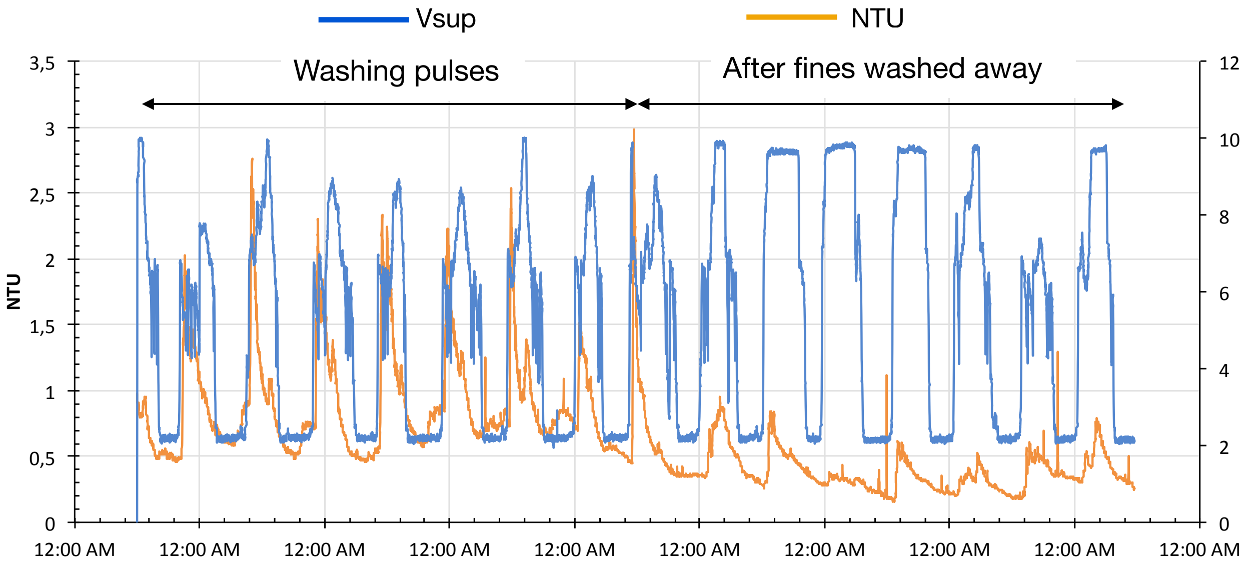

Fig. 4.3.1: Effect of changing flowrates on turbidity during washing pulses and after fines washed away. Upflow contactor Ø 0.6 m with bed height 2 m.

Figure 4.3.2 shows the data from a stop-start event in a cell of 23.22 m². The cell had been filled with clean calcite and then left running for 2 days at 15 m/h. Thereafter, it was stopped for 20 minutes and restarted, again at 15 m/h. As can be seen turbidity after restarting remained for only 20 minutes above 1 NTU.

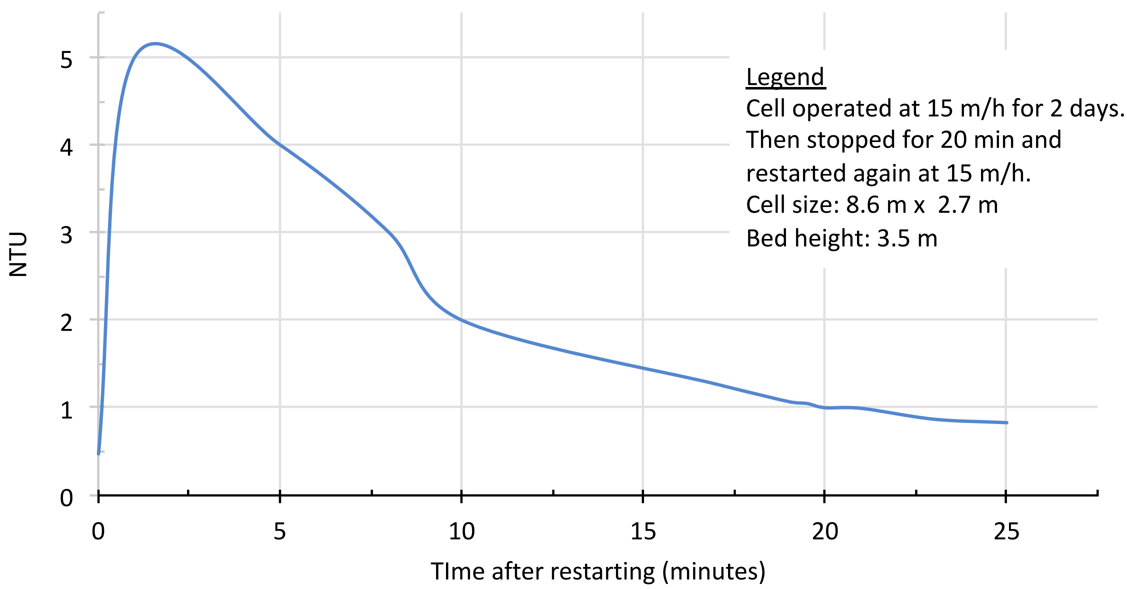

Fig. 4.3.2: Turbidity as affected by a for a stop-start event in a cell of 8.6 m x 2.7 m. See legend for details.

New racks entering production may also alter flow to the contactors, generating turbidity peaks.

Depending on the (a) quality of the calcite; (b) previous history of operating at too low Vsup; (c) proportional increase in flow compared to previous flow and (d) size of the reactor, the duration of the peak may vary from 10-20 minutes as seen on Figures 4.3.1 and 4.3.2 to 5-8 hours as shown on Figure 4.3.3 below.

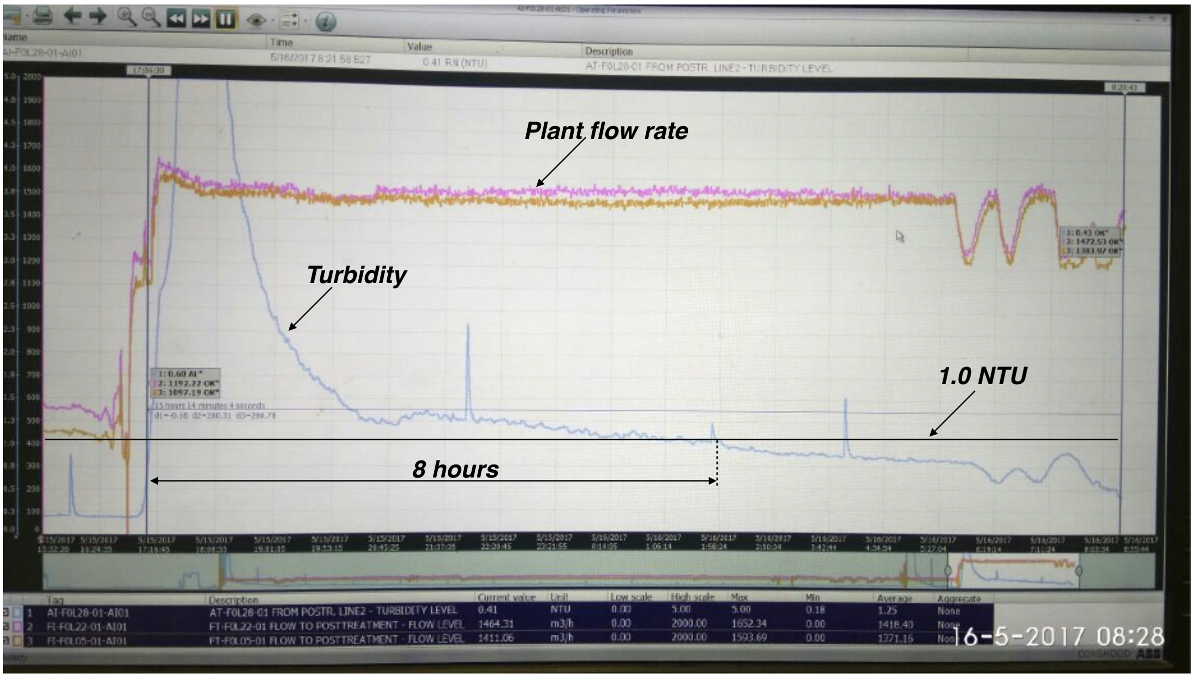

Fig. 4.3.3: Practical example of a turbidity peak in a plant having several cells of 21 m² cells, that had been operating for several weeks at 2 m/h Vsup and then suddenly increase jumped to 7 m/h.

4.4 Air from the RO plant

Air coming from empty pipes during start-up of the RO plant, or from other intake points in the installation, can cause sponging of the bed allowing the release of the fines.

Plant design should, therefore, maintain pipelines to the contactors always full of water and control any possible air suction points. To avoid air getting into the cells, inlet manifold to the contactors should be higher than cell inlets and a good sized air purging system should be placed along the inlet manifold and at the end of it.

Special stripping towers to remove the incoming air before the limestone contactors have also been designed.

4.5 Overdosing NaOH

Frequently, NaOH is added after the limestone contactors to raise pH and obtain a positive saturation index (SI).

Overdosing NaOH increases pH above 8.3 and initiates the formation of carbonates. At high NaOH dose, calcium carbonate clouds may be formed around the NaOH dosing points, causing an increase in turbidity.

Inadequate NaOH dosing can increase final turbidity by approximately 0.1 ± 0.05 NTU, especially if the pH exceeds the value of 8.3.

5. STRATEGIES TO ATTENUATE SUDDEN INCREASES IN V_{SUP}

There are different strategies for the design and operation DrinTec contactors when continuous changes in Vsup are expected.

One option is to maintain high Vsup, i.e. > 14 m/h. However, this requires calcite to be of very good quality, i.e. > 98% $CaCO_3$ or higher, and with little amount of fines, i.e. < 1% with Ø < 100 μm, to minimise continuos feeding of impurities and fine material.

Operating the contactor at low superficial velocities usually helps reduce turbidity but then more frequent backwashing is required to eliminate fines accumulated in the bed.

When using a calcite that meets DrinTec quality specifications (Table 5.1), backwashing is done about once a year. With poorer quality calcite, backwashing may be required every 3 to 6 months.

Different equipment have also been designed to control flow peaks such as balance towers or specific flow control meters as shown below on Figures 5.1 and 5.2.

Table 5.1: Specifications of calcite quality for DrinTec™ contactors.

Purity (%$CaCO_3$)	> 98 %
Diameter	2 - 5 mm
CaO	> 54.9 %
SiO_2	< 0.4%
Al_2O_3	< 0.4%
MgO	< 0.8%
Fe_2O_3	< 0.12%
Mn_3O_4	< 0.01%
Specific weight (t/m^3)	2.7
Specific weight dry granulated material (t/m^3)	1.5
Specific weight wet granulated material (t/m^3)	1.8
Hardness (mhos)	≥ 3
Ø < 0.3 mm (raw material dry screening)	< 3%
Ø < 0.1 mm (raw material dry screening)	< 1%
Material in wash water Ø < 0.1 mm	< 1%
Insoluble material with Ø > 0.1 mm	< 0.2%
Recommended water content (dry)	< 0.2%
Maximum water content (slightly moist not wet)	< 1.0%

Fig. 5.1: Control tower for flow peaks with overflow (right) next to a DrinTec™ CO_2 low pressure dissolver with translucent strip (left).

Individual flow meters and flow control valves for each cell have been installed to avoid changes in flow rate to the cells. The level of engineering dedicated to maintaining constant flow to each cell, while ensuring a compact design, is illustrated in Figure 5.2.

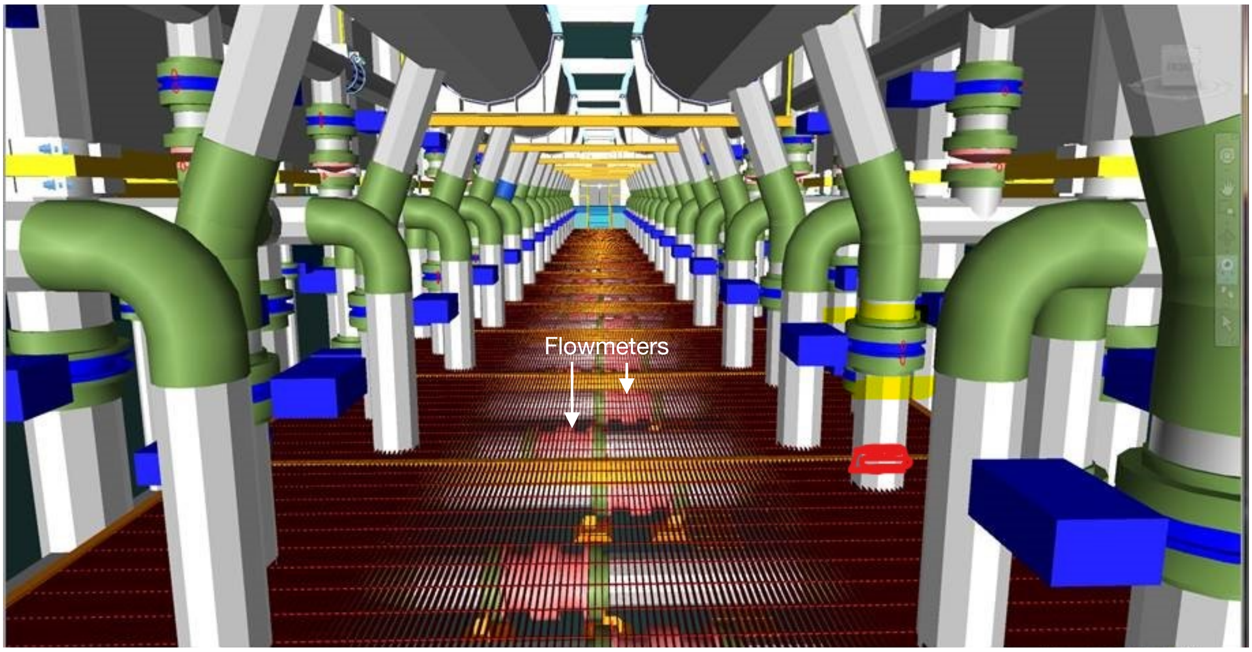

Fig. 5.2: Appearance of the inlet water corridor of a large plant with 32 cells, with two elevated manifolds and individual flowmeters for each cell accompanied by automatic flow regulating valves.

6. BLENDING WITH PERMEATE TO REDUCE TURBIDITY

Blending with permeate is a convenient manner for reducing final turbidity at the outlet of the remineralisation plant. Proportions depend on the turbidity of the remineralised water and that of the permeate. As shown on Fig. 6.1, turbidity is directly proportional to the percentage of blending.

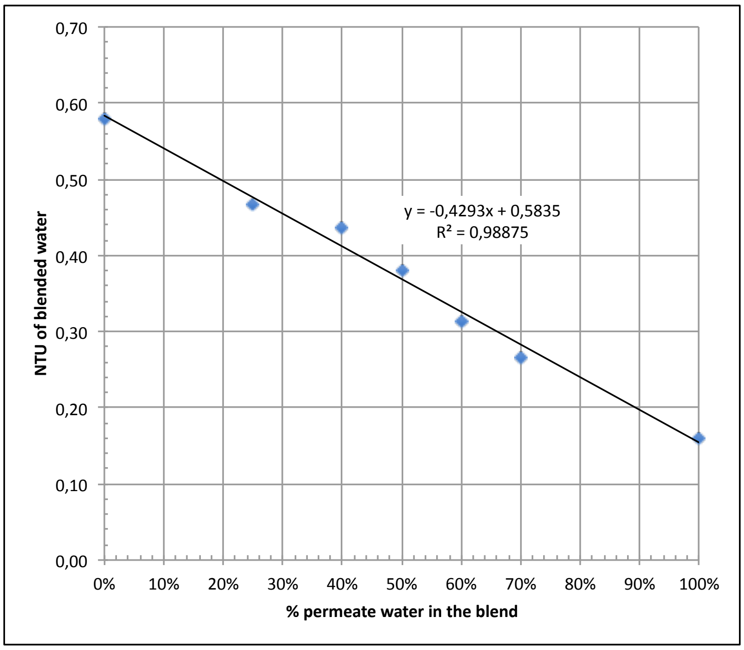

Fig. 6.1: Relationship between NTU of the blended water and percentage of permeate in the blend. Conditions of calcite with 99% purity and permeate with 0.16 NTU.

7. RECOMMENDATIONS FOR MAINTAINING LOW TURBIDITY

The following recommendations to maintain water turbidity below 0.8 NTU or even below 0.5 NTU:

- Use calcite free of powder and dust;
- Use purest calcite free of clayish impurities;
- Avoid accumulation of fines inside the reactor and sudden changes in flow;
- Avoid air entrance to the contactors;
- Avoid applying large doses of NaOH at a single point;
- Acidify the permeate adequately to obtain remineralised water with pH ≤ 8.3;
- Foresee if blending of remineralised water with raw permeate will be required.

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