Intermittent Backwash of Continuously Washing Up Flow (CWUF) Filters

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Abstract

Continuously Washing Up Flow (CWUF) filters are sand filters which enable simultaneous filtering of process water and backwashing of the sand bed to remove accumulated impurities. The Water Corporation use these filters in groundwater treatment to primarily remove dissolved iron and manganese, supplying potable water to regional towns. These filters have the drawback of a high rate of reject water output, which requires reprocessing. Operating these CWUF filters with an intermittent backwash regime in applications overseas has shown effective results with reduced reject water output. This intermittent backwash technology is patented in Australia by a company based in the United States, who have offered their support to undertake piloting before the Water Corporation commit to the technology. However, there are no pilot units available in Australia, and so the Water Corporation will re-configure its existing CWUF filter pilot unit for intermittent backwashing. This CEED project will inform the re-configured CWUF filter pilot trial, through CFD modelling of the backwash airlift to provide guidance for the air flows and pressures of the airlift associated with the re-configured pilot unit. A cost benefit analysis of implementing intermittent backwashing at three future treatment plants will also be conducted.

1. Introduction

The Water Corporation employ Continuously Washing Up Flow (CWUF) filters as part of groundwater processing primarily for the removal of dissolved iron and manganese for the supply of potable water throughout regional towns in Western Australia. Compared to conventional filters, these CWUF filters have a much smaller physical footprint, and they do not require filtration downtime during their backwash. The drawback of CWUF filters is their high reject water output, as they continuously backwash anytime the filter is online. This backwash water is then reprocessed in backwash recovery systems, increasing the operating cost of these filters.

Conventional sand filters operate in an intermittent backwash regime, which works in two separate modes: the filtration of feed water through the bed of sand, which is then stopped to execute a backwash of that sand to remove accumulated impurities (England et al., 1994). Production of filtered water must be halted during the backwash mode with conventional filters, and additional dedicated backwash tanks, pumps and pipework are required. The short duration of backwashing minimises reject water output and reprocessing.

CWUF filters simultaneously filter feed water and clean the filter media (sand bed). This is done through an airlift pump which transports the sand and accumulated impurities from the bottom of the filter to the top, where a sand washer at the top of the filter rejects dirty water and deposits clean sand back on top of the filter bed. The sand in the filter is continuously cycling through the filter as it is producing water. The airlift operates by injecting compressed air at the bottom of the airlift pipe, which creates a fluid mixture of air, water, and sand. This mixture is less dense and thus more buoyant than the surrounding water and sand, which enables hydrostatic transport through the airlift (England et al., 1994). An intermittent backwash regime of CWUF filters would reap the benefits of both CWUF and conventional filtration operation. This intermittent backwashing technology of CWUF filters is patented in Australia by a company based in the United States.

The Water Corporation is interested in the potential of intermittent backwashing at three sites in particular, where there are capital works planned in the near future, and where CWUF filters are likely to be used. Before committing to the patented technology, the Water Corporation wishes to undertake pilot trials. The company based in the United States have offered their support to the Water Corporation to undertake piloting in this application but do not have a pilot unit available in Australia. Therefore, the Water Corporation will re-configure its existing CWUF filter pilot unit for intermittent backwashing.

Critical to the success of intermittent backwashing is an airlift regime that can restart the sand circulation in the filter, without causing a filtrate turbidity spike. The Water Corporation is anticipating that getting this airlift correct will be the most challenging aspect of piloting the CWUF filter unit intermittently.

1.1 Project Objectives

This CEED project will inform the re-configured CWUF filter pilot trial, through Computational Fluid Dynamics (CFD) modelling of the backwash airlift to provide guidance for the air flows and pressures of the airlift associated with the re-configured pilot unit. The aim is to mitigate the filtrate turbidity spike during the airlift start up. A cost benefit analysis on operating and capital costs of intermittent backwash implementation at three future treatment plants will also be conducted.

1.2 CFD Background

The Computational Fluid Dynamics (CFD) modelling process involves four key parts: defining the model geometry (fluid domain), breaking down the domain into a mesh of finite volumes, setting up the model solution settings, and finally executing the iterative calculation and displaying the results. The CFD software (ANSYS Fluent) iteratively solves the governing equations of fluid flow, set into a system of algebraic equations for each finite volume, which collectively make up the whole fluid domain (Versteeg & Malalasekera, 2011). Smaller finite volume sizes (finer mesh / greater number of finite volumes) play a significant role in improving accuracy of the calculations and reduces spatial discretisation errors (related to Taylor series expansion to express the fluid properties at the cell faces). The drawback of a finer mesh is a significant increase to computation time (Versteeg & Malalasekera, 2011).

2. Process

2.1 CFD Model

The fundamental aspects of the model were decided upon before formation in the software. The model is 3D and of the entire airlift pipe domain. The airlift restart will be investigated using a transient two-phase model of water and air. The model begins with air injection at the air inlets which starts the airlift. A two-phase model will be developed first to investigate the airlift restart, when the airlift is offline the sand would be settled at the bottom of the airlift, and the initial hydrostatic transport will be water and air. If time allows a three-phase model including sand to the model may be developed.

The multiphase model selected for the liquid-gas interface of airlift operation is the Volume of Fluid (VOF) model. This model solves a set of momentum equations and tracks the volume fraction of each immiscible fluid to calculate the properties and variables at each finite volume (ANSYS Inc., 2024). The k-epsilon turbulence closure model has been selected due to effective results in literature of two-phase VOF airlift modelling (Guerrero et al., 2017; Hernandez-Perez, 2011).

The airlift to be modelled is from a scaled down pilot CWUF filter. The actual airlift to be used in the pilot trial was measured and used to build the CFD model geometry in Design Modeller. The airlift is a polyethylene pipe with an internal diameter of 26 mm, and a length of 3,500 mm, with eight air inlets on the pipe.

The next step of the model formation is the meshing configuration and sizing. Guidance will be taken from previous works done in two-phase VOF models, where a study specifically comparing different mesh configurations concluded the mapped grid had the best agreement with experimental results and enabled a finer mesh at the pipe walls while a coarser mesh was used at the centre of the pipe (Hernandez-Perez, 2011). The mapped mesh configuration is presented in Figure 1.

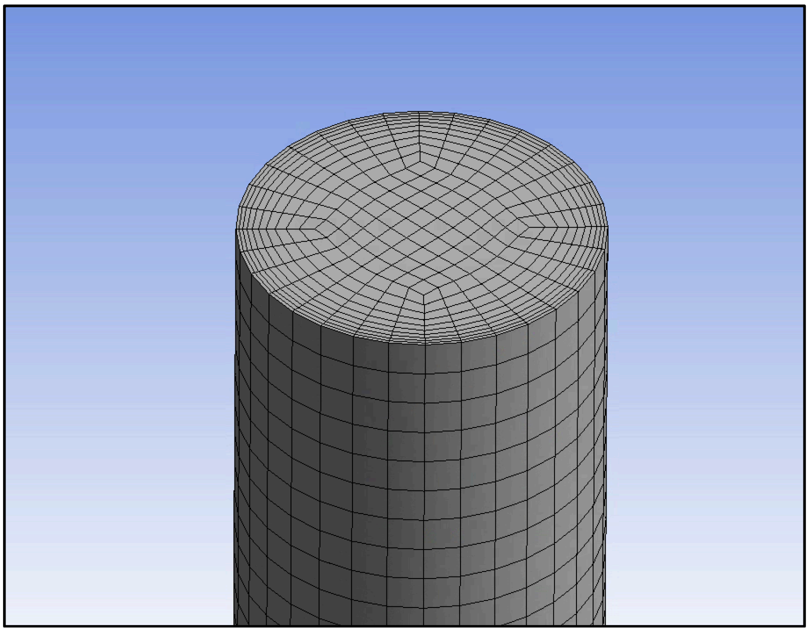

Figure 1 Mapped mesh configuration on the airlift geometry.

The airlift operation is controlled by air entering the pipe, which then enables transport up the airlift. The air inlet boundary condition to model this environment is a velocity-inlet, which requires a defined velocity and pressure. The flowrates to test have been based on the filter recommended flows, and the range of testing will be between 10 NL/min to 50 NL/min at a pressure of 4 bar. The main inlet at the bottom of the airlift is set as a pressure-inlet, with a gauge pressure equivalent to the hydrostatic head above the inlet boundary. The outlet at the top of the airlift is set as a pressure-outlet, with a gauge pressure of 0 Pa.

The calculations need to be executed and analysed for convergence quality. The mesh and time-steps need to be adjusted to find a balance between consistent answers and computation time. The modelled air flow rates that provide the best predicted results will be tested as the starting point of the pilot unit trials. The turbidity of the filtrate water will be measured during testing and will be used to assess whether the model provided accurate predictions.

2.2 Cost Benefit Analysis

The focus of the cost benefit analysis is the implementation of intermittent backwashing at three future CWUF filter sites. The cost benefit analysis began with collection of existing and future planning data. This included process data with inlet and reject flowrates, raw water iron loading, chemical dosing rates (chlorine for oxidation and disinfection dosing, soda ash for pH adjustment, and flocculants for filter and backwash recovery dosing), energy consumption through air compressor runtime and backwash recovery equipment sizing. Costing data was also collected for chemical unit prices, energy unit price and backwash recovery equipment cost. The capital costs include the extra equipment required for intermittent operation such as powered valves, process control requirements, sand movement verification systems, and backwash recovery systems.

Existing groundwater treatment plants were used to provide a realistic benchmark for continuous backwash CWUF filter operation. Sites with low (<2.5 mg/L), medium (between low and high), and high (>7.5 mg/L) iron feed water loading were chosen to provide a wide range of examples. A mass balance across the CWUF filter in both continuous and intermittent backwashing mode were calculated for the three implementation sites. A 24-hour basis allowed a comparison between the backwashing modes, and an assumption on the backwashing time reduction while in intermittent mode was invoked. The assumption used for this analysis was a backwash runtime reduction of 90% from continuous backwashing, which is based on an overseas wastewater application of intermittent CWUF filters which were able to achieve this rate of reduction (Parkson Corporation, 2010).

The analysis calculations allow adjustment of this assumption, and a future pilot trial will provide experimental data to feedback into the mass balance analysis to recalculate the operating cost reductions. The collected and calculated data was normalised with the specific site flowrates to provide an AUD cost per kilolitre of water produced by the plant. The normalisation of the data allows a comparison of operating costs between sites with different production rates and considers the increased filtrate production when intermittently backwashing.

3. Results and Discussion

The preliminary intermittent backwashing results estimate reductions in operating costs (AUD per kilolitre of filtrate produced) at the three specific sites, at 53% for Site A, 13% for Site B, and 75% for Site C. The savings predominately come from the reduction in electrical energy consumption, due to the reduced backwash runtime and thus reduced air compressor usage. During intermittent backwashing, the reject water is redirected through the filter resulting in a greater filtrate flowrate, producing more filtrate in a 24-hour operating period, which further reduces the operating cost per kilolitre. In treatment plants the additional filtrate water production would result in a reduced filter runtime per day. The chemical dosing contributes to a lesser extent, as most of the dosing at these three sites will occur before the CWUF filter (for oxidation and pH correction) and was assumed constant between continuous and intermittent backwash operation. The additional water production also requires greater chemical dosing for downstream disinfection, which offsets some of the reduced chemical costs, which was the case for Site B and Site C.

The case with the lowest relative cost reduction for intermittent backwashing is Site B at 13%, as the feed water chemical dosing costs make up such a large proportion of the overall operating costs and assumed unchanged when backwashing intermittently. This resulted in a lower operating cost reduction estimate compared to the other two sites. The overall economic analysis including capital expenditure considerations are still to be assessed.

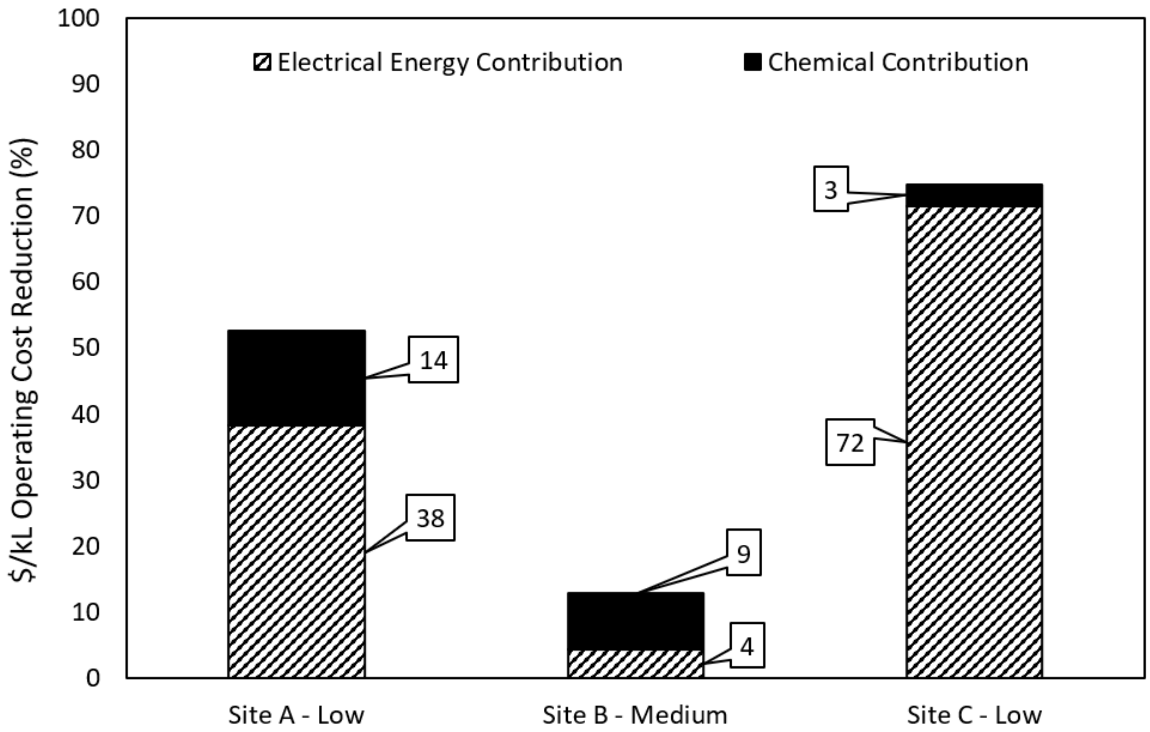

Figure 2 Operating cost reduction estimates of intermittent backwashing relative to continuous backwashing of CWUF filters. For Sites A (low feed iron loading), Site B (medium feed iron loading), and Site C (low feed iron loading).

4. Conclusions and Future Work

The results of the operating cost analysis highlight the potential of intermittent backwashing, which ranged from a 13% to 75% reduction in operating costs, relative to continuous backwashing. Site B had the lowest reduction in operating cost at 13%. For two of the three sites the most significant cost reduction came from the reduced electrical energy consumption of the air compressor. While the additional filtrate production during intermittent backwash operation also contributes to the reduced operating cost per kilolitre of all three sites. The chemical dosing contributes to a lesser extent, as most of the dosing at these three sites will occur before the CWUF filter and was assumed constant between continuous and intermittent backwash operation. The overall economic analysis including capital expenditure considerations are still to be assessed.

Moving forward, the CFD modelling will continue and be refined via the mesh and solution time-steps until consistent results are obtained. Additional work on the CAPEX analysis and the subsequent NPV analysis to compare continuous and intermittent backwash regimes will also be finalised. The CAPEX considerations include implementation costs required for intermittent operation such as powered valves, process control requirements, sand movement verification systems, and upgraded compressed air delivery.

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