MIEX Resin Pump Assessment

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Abstract

Magnetic Ion Exchange (MIEX) technology is used at a Western Australian Groundwater Treatment Plant for removing dissolved organic carbon (DOC) particles (and other anions) from raw water via the use of magnetic resin beads. Although the resin in the plant is regenerated, MIEX resin must be regularly added in batches (to ensure optimal DOC removal) as it is continually 'lost' to the downstream section of the plant. This resin loss is believed to be due to attrition possibly caused by the current pumping arrangements. The objective of the project is to obtain results that inform whether new pumps should be considered to replace the existing pumps at the site. This is to be carried out by developing computational fluid dynamics (CFD) models to quantify shear fields of the pumps currently used, as well as the shear fields associated with alternative pump types or methods of fluid transport. Furthermore, microscopic analysis of the resin particles at different stages of the MIEX process is undertaken to understand particle properties, particle size distribution, and the ways in which the particles fracture.

1. Introduction

The Groundwater Treatment Plant (GWTP) uses two processes for treating incoming water – Magnetic Ion Exchange (MIEX) and advanced coagulation. It is the first large-scale MIEX facility in the world, processing up to ~100 ML/day of water in the MIEX circuit (Boarlage, 2003; Cadee et al., 2001). The plant uses a MIEX resin to remove dissolved organic carbon (DOC) particles, along with other water impurities, from a blend of bore water sources. The resin particles are magnetic, which enables these fine particles to agglomerate and settle at relatively high velocities for recovery and subsequent recycle in settler units (Boarlage, 2003; Quach, 2018; Quach 2019). Approximately 5-10% of the recovered resin is directed to the regeneration stage, with the remaining resin recycled to the contactor.

The structure of the MIEX DOC resin features a microporous methyl acrylate resin bead crosslinked with divinylbenzene (DVB). MIEX resin is highly selective for negatively charged DOC and has no affinity for other anions except sulphate. The DOC, together with some additional minor contaminants, is removed via exchange with chloride ions on active sites of the resin surface. The MIEX process is illustrated schematically in Figure 1.

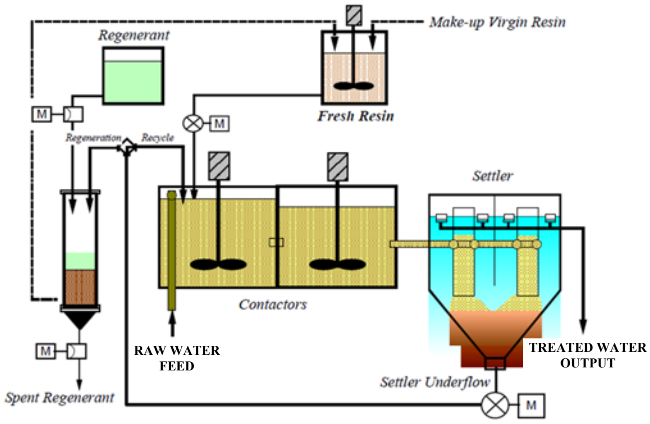

Figure 1 MIEX Flow Diagram (Slunjski et al., 2015)

Currently, the Water Corporation purchases ‘top-up’ resin to be added to the MIEX circuit as the resin is lost to the downstream section of the plant. As part of Water Corporation’s continued commitment to process efficiency and improvement practices, the organisation has realised an opportunity to reduce operating costs following a more detailed understanding of the cause(s) of resin loss.

The issue of resin loss has been apparent at the GWTP since its inception. Prior studies on the MIEX resin at the plant have considered the design and operation of the settlers, as well as MIEX resin impurities caused by particle attrition (expected from pumps). While useful, these reports do not detail reasons for resin attrition, making this area ripe for research in an attempt to reduce annual resin costs. To positively identify the pumping system as the reason for resin attrition and to generally understand the ways in which the resin particles can erode, resin sample collection and subsequent laboratory analysis is required. Particle size distributions at various points in the MIEX circuit will be analysed to evaluate particle degradation and qualitatively indicate the means of particle break down.

It is believed that a potential source of resin attrition is in the pumping system, due to the inherently high shear and turbulence associated with centrifugal pumps. In the MIEX system, there are three pump sets which contact resin particles: resin recycle/settler, fresh resin feed, and exhausted resin pumps. All three pump sets are centrifugal and fitted with ‘low-shear’ impellers. A summary of the pump operating conditions is presented in Table 1.

	Size (mm)	**Motor Rated Output (kW)**	**Speed (rpm)**	**Flow (m^3/h)**	**Head (m H_2O)**
Resin Recycle/Settler Pumps no. 1-6	150 x 100 – 245	3	980	100	9
Fresh Resin Feed Pumps no. 1, 2	80 x 50 – 200	3	1420	36	12
Exhausted Resin Pumps no. 1,2	80 x 50 – 200	3	1420	36	12

Table 1 MIEX Resin Transfer Pump Specifications

Due to the age of the existing resin recycle/settler pumps, no accompanying 3D drawings are available. Consequently, Keto Pumps was contracted to perform a 3D scan of the pump geometry to assist with the computational fluid dynamics modelling effort. A schematic of the existing resin recycle pump is depicted in Figure 2 (1).

Contact was made with various pump suppliers to explore the potential to use alternate (new) pump technologies, but detailed drawings or CAD files could not be obtained due to intellectual property limitations. (CAD files are necessary for CFD modelling as results are likely to be inaccurate if detailed internals of the pump geometries are not applied.) Keto Pumps has supplied CAD drawings for a range of different centrifugal pumps that meet the duty requirements of this application. These pump types include: K-TC4 (torq cyclo pump), K-HSF3 (open vane froth pump), and K-HS3 (closed vane slurry pump).

K-TC4 – Torq Cyclo Pump

The TC4 pump features a recessed vortex-style impeller which delivers 9.1 m of differential head at an impeller rotation speed of 700 rpm. Recessed impeller pumps typically exhibit low-efficiencies due to the lack of fluid contact with the impeller compared to their closed impeller counterparts. The TC4, operating at the specified conditions, is anticipated to have an overall efficiency of ~47%. This low impeller rotational speed, together with the recessed impeller design, is expected to minimise resin degradation and thus the TC4 may be an appropriate pump selection for practical implementation. A schematic of the TC4 pump is shown Figure 2 (2).

K-HSF3 – Open Vane Froth Pump

While the HSF3 pump was originally designed for minerals processing applications, it has been suggested as a possible alternative to the TC4 pump due to its open impeller configuration (non-recessed). The configuration is similar to the existing resin recycle pump but features a less angular impeller which may reduce resin erosion. The HSF3 pump has a higher rotational speed (980 rpm), improved efficiency (~54%), and is shown in Figure 2 (3).

K-HS3 – Closed Vane Slurry Pump

The HS3 pump has a typical closed impeller design. This pump was selected for CFD analysis as a confirmation that an open impeller design is superior for use in this resin transport application. It is unsurprising that, at an efficiency of ~68% for a 1020 rpm impeller speed, this style pump has the best head curve performance characteristics. A schematic of the closed vane slurry pump is presented in Figure 2 (4).

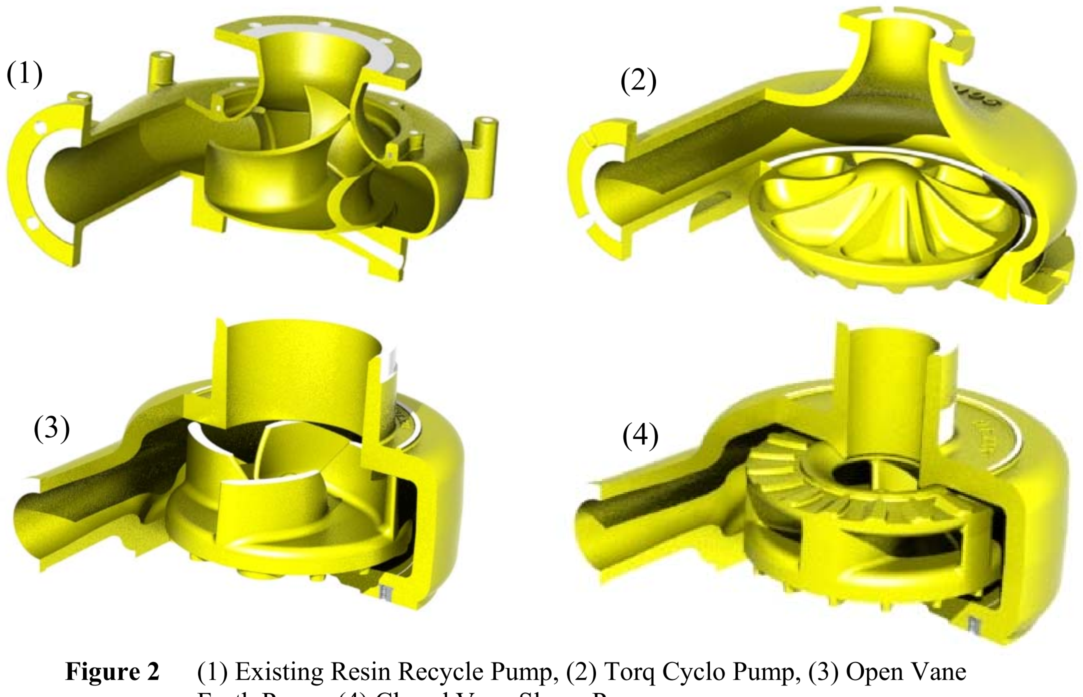

Figure 2 (1) Existing Resin Recycle Pump, (2) Torq Cyclo Pump, (3) Open Vane Froth Pump, (4) Closed Vane Slurry Pump

2. Laboratory Analysis

Characterisation of the MIEX resin particles is currently being carried out at the Centre for Microscopy, Characterisation, and Analysis (CMCA) at UWA. Scanning electron microscopy is used to determine properties, including particle composition, fracture patterns, and size distributions. Prior to conducting CFD simulations, resin analysis is important to evaluate the validity of the supplied particle size distribution, that the resin being 'lost' to the downstream sections of the plant is of expected size and magnetism, and that the primary reason for resin attrition is due to the currently installed pumping system.

MIEX resin is supplied to the GWTP as brown opaque beads in 1000L intermediate bulk containers (IBCs) which contain 90%$^{v}/_{v}$ resin in water. The resin contains 24-25% magnetic material with mean particle sizes specified to be in the range of 200-250 µm. In 2012, the resin supplier contracted CSIRO to determine a particle size distribution of virgin resin which indicated mean and median diameters of 211.5 µm and 191.2 µm respectively (CSIRO, 2012).

The plant locations that have been considered for resin sampling include: IBC, pre- and post-pump, and settler supernatant. IBC resin sampling indicates the extent of similarity between particle size distributions of the resin at the plant with that supplied by the vendor, and also provides insight into particle shape and composition before exposure to the MIEX process. The pre- and post-pump samples not only show qualitative particle degradation, but also indicate whether there is any reduction in particle size through the pump.

3. Computational Fluid Dynamics (CFD)

The Reynolds-Averaged Navier-Stokes (RANS) equations form the basis for all CFD modelling to describe the relationship between pressure and the instantaneous velocity field. Reports by Kim et. al (2014), Shah et al. (2010), and Ayad et al. (2015) favour use of the k-ω model with shear stress transport (SST) and second order discretisation solution methods. The idea behind this turbulence closure model is that it combines k-ω for describing flow near walls and k-ε for describing flow in a flow field / fully developed turbulent flows.

ANSYS Fluent®, as the industry standard software for CFD, has been selected for use in analysis of the flow field in this research. A summary of the Fluent® parameters used in the simulations are indicated in Table 2.

Parameter	**Chosen Option**	**Parameter**	**Chosen Option**
Turbulence Closure Model	SST k-ω	Simulation Time Scale	Transient
Discretisation	Second Order	Residuals	Local Scaling (10^{-5})
Inlet	Pressure Inlet	Timescale Factor	1
Outlet	Mass Flow Outlet	Timestep Size	0.0001
Casing	Non-Slip Boundary	Iterations per Timestep	10
Solution Scheme	Coupled	Number of Iterations	20000
Spatial Discretisation Gradient	Green-Gauss Node Based	Initialisation	Hybrid

Table 2 ANSYS Fluent® Setup Parameters

Mesh convergence is to be evaluated using Roache's Grid Convergence Index (GCI) which sees the number of elements in a coarse to medium to fine mesh approximately double through each stage. This is accomplished by reducing the element size by a factor of $\sqrt[3]{2}$. Therefore, it is anticipated that the resulting number of elements in each model will be ~600,000 for the coarse mesh, ~1.2 million for the medium mesh, and ~2.4 million for the fine mesh.

4. Results and Discussion

Laboratory analysis has been conducted on 2 sets of samples from the IBC, pre- and post-pump, and settler supernatant on dates 15/05/2020 and 21/07/2020. The samples have been taken from both the top (15/05/2020) and bottom (21/07/2020) of the IBC to observe any possible particle size differences. The virgin resin beads present in the IBC are spherically shaped which is to be anticipated as these particles have not yet entered the MIEX process and so no erosion has occurred. However, both samples of the virgin resin have indicated a similar particle size distribution that is noticeably smaller than expected (virgin resin size is in the range of 72-75 µm). Smaller particles are more prone to loss from the MIEX circuit which would lead to the increased addition of virgin resin and thus greater operating costs. Particle size distributions and microscopy images for the various samples are shown in Figure 3.

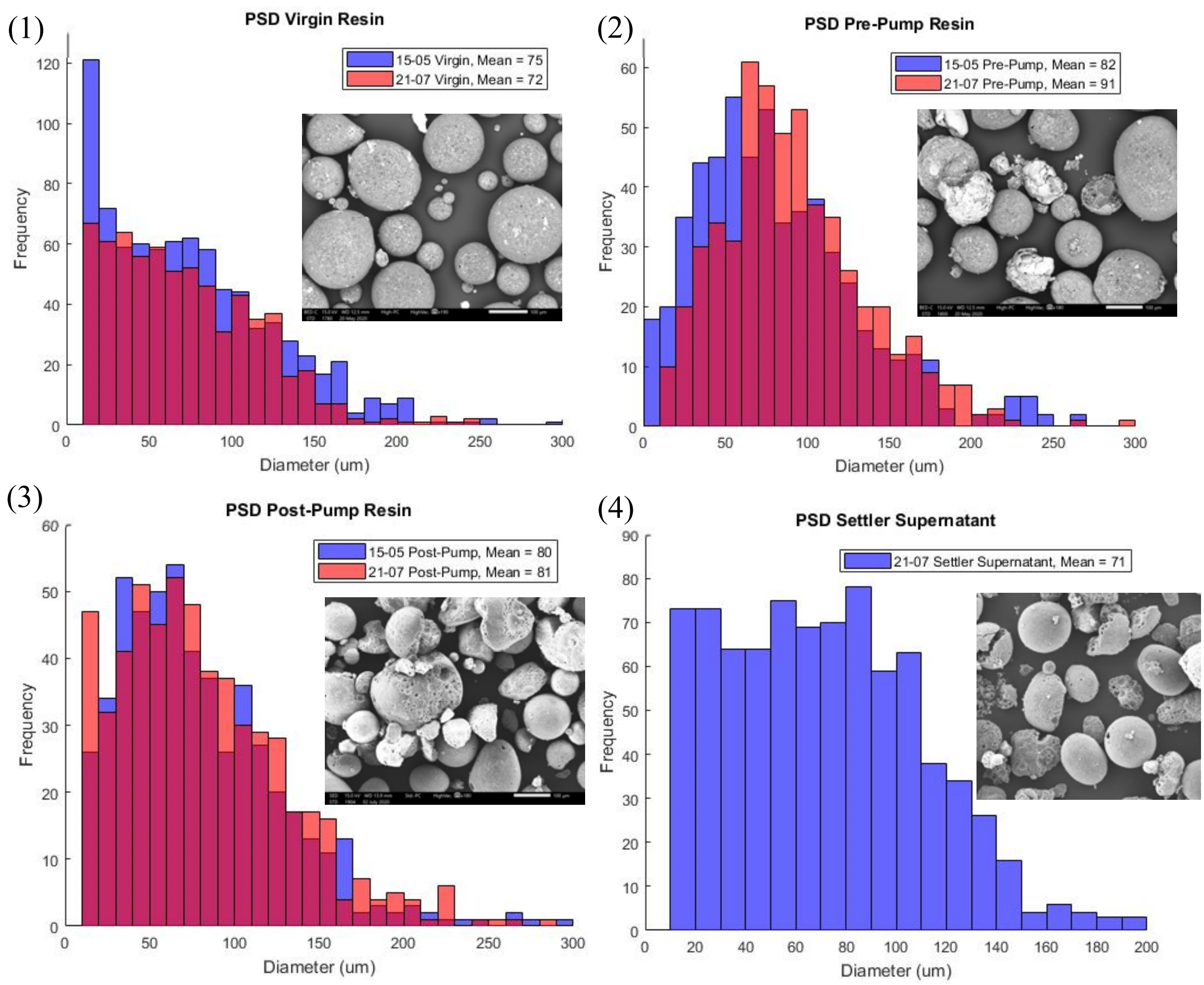

Figure 3 PSD and Microscopy of (1) Virgin Resin, (2) Pre-Pump Resin, (3) Post-Pump Resin, and (4) Settler Supernatant

Particle size analyses indicate a slight reduction in particle diameter through the pump which would imply that the pump is a prominent source of resin attrition. The settler supernatant has a larger than expected particle size as it is similar to that of the virgin resin. There is also a significant quantity of non-eroded resin particles which may suggest that some of the resin is not being used effectively in the process and is prematurely reporting to the settler supernatant.

4. Conclusions and Future Work

Laboratory particle analyses have yielded some surprising results which indicates reason for additional sample gathering (4-5 total samples) to confirm current findings. More rigorous sampling and PSD measuring techniques using purpose-built particle size analysis equipment (e.g. Horiba® instruments) is, therefore, required to confirm deviation from the expected particle size.

CFD models for the different pump types are producing head values slightly lower (~20%) than expected with convergence at 10^{-5} residuals. CFD modelling using smaller element sizes (finer mesh) is currently being undertaken to better align the pump head with the relevant manufacturers pump curves in an effort to produce reliable strain rate results for the different pump options.

5. Acknowledgements

I would like to express my appreciation to my academic supervisor Dr. Jeremy Leggoe, as well as Brendan Vernall and Troy Jansen from the Water Corporation, for providing the tools and guidance necessary to undertake this research. I would also like to extend thanks to Pete Kilner and the Keto Pumps team for their assistance and for providing proprietary information that will prove instrumental in the success of this project.

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