GREENING OF A WATER TREATMENT PLANT

Philip La Roche, CH2M Beca Ltd
Clive Rundle, CH2M Beca Ltd
Howard Wilkinson, South Taranaki District Council

ABSTRACT

South Taranaki District Council is currently constructing a new water treatment plant to supply potable water to the Hawera urban area and some industrial and rural customers. The plant is a membrane-based process with initial treated water capacity of 13,000m^3/d and ultimate capacity of 19,000m^3/d.
To meet the Council's objectives of minimising operational and whole of life costs and being environmentally responsible, several innovative features were incorporated into the plant design, including:

- A heat pump utilising bore water as the heat source to heat water for membrane chemical cleaning solutions.
- Purchase of chemicals in forms that minimise the purchase costs, primarily by using forms that reduce freight costs.
- Modifications to plant hydraulics to maximise energy efficiency.
- A self-adjusting hydraulic flocculation baffle system which minimises energy use.
- Environmentally sustainable design features included in the amenity area design.

This "greening" approach to the plant design has resulted in an estimated reduction in operating costs in excess of $36,000/annum at the initial plant capacity in comparison to conventional approaches. The cost reductions implemented are all energy related - either directly by reduced electricity usage for pumping and heating, or indirectly in the case of reduced transportation costs.

KEYWORDS

Treatment Plant Energy Efficiency, Heat Pump, Chemical Procurement

1 INTRODUCTION

South Taranaki District Council (STDC) is currently constructing a new water treatment plant to supply potable water to the Hawera urban area, as well as some industrial and rural customers. The plant is a membrane based process with an initial capacity of 13,000m^3/d and an ultimate capacity of 19,000m^3/d.

In order to meet the Council's objectives of minimising operational and whole of life costs and being environmentally responsible, a number of innovative features were incorporated into the plant design that have resulted in significant reductions in energy use and operating costs. Emphasis was placed on analyzing the operational costs of all aspects on the plant including chemical procurement and energy consumption (pumping and other uses including heating). This also extended to energy use in the amenity area, where a number of environmentally sustainable design features were included in the plant design.

2 DESCRIPTION OF FACILITIES

The raw water supply to the plant is a blend of water abstracted from the Kapuni Stream and a 450m deep bore which is being established as part of the project.

Water from the two sources is blended, passed through grit tanks to remove any settleable grit, coagulated with aluminum chloral hydrate (ACH) to remove organic matter and then flocculated with a self adjusting hydraulic baffle system. The coagulated water is then passed through a microfiltration membrane, prior to chlorination, fluoride dosing using hydrofluorosilicic acid (HFA) and pH correction using caustic soda.

The membranes are chemically cleaned to maintain the membrane permeability and to remove foulants. Cleaning will include an Enhanced Flux Maintenance (EFM) clean with a heated chlorine solution at a frequency no greater than daily, and a Clean in Place (CIP) with a heated citric acid solution, or a caustic soda and sodium hypochlorite solution at a frequency no greater than monthly.

Backwash wastes generated by the plant are settled in two sludge lagoons, which will be periodically dewatered by drainage and natural drying through the summer season with the dewatered sludge excavated and disposed to landfill. Supernatant water from the lagoons will be discharged back to the Kapuni Stream. The sludge lagoon wave band is being planted in reeds in part to create a sense that the ponds are an extension of the receiving environment, and the health of the reeds will serve as an indicator of water quality issues in the discharge.

The plant has been designed with manifolds separating backwash wastes from chemical cleaning wastes to allow for the future recovery of the backwash wastes as part of the planned staged expansion of the plant. This provides the flexibility to recover the water resource whilst minimising discharges back to the Kapuni Stream and is planned to be implemented in the future expansion.

3 PROCUREMENT

The plant is being constructed under two main contracts:

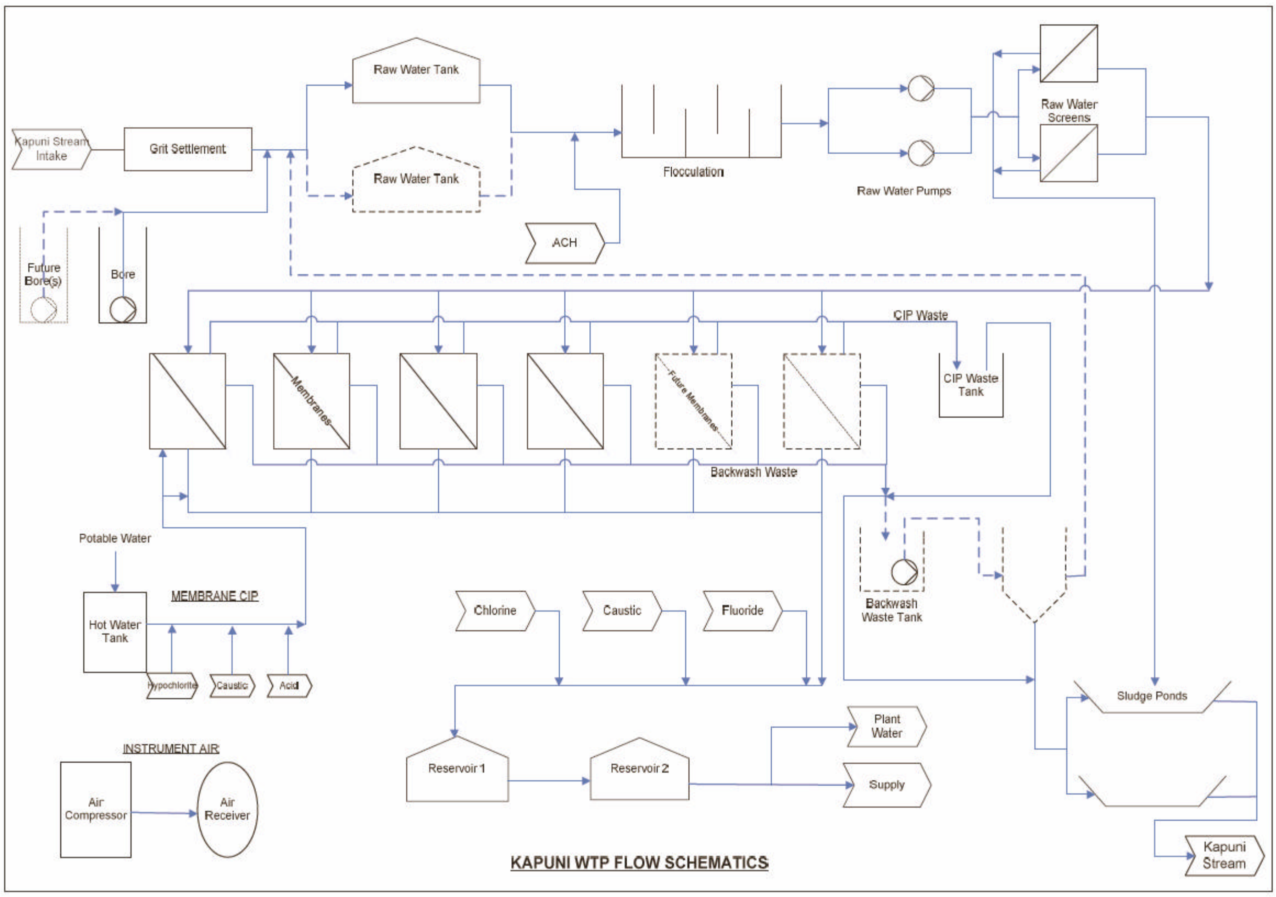
- A membrane supply/install/commission contract which is being completed by the South Taranaki Water Consortium comprising the two companies of PALL NZ Ltd and Marshall Projects Ltd.

- A civil/mechanical/electrical contract to complete the building, amenities, chemical dosing and ancillary works including sludge ponds, raw and treated water pipework. This contract is being completed by Fulton Hogan Ltd.

The project is currently under construction and commissioning is scheduled for October 2009, ready to meet the summer peak demand period.

The treatment process at the Kapuni Water Treatment Plant is shown in Figure 1.

Figure 1: Kapuni Water Treatment Plant Flow Schematic



4 CHEMICAL PROCUREMENT

The form of delivery of chemicals was considered with the aim to achieve the most economical operating cost. For most chemicals bulk delivery in standard commercially available concentrations and bulk storage tanks were sized to minimise the frequency of delivery. For some chemicals, significant changes to or departures from standard procurement practice were made. These changes are outlined below.

4.1 CAUSTIC SODA

Purchase of Caustic Soda at both 50% w/w and 30% w/w strength were evaluated. Table 1 compares both options.

Table 1: Caustic Soda Procurement Options

Strength	30% w/w Caustic Soda	50% w/w Caustic Soda
Annual Purchase Cost	$35,000/annum	$27,000/annum
Freezing Temperature	0^{o} C	12-15^{o}C

The use of 50% caustic soda would require heat tracing of dose lines and the dose tank to avoid freezing. Use of 50% caustic soda also increases the risk of failures due to freezing and blockages if heat tracing is incomplete or fails. Hence, use of 30% caustic is preferred due to the operational simplicity.

The system was therefore designed to receive 50% caustic soda and dilute to 30% on delivery, thereby reducing operational costs by $8,000/annum, due largely to the reduced freight cost and elimination of the need for trace heating.

The system uses a circulation pump to mix and dilute the caustic solution in the storage tank following delivery. The circulation pump was considered preferable over a mixer to eliminate the possibility of personnel having to enter the tank and the associated hazards if a conventional tank mixer was used. Following delivery of 50% w/w caustic, the dilution pump is started, and dilution water is metered into the discharge of the pump. Following completion of the dilution, mixing is continued to turn the tank volume over approximately 3 times to ensure good mixing is achieved. The dilution of the caustic is exothermic, and to control the effects of the heat release, suitably rated materials are selected for the dilution system and the rate of water addition is controlled.

The capital cost of the dilution system was similar to the estimated cost of heat tracing the dose lines, the energy cost is lower due to the elimination of the heating requirement and the chemical purchase cost is reduced by an estimated $8,000 per annum.

4.2 CITRIC ACID

The membrane supplier's tender was based on delivery of liquid citric acid. Citric acid is used in the membrane cleaning process and each train is expected to be cleaned with citric acid approximately monthly. By purchasing as a powder, the freight and total purchase costs are substantially reduced. A comparison of operating costs showed the annual cost could be reduced from $13,700 for liquid citric acid supply to $7,500 for purchase as a powder. Citric acid is easily dissolved into solution, and the costs of providing dissolution equipment were considered low in relation to the annual $6,200 cost saving. This approach also reduces the energy consumed transporting chemical to site.

4.3 CHLORINE

Chlorine is used both for disinfection of the treated water and as part of the chemical cleaning process for the membranes. It is estimated that 12.4 tonnes of chlorine will be consumed per annum for disinfection plus 2.7 tonnes/annum for membrane cleaning.

The available forms of chlorine considered were:

- Commercial Sodium Hypochlorite, purchased as a 15% chlorine solution.
- Chlorine Gas, in 920kg drums.
- On-site generated sodium hypochlorite by the electrolysis of a salt solution.

In comparison with chlorine gas:

- The annual operating costs of on-site generation of sodium hypochlorite was estimated to be around 25% less than that of chlorine gas ($15,000 per annum saving initially and $22,000 at the ultimate plant development).
- Commercial sodium hypochlorite costs around 2.25 times that of chlorine gas, although the cost differential is partly offset by the reduction in caustic soda dosing required.

4.3.1 DISINFECTION

The on-site generation of sodium hypochlorite results in chlorate being formed as a byproduct. Chlorate also forms in commercial hypochlorite with prolonged storage in particular. Under the Drinking Water Standards for New Zealand (DWSNZ), chlorate is limited to a Maximum Allowable Value (MAV) of 0.8g/m^3. Due to the relatively high levels of ammonia present in the bore water source, the total chlorine dose rate is high, estimated at an average of $4.25g/m^3$. At this dose rate the chlorate concentration with on-site generated sodium hypochlorite was estimated to be in the range of 50 to 100% of the MAV. This was not considered acceptable to STDC, and hence chlorine gas was selected as the form of chlorine to be used.

4.3.2 MEMBRANE CLEANING

Once chlorine gas had been selected as the preferred option for disinfection, consideration was also given to using chlorine gas for membrane cleaning,. There was a significant potential cost saving in using chlorine gas, (approximately $11,000 per annum). However the membrane supplier had not previously used chlorine gas for this application. The prime issue identified was that the cleaning efficiency is reliant on a high concentration (circa 500 to $1,000g/m^3$) slug of chlorine. With chlorine gas eductors, a delivery rate of 20kg/h was the maximum rate at which chlorine gas could be delivered. This would be utilising a 2 duty/1 standby 920kg chlorine drum configuration and vacuum regulators. Higher delivery rates would require the use of liquid chlorine delivery systems with the inherent hazards of dealing with chlorine gas under pressure and vaporization, or a greater number of connected drums. With this rate of delivery, the chlorine would be delivered over a 7 minute period and there was a concern that this extended delivery period could compromise the cleaning efficiency. On balance, sodium hypochlorite was considered the best option for membrane cleaning.

The chemical cleaning system was modified to allow for the re-use of the daily chemical cleaning solution, thereby reducing the hypochlorite consumption. The spent chlorine cleaning solution is then neutralised with sodium bisulphite prior to discharge. By re-using the chlorine solution there is a significant reduction in the use of sodium bisulphite for neutralization of the spent cleaning solution.

5 HEATING OF MEMBRANE CLEANING SOLUTIONS

5.1 EFM/CIP HEATING

Each membrane train will have an EFM clean at up to a daily frequency. Each of the three membrane trains will require $4.5m^3$ of cleaning solution at 35°C which has an annual energy consumption of 120MWh. The membrane supplier's tender was based on using 2 x 45kW electric heaters, which is the conventional approach to heating cleaning solutions. Heating water to 35°C is a duty that enables low grade heat sources to be used, and options of both solar heating and heat pump heating were identified as potentially being able to provide the required heat output efficiently.

5.1.1 SOLAR HEATING

An analysis of solar hot water heating including preliminary system sizing was undertaken. The cost analysis of the solar panels with typical annual climate data showed that installing solar panels to provide greater than approximately 50% of the total annual heating energy demands became uneconomic. The optimal solar heating system was expected to provide around 60MWH of energy/annum, with the balance of the heat input made up with conventional electrical heating. This would require approximately $90m^2$ of solar panels.

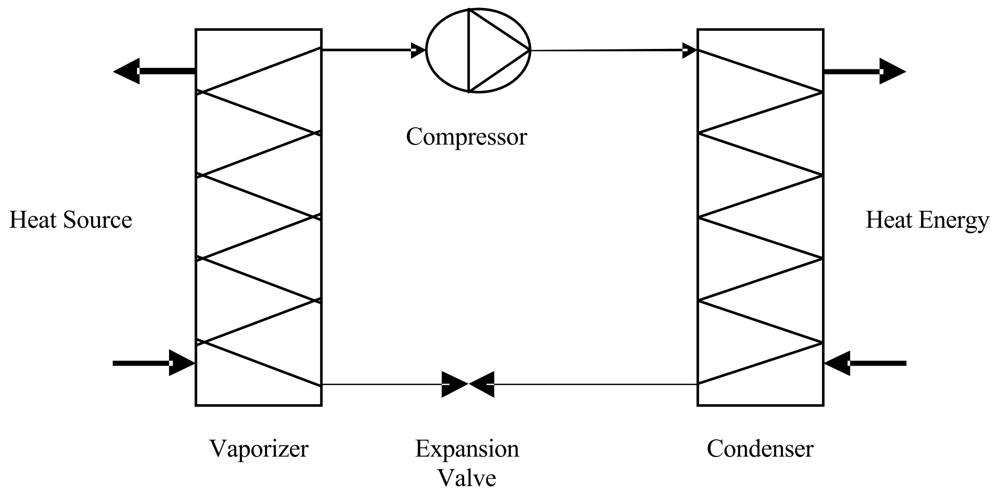
5.1.2 HEAT PUMP

Heat pumps use the liquid to gas phase change with pressure of a condensing refrigerant, allowing heat to be transferred from a lower temperature source to a higher temperature fluid. The components of a heat pump are:

- A heat source – most commonly air sourced, but water is also used.
- An evaporator – the pressure of the refrigerant is reduced to below its vapor pressure and therefore evaporates, absorbing the heat energy from the heat source.
- A compressor – The compressor both increases the pressure of the gaseous refrigerant and circulates the refrigerant through the evaporator /condenser circuit.

- A condenser – At the higher pressure, the gaseous refrigerant condenses, releasing heat energy.
- Expansion Valve – the expansion valve causes the pressure of the refrigerant to drop, allowing the refrigerant to again evaporate in the evaporator.

Figure 2: Heat Pump Schematic



For the Kapuni application, the bore water is expected to be available at a consistent year round temperature of 18°C. This is significantly above the average river temp and above winter ambient air temperatures. Being above the ambient river temperature in winter makes this a very effective heat source in the period where heating loads will be highest.

Options of using a conventional ambient air source heat pump or using bore water were considered. The bore source has the benefits of providing a year round consistent performance and eliminates problems of icing associated with ambient air source heat pumps. A water source heat pump was therefore selected as the basis for comparison.

Based on the information provided by the vendor, a heat pump suitable for this application will produce 36kW heat energy with a 7.3kW compressor. Allowing for the additional energy consumed by the circulation pumps, an efficiency of approximately 400% is achievable, or 25% of the energy required in comparison to conventional electric heating.

5.1.3 COMPARISON OF HEATING OPTIONS

Table 2 provides a comparison of the EFM/CIP heating options.

Table 2: EFM/CIP Heating Options

	Electric Heating	**Solar + Electric Heating**	**Heat Pump**
Equipment Capital Cost	$10,000	$54,000	$36,000
Estimated Equipment Installation Cost	-	$25,000 (1)	$15,000 (2)
Annual Energy Requirement (3)	121 MWH/annum	61 MWH/annum (4)	$31 MWH/annum (5)
Annual Energy Cost (6)	$24,312	$12,156	$5,580
10 year, 8% Capex/Opex NPV	$173,141	$160,570	$88,442

	Electric Heating	Solar + Electric Heating	Heat Pump
(Cost)			

(1) Allowance for hot water tank and panel/pipework installation
(2) Allowance for pipeline from bore and assumes heat coils direct to CHN tank.
(3) Assumes 3 x 4.5 m^3 batches per day.
(4) Estimated annual average energy demand met by solar = 50%
(5) Based on 7.3 kW heat pump, plus 1.5 kW allowance for water circulation pump, giving 36kW heat output
(6) Based on 18 c/kWH

The heat pump option stands out as being the best option. It is estimated to use less electricity than the solar heating proposal, and has a lower capital cost. It can be relied on to provide the required heat output regardless of the prevailing weather conditions. The heat pump was therefore selected for implementation.

The actual contract variation cost for the installed heat pump exceeded the concept design estimate by approximately $40,000, partly due to the one of nature of the installation and partly due to additional costs of incorporating the additional functionality to provide underfloor heating for the facility (refer section 7.1).

The system uses 3 l/s of water from the borehead, circulated through the heat pump loop and returned to the bore pipeline. Water will be drawn from the chemical solutions tank, and pumped in a loop through the heat pump exchange and returned to the chemical solutions tank. This recirculation would continue until the design 35°C temperature is reached in the chemical solutions tank.

The heat pump will be a custom built heat pump, and will have two condensers in series. The first condenser will have water or cleaning solution circulated from the cleaning solution tank, with circulation continuing until the 35°C temperature is reached. This condenser will be constructed in titanium for chemical resistance. The second condenser in series will provide heat to the underfloor heating to the amenity area as described in section 7.1, via a water circulation circuit to a buffer storage tank.

It was important to ensure any risk of contamination of the supply was minimal as the bore water is used as the heat source and is returned into supply. A twin wall evaporator was therefore specified. This evaporator has an air gap between the bore water circulation and refrigerant circuit. Should either side fail, the liquid will drain from the gap between the two sides, preventing contamination.

6 OPTIMISATION OF PLANT HYDRAULICS

6.1 HYDRAULIC GRADE LINE

The water treatment plant is situated approximately 1.5km downstream from the intake. As is typical in the Taranaki landscape, the raw water pipeline has around a 2% fall along the pipeline route. This results in an excess head at the inlet to the treatment plant.

Various options were considered to fully utilise the available hydraulic head at the plant inlet, minimising the pumping required through the membrane plant. The selected option was to construct a tall tank (8.5m above ground level), with the top water level close to the hydraulic grade. Every additional metre of tank height reduces the plant energy consumption by approximately 3.5kW at the ultimate plant production rate and around 2.2kW at average flows saving approximately $3,500/annum.

6.2 RAW WATER PUMP DUTY

Pumps are commonly selected based on the maximum operating duty point, and hence achieve their best efficiency at this duty point. However the average or typical operating point is often significantly different to this duty.

The original intent was to use 75kW raw water (membrane feed) pumps in order to meet the worst combination of conditions. Closer examination revealed that the typical duty is only 11kW. The motor size was able to be reduced down to 55kW with minimal compromise on the peak duty. The motor efficiency at the typical duty point was thereby improved, saving an estimated 0.7kW per motor or 1.4kW reduction with 2 pumps typically operating. This seemingly small energy reduction provides an estimated $2,200 reduction in the annual energy cost.

6.3 HYDRAULIC FLOCCULATION

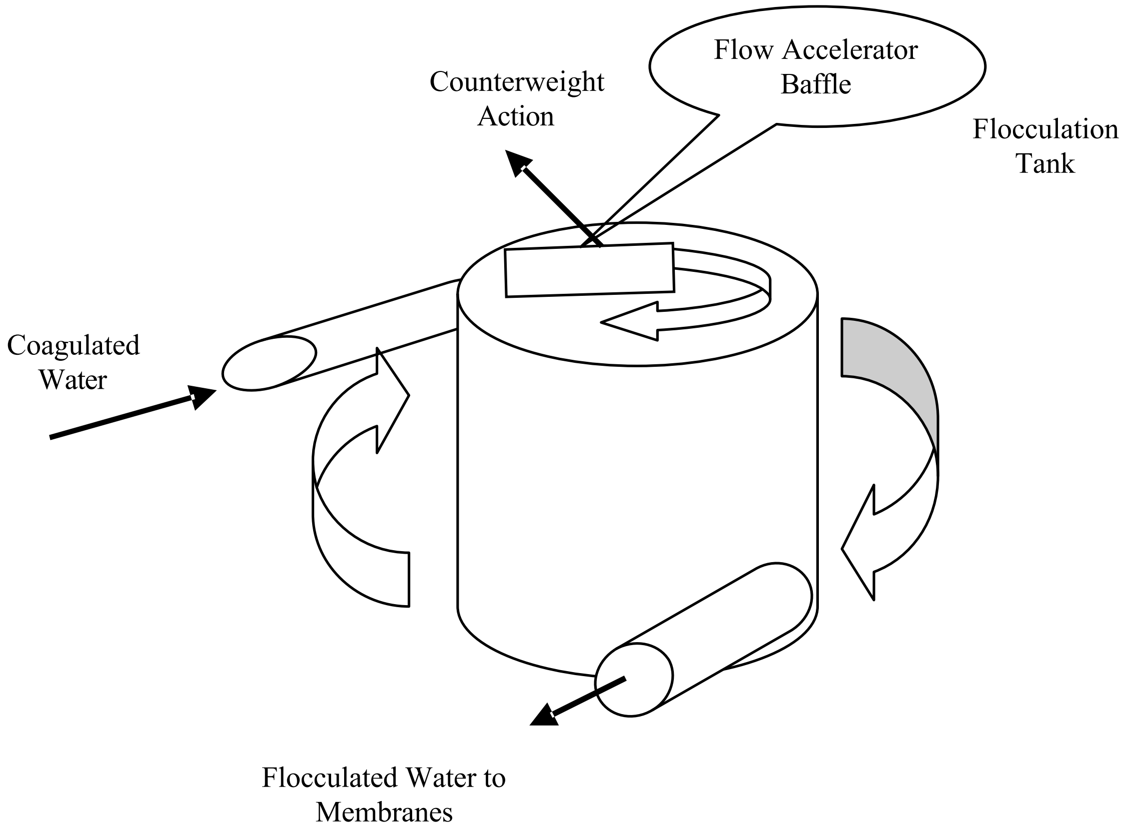
A flocculation process is included ahead of the membranes to ensure an adequate floc is formed, maximizing viral removal and minimising membrane fouling.

Flocculation mixing energy is typically provided either by mechanical mixers or hydraulic flocculation systems which utilise fixed baffles to create turbulence and the mixing energy required.

The benefits commonly quoted for mechanical systems over hydraulic systems are that they provide the ability to adjust the mixing intensity through variable speed drive control of the motors and that the mixing intensity is independent of the flow rate. With conventional hydraulic flocculation systems which utilise fixed baffles, the mixing intensity varies with the square of the flow, and hence there is a substantial variation in mixing energy across the range of flows typical in municipal water treatment plants.

The flocculation system designed for the Kapuni water treatment plant utilises a hinged "flow accelerator baffle" with an external counterweight. The baffle opens up automatically as the flow increases maintaining a uniform mixing intensity across the full range of plant flow rates. The ability to adjust the mixing intensity is also provided by adding or removing counterweights.

Figure 3: Hydraulic Flocculation System Schematic



7 BUILDING SERVICES

The Kapuni plant will become South Taranaki District Council's operations base from which their other plants will be serviced. The plant therefore includes a significant amenities area to cater for the operators. Elements were included in the building design to minimise energy consumption for the building services.

7.1 AMENITY AREA HEATING

The opportunity was recognised to utilise the heat pump to provide low cost heating of the amenity area.

Underfloor heating is ideal for an amenity area of this type because it provides radiant heat, making people feel warm even though the air temperature may still be relatively low. It is therefore less affected by heat loss through opening doors which occurs frequently in an operating plant situation.

A second condenser has been included in the heat pump to provide heating to the amenity area using the single heat pump. Heat is stored in a buffer tank, and circulated in a closed loop through the underfloor heating.

The underfloor heating was also extended to the chlorine drum room, to provide heat for the vaporization of the chlorine gas and prevent icing of the chlorine drums.

7.2 AMENITY AREA COOLING

In order to maintain a comfortable working environment in summer, a number of measures are incorporated into the building design.

Exterior Louvers and Eaves

Substantial eaves will be provided on the north facing side of the amenity building, cutting down glare and heat gain during the hottest part of the day.

Exterior louvers will be installed on the west facing windows to cut down the heat gain from the low angle, hot afternoon sun. The eaves would not be sufficient to cut down the heat from this low angle afternoon sun.

Roof Space Ventilation

To avoid heat gain from the roof during the summer, passive cross ventilation will be provided through the ceiling space, between the roof and insulated ceiling. Ceiling insulation was also increased above the minimum requirements to R 3.0, 150mm fiberglass batts in order to reduce heat loss when heating and heat gain from the roof during hot periods.

7.3 LIGHTING

The use of natural lighting was maximised through both the amenity area and the plant area. North facing clerestory windows are used in the plant area to provide natural lighting to the plant area. These clerestory high level windows also open to allow passive natural convective cooling during summer, rather than using mechanical ventilation.

High efficiency fluorescent lighting was used in all areas. Recognising that much of the lighting needs will be met by natural lighting most of the time, the switching of the lighting has been arranged such that one circuit turns on only approximately 20% of the lights, which is expected to be sufficient to boost the lighting levels for the majority of the time, with the balance of the lighting able to be turned on when required, (eg working at night).

8 CONCLUSIONS

Focused consideration of the environmental and energy impact through the design process can yield significant reductions in the energy consumption and operating costs that will be incurred in the operating lifecycle of water treatment plants. Optimised performance can be achieved by carefully examining chemical procurement options, plant hydraulics, alternative energy sources and building services options.

A number of the approaches used on this plant are innovative or unique applications. This was the first application of a heat pump to heat CIP chemicals that we are aware of. On the back of this project, the membrane vendor PALL is now implementing a heat pump at another project. By pushing the implementation of innovative technologies, these technologies become commonplace in the industry, and with time, incremental improvements in the efficiency of the delivery of potable water are achieved.

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