# Feasibility of Grey Water Reuse for Coal Dust Suppression in a Coal-Fired Power Station

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*Abstract:* - Currently, potable water is being used for coal dust suppression in a power station in Gladstone, Australia. The feasibility of reclaiming a close source of $2^{nd}$ class effluent supplied by the Gladstone city council, to replace the potable water supply for coal dust suppression is investigated in this paper. Due to the nature of the water, specific attention is given to understand and determine the physical properties of the $2^{nd}$ class effluent in regards to environmental and work place health and safety (WH&S) issues. UV treatment system has been identified as a suitable treatment technology in order to raise the rating of $2^{nd}$ class effluent to Class A which is suitable for coal dust suppression. Safety and environmental concerns of UV treatment system is elaborated. Then, the fluid flow system design and calculation is presented to meet the requirements for safe operations of reclaimed water re-use for coal dust suppression.

*Key-Words:* - Grey water, re-use, dust suppression, fluid systems, water quality, UV treatment technology

## 1 Introduction

Grey water (neither being fresh or heavily polluted), also known as “sullage”, is named from its appearance and composition of its chemical and biological contaminants [1]. It comprises about 50-80% of residential and municipal waste water. Although, from the treatment and pollution prevention point of view, the grey water decomposes much more quickly and is easier to treat and eliminate pollution compared to black water (heavily polluted water), but still considered to be a health and pollution hazard if released into natural environment untreated. Despite this, grey water is often reused for irrigation in drought zones. Some of the benefits of grey water reuse can include lower fresh water use, less train on failing septic tank, groundwater recharge, plant growth and reclamation, etc [1].

Presently there is a great need to save water throughout the Gladstone region, especially in industry, due to extreme drought conditions and previously low levels in the Awonga Dam. Coal handling facility of power station uses estimated 1 to 3% water per weight of the supplied coal for dust suppression at the unloading bays. Potable water is being used on coal dust suppression at the train unloading bays of power station (coal terminal for the power station). Dailey about 6 trains, each weigh 7000 tons, of coal is being used in the power station. Therefore, the amount of water required, @ 3% of the coal supplied, equates to 1260 kL (worst case scenario) per day for coal dust suppression. Potable water can be saved by reclaiming water from power station’s maturation pond, 700m far from site, which operates by accepting $2^{nd}$ class effluent from the Gladstone city council in the inlet side. A period of 60 days oxidation is used to kill bacteria and viruses in the water before the water finishes its cycle at the outlet side of the pond.

The feasibility of grey water reuse to replace the current potable water supply for coal dust suppression is investigated in this paper. Specific attention is given to understand and determine the physical properties and quality of the effluent in regards to environmental and work place health and safety issues. A suitable technology for the treatment of effluent is identified and described in order to raise the rating of effluent to Class A which is suitable for coal dust suppression. Safety and environmental concerns of the identified treatment system is elaborated. An appropriate fluid system is necessary to supply treated reclaimed water from the maturation pond to the unloading bays. An outline of fluid flow system design and calculation is presented in order to meet the requirements for safe operations of reclaimed water re-use for coal dust suppression.

## 2 Water Quality and Environmental Issues

The major risk of human contact with this wastewater is infection from micro-organisms. Of the wide variety of human pathogens present in wastewater, those of particular concern are: viruses, bacteria, protozoa and helminths. Conventional treatment – primary and secondary followed by disinfection – does not substantially remove helminths and protozoa. The water quality of waste water can be described by *BOD* (a measure of the amount of oxygen used in the biochemical oxidation of organic matter), *NTU* **(**nephelometric turbidity units), *pH (*a measure of the hydrogen-ion concentration in a solution), *SS* **(**suspended solids measured in water), *Total Coliforms (*an indicator of faecal contamination of water - FC and E.Coli) and *Turbidity* **(**a condition in water or wastewater caused by the presence of suspended matter). Six samples of waste water from maturation pond have been analysed and the results are presented in Table 1.

Table 1: Properties of water from maturation pond

| Sample | FC (counts/100 ml) | E.Coli/thermo. (counts/100ml) | Nitrogen (mg/L) |
|---|---|---|---|
| 1 | 27 | 0 | 4.2 |
| 2 | 130 | 0 | 5.5 |
| 3 | 860 | 0 | 4.2 |
| 4 | 9 | 0 | 4.6 |
| 5 | 27 | 0 | 3.8 |
| 6 | 66 | 0 | 3.7 |

Table 1(contd.)

| Test | Phosphorus (mg/L) | BOD (mg/L) | SS (mg/L) | pH |
|---|---|---|---|---|
| 1 | 1.5 | 15 | 25 | 9.6 |
| 2 | 1.4 | 19 | 30 | 9.9 |
| 3 | 1.1 | 16 | 15 | 9.8 |
| 4 | 0.86 | 16 | 40 | 9.8 |
| 5 | 0.67 | 10 | 25 | 9.8 |
| 6 | 0.87 | 13 | 30 | 9.7 |

Also,

- Turbidity = 5.7 NTU
- %UV transmission @ 254nm = 56%.
- Particle size, 50% is smaller than 56.1 μ with largest particle being 400 μ at 0.2% retained.

The specifications for Class A water, suitable for dust suppression, available from Australian guidelines are as follows [2]:

- Coliform count<10 (e.coli & thermotolerant)
- Turbidity <2 NTU
- BOD < 20mg/L

Therefore, the water from maturation pond is not suitable for coal dust suppression mainly because of higher turbidity content. Tertiary treatment of 2nd class effluent through disinfection units and filtration should be done in order to raise the rating of this water to Class A, which is suitable for dust suppression. Tertiary treatment processes include [3]:

- Detention in lagoons
- Conventional filtration via sand or dual media
- Dual media or membrane conventional filtration, both may include coagulant dosing
- Artificial wetland processes
- Pathogens and viruses reduction through UV disinfection system and nutrient reduction (level of treatment = industrial usage).

Among these systems, UV disinfection system offers a number of operating advantages. An UV system is safe and easy to operate compared to other systems. UV system has a small footprint, thus can readily be adapted to fit into an existing treatment facility. The use of UV does not inject any taste or odor into the processed water, nor does it produce any undesirable by-products. In this study UV treatment system is recommended, the details of which are described below.

# 3 UV Treatment Systems

## 3.1 Treatment Technology and Effectiveness

UV light has been known for over 100 years as an effective method for inactivating waterborne pathogens and viruses [4]. UV light disinfects when it is applied to the water at a specified intensity and length of time, rendering waterborne microorganisms “microbiologically dead” by penetrating the cell wall and affecting the microorganisms DNA such that it is unable to reproduce. In other words, the principle behind UV light disinfection is that the genetic core of the bacteria and virus cell is ruptured from the light. UV light then effect the thymine-adenine band by breaking the band and forming a double bond. With this formation of the double bond the DNA cannot split itself anymore, rendering propagation of the microorganism terminated [3].

Light with a wavelength of 265nm is most effective. Dose rate of UV required to kill bacteria/viruses can be stated as; UV dose rate (D) = Intensity (I) × time (t) where dose rate (D) is in mj/cm$^2$, intensity (I) in mw/cm$^2$ and time (t) is in second.

Normally, UV dose rates and contact time which depends on flow rates are known for microorganisms to kill. Details about intensity can be found elsewhere [3,5]. Three factors that affect the performance of an UV disinfection systems are water clarity (transmissivity), exposure period and radiation energy. These three factors must be balanced to treat large volumes of water quickly, safely and economically. The most significant way to increase treatment effectiveness is by removing suspended sediment and other particulates via primary filtration. Filtration allows exposure periods and energy consumption to be decreased, and flow rates increased. Optimal treatment effectiveness is achieved when the transmissivity of the water approaches 100%. UV treatment is significantly improved with fine scale filtration e.g. filtration <100 μ. The effectiveness of UV radiation treatment is measured by determining the amount of energy required to achieve a specified reduction in target populations. Table 1 provides the range of energy inputs required to achieve 99% population reductions in a variety of organisms using continuous-wave UV techniques [4].

Table 1: Energy Requirements for UV Treatment Systems on Selected Organisms [4].

| **Organism** | **Energy required ($mW\text{-}s/cm^2$)** |
|---|---|
| Cryptosporidium[1] | 330 |
| Escherichia coli[1] | 7-16 |
| Staphylococcus aureus[1] | 7 |
| Vibrio cholerae[2] | 7-13 |
| Infectious hepatitis[2] | 8-15 |
| Poliovirus[2] | 6-13 |
| Nematode eggs[3] | 92 |
| Chlorella vulgaris[4] | 22 |
| Blue-green algae[4] | NA |
| Infectious pancreatic necrosis[5] | 60 |

*Note*: [1]Bacteria, [2]Viruses, [3]Protozoan, [4] Algae, [5]Fish Related Disease.

UV treatment process requires water flow through a "treatment chamber" where it is "dosed" to disinfect the target microorganisms. The treatment chamber must be installed in the water supply pipe between the primary filtration system (if applicable) and the dust suppression system at the unloading bay as shown in schematic diagram of fluid flow system in Fig. 1. The details of fluid flow system design are given in Section 4. The depth of UV transmittance through water in the treatment chamber and water clarity is inversely related. Clearer water (low concentration of suspended sediments) allows for deeper UV transmittance whereas more turbid water (higher concentrations of suspended sediments) decreases UV transmittance. Suspended sediment absorbs and deflects UV energy, thereby decreasing the effectiveness of the treatment process to kill microorganisms. To compensate for turbidity, most treatment plants have an "auto feedback system" that continually adjusts the UV radiation (i.e., power) to keep the system operating at a predetermined treatment level.

In this study, UV system has been scoped on %UV transmission and turbidity, and coliform counts. Also, filter has been scoped based on particle size analysis of the effluent, chosen 110 μ. These units raise the quality of 2$^{nd}$ class effluent from maturation pond to class A which is suitable for coal dust suppression.

### 3.2 Safety and Environmental Concerns

There are several specific safety concerns that should be addressed when UV technology is applied for water disinfection. The first issue is the use of high voltage electricity (220/440 V) to power the system. The operation of the UV radiation systems should raise no additional concerns if the system is installed and maintained properly. If the system is improperly installed or poorly maintained, there is risk of electrical accident. The second issue is the use of mercury-containing lamps to generate the UV radiation. The lamps are protected within the treatment chamber by the use of a quartz sleeve. The use of mercury containing lamps could be a concern if there is high potential for physical damage during storage and installation. The third potential safety issue is related to UV exposure to plastic pipe works and fittings. If UV radiation is exposed to plastic pipe works for prolonged periods, the pipes could potentially degrade and fail and the risk of injury or operational failure of equipment would occur.

The major environmental concern with UV treatment is accidental release of low-level mercury if mercury-containing lamps are broken or improperly disposed. Mercury is a well-known environmental toxicant, the release of which is regulated by numerous laws and agency programs. Another environmental concern, which has postulated but not investigated in detailed by others is genetic mutation. Aquatic microorganisms that survive the UV treatment process could be genetically mutated (by damage caused to their DNA from action of UV photons).

## 4 Fluid Flow System Design

Power plant's maturation pond is 700m far from coal dust suppression site as mentioned earlier. The fluid flow system has been divided into two sections, Section 1 and Section 2 as shown in Fig. 1 and defined in right hand side as follows:

Sec 1: From the submersible pumps at the maturation pond to reclaimed water storage tank [2 ML storage].

Sec 2: From the outlet side of the storage tank to the dust suppression system at the unloading bays (track hopper building) through a booster pump and filter/UV treatment units.

The schematic diagram of the fluid flow system, with components and relative levels, is shown in Fig. 1. Theoretical considerations, calculation procedures and the results of calculations are discussed below.

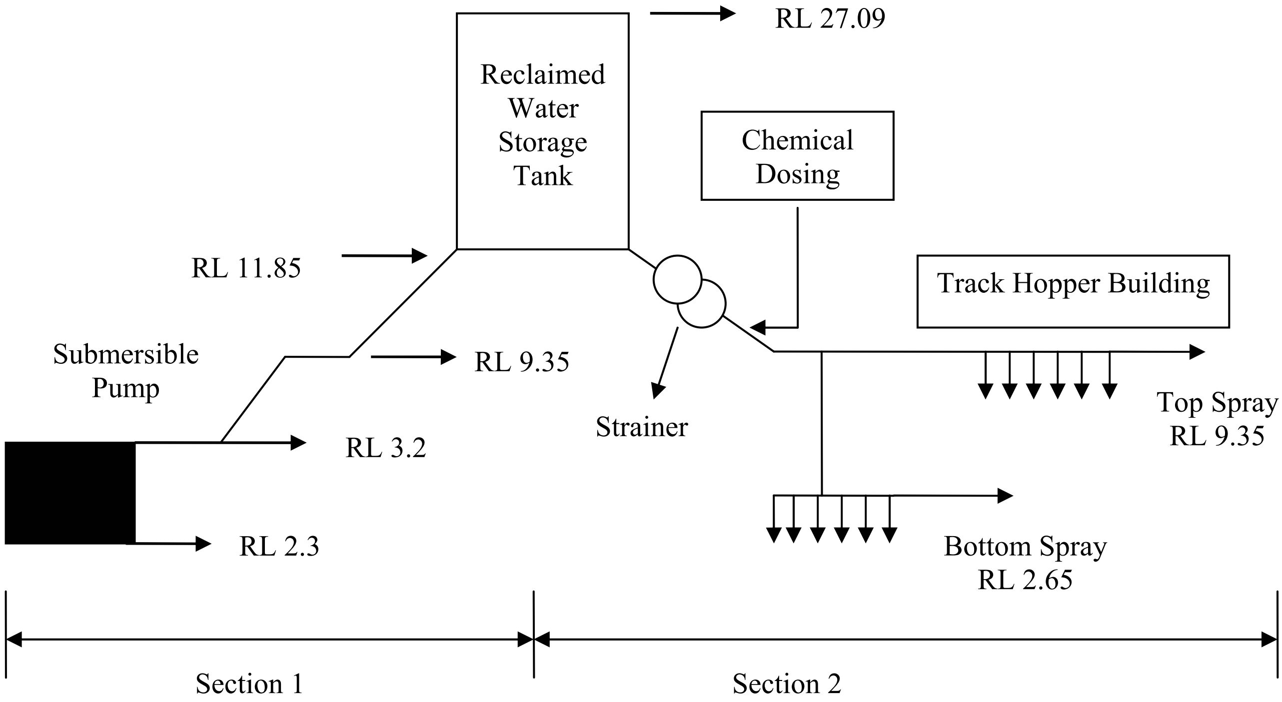


Fig. 1: Schematic diagram of Section 1 and 2 of the fluid flow system

### 4.1 Theoretical Consideration

Bernoulli's equations were used to determine duty curves of the fluid flow system [6]. The equations used were:

$$E_p = (Z_2 - Z_1) + \left(\frac{P_2}{\gamma} - \frac{P_1}{\gamma}\right) + \left(\frac{V_2^2}{2g} - \frac{V_1^2}{2g}\right) + Losse \qquad (1)$$

Where, $E_p$ is the required pump head which can be converted to fluid energy required by the pump impeller, Z is the elevation level at the designated point (in meter), P is the pressure acting at the designated point (in Pa), V is the fluid velocity in the pipe (in m/s), and Losses is the summation of pipe and fitting losses of the system (in meter).

The flow rate (Q) was assumed conserve, given by,

$$Q = AV \qquad (2)$$

where, A is the cross-sectional area of pipe in $m^2$ and V is the fluid velocity in m/s.

Pump power, in kW, can be determined by,

$$Pump\ Power = \rho g Q E_p \qquad (3)$$

Cavitation (net positive suction head available, NPSHA) and specific speed ($N_s$) check was done by,

$$NPSHA = \frac{P_o}{\rho g} - \frac{P_v}{\rho g} - Z_s - h_L \qquad (4)$$

Where $P_o$ = atmospheric pressure (Pa), $P_v$ = vapor pressure fluid (in Pa), $Z_s$ = height of suction side (in m) and $h_L$= head loss in suction side (in meter).

$$N_s = \frac{N\left(Q^{\frac{1}{2}}\right)}{\left(gE_p\right)^{\frac{3}{4}}} \qquad (5)$$

Where N = speed of pump in rad/s

Losses were calculated as follows:

$$h_L \ pipe \ friction = f \frac{L}{d} \frac{V^2}{2g} \tag{6}$$

$$h_L \ valves = k_L \frac{V^2}{2g} \tag{7}$$

$$h_L \ enl\arg ement = k_L \frac{(V_1 - V_2)^2}{2g} \tag{8}$$

Where f = pipe friction factor, L = length of pipe (in meter), V = velocity of fluid (in m/s), d = internal diameter of pipe (in meter) and $k_L$ = valve friction factor.

## 4.2 Calculation Procedures

The following steps were used to calculate system head curves for both Section 1 and Section 2.

1. Appropriate flow rates (in l/s) were chosen to calculate fluid velocity using Eq 2 for each pipe id change. Point 1 (inlet) and point 2 (outlet) were marked.
2. Elevation levels and pressure conditions of points 1 and 2 were recorded.
3. Pipe, valve and fitting losses for the fluid system were determined using Eqs 6, 7 and 8. $k_L$ factors were obtained from manufacturers specifications [7].
4. $E_p$ (pump head) required to overcome frictional losses was calculated using Eq 1.
5. Pump power was calculated using Eq 3. This power can be converted to electrical energy of motor with respect to pump and electrical motor efficiency and power factor.
6. Cavitation check of the pump was done by using Eq 4. If NPSHA>NPSHR {NPSHR from pump charts}, cavitation shall not occur.
7. Specific speed check was done using Eq 5 to evaluate what type of pump is required for this design.
8. Steps 1 to 7 were repeated for a range of flow rates to produce $E_p$ results. $E_p$ vs flow rate were plotted on a certain pump chart. Intersection between $E_p$ and impeller curve gives duty point. Duty point also gives NPSHR and pump efficiency and power from intersection of relevant graphs.

## 4.2 Results and Discussion

Using the above mentioned steps, the calculations were made based on the following known and assumptions for Section 1. Polyethylene pipe PE80 (12m welded lengths) was chosen to use for this work. Grade 12 (PN 12.5 respectively) and outer diameter of 200mm was selected for use. Point 1 and 2 are known between RL's 2.3 and 27.09m respectively. Flow rates were set from 14 to 32 l/s [2 l/s intervals]. The losses for a set flow rate of 16 l/s were taken from manufacturer's catalogue. The calculated results of Section 1 for a flow range of 14 l/s to 32 l/s are given in Table 2.

Table 2: Pump power, cavitation and specific speed check for Section 1

| Flow Rates (L/s) | Ep (m) | Power (kW) | Power (HP) |
|---|---|---|---|
| 14 | 29.95 | 4.01 | 5.41 |
| 16 | 31.76 | 4.98 | 6.68 |
| 18 | 33.57 | 5.93 | 7.95 |
| 20 | 35.67 | 7 | 9.39 |
| 22 | 37.91 | 8.18 | 10.97 |
| 24 | 40.29 | 9.49 | 12.72 |
| 26 | 42.59 | 10.86 | 14.57 |
| 28 | 45.6 | 12.53 | 16.8 |
| 30 | 48.39 | 14.24 | 19.1 |
| 32 | 52.36 | 16.44 | 22.04 |

Table 2 (contd.)

| Flow Rates (L/s) | NPSHA | Ns 1500 RPM | Ns 3000 RMP |
|---|---|---|---|
| 16 | 9.1 | 0.268 | 0.536 |
| 18 | 9.1 | 0.272 | 0.545 |
| 20 | 9.1 | 0.274 | 0.549 |
| 22 | 9.1 | 0.275 | 0.55 |
| 24 | 9.1 | 0.274 | 0.549 |
| 26 | 9.1 | 0.274 | 0.548 |
| 28 | 9.1 | 0.27 | 0.54 |
| 30 | 9.1 | 0.267 | 0.535 |
| 32 | 9.1 | 0.26 | 0.521 |

KSBajax (E100-340, impeller 311 mm) submersible pump was selected for this duty. The duty curve for this pump is shown in Fig. 2. The duty point was found as 15 l/s @30.5 m head, Efficiency = 40% [8].

For Section 2, calculations were done from the storage tank [point 1] to the dust suppression sprays [point 2]. This was completed to collect head losses for the system at two different outlets as the pressure was known for connection into the dust suppression system and the outlet at sprays. These values were than averaged to complete the finalized duty curve. Note; impeller size of section 2 pump is 324mm. System was designed with solenoid valves completely open to find duty point. Restriction shall add loss and reduce flow rate along impeller curve to 13 l/s [min].

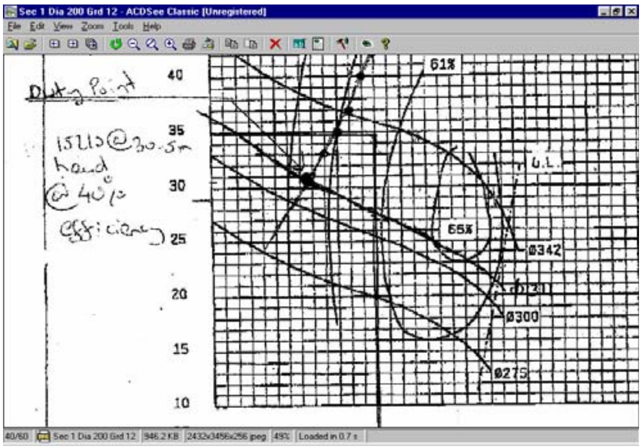


Fig. 2: Duty curve for KS Bajax (E100-340, impeller 311 mm) submersible pump.

Flow rates were set from 13 to 22 l/s. For a set flow rate of 22 l/s, the losses were taken from manufacturer's catalogue. The calculated results and duty curves, similar to that shown in Table 2 and Fig. 2 for Section 1, were produced for Section 2. Due to the page limitation these results and duty curves are not provided here.

KSBajax (Mega M80-315, impeller = 324 mm) pump was chosen for this duty. The duty point was found as 22 l/s @36 m head, Efficiency = 71%.

NPSHA for both sections 1 and 2 were greater than NPSHR, therefore no cavitation will occur at duty of 15 l/s and 22 l/s. The maximum pressure of the system shall occur if the system becomes blocked, this is referred to as a "dead head". Tracing the pump impeller curve back to the 0 l/s flow rate and quoting the head loss value, one can find the dead head pressure. From pump charts the following values were found;

- Maximum pressure in Section 1 = 36m+atm {where atm=101.3 kPa) = 450 kPa (note $p=\rho gh$)
- Maximum pressure in Section 2 = 39m+atm+(27.09-13) height from pump slab to top of tank = 620 kPa.
- Operational pressure in Section 1 =30.5m + atm = 400 kPa.
- Operational pressure in Section 2 = 36m + atm + (27.09-13) = 590 kPa

In regards to minimum flow problems, KSBajax stated that pumping against a dead head is much better for the pump than having an overrun problem. Pumps can quite easily operate as low as 20% of the most efficient flow rate on the curve without causing damage.

## 5 Conclusions

This paper presented a view into natural resource recycling and savings potable water use for coal dust suppression. Issues related to environmental, WH&S, water quality and requirements to be met for safe operations of reclaimed grey water were addressed. An appropriate technology (UV treatment) to raise the rating of 2nd class effluent to class A which is suitable for dust suppression has been discussed. Attention has also been given towards the design of fluid flow system. Calculations were made to determine duty curves for fluid systems. Cavitation and specific speed check were completed for the selected pumps. The recommended system is feasible and safe to construct and operate to reach water targets for industry.

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