Effect of Temperature on the Performance of Rheofloc: Conductivity Removal from RO-reject

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***Abstract*— South Africa is an arid country with an annual average rainfall less than half of the world's average rainfall. The industrial sector uses 11% of this limited amount of water. Eskom is one of these users. Within the water treatment system at the Grootvlei power station, reverse osmosis (RO) is used. The retentate from the membranes is pumped into a sump. This water can be treated for further usage, which ensures that the plant abstracts less water from the environment. Rheofloc, an inorganic polymeric flocculant was used in this study in conjunction with lime treatment, to reduce the conductivity of the water. As the conductivity decreases, the number of ions in the water decreased. The jar test method consisted of the addition of the coagulant and flocculant during rapid mixing for 5 minutes at 240 rpm, thereafter the lime was added to increase the pH to 10.1 during slow mixing which occurred for 90 minutes at 80 rpm. This was done at 40°C and at 60°C to observe the effect that temperature has on the reduction of the conductivity in the water. Results showed that the reduction of conductivity levels was higher at 60°C. This is due to the increase of the rate of reaction with an increase in temperature. Thus the treatment of RO- reject is preferred at 60°C to achieve effective removal of ions with the potential of scale formation**.

***Index Terms*—** Conductivity removal, Lime softening, Temperature effect

I. Introduction

South Africa is an arid country with an average rainfall of 492 mm, more or less half of the 985 mm average rainfall worldwide. An estimation was made that the supply of water will be inferior to the water demand by 2025, hence the prospect of water shortage problems in the future [1-12]. Surface water is used by Eskom for several purposes, including in the cooling systems.

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The highly saline water resulting from such systems is often treated through chemical methods and reverse osmosis (RO) [13-20]. The reject from reverse osmosis contains high amount of ions, therefore requiring treatment prior to further passing through the RO membrane. The RO-reject from the Grootvlei power station situated near Balfour, Mpumalanga, was considered in this study.

Reverse osmosis is used to remove dissolved solids from the water through a semipermeable membrane. Several scaling agents such as calcium and magnesium compounds are unable to pass through the membrane. The brine that contains these particles is the RO-Reject. This brine can be reused in the cooling system if treated; this will allow the plant to reduce water intake from the environment [20]. The above mentioned scaling agents should be removed from the water as scaling can negatively influence the efficiency of downstream processes such as heat exchange. Flocculation and crystallization were used to achieve the removal of these scaling agents. Rheofloc, an inorganic polyamine was used in conjunction with calcium hydroxide (lime) and a polymeric coagulant [21].

The polyamines are cationic polymers with medium molecular weight, which are mostly linear. They are soluble and can be used over wide pH ranges. This is important as the pH should be increased to a value of 10.1. The molecules have a lengthy structure which enables them to wrap impurities together to increase floc size and weight. This promotes settling and stability of the flocs [22-28].

The lime is used to increase the pH to 10.1. This ensures that the calcium and magnesium ions are insoluble in the water. Thus making it possible to remove these ions from the water. At a pH of 10.1 the $Mg(OH)_2$ becomes insoluble and precipitate. Along with the above mentioned polymeric and polyquarternary amines, strontium, calcium and magnesium can be removed by making insoluble larger and heavier [29].

The conductivity will be used to observe the effect of temperature on the efficiency of the flocculation and crystallization process. Conductivity is the potential for a substance to conduct or transmit heat, electricity and sound. The presence of metal ions increases the conductivity of a solution. Thus a reduction in the conductivity indicates the removal of metal ions in water. The conductivity is measured with a probe that is connected to a conductivity meter and measured in Siemens per centimeter (S/cm) [30]. To use water in the cooling system of a power plant, the conductivity should be less than 4 mS/cm.

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II. Methodology

The jar test method was used to conduct these experiments. It consists of a six paddle stirrer with a variable speed motor. A simplified schematic illustration can be seen below:

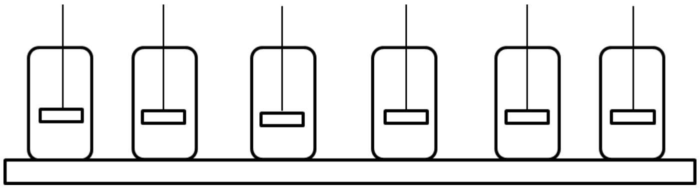

Fig 1: Representation of the jar test apparatus

The jar test is connected to a water bath to ensure that the temperature of the samples remain constant.

Six 1000 ml beakers were each filled with 500 ml of RO-Reject sample water. These beakers were placed in the jar test where they were kept until a temperature of 40°C was reached. Thereafter the coagulant (Rheofloc 5023) was added into the beakers. Each beaker contained a different dosage of the coagulant. These dosages were 0.2ppm, 0.5ppm, 0.7ppm, 2ppm, 5ppm and 7ppm.

The flocculant (Rheofloc 5414) was added. The dosage was kept constant in each beaker, 0.2ppm. Rapid mixing then occurred for 5 minutes at 240rpm. Thereafter slow mixing occurred for 90 minutes at 80 rpm. At the start of the slow mixing period, lime was added, 220 ppm. This dosage was necessary to achieve the set pH. After the slow mixing a settling time of 30 minutes occurred. The above mentioned method was used for another three different flocculant dosages (0.5ppm, 1ppm and 7ppm). This whole process was repeated at 60°C.

The pH was measured to ensure that it was high enough for optimal removal of scaling agents.

The conductivity was measured by inserting the probe into the sample.

III. Results and Discussion

The results of the conductivity tests can be seen in the tables below:

Table I: Conductivity results with a 0.2 ppm flocculant dosage @ 40°C

0.2 ppm flocculant dosage @40 ℃		
Coagulant dosage (ppm)	Conductivity after treatment (mS/cm)	Conductivity removal (%)
0.2	3.61	8
0.5	3.64	7
0.7	3.62	8
2	3.60	8
5	3.60	8
7	3.66	7

Table illustrates the conductivity and conductivity removal at 40°C and a 0.2 ppm flocculant dosage. It can be compared to the same dosage at 60°C. It should be noted that the starting conductivity of the water differs between the 40°C and 60°C tests as the water was collected at different times through the year. Thus the conductivity removal is the important parameter to consider.

Table II: Conductivity results with a 0.2 ppm flocculant dosage @ 60°C

0.2 ppm flocculant dosage @60 ℃		
Coagulant dosage (ppm)	Conductivity after treatment(mS/cm)	Conductivity removal (%)
0.2	3.45	46
0.5	3.43	46
0.7	3.44	46
2	3.43	46
5	3.42	46
7	3.40	47

It can clearly be seen that the increase in temperature has an enormous effect on the conductivity removal in RO-Reject water. The conductivity of the treated water is also low enough to be suitable for use in the cooling water system.

Table is the representation of the conductivity and conductivity removal with a 0.5ppm flocculant dosage at 40°C.

Table III: Conductivity results with a 0.5 ppm flocculant dosage @ 40°C

0.5 ppm flocculant dosage @40 ℃		
Coagulant dosage (ppm)	Conductivity after treatment (mS/cm)	Conductivity removal (%)
0.2	3.69	7
0.5	3.68	7
0.7	3.68	7
2	3.65	8
5	3.63	8
7	3.62	8

This can be compared to the same flocculant dosage at 60°C as can be seen in Table .

Table IV: Conductivity results with a 0.5 ppm flocculant dosage @ 60°C

0.5 ppm flocculant dosage @60 ℃		
Coagulant dosage (ppm)	Conductivity after treatment (mS/cm)	Conductivity removal (%)
0.2	4.32	32
0.5	4.38	31
0.7	4.41	31
2	4.41	31
5	4.39	31
7	4.37	32

As can be seen from Table , once again the dosages at 60°C were more efficient; however, the treated water cannot be used in the cooling system as the conductivity is more than 4 mS/cm.

The 1ppm flocculant dosage at 40°C can be seen in Table .

TABLE V: CONDUCTIVITY RESULTS WITH A 1 PPM FLOCCULANT DOSAGE @ 40°C

1 ppm flocculant dosage @40 ℃		
Coagulant dosage (ppm)	Conductivity after treatment (mS/cm)	Conductivity removal (%)
0.2	3.65	8
0.5	3.65	8
0.7	3.65	8
2	3.57	9
5	3.71	6
7	3.72	6

This can be compared to the same flocculant dosage at 60°C as can be seen in Table .

TABLE VI: CONDUCTIVITY RESULTS WITH A 1 PPM FLOCCULANT DOSAGE @ 60°C

1 ppm flocculant dosage @60 ℃		
Coagulant dosage (ppm)	Conductivity after treatment(mS/cm)	Conductivity removal (%)
0.2	3.95	38
0.5	3.94	38
0.7	3.96	38
2	3.96	38
5	3.94	38
7	3.84	40

At 60°C, there is a conductivity removal increase of more or less 30%. The conductivity is also low enough to use the water in the cooling system. Thus implying that with a flocculant dosage of 1ppm, 60°C is more efficient than 40°C.

The last flocculant dosage that was used was 7ppm. The 7ppm flocculant dosage results at 40°C can be observed in Table .

TABLE VII: CONDUCTIVITY RESULTS WITH A 7 PPM FLOCCULANT DOSAGE @ 40°C

7 ppm flocculant dosage @40 ℃		
Coagulant dosage (ppm)	Conductivity after treatment (mS/cm)	Conductivity removal (%)
0.2	3.71	7
0.5	3.71	7
0.7	3.75	5
2	3.76	6
5	3.76	6
7	3.72	6

This can be compared to the 7ppm flocculant dosage at 60°C as can be observed in Table.

TABLE VIII: CONDUCTIVITY RESULTS WITH A 7 PPM FLOCCULANT DOSAGE @ 60°C

7 ppm flocculant dosage @60 ℃		
Coagulant dosage (ppm)	Conductivity after treatment (mS/cm)	Conductivity removal (%)
0.2	3.94	38
0.5	3.97	38
0.7	3.94	38
2	3.98	38
5	3.96	38
7	3.96	38

As can be seen from table, the conductivity of the treated water is less than 4 mS/cm. Thus this water can be used in the cooling system. The higher temperature has a greater effect on the conductivity remobval as well.

A trend can be seen in the figure below on the effect different coagulant and flocculant dosages have on the conductivity removal at 40°C and at 60°C.

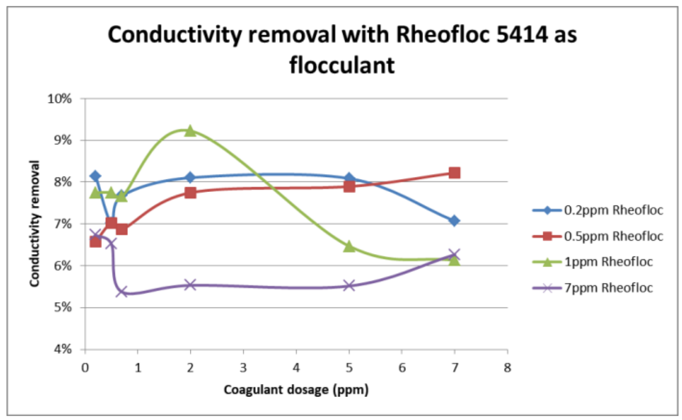

Fig 2: Conductivity removal @ 40°C

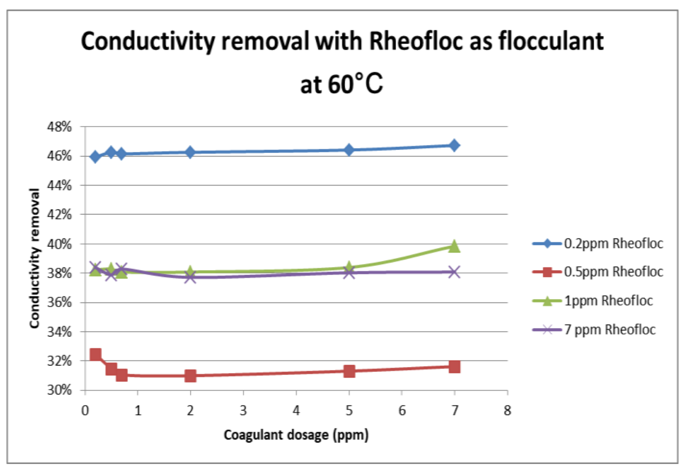

Fig 3: Conductivity removal @ 40°C

As can be seen from Figure 1 and Figure 2, the conductivity removal is more efficient at higher temperatures, as well as less of the flocculant is needed at higher temperatures. This confirms the literature by [31] that hot lime softening is more efficient than cold lime softening due to the reduction in solubility of calcium, magnesium, barium and strontium with an increase in temperature. Precipitation of these ions will occur more readily with the decrease in solubility which in turn will reduce the dissolved solids in the water, reducing the conductivity in the water.

IV. Conclusion and recommendations

There is a clear effect of temperature on the conductivity removal when using Rheofloc as coagulant and flocculant in conjunction with lime. For optimal conductivity removal, 0.2 ppm Rheofloc 5414 and 0.2 ppm Rheofloc 5023 should be used at 60°C in conjunction with 220 ppm lime. With this dosage, the conductivity of 3.45 mS/cm was measured, which is below the required 4mS/cm. This resulted into a conductivity reduction of 46%, therefore decreasing the amount of ions in solution. Thus indirectly implying that the chances for scaling could to occur have been reduced by half.

Recommendations include that other flocculants should be tested to observe if a better decrease in conductivity can be achieved and to test if using other chemicals such as sodium hydroxide, can be used to increase the pH faster.

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