The Effect of Different Types of Wash Water on Solar Panel Efficiency

JC van der Linde[1], and CJ Schabort[2]

Abstract— Solar energy is not only renewable, but also the most abundant energy source available to meet the global energy demand. Photovoltaic (PV) solar panels play an important role in converting the solar energy into usable electricity. Extensive research is being done to improve the efficiency of solar panels. One factor that may impact the efficiency of solar panels is the cleanliness of the panel surface. Manufacturers of solar panels specify that distilled water should be used in the cleaning of solar panels. Distilled water, however, is more expensive to other wash water options. In this study different types of wash water were used to clean solar panels, namely Potchefstroom municipal tap water, demineralised water and distilled water. The effect of the wash water type on the solar panel efficiency was noted in the two sets of experiments that were conducted. In one set of experiments the solar panels were sprayed with the wash water and afterwards mechanically cleaned using a cloth. In the second set of experiments the solar panels were only sprayed with wash water to allow evaporation of the wash water and deposits to precipitate onto the solar panel surface. It was found in both sets of experiments that the type of wash water had no considerable effect on the efficiency of the solar panels. It could be concluded that either tap water, demineralised water or distilled water can be used to wash photovoltaic (PV) panels on the short term.

***Index Terms* —**photovoltaic, solar efficiency, solar energy, solar panels

I. Introduction

According to Sotehi, et al. [1], solar energy is the most abundant renewable energy source available. It has been determined that 84 minutes of solar radiation on the earth could produce enough energy for the entire world for one year. With solar energy's affordability, quantity and lower environmental impacts compared to other energy sources, it can be seen as an important contributor to renewable energy. There is an increase in global energy demand due to the increase in global population. Fossil fuels contribute around 81% to the global energy supply, with about 30% of the world's energy produced by coal and more than 40% of the world's electricity produced through coal[2]. According to Eberhard, et al. [3], 70% of South Africa's energy is generated by fossil fuels and 90% of the country's electricity was generated by fossil fuels. Unfortunately fossil fuels are being depleted rapidly. According to Shafiee and Topal [4], oil will be the only fossil left after 2042 and will be exhausted by 2112. Furthermore, fossil fuels are the main contributor to greenhouse gas emissions [2].

To curb both the problem of depletion and pollution, renewable energy production has grown exponentially. According to Anon. [2], renewable energy sources include wind, solar, water, geothermal, hydropower, bio-energy and ocean power. It is reported that by 2020, 26% of global energy will be produced using renewable sources. Between 2013 and 2014 the production of renewable energy grew by 2.3%. By the end of 2014, 13.8% of energy were produced using renewables, 4.8% through nuclear and 0.3% through other methods. Renewable energy is thus the fourth largest source of energy globally[2].

Solar energy is the fastest growing renewable energy globally, with an increase of 42.6% from 1990 to 2014 [1]. It is estimated that about 16% of the world's electricity could be generated by PV panels by 2050 and an additional 11% by other solar energy sources [2]. Solar energy has also been found to be more cost-effective than non-renewable energy sources [1].

According to Abd-Elhady, et al. [5], there are five factors that may influence the efficiency of PV panels, namely surface temperature, adsorption of solar radiation, solar tracking, design configuration and the cleanliness of the panel surface.

The first factor is the surface temperature of the panels. According to Abd-Elhady, et al. [5], overheating of the solar panels decreases the efficiency of these panels. Improvements made on the surface temperature include the use of photovoltaic/thermal (PV/T) systems (Abd-Elhady, et al. [5]), by addition of channels (Damian, et al. [6]), the addition of fins (Tonui and Tripanagnostopoulos [7]) and jet impingement devices (Royne and Dey [8]).

The second factor is the adsorption of solar radiation by the surface of the panels. A study was done by Abd-Elhady, et al. [5] to improve the amount of light transmitted to the PV panel, which will in turn increase the system's efficiency. Oil coatings were added to the surface of the solar panels, which increased the light transmission of the panels. According to Anon. [9], a dye-sensitizing cell could be added to the interior of PV cells which would ensure that a larger variety of light wavelengths can be adsorbed and thus more energy can be produced. Different coatings can be added to the PV panels to improve their efficiency.

The third factor is solar tracking. Sun tracking can be also used to improve the efficiency of PV panels. Solar tracking

JC van der Linde[1] is with the School of Chemical and Minerals Engineering of the North West University, Potchefstroom, South Africa

CJ Schabort [2] is with the School of Chemical and Minerals Engineering of the North West University, Potchefstroom, South Africa

can be applied by using one axis and two axis sun tracking systems. The tracking systems are used to increase the collection of energy by keeping The PV panels perpendicular to solar radiation which is the optimum position for the generation of solar energy [10]. According to Mousazadeh, et al. [11] the efficiency of solar panels can be increased by 10-100% depending on the time of year and the geographical location of the solar PV plant. Another study done by Ren, et al. [12] indicates that there are two main methods for optical alignment of solar panels. The first is the mechanical method, and the second is the optical alignment method.

The fourth factor is the design configuration of the solar panels. The efficiency of PV panels can be improved by the correct designing of the panels [10]. Bhagoria, et al. [13] investigated the use of transverse wedge shaped ribs. A study conducted by Bhushan and Singh [14] proved that a solar duct with circular protrusions had an enhancement of 3.8 times and 2.2 times for the Nusselt number and the friction factor respectively.

The fifth and final factor that influences solar panel efficiency has to do with the cleanliness of the panels. Most of the large solar farms are located in semi-arid regions. These regions have dust that accumulate on the solar panels which in turn reduce the efficiency of the panels. The particulates contaminating the optical surface absorb and scatter parts of the incident light. There are different dust properties that are relevant to the drop in efficiency of PV panels. These properties are size and charge distribution [15].

There are four main methods used to clean solar panels. These are manual, automatic, natural and passive methods[15].

Passive methods include the modification of solar panels to ease cleaning and to minimize the adhesion of the dust on the surface. A natural way of cleaning PV panels is with rainfall. A study conducted by Hegazy [16] revealed that smaller particles will most likely be collected on high incline panels and larger particles will be more likely to collect on low – inclined panels. Thus depending on the area where the solar panels are installed, the incline of the panels will change to ease natural cleaning.

The most common way of cleaning solar panels is using distilled water with detergent and a soft cloth in small scale systems. In large scale systems, high pressure water jets are used in combination with brushing. According to El-Nashar [17], the pressure water jets are one of the best methods to clean solar panels. A study done by Moharram, et al. [18] concluded that over a long period of time, washing with surfactants reveals a higher efficiency than panels washed with only water. Automated cleaning systems were developed to minimize the amount of water used when washing the PV systems. An example of a cleaning system is the azimuthal angle tracking system[19]. Another automated cleaning system is the application of nozzles along the top of PV arrays. When the system is activated, a washing solution is sprayed over the surface of the panel through the nozzles, thus washing the panels[15]. Robots have been developed as well to wash solar panels [20]. Dust accumulation thus plays a role in the efficiency of PV panels and it is important to find an effective, economically viable method to remove the dirt accumulated on solar panels.

There were no previously documented studies found on determining which water type is best for the washing of solar panels.

There are three different types of wash water that will be used in this study. These include Potchefstroom municipal tap water, demineralised water (tri-osmosis) and distilled water.

Potchefstroom's municipal water tends to be hard due to the high carbonate and sulphate content, which can precipitate as salts on the surface of solar panels and decrease the efficiency of the panels[21]. This is the most cost effective water source that is used in this experiment. The estimated tariff is 71c/L in Johannesburg[22], thus this can be taken as an approximate value for water prices in South Africa.

In the case of demineralised water most of the minerals and salts, including calcium, magnesium, sodium, chloride, sulphates, nitrates and bicarbonates, have been removed [23]. There are thus less substances that can precipitate on the solar panels. This water can be bought for R1.20/L.

Distilled water has all the minerals and salts removed through boiling and re-condensing. This allows the removal of salt ions[23]. Although distilled water is the cleaner than the other two water sources that will be used, it is also the most expensive of these three sources and in some cases can be up to R20/L.

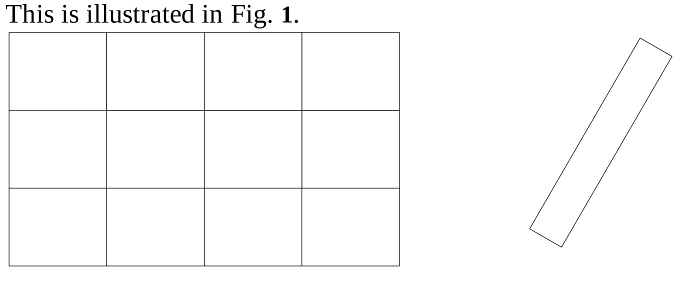
This study was executed to determine if the water type that is used to wash PV panels have an effect on the efficiency of the panels.

II. Experimental Setup

A. Solar panels and inverters

Systems 2 and 3 of the NWU solar farm have been used in these experiments in tandem with inverters 2 and 3. These two systems differ in angle and configuration.

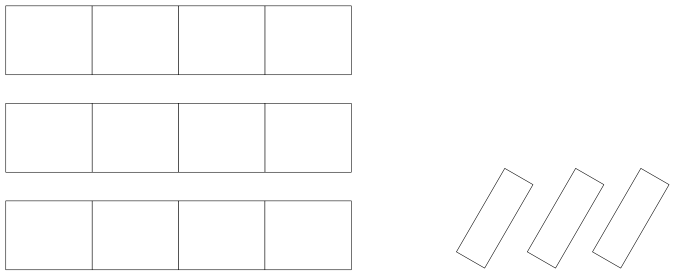
System 2 consist of 12 PV panels that are fitted next to each other without gaps in between them. They consist of three rows of four panels. The panels are coated with glass. This is illustrated in Fig. **1**.



a b

Fig. 1: Top view (a) and side view (b) of system 2

System 3 consist of 12 PV panels that are connected in tree rows with four panels in each row. There are spaces between the three rows. These panels are coated with glass. This system is illustrated in Fig. **2**



a b

Fig. 2: Top view (a) and side view (b) of system 3

B. Extracting data from inverters

A laptop was used with a data cable to collect the stored power data (daily averages) from the inverters. The data was extracted after each type of wash water was used. Instantaneous readings could also be taken from the inverter screen when required.

C. Conductivity, pH and Oxidation Reduction Potential (ORP)

Probes connected with the Lovibond SensoDirect 150 was used to measure the conductivity, pH and the ORP of the samples. .

D. Sulphates

A buffer and photometer were used to determine the sulphate concentration of the samples.

E. Alkalinity

The end point method was used to determine the alkalinity. A 98% sulphuric acid solution was used to titrate the samples to reach a pH of 4.5, while the sample was continuously stirred. The Lovibond Sensodirect 150 was used to determine the temperature and the pH of the samples.

F. Metal concentration

The samples were sent for an Inductively Coupled Plasma optical emission spectrometry (ICP-OES) analysis to determine the concentration of the various metals in the water.

III. Experimental Procedure

A. Determining the comparison factor

A factor had to be calculated to compare the two solar panel systems. These two systems' energy generation will differ because of the difference in their configuration. This was done by dividing the power generated by system 3 with the power generated by system 2.

$$Comparison\ factor = \frac{Power\ generated\ by\ System\ 3}{Power\ generated\ by\ System\ 2}$$

As system 3 was washed and system 2 not washed, an increase in this factor, means that the washing had a positive effect on the efficiency of the solar panels. A decrease in this factor, means that the washing had a negative effect on the efficiency of the solar panels.

B. Washing the solar panels

Prior to the execution of the experiments, the panels were not washed for 14 days to justify the factor being used.

After these 2 weeks, two methods of washing were used during these experiments. Both methods comprised of an initial step where all the solar panels of system 2 and 3 were washed using demineralised water. The first method entailed spraying the panels of system 3 with wash water using a fertilizer sprayer after sunset to eliminate the effect of a surface temperature reduction of the PV panel efficiency. The panels of system 2 were not sprayed or washed during the experimental period to aid as a control. This method was first performed using Potchefstroom municipal tap water as wash water every evening for a period of 2 weeks. At the end of the 2 week experimental period, all the solar panels were washed again using demineralised water. The above mentioned experimental procedure was repeated using demineralised water as wash water for 2 weeks and lastly using distilled water as wash water for 2 weeks. After each of the 2 week periods, the aim was to determine the quantity and quality of deposits on the solar panels. Demineralised water with a known composition was used to wash the deposits from the solar panels. This water sample was collected and analysed. The change in composition was used to determine the quantity and quality of the deposits on the solar panels. The comparison factor was also determined for the specific type of water. A total of 6 weeks were thus required for the first set of experiments.

The second method comprised spraying the panels with wash water at 12:00 noon without any mechanical cleaning afterwards. Once again only system 3 was washed and system 2 was left unwashed for the experimental period as a control. These experiments were conducted at 12:00 noon to ensure evaporation of the wash water and the precipitation of salts. The first wash water to be used was Potchefstroom municipal tap water. The PV panels were sprayed daily for two weeks with the wash water. Samples of the deposits were collected after 2 weeks and the comparison factor was determined. The panels of both systems were washed with demineralised water to ensure all solar panels were clean. The procedure was repeated with demineralised water as wash water. No distilled water was used for the second experimental method as no precipitation of salts were expected. A period of 4 weeks was required to complete the second set of experiments.

IV. Results and Discussion

A. Factor calculated before washing

Fig. 3 shows the power generated by each of the solar panels in the two weeks prior to the experiments where the control factor was calculated.

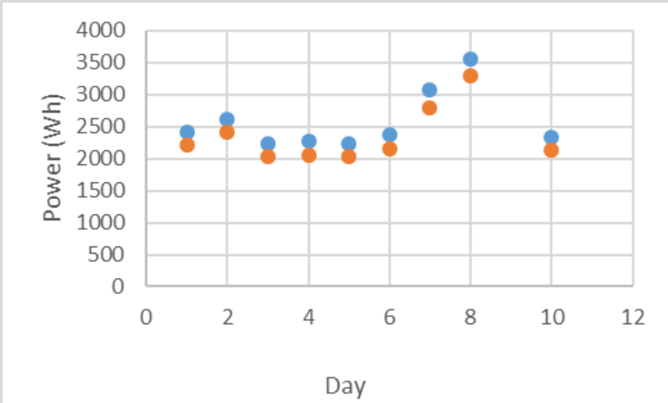


Fig. 3: Calculating the control factor (•System 2, • System 3)

In this graph it can be seen that the power generated varies and on some days it is higher than on other. This is due to solar radiation strength on the different days. The average comparison factor, f, was determined to be 0.91 ± 0.01

B. Spraying of wash water followed by mechanical cleaning of solar panels

Fig. **4** is the representation of the results obtained from the experiment conducted where Potchefstroom municipal water was used in tandem with mechanical washing.

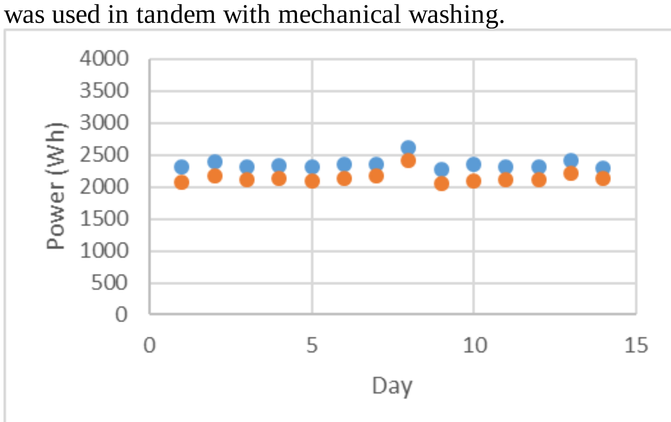


Fig. 4: Potchefstroom water with mechanical washing (•System 2, • System 3)

As seen in the graph, the power generated each day is constant. The average comparison factor, f, determined over the 2 week period was 0.91 ± 0.01, which is identical to the initial comparison factor.

Washing the solar panels with Potchefstroom tap water with a cloth has no effect on the efficiency of the solar panels in 2 weeks.

Figure 5 shows the results obtained from washing the panels with demineralised water in tandem with mechanical washing.

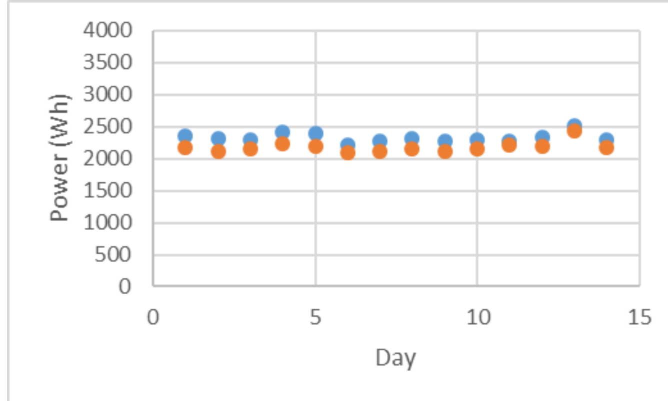


Fig. 5: Demineralised water with mechanical washing (•System 2, • System 3)

As seen from Figure 5, the daily power generated by the two system is constant over the 2 weeks. The average control factor, f, was determined to be 0.94 ± 0.01

Using the factor determined above, it can be seen that there is an increase in the factor, but not substantial enough to conclude that demineralised water in tandem with mechanical washing improves the efficiency of the solar panels.

Figure 6 is the representation of the results obtained from washing the panels with distilled water with mechanical washing.

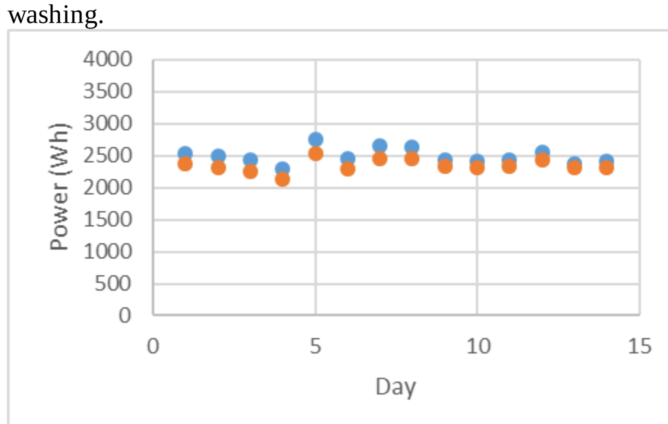


Fig 6: Distilled water with mechanical washing (•System 2, • System 3)

Figure 6 indicates that the daily power generated by the systems are more or less constant. The average control factor, f, was determined to be 0.94 ± 0.01

Using the factor determined above, it can be seen that the factor is higher than the control factor, but not substantial enough to conclude that using distilled water with a cloth increases the efficiency of solar panels.

Thus with mechanical washing there are no conclusive evidence that over a period of two weeks one type of water used to wash the panels are superior to the others.

C. Spraying of wash water without any mechanical cleaning of the solar panels

Figure 7 represents the data obtained from the experiment where Potchefstroom municipal tap water was used without a cloth.

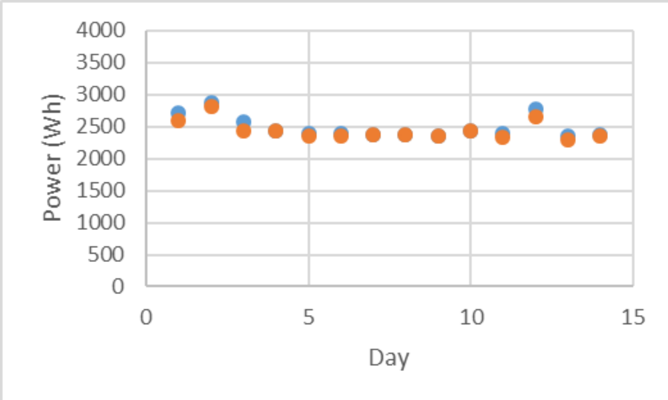


Fig. 7: Potchefstroom water without a mechanical washing (•System 2, • System 3)

Figure 7 indicates that the daily power generated by the systems are more or less constant. The average factor, f, was determined to be 0.98 ± 0.01.

This factor is larger than the control factor, which indicates an increase in the efficiency of solar panels. This increase is however from the decrease in temperature, as is shown in Figure 9.

Figure 8 is the representation of the results obtained by washing the solar panels with demineralised water and no mechanical washing.

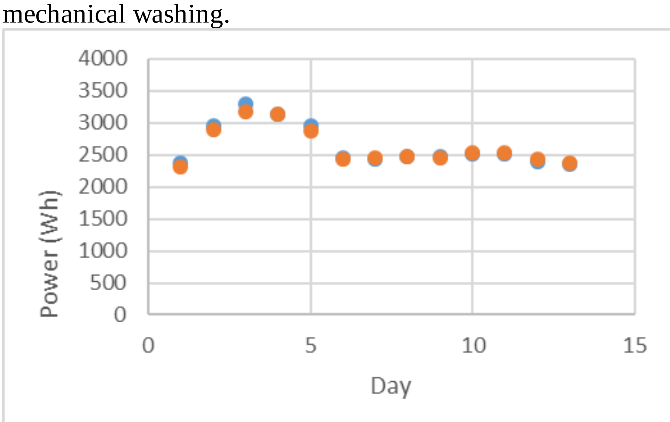


Fig. 8: Demineralised water without mechanical washing (•System 2, • System 3)

Figure 8 indicates that the daily power generated by the systems are more or less constant. The average factor determined was to 0.99 ± 0.01.

It can be concluded from the factor calculated that the efficiency of the solar panels increased, because the factor is higher than the control factor calculated. This however is also due to the decrease in the panels' surface temperature as illustrated in Figure 9.

As the increase in the factor was observed near the end of the experiment, the thought of temperature difference came to mind. Figure 9 is the representation of the hourly power produced by the two systems before and after washing.

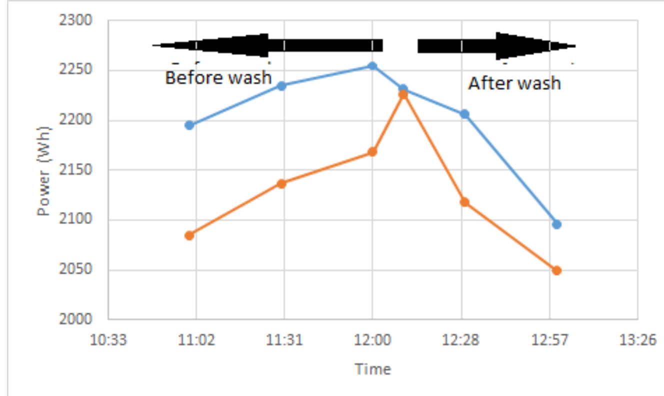


Fig. 9: Power before and after wash to determine effect of temperature (•System 2, • System 3)

As seen in Figure 9, there is a spike in the graph. This spike occurs directly after the panels are washed. This clearly indicates an increase in the factor and thus an increase in the efficiency of system 3.

If only the data of the last 3 days before 12:00 is observed, the factor, f, determined to be 0.97 ± 0.02.

This is done to eliminate the effect of temperature, which has a substantial effect on the efficiency of solar panels. The data that remains will then only be data that was influenced by precipitation. It can be concluded with this factor that the precipitation has no substantial effect on the efficiency of the solar panels, because the factor does not differ significantly from the other factors calculated.

D. Results obtained from sample tests

Table 1 is the representation of the pH, TDS and water hardness results.

Sample	*Change in pH*	*Change in TDS (mg/L)*	*Change in total hardness (mg $CaCO_3$/L)*
Potchefstroom water with cloth	-0.83	1.063	8.995
Demineralised water with cloth	-0.12	0.058	12.968
Distilled water with cloth	-0.78	0.423	17.32
Potchefstroom water without cloth	-0.48	1.563	98.327

TABLE 1: pH, TDS AND WATER HARDNESS RESULTS

The pH of the effluent water is lower than the pH of the water from the sprayer in each case. This could be due to the sulphate formation on the panels. The sulphate however could have been added by bird droppings on the surface, as there was droppings on the panels when the samples was taken. The amount of total dissolved solids are more in the effluent samples than in the sprayer samples. The most significant increase is where Potchefstroom water was used without a cloth. This indicates that there were salt precipitation on the solar panels during this experiment. In the same experiment, the water hardness in the effluent samples are significantly higher that the hardness in the sprayer sample. Thus significant precipitation of calcium and magnesium salts took place.

Table 2 is the representation of the sulphates, ORP and carbonates results.

TABLE II: SULPHATES, ORP AND ALKALINITY RESULTS

Sample	*Change in sulphates (mg/L)*	*Change in ORP (mV)*	*Change in alkalinity (mg/L)*
Potchefstroom water with cloth	0	1.65	0
Demineralised water with cloth	0	1.2	0
Distilled water with cloth	15	3.05	7.7
Potchefstroom water without cloth	20	2.4	51.3

The sulphates in the experiment with the Potchefstroom municipal tap water without mechanical washing had the most significant amount of sulphates precipitated. The largest increase in alkalinity is in the experiment where Potchefstroom municipal tap water was used without a cloth. This relates to the water hardness values for this experiments. Thus a significant amount of carbonates precipitated on the solar panels.

E. Cost of wash water

Approximately 5L water was used per day to wash the 12 solar panels. Thus per day, it costs approximately R3.55 to wash with tap water, R6.00 to wash with demineralised water and R100 to wash with distilled water. Thus it is 28 times less expensive to wash with tap water.

V. CONCLUSIONS AND RECOMMENDATIONS

As can be observed from the results of the factors where mechanical washing was used, there are no factors that differ substantially from the control factor. Thus washing the solar every evening for two weeks with mechanical aid have no influence on the efficiency of the solar panels. If the panels are washed at 12:00 noon with no mechanical washing the factor increases substantially, but this is due to the decrease in surface temperature of the panels. The factors does not differ significantly from the control factor when the cooling effect is neglected. Although precipitation occurred, it had no significant effect on the efficiency over a period of two weeks. Thus the effect of different types of wash water on the efficiency of solar panels over a 2 week period is miniscule. From the data and the cost analysis, it can be recommended to wash the panels each day at 12:00 noon without mechanical washing. However, further studies have to be done to determine the duration of washing period before precipitation starts to negatively influence the efficiency of solar panels.

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