1. Introduction

844 million people do not have access to clean water. As water shortages affect all aspects of life, drinking water scarcity is becoming one of the most pressing global problems, especially in remote areas. Ninety-six percent of the world's water is within the oceans, which, due to their excessive salinity, cannot be used for drinking water. The most commonly used technologies for seawater desalination are membrane processes and thermal processes. Among all current desalination technologies, reverse osmosis (RO) is the most reliable and simplest method.

In the reverse osmosis process, high pressure is generated to push water against the osmotic pressure from the contaminated side of the membrane to the clean water side. A significant amount of energy is required to achieve such high pressures. Although fossil fuels are the most commonly used energy source for desalination plants, less than 15% of people in developing and sub-Saharan countries have access to these energy sources. Solar energy offers a promising alternative and would also be a widely available renewable energy resource [1] [2].

However, the large fluctuations in solar output, are a major challenge for photovoltaic-powered reverse osmosis (PVRO) systems. Therefore, the conventional systems currently available on the market require electricity storage (batteries) to compensate for these fluctuations and provide a constant situation for the operation of the system. However, batteries are very expensive and have a limited lifetime (3-5 years) [3], which is further reduced in hot and humid areas. The need for a replaceable battery increases production and maintenance costs for potable water. In addition to the above costs, the use of batteries requires several energy conversions steps. These conversions increase the complexity of the system and result in energy losses at each step, decreasing the efficiency of the overall RO process.

In the Grino system, the battery unit is replaced by an innovative variable frequency generator (VFG) (patent pending). Standard RO units typically operate under constant conditions. Since the output power of photovoltaic (PV) modules varies between 0 and 1300 W/m² throughout the day depending on the position of the sun, a conventional RO system pump can only operate at constant rated power for a limited period of time using a photovoltaic supply. Compared to the systems available on the market, the Grino system is said to be fully adaptable to the available solar power. For this purpose, Grino Water Solutions GmbH developed the power management unit (Fig. 1 and 2). This is intended to compensate for fluctuations in solar energy by regulating the speed of the pump and the pressure on the membranes.

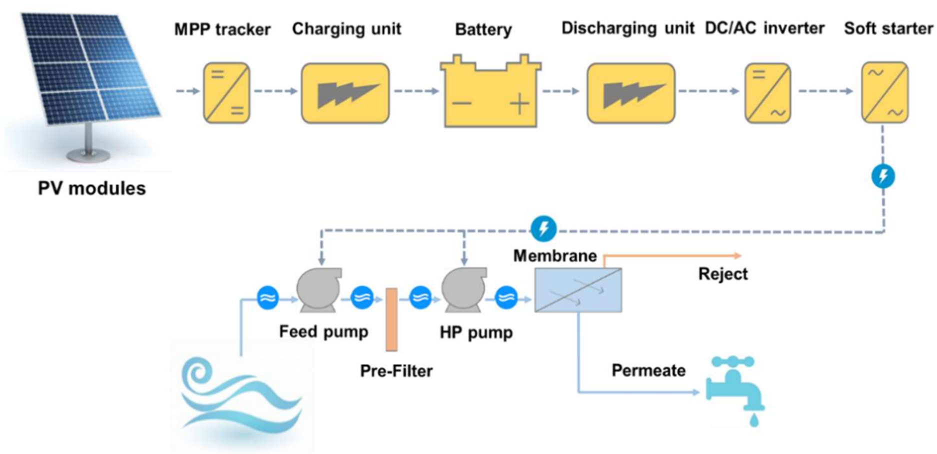

Figure 1 Conventional desalination system with batteries

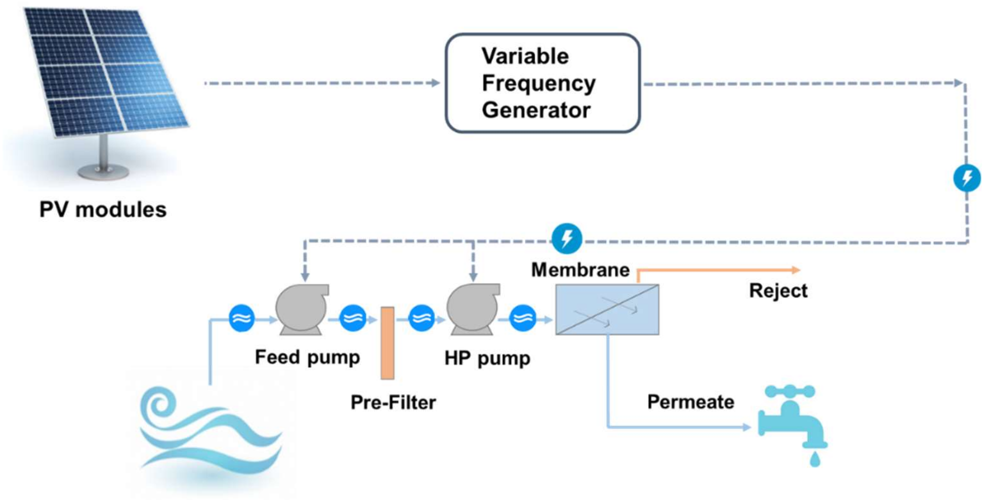

Figure 1. Grino eliminates costly batteries and replaces them with a variable frequency generator (VFG)

2. System Assembly

The system for this project is designed to test the durability of membranes in variable running conditions with simulated feed water of a borehole in Ghana, where the pilot system of Grino is located. At the end of the project, test results will be compared with the performance of membranes within the real condition in Ghana, the pilot project in Cape Cost is shown below.

The design of the system will be explained separately in a hydraulic part and an electrical part. Both parts of the project system are adjusted with the goal of observing the system parameter.

2.1 The hydraulic part:

To minimize water usage, the hydraulic system runs in a cycle. The feedwater is stored in a 640l IBC container, contains the exact proposition of chemicals, which are simulating the feed water of the real system in Ghana. From this container, water is dragged by a feed pump (Model LOWARA 1HM08N) into the system. The feed pump is necessary to provide a certain input pressure for the RO pump to overcome the pressure loss of the pre-filtration system and to avoid cavitation in the input lines. The system pipes contain pressure gauges, a pre-filtration system, which contain a cartridge filter, in the filter size of 20µm, 5µm, and an active carbon filter. In the feed line, an analog flowmeter shows the current water flow. Besides an electrical pressure sensor is located after the pre-filter system. This pressure sensor observes the input pressure of the RO-pump and sends the data to the control board.

Further in line, the RO-pump (Model: Interpump - SS 1414) is installed. This triplex plunger pump generates the Water flow for the Membranes. To reduce the vibration of the plungers, a vibration dampener is installed at the pumps output, also another pressure gauge is connected to the pump output to measure the membranes pressure.

Via a hydraulic tube, the RO pump is connected to the membrane housings, which containing four brackish water membranes in series. Series connection means that the brine of the upstream membrane is the feed water of the downstream membrane. At the end of the membrane housing an electric proportional valve is connected. By opening or closing this valve and therefore setting the diameter of the output line, the system pressure at the membranes is adjusted. Another electrical pressure sensor is located at the membranes output, to measure and send the data of system pressure to the control board. If the hydraulic pressure in the membrane housings exceeds the osmotic pressure of the feedwater, the water is split into two streams. The first stream, leading as the brine flow through the proportional valve and second one as permeate through the membrane pores. The permeate temperature is measured by a using a temperature sensor (PT1000). Besides, the permeate flow, is measured by an electric vortex flowmeter. A conductivity meter is used to measure the remaining salt concentration in the permeate stream. Another analogue floating flowmeter is installed in the output line, to observe the permeate production.

The permeate line has a non-return valve, to prevent the produced water to diffuse back to the membranes, when the system is off. Both lines, brine and permeate are leading back to the feed tank and therefore the system works in a closed cycle.

2.2 The electric board:

The electric board is responsible to convert the DC solar power, generated by Photovoltaic modules into AC power with different frequencies to supply the pumps. The control board includes one master controller, and two slave controllers. The master controller receives the sensor inputs of the system. The sensors' data are measured in digital or analogue signals (4-20 mA). The supply voltage of the control system is 24 V DC. The controller is built to receive additional sensor inputs which would be required in real case scenarios, for example inputs for solar sensor or tank level sensors. The master controller also receives the data of the PV-voltage and calculates the duty cycle of the MPP-Tracker, the frequencies of the system pumps and the system pressure by controlling the proportional valve. The first slave controller is designed to control the MPP-Tracker. Besides, an IGBT-Module for frequency inverting of a third external pump, for example a borehole pump, is driven by this controller. This external pump is independent from the hydraulic cycle of the system, but in practical cases, it is necessary for pumping the feedwater to the systems. In this project this pump is simulated by an external centrifugal pump. With this pump the electrical consumption of a borehole pump can be simulated and therefore the MPP-Tracker can be tested in real-case power consumption. The second slave controller is controlling the frequencies of the two system pumps. The AC-frequency of the pumps determines proportionally the speed of the pumps and consequently the flowrate of water. With adjusting the frequency, the power consumption of the pumps can be varied and therefore the systems energy consumption can be adapted to the available solar power.

The PV-Panels are simulated by a DC-Power supply (DataTec PSI 9750-20 3U). This power supply is capable of simulating PV-panels based on DIN EN 50530 And can be programmed with solar data in a timeline with the parameter of irradiation (from 0-1000W/m²) and panel temperature (in °C).

Besides two batteries supplying 24V power for the controller, when solar power is zero. The batteries (12V AGM-batteries) are connected in series, with a total capacity of 45 Ah.

3. New Developments:

For improving the system, some new features should be developed during this project. By adjusting the hardware and software of the controller, the sensors of the system can be simplified, and costs of expensive transmitters can be saved. First, a conductivity measurement system should be implemented in the controller. Conventional systems are using conductivity transmitter, which are delivering a 4-20 mA signal to the control board, giving information about the conductivity about the permeate water. The idea of this development was, to implement a conductivity probe inline of the permeate water and supply it with an AC voltage to measure the electrical resistance of the water and therefore get conclusions of the conductivity of the permeate water.

Another development goal is the implementation of a digital flowmeter, which is working with a P/N signal, with a certain frequency. It's basically a turbine flowmeter with reed- sensors. The faster the volume flow, the higher is the frequency given from that flowmeter to the controller. The implementation of the reed-sensor flowmeter and replace the vortex flowmeter has the advantage that this sensor can be implemented as a stainless-steel part, which has more durability than the PP vortex sensor, but also increase in price.

To run the system as a stand-alone solution in a mini grid, the supply battery needs to be charged, during daytime from the PV power. The available, nearly constant voltage source in the inverter is the 600V DC intermediate circuit, which is fluctuating in the range of 500 to 610 V. This source is transformed down a battery charging or discharging voltage from 20-28V. That battery charger can be used to stabilize the intermediate circuit, if quick sunlight fluctuations appear. During the time interval of decreasing PV-Power, the battery controller uses the stored energy in the battery to stabilize the intermediate capacitator, thus the voltage decrease slows down, and the pumps regulate slower. Due to this, the pressure loss in bar/s at the membranes is lower and the lifetime of the membranes can be expended significantly. The used energy of the battery is diminishing low because the time span of discharging is very short.

4. Test conditions

4.1 Feed water mixture

To simulate the real-case water conditions, the well water of Grino's first pilot project in Ghana is simulated. The water Analysis of the well water can be found in Appendix 1. The composition of the tab water in Nuremberg is subtracted from the compositions of the feed water in Ghana and chemicals are added. Table 1. shows the information of chemicals added to the feed tank in the labour.

Table 1. Composition of feed water

			Zugabe mol	Zugabe mol	Zugabe moL	Zugabe Salz		
	Salze	M g/mol	Salz	Kation	Anion	g	g Kat	g Anion
1	Fe(II)Cl2x4H2O	198,81	0,01980	0,01980	0,05939	3,9	1,10550	2,10545
2	K2SO4	174,26	0,17136	0,34273	0,17136	29,9	13,40000	16,46174
3	MgCl2x6h2O	203,3	1,86900	1,86900	3,73800	380,0	45,42600	132,52206
4	CaCl2x2H2O	147,02	2,00609	2,00609	4,01218	294,9	80,40000	142,24248
5	NaCl	58,44	8,78362	8,78362	8,78362	513,3	201,93375	311,40318
6	Mn(II)SO4xH2O	169,02	0,01073	0,01073	0,01073	1,8	0,58960	1,03096
7	NH4Cl	53,49	-0,00037	-0,00037	-0,00037	0,0	-0,00670	-0,01317
8	Na2SO4	142,04	0,52931	1,05862	0,52931	75,2	24,33740	50,84729
9	NaF	41,99	0,00670	0,00670	0,00670	0,281	0,12730	0,12730

4.2 Simulating PV-panels:

The PV-Panels parameters are displayed in Fig.3:

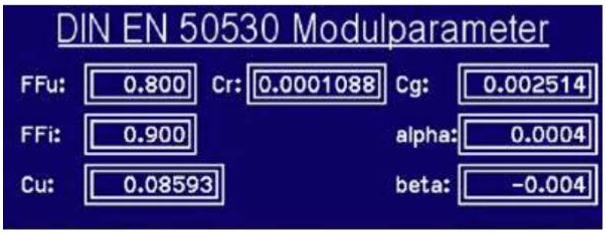

Figure 3. PV-Panels parameters

Besides the power parameter are set as followed:

Uoc: 505.0 V
Isc: 10.0 A
Umpp: 440.0 V
Impp: 9.0 V

And therefore, results in a total power of 3.960 kWp.

4.3 Simulating daily operation:

To observe the quality during the lifetime of the membrane a harsh test simulate as an accelerated test of the real condition is designed. Daily operation time of the system in real case is 6 hours, which is simulated in 90 min drive. During the day, sunlight fluctuations due to clouds' movements cause a power change and the system needs to react to it. For test condition a high fluctuation PV-curve is presumed i.e., every ten minutes the sunlight has a sharp reduction to the minimum operation power. The x-axis shows the time in ten second steps, so in total 540 measurement points are considered as it is shown in figure 4. The reduction of the power occurs in 10 sec steps.

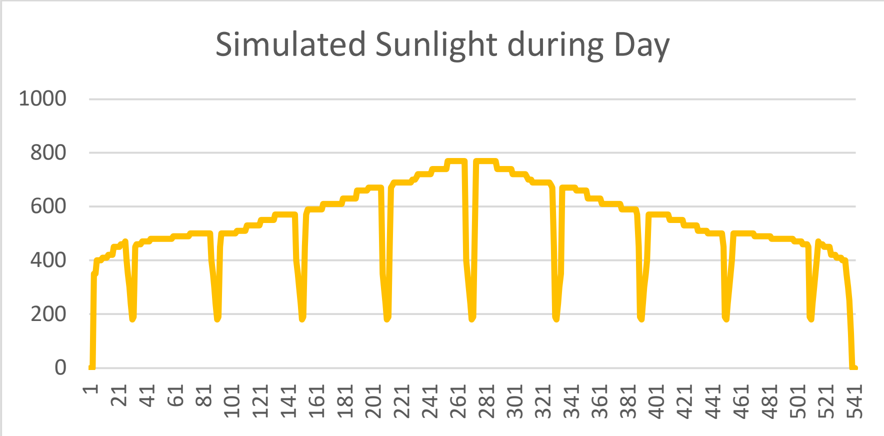

Figure 4. Simulated fluctuation of sun light in 90 min.

After 90 min the system is shut down and starts another operation round again. This procedure is repeated four times a day.

4.4 Logging and observation

The water quality and the systems behaviour should be monitored continuously. For this reason, the system is connected to a logging device, which is saving the data in a ten second resolution. Parameters which are recorded, are battery voltage, system power, pressure one, RO-pressure, TDS-value, Temperature of the Water, flowrate of the permeate, and voltage of the intermediate circuit. Logging samples can be found in Appendix 2.

To observe the water circuit, water samples are sent to the water analysis laboratory of the project partner, FEM. In regular time periods the samples are send in a temperature-controlled condition with the overnight express to FEM. Every stream is tested separately including feed, permeate and brine flow.

5. Result and discussion:

Figure 5 shows the results during the fluctuation phase and when the frequency is dropped from 50 Hz to 30 Hz. The data are extracted randomly and on different days through times of the operation to avoid any determined order. The results confirm that the system works in dynamic situations and adoption in frequency did not make any problem for the operation. Therefore, the pressure has been adjusted and the system worked continuously. Furthermore, Figure 5 (d) indicates that, though the frequency is reduced to 30 Hz, the flow rate is just changed a little bit to 8 l/min and TDS stays almost the same.

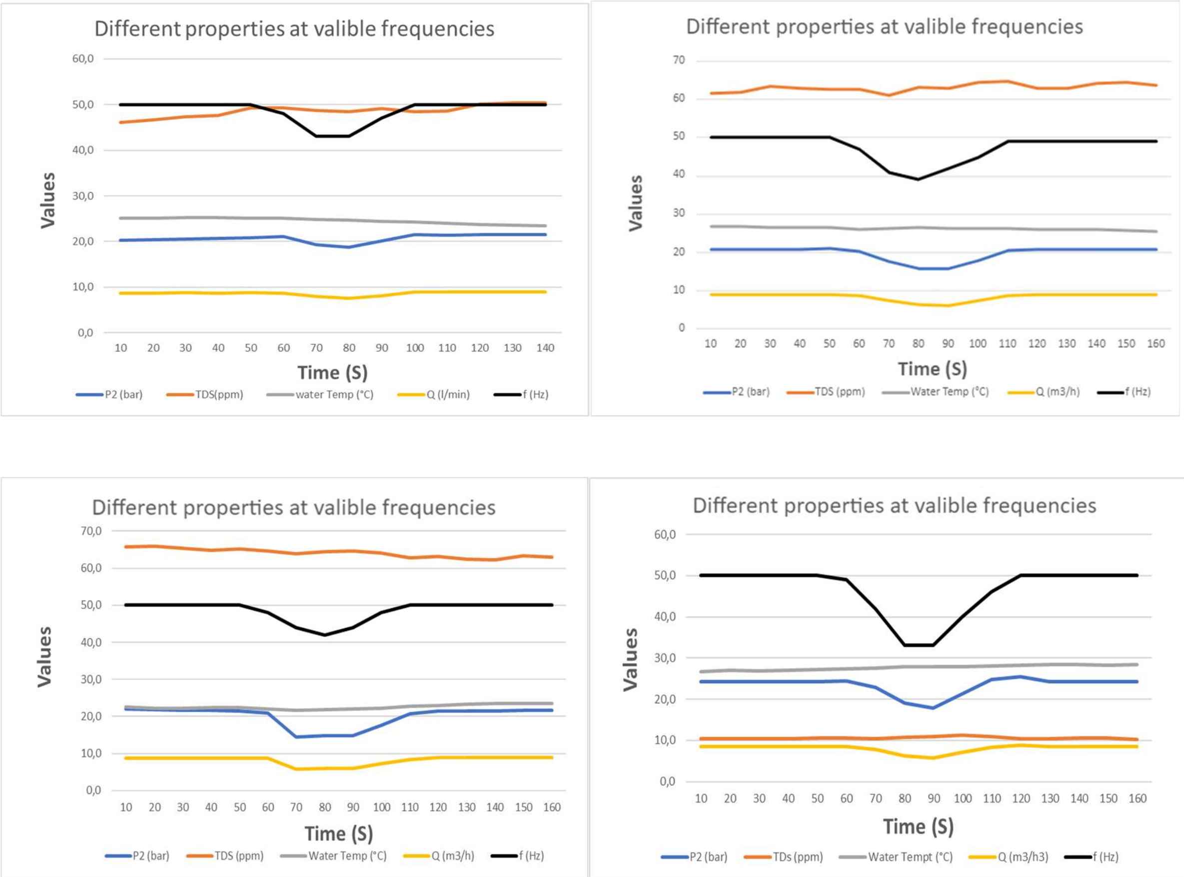

Figure 5. Different properties of four sample in fluctuation phase, First Phase

Figure 6 shows the condition of the system under dynamic operation for 4 months. The samples are taken all at 50 Hz when the system is stable to neglect other variations. As it is shown in Figure 6. The TDS of the permeate water has been increased from 50 ppm in the first month to 70 ppm in the 4th month which confirmed the formation of a scaled layer on the surface of the membrane. However, the other factors like flow rate, pressure, and the temperature stayed the same and verified that dynamic operation did not damage the membrane.

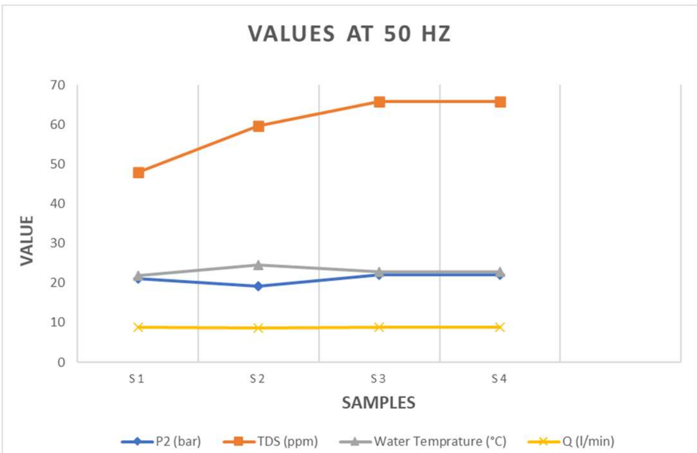

Figure 6. All properties during four-month operation, First Phase

Table 2. The operation parameters during 4 months operation, First phase

	P2 (bar)	TDS (ppm)	Water T (°C)	Q (l/min)
S1	21,2	48	21,9	8,9
S2	19,2	59,6	24,6	8,7
S3	22,1	65,7	22,8	8,8
S4	22,1	65,7	22,8	8,8

6. Analysis of SEM images:

To identify the specific foulants and scalants on the membrane surface and determine the chemical or mechanical damage that has occurred during operation, we autopsied the membrane. The data and conclusions from an autopsy help to recognize, the operational issues and plan the second phase and future design of the system in the most efficient way.

In our test, one membrane from the first stage and one from the end is removed. Since:

1. The lead element in the system will see the highest concentration of suspended solids.

2. The last membrane in the system receives water that has been concentrated and is the most likely to scale.

3. Biological fouling, and organics can be found on all membranes in the system. However, bacteria which are hydrophobic tend to be attracted to the membrane surface which is also slightly hydrophobic. Biofouling is therefore always worst at the first stage where the bacteria attach to the first available hydrophobic surface that they find. By contrast, humic acids are hydrophilic at non-acid pH levels. They can therefore spread evenly throughout, or in some cases, even concentrate and cause heavier fouling at the tail end.

4. Suspended solids and precipitated metals (such as iron) can also end up on any membrane in the system. Therefore, if suspended solids such as limestone particles are found in a tail element, they can be confused for scale if a lead element is not also autopsied.

In our first phase, the first and last membranes from the test plant in Nuremberg were examined, as well as the first membrane from the practical plant, which has been running trouble-free for over a year in Ghana.(see Appendix 3, photos of Project in Ghana)

The membranes were cut with a band saw, from the wound and rolled membranes Fig.7 .

Figure 7. cut cross section of membrane

The samples of the membrane were cut from the wound and rolled membranes to approx. 1x1cm, then dried at 105°C and stored in a desiccator over desiccant.

The scanning electron microscope images (See Fig.8, numbers included in the images indicate the positions of the recorded EDX spectra) were acquired on a Gemini SEM 300 (serial number 8202017062 from Carl Zeiss Microscopy GmbH).

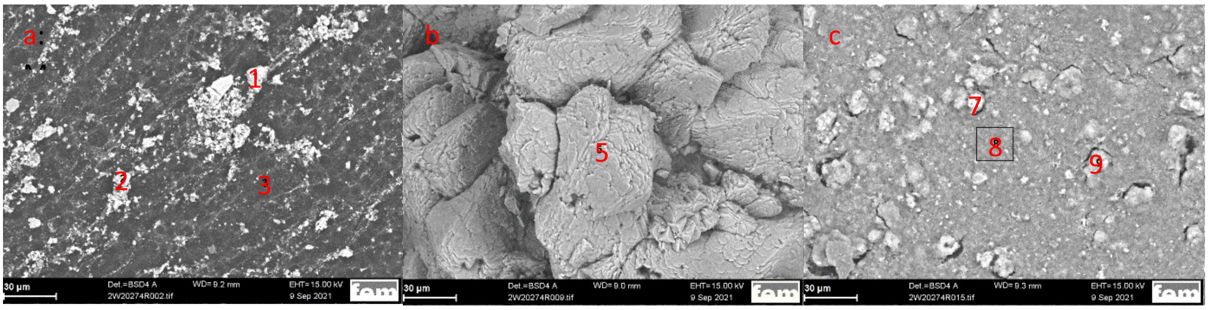

Fig 8. Membrane 1st Nuremberg (a), Membrane 4te Nürnberg (b), Membrane Ghana (c)

The images show that all membranes have a significant coating. As can be seen in Fig. 8 (a), there is a complete coating of amorphous material. This is interspersed with probably crystalline particles. In contrast, Fig. 8 (b) shows exclusively crystalline structures over the entire surface of the membrane. This could be explained by the fact that the first membrane traps all coarse suspended matter such as organic material or rust particles that pass through the pre-filters. The last membrane, on the other hand, only sees "process water" that is already highly concentrated, where further separation of water causes the solubility product of the inorganic salts to be exceeded and they begin to crystallize. The images of the corresponding membrane from Ghana Fig. 8(c) show a similar picture to first membrane from Nuremberg Fig. 8 (a), a two-dimensional coating with an apparently amorphous substance, interspersed with particles that may be crystalline.

The EDX detector (X-Max 150 serial number 74553, software INCA from Oxford Instruments GmbH) EDX spectra of the marked areas were also is taken for this test procedure. These spectra proved the assumptions made on the basis of the SEM images. Thus, the spectra of the 1st membrane from Nuremberg show high values of oxygen and iron in the EDX for crystalline areas. For the amorphous areas high carbon contents. (See Fig. 9)

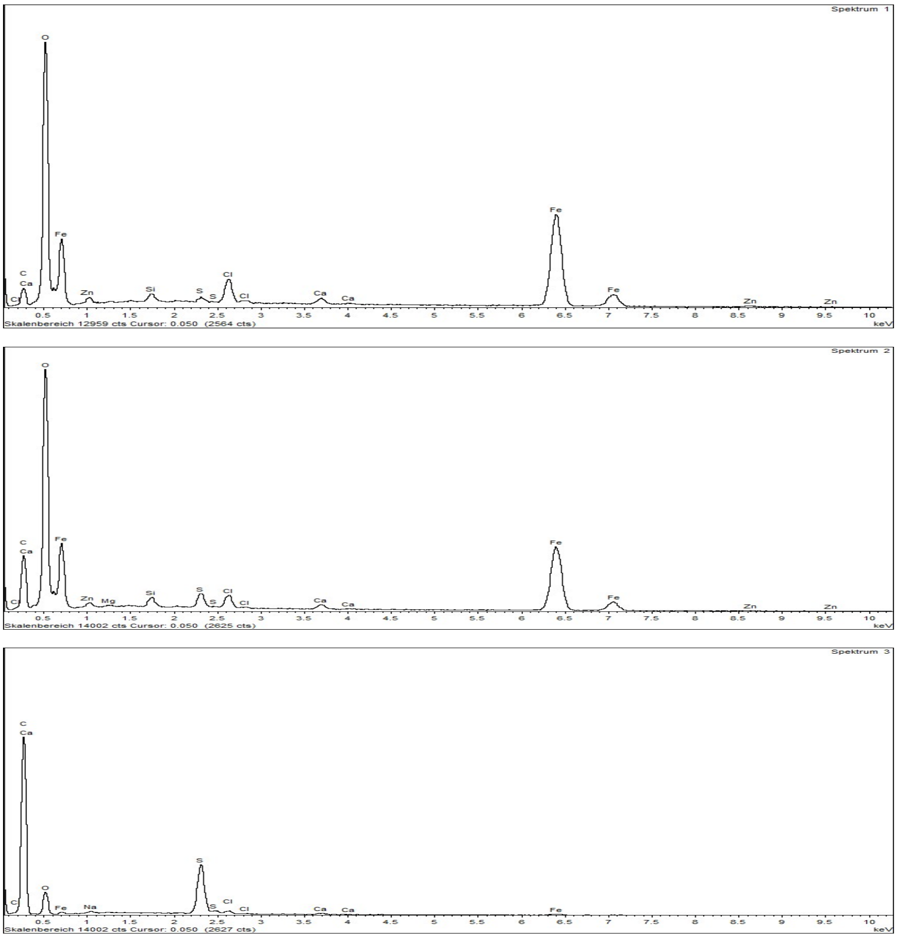

Fig. 9: Membrane 1st Nuremberg, EDX spectra, spectra 1-3 belong to the corresponding locations in the SEM image Fig. 7

The situation is different for the 4th membrane from Nuremberg, where the EDX spectrum shows very high calcium values in combination with high signals for oxygen and carbon, which at first glance, in combination with the strong crystal formation, fits very well to the thesis of lime deposition on the membrane (see Fig. 10).

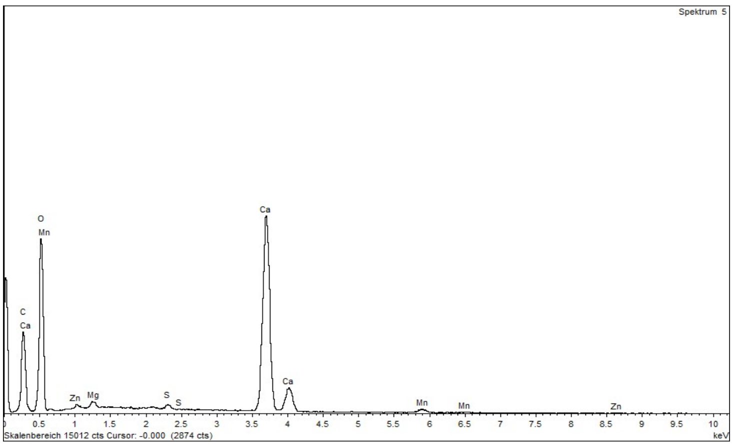

Fig. 10: Membrane 4th Nuremberg, EDX spectra, spectrum 6 belong to the corresponding locations in the SEM images Fig. 1 (b)

The examination of the reference membrane from Ghana provided a similar picture to the corresponding membrane from Nuremberg. In addition to the signals for iron and oxygen, there were also increased signals for aluminum, manganese and silicon. This is probably due to the special conditions on site. Since in the real plant more sediment particles break through the pre-filters which cannot be taken into account in the test plant, such as sand particles as an explanation for the silicon finding.

7. Second Phase:

Since the first phase operation shows a huge, coated layer fouling and scaling was formed on the surface of the membrane. Therefore, we have decided to search for the best solution which can prevent scaling.
Since our system operates in a circulation mode, chemical anti-scaling cannot be added. As the brine from our lab system goes back to the tank, the concentration would be excessive.
Furthermore, the addition of anti-scaling, in most cases, contains phosphate, which would encourage microorganisms to grow and the anti-scaling chemical should only be stored with demineralized water. therefore, we have selected Molkat in the line which is more environmentally friendly than conventional solutions because additional biocides are largely dispensed with Fig 11. At the same time, biofilms and Legionella are reliably removed. The core of the Molkat technology is a high-performance, long-lasting metal catalyst made of nickel, chromium, iron and an optimally matched mineral layer.

Fig 11. MOL®LIK SW30

The figure 12 illustrates the results during the fluctuation phase as well as when the frequency is lowered from 50 Hz to 40 Hz and 30 Hz. In order to avoid any orderly data collection, the data was extracted randomly. Results from the second pass showed that the system worked in dynamic circumstances and change in frequency had no negative effect on operation.

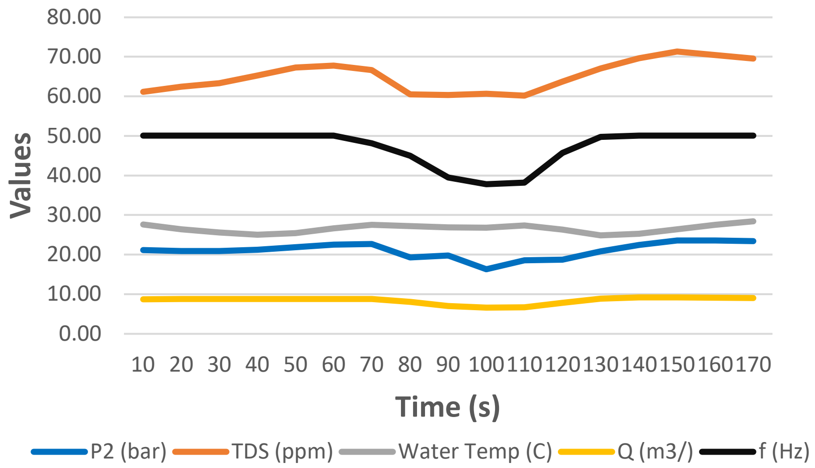

Fig 12. Different properties of four sample in fluctuation phase, First Phase

Figure 13 shows the condition of the system under dynamic operation for 4 months. The samples are taken all at 50 Hz when the system is stable to neglect other variations exactly like first phase. As it is shown in Figure 13. The TDS of the permeate water has been increased compare with the first phase but it stays almost the same value during whole 4 months. In addition, the other factors like flow rate, pressure, and the temperature stays constant and prove the success of dynamic operation.

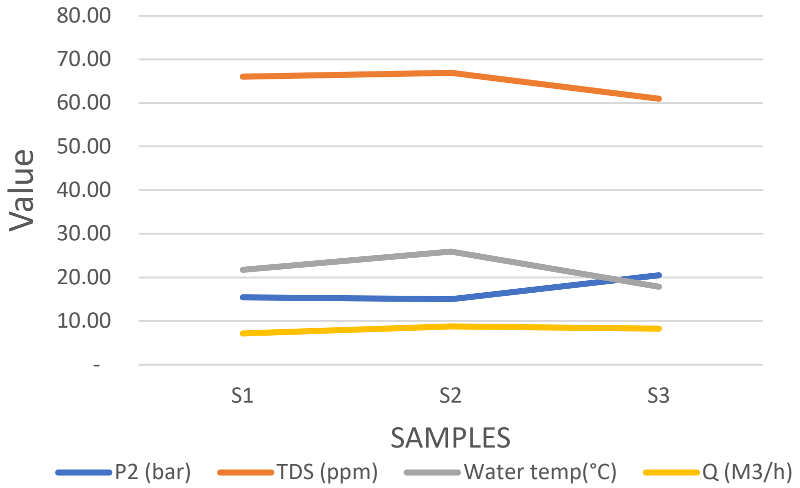

Fig 13. All properties during four-month operation, Second Phase

Table 3. The operation parameters for 4 months operation, Second phase

	P2 (bar)	TDS(ppm)	Water temp(°C)	Q (M3/h)
S1	15,44	66,03	21,73	7,15
S2	15,0	66,9	26,0	8,8
S3	20,5	60,97	17,87	8,218

8. Analysis of SEM images:

To identify the specific foulants and scalants on the membrane surface and determine the chemical or mechanical damage that has occurred during the operation after adding the filter cartridges and compare the result with the first phase, membranes were removed from the system, cut with a band saw, and the filter membrane was prepared out. Care was taken to extract a section from the wound and roll membranes that were as localized as possible. All steps were followed by the first phase.

The membranes from the experimental plant in Nuremberg were examined and compared with the previously examined membranes from the first round. Therefore, the membrane pieces were cut to approximately 1x1cm, dried at 105°C, and then stored in a desiccator over desiccant.

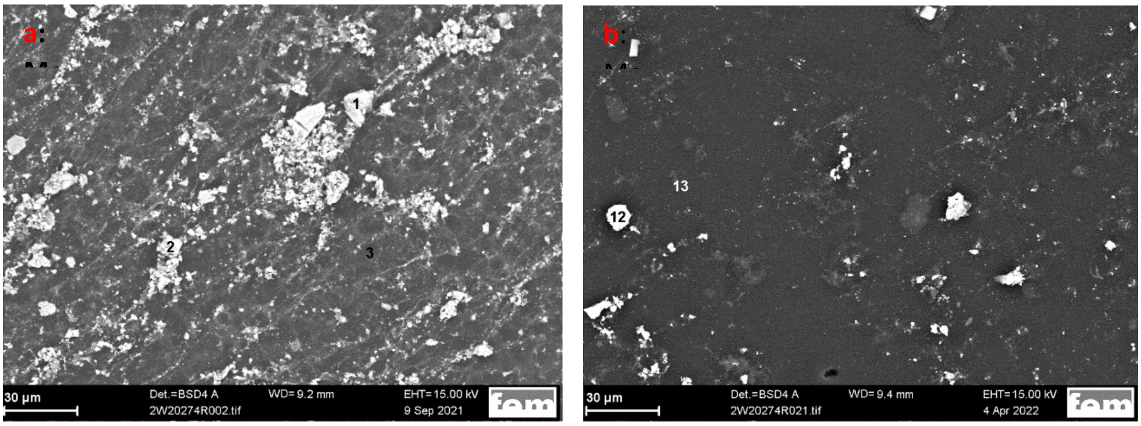

Fig. 14: Membrane 1st Nuremberg phase 1 (a), Membrane 1st Nuremberg phase 2 (b)

The comparison of the images of the 1st membranes from the different time points shows fewer inorganic particles as a coating layer has formed on the that a first membrane from the second round compare with the first round and before applying the MOL®LIK SW30 filter (Fig 14). As already known from the first round, these can be identified mainly as rust particles (see spectrum 9). The amorphous presumably organic coating seems to be similarly pronounced, as the recorded Fig 15 shows by the high value for carbon.

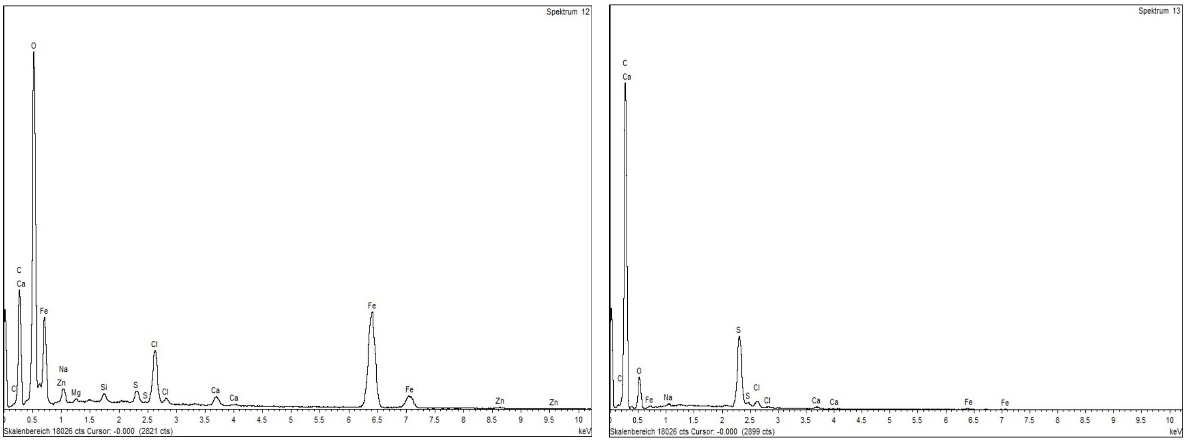

Fig. 15: Membrane 1st Nuremberg, , phase 2, EDX spectra, spectra 12-13 belong to the corresponding locations in the SEM image Fig. 14 b.

The SEM images of the fourth membrane in the system shows a serious difference Fig. 16. In contrast to the membrane from the first phase, the membrane from the second phase does not show a complete coating with inorganic crystals. Instead, the coating is similar to that of the first membrane, a mixture of organic coating with isolated inorganic particles (Fig.16). However, according to EDX measurements with a strong signal for calcium, carbon and sulfur, these are not rust particles, but presumably isolated lime and dust particles (Fig 17).

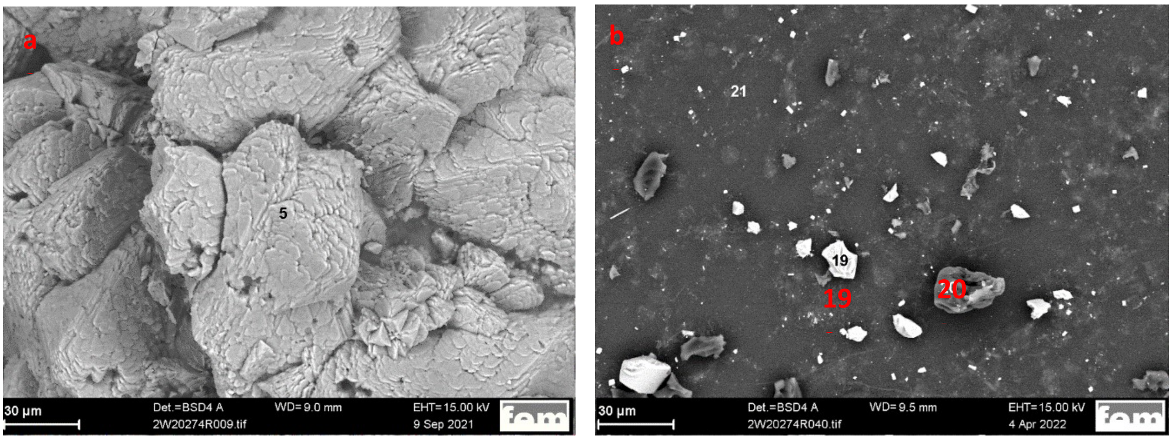

Fig. 16: Membrane 4th Nuremberg phase 1 (a), Membrane 4th Nuremberg phase 2 (b).

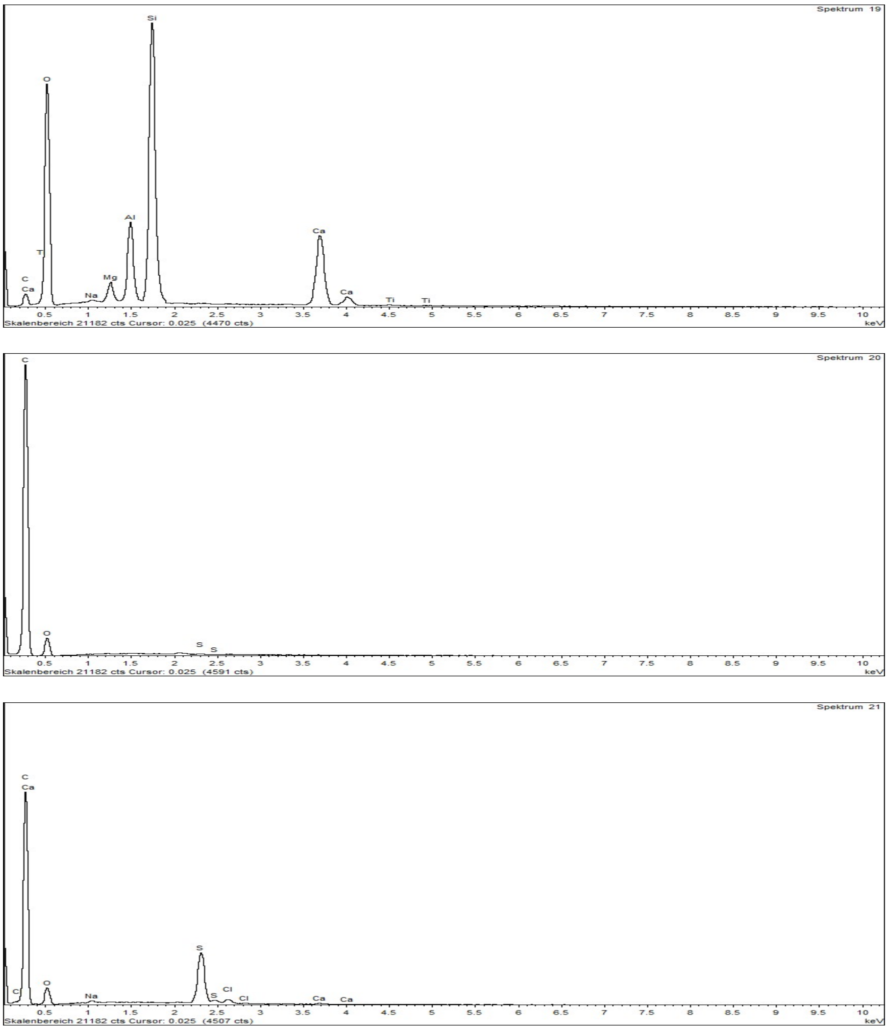

Fig. 17: Membrane 4th Nuremberg, , phase 2, EDX spectra, spectra 19-21 belong to the corresponding locations in the SEM image Fig. 2b.

Appendix 1 – Water analysis form the borehole in Ghana

GHANA WATER COMPANYLIMITED

Main Bankers: GCB Bank Limited
Societe Generale Ghana
National Investment Bank

Water Quality Assurance
Department
Weija - Accra.

Source: BOREHOLE WATER SAMPLE (RAW)
Location: BACANO POL S. CAPE COAST - C/R
Date of Submission: 25/03/2021
Date of Analysis: 25TH – 31ST/03/21
ATTN: PHILIP QUARCOO SCHOOL
TEL:

31ST APRIL, 2021

PHYSICO-CHEMICAL ANALYSIS REPORT

PARAMETERS	UNIT	STANDARD METHOD TEST CODE	RAW SAMPLE VALUES	GHANA STANDARD LIMIT
Appearance		-	Brown	Clear
pH		4500-H+-B	7.1	6.5 – 8.5
Colour (Apparent)	HEZEN	2120-B	**25**	5
Turbidity	NTU	2130-B	**12.2**	≤5.0
Temperature	°C	2550-B	26.3	-
Conductivity	µS/cm	2510-B	**6360**	1500
Total Dissolved Solids (TDS)	mg/l	TDS Meter	**3192**	1000
Total Suspended Solids	mg/l	Spec'photometer	**10**	0
Total Solids	mg/l	Spec'photometer	3202	-
Salinity	‰	TDS Meter	4.19	-
Nitrite (NO_2)	mg/l	4500-NO_2-B	0.013	1.00
Nitrate (NO_3)	mg/l	4500-NO_3-B	-	10.0
Chloride	mg/l	4500-Cl-B	**1413**	250
Total Alkalinity (as $CaCO_3$)	mg/l	2320-B	24	-
Total Hardness (as $CaCO_3$)	mg/l	2340-C	**1260**	500
Calcium Hardness (as $CaCO_3$)	mg/l	3500-Ca-D	960	-
Mg. Hardness (as $CaCO_3$)	mg/l	2340-C & 3500-Ca-D	300	-
Calcium	mg/l	3500-Ca-D	**384**	200
Magnesium	mg/l	3500-Mg-E	72.9	150
Iron (Total)	mg/l	3500-Fe-D	**0.74**	0.30
Fluoride	mg/l	4500-F-D	0.64	1.5
Sulphate	mg/l	4500-SO_4^{2-}-E	348	500
Phosphate	mg/l	4500-P-C	-	15
Manganese	mg/l	3500-Mn-D	**0.88**	0.5
Arsenic	mg/l	3500-As C	0.00	0.01
Copper	mg/l	3500-CU D	0.01	2.0
Zinc	mg/l	3500-Zn F	0.15	3.00
Potassium	mg/l	3500-K B	19	30
Chromium	mg/l	3500-Cr D	0.00	0.05
Cabonate (as CO_3^{2-})	mg/l	2320-B	0	-
Bicarbonate (as HCO_3^-)	mg/l	2320-B	29.28	-

NOTE: Test code- 19th edition standard method as reference

REMARKS: All parameters conformed to Ghana standards for drinking water except **Colour, Turbidity, Conductivity, TDS, TSS, Chloride, Total Hardness, Calcium, Iron and Manganese.**

RECOMMENDATION: A reverse osmosis (RO) machine is required to correct all the failed parameters to the acceptable standards for drinking water.

JOHN SUOBOBGIREE
(HEAD - WQA)

Appendix 2 – sample of the logging data

Log-File 2021-05-03_20-23-38

	3.005989544	21.02018787	65.11167111	23.38029651	8.313565271	48.8877551	47.60204082
Uhrzeit	P1	P2	TDS	Watertemp	Qperm	f1	f2
20:23:40	0.7811342	0.95447206	1234.6412	22.555159	0.03994748	22	0
20:23:50	2.781548	2.7668056	490.01477	22.499502	0.45076573	40	11
20:24:00	2.2659018	11.503517	401.79813	22.981987	0.028263668	42	32
20:24:10	2.7210414	17.20797	295.65356	23.786434	6.8288407	46	38
20:24:20	3.1552992	20.754637	103.117096	24.292833	7.8724275	50	45
20:24:30	3.0141504	23.38578	65.63244	24.491186	8.919496	50	50
20:24:40	3.0294056	23.249956	66.61959	24.525692	8.77281	50	50
20:24:50	3.041134	23.363396	66.93383	24.33548	8.755102	50	50
20:25:00	3.0623477	23.367937	68.61785	23.957188	8.8356285	50	50
20:25:10	3.0517685	23.299328	68.29363	23.630856	8.868308	50	50
20:25:20	3.0670323	23.212347	69.0646	22.93457	8.867792	50	50
20:25:30	3.0580184	23.051203	68.62157	22.562246	8.87791	50	50
20:25:40	3.0543723	22.748695	68.36697	22.194126	8.87179	50	50
20:25:50	3.0709574	22.401028	67.860756	21.77335	8.837632	50	50
20:26:00	3.0444374	22.10853	66.74721	21.60981	8.852394	50	50
20:26:10	3.050701	21.923813	66.28424	21.689465	8.827012	50	50
20:26:20	3.0652437	21.848953	66.681366	21.863272	8.85116	50	50
20:26:30	3.0668042	21.784388	65.54623	22.22681	8.819581	50	50
20:26:40	3.0688531	21.745167	65.32931	22.528555	8.849152	50	50
20:26:50	3.0668402	21.725355	61.77372	22.97008	8.835094	50	50

20:27:00	3.060399	21.721579	61.205452	23.438013	8.833603	50	50
20:27:10	3.0637167	21.788235	61.83619	23.802727	8.81801	50	50
20:27:20	3.0636263	21.985989	62.211758	24.275114	8.837779	50	50
20:27:30	3.0488062	22.18865	62.508553	24.423315	8.819165	50	50
20:27:40	2.6604433	21.550856	64.13809	24.51256	8.545401	47	47
20:27:50	2.051731	18.963541	63.750416	24.7503	7.409481	42	41
20:28:00	1.8901892	16.410759	65.28895	24.787495	6.009094	39	35
20:28:10	2.2296207	16.499126	68.82429	25.128605	6.025588	41	35
20:28:20	2.87908	18.534838	68.97972	24.647387	6.844678	46	40
20:28:30	3.2830071	21.408981	67.322525	24.276388	8.092804	50	46
20:28:40	3.1211522	23.3	67.8	24.1	9.0	50	50
20:28:50	3.1206133	22.7	66.1	24.3	8.8	50	50
20:29:00	3.1232727	22.7	65.9	23.9	8.8	50	50
20:29:10	3.1175795	22.7	66.1	23.9	8.8	50	50
20:29:20	3.1378644	22.7	68.1	23.6	8.8	50	50
20:29:30	3.1259606	22.7	67.4	23.3	8.8	50	50
20:29:40	3.130065	22.6	67.8	23.0	8.8	50	50
20:29:50	3.1296704	22.5	67.6	22.7	8.8	50	50
20:30:00	3.1191788	22.3	66.5	22.5	8.8	50	50
20:30:10	3.1283011	22.2	65.7	22.4	8.8	50	50
20:30:20	3.1225283	22.0	65.8	22.2	8.8	50	50
20:30:30	3.114752	21.8	65.6	22.1	8.8	50	50
20:30:40	3.129338	21.7	64.9	22.1	8.8	50	50
20:30:50	3.132138	21.6	64.5	22.1	8.8	50	50
20:31:00	3.1173463	21.5	65.6	22.2	8.8	50	50
20:31:10	3.117282	21.5	64.7	22.1	8.8	50	50

20:31:20	3.1162684	21.4	64.1	22.1	8.8	50	50
20:31:30	3.1236484	21.4	64.2	22.4	8.8	50	50
20:31:40	3.124243	21.3	63.2	22.5	8.8	50	50
20:31:50	3.115841	21.3	61.8	22.6	8.8	50	50
20:32:00	3.1171672	21.252855	62.379627	23.057594	8.777496	50	50
20:32:10	3.1154883	21.229563	62.551853	23.256845	8.802368	50	50
20:32:20	3.111762	21.220842	62.08422	23.416748	8.778342	50	50
20:32:30	3.1147482	21.222525	61.851803	23.761845	8.803336	50	50
20:32:40	3.133287	21.281857	63.086826	23.70381	8.76845	50	50
20:32:50	3.1124616	21.333899	62.284073	24.01253	8.795868	50	50
20:33:00	3.1155343	21.44352	62.194656	23.993744	8.818654	50	50
20:33:10	3.123273	21.553667	62.82879	24.351265	8.803498	50	50
20:33:20	3.1204176	21.698042	62.209587	24.435982	8.803339	50	50
20:33:30	3.1105134	21.840805	62.33602	24.819094	8.803596	50	50
20:33:40	3.1178024	21.993532	63.3099	25.034037	8.7977295	50	50
20:33:51	3.1218104	22.127308	64.23546	25.103048	8.766789	50	50
20:34:01	3.1123214	22.243559	64.39233	25.129948	8.775315	50	50
20:34:11	3.109347	22.349234	64.55728	25.251608	8.803697	50	50
20:34:21	3.131545	22.432196	66.63885	25.068796	8.803628	50	50
20:34:31	3.1237035	22.504793	66.211365	25.056879	8.806444	50	50
20:34:41	3.1245177	22.55645	66.46058	24.850668	8.795928	50	50
20:34:51	3.1259406	22.577755	66.58364	24.687517	8.816566	50	50
20:35:01	3.1211193	22.594885	65.765755	24.474037	8.796863	50	50
20:35:11	3.1164145	22.577885	65.75476	24.33021	8.777661	50	50
20:35:21	3.1215334	22.588911	66.428085	24.208998	8.795309	50	50
20:35:31	3.1212113	22.575808	66.61389	24.07401	8.767345	50	50

20:35:41	3.1177943	22.564514	66.468346	23.871096	8.793361	50	50
20:35:51	3.1275768	22.551247	66.99305	23.846958	8.805888	50	50
20:36:01	3.1202085	22.566444	68.29655	23.517895	8.815039	50	50
20:36:11	3.134445	22.50122	67.727295	23.30716	8.808533	50	50
20:36:21	3.1344237	22.446291	68.05723	23.055473	8.83121	50	50
20:36:31	3.1257448	22.316542	67.68878	22.680855	8.789605	50	50
20:36:41	3.1358283	22.142036	66.045265	22.57331	8.822387	50	50
20:36:51	3.134713	21.980974	65.80649	22.485476	8.784573	50	50
20:37:01	3.1144679	21.83076	65.96478	22.270248	8.814374	50	50
20:37:11	3.113659	21.682673	65.380585	22.226719	8.812016	50	50
20:37:21	3.1199749	21.550852	64.8353	22.302456	8.774246	50	50
20:37:31	3.095867	21.460232	65.20228	22.386055	8.796518	50	50
20:37:41	2.7228107	20.873812	64.61685	22.030142	8.657567	48	47
20:37:51	2.5623043	14.50506	63.965027	21.63361	5.817791	44	36
20:38:01	2.3566368	14.766495	64.35608	21.741947	5.975722	42	35
20:38:11	2.584091	14.768247	64.56145	21.99107	6.024085	44	36
20:38:21	2.9843524	17.57081	63.986744	22.205557	7.160079	48	42
20:38:31	3.1314871	20.653511	62.73105	22.729866	8.42792	50	49
20:38:41	3.1099563	21.533974	63.061382	22.973646	8.900426	50	50
20:38:51	3.1183093	21.532434	62.44344	23.214409	8.897803	50	50
20:39:01	3.12234	21.520401	62.281403	23.413027	8.873478	50	50
20:39:11	3.1114736	21.5526	63.37644	23.511318	8.884521	50	50
20:39:21	3.1099138	21.591064	63.004524	23.553345	8.892506	50	50
20:39:31	3.1225247	21.614395	62.4453	23.706371	8.889323	50	50
20:39:41	3.1186707	21.623344	62.249413	24.029186	8.879057	50	50
20:39:51	3.1208286	21.663134	61.418106	24.219713	8.9186945	50	50

Appendix 3. Photos of the project in Ghana

References:

[1] H. J. M.C. Garg, „A Review on PV-RO Process: Solution to Drinking Water Scarcity due to High Salinity in Non-Electrified Rural Areas,“ *Separation Science and Technology,* pp. 1270-1283, 2015.

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