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Test and Modeling of Innovative Pump for Desalination by Solar Reverse Osmosis

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Abstract: This paper presents experimentation of PV model automated for innovated pump to use for seawater desalination. We give here the method to benefit from solar radiations based on changing PV position. In fact, this application has many advantages because it depends on water which is vital element of life. Thereon, we have fabricated a special pump that it recuperates the energy under pressure gradient above it works in double direction and ensures osmosis pressure required for desalination. The pump motor executes 780 tr/min and it requires the power higher than192W. More that refer to old researches, the measured specific energy consumption of the SWRO is about 8 KWh/m^3 with an average value of fresh water production of 60 L/h so we keep high performances with minimum of energy.

Key words: Renewable energy · Reverse Osmosis · Membrane · Desalination

INTRODUCTION

Water is a gift on this earth to flourish our life. Many regions are suffering from fresh water shortage. Thereon, reverse osmosis is among suitable techniques of desalination [1, 2, 3, 4]. Latest researches focus more on how to implement renewable energy as sources of energy to minimize costs [5, 6, 7]. Thus, we present in our study the development of new desalination unit based on photovoltaic technology [8, 9]. This choice is justified thanks to many advantages such as low specific energy consumption and simplicity of maintenance and it can be used widely. According to various experimental studies reverse osmosis desalination unit combined with energy recovery device decreases specific energy consumption of the SWRO [10, 11]. Moreover, to minimize energy consumption we should operate at specific conditions of load rely to functioning point in electronics [12, 13]. With these considerations, our desalination system ensures excellent efficiency. To sum up, we exploit innovative pump changing high pressure pump required for reverse osmosis. We study motor pump costs and performances of our system and their efficiency.

Modelization of Photovoltaic Panel: PV Unit has many interconnections between lots of solar cellular for the aim at getting enough power. Based on synoptic schematic, we can study photovoltaic panel. The essential parameters are shown in the Fig. 1 [14]. According to interconnections between parameters as it is clear in the schematic, we establish these equations for a photovoltaic cellular [15]:

$$I = I_{ph} - I_d - I_r \quad (1)$$

$$I_{ph}=I_{sc}.\ (E_s/1000) \quad (2)$$

$$I_d=I_0.(Exp\ (q(V+Rs.I/n.K.T)-1) \quad (3)$$

$$Ir= (V+R_s.I)/R_{sh} \quad (4)$$

As a result we obtain:

$$I=I_{ph}=I_{sc}.\ (E_s/1000)-I_0.(Exp\ (q(V+R_s.I/n.K.T)-1)-(V+R_s.I)\ /R_{sh} \quad (5)$$

Thanks to these equations we build a suitable model in Matlab Simulink as shown in Fig. 2.

Simulation of PV Model: The power delivered by PV depends on solar irradiance so, we represent here the intensity of current and the power in function of voltage for different irradiances. We illustrate results in given Fig. 3.

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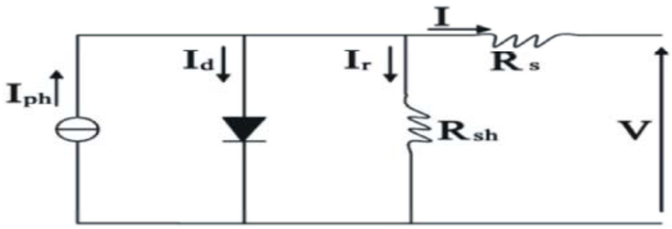

Fig. 1: Equivalent schematic of photovoltaic cellular

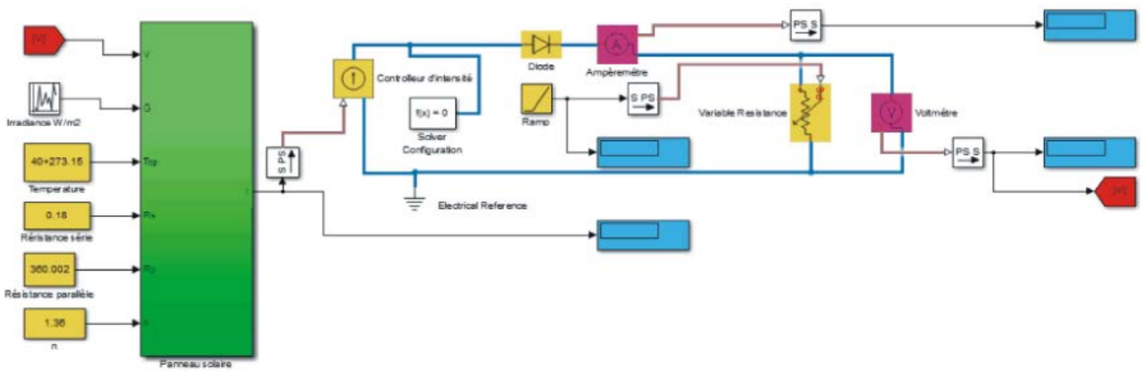

Fig. 2: Photovoltaic panel model under Matlab and Insel

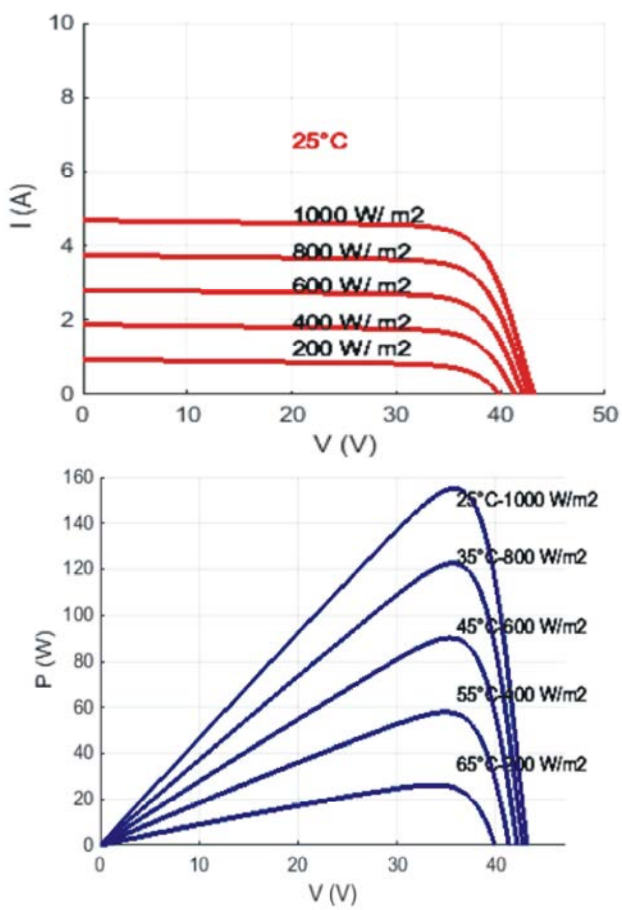

Fig. 3: Simulations of current intensity and power in function voltage and irradiance

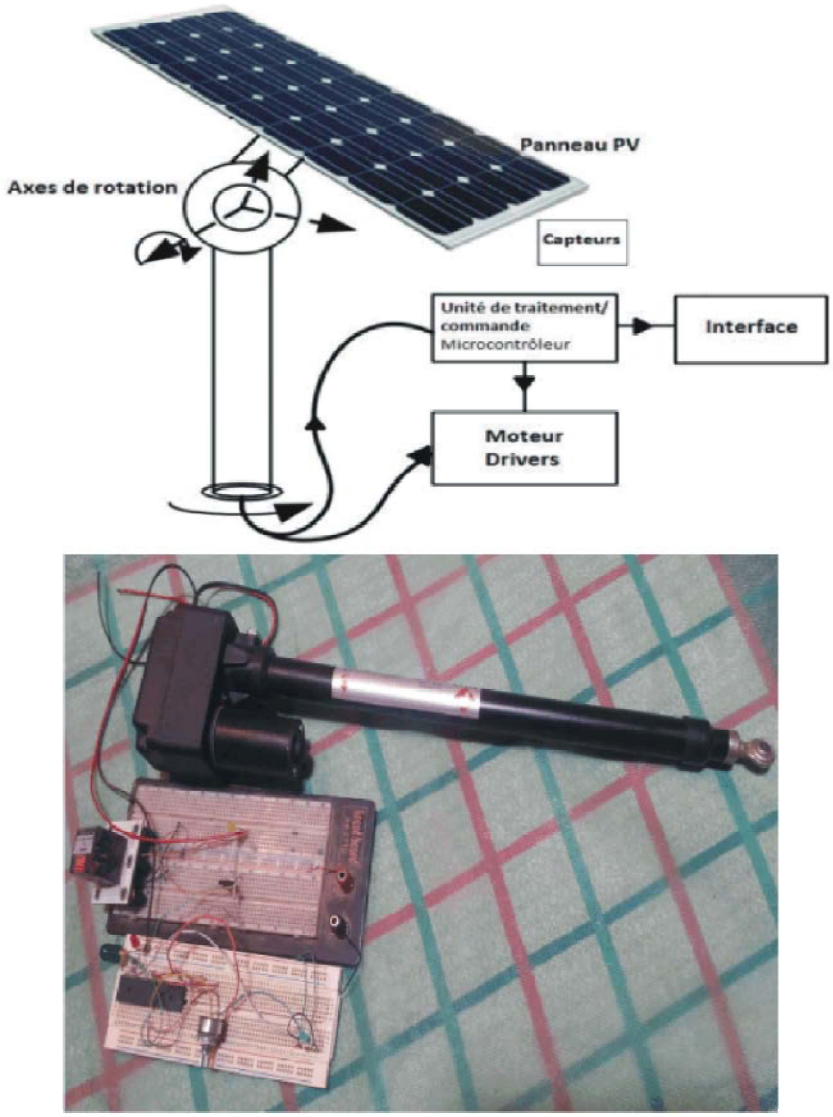

Fig. 4: Sun tracking automatization for PV panel

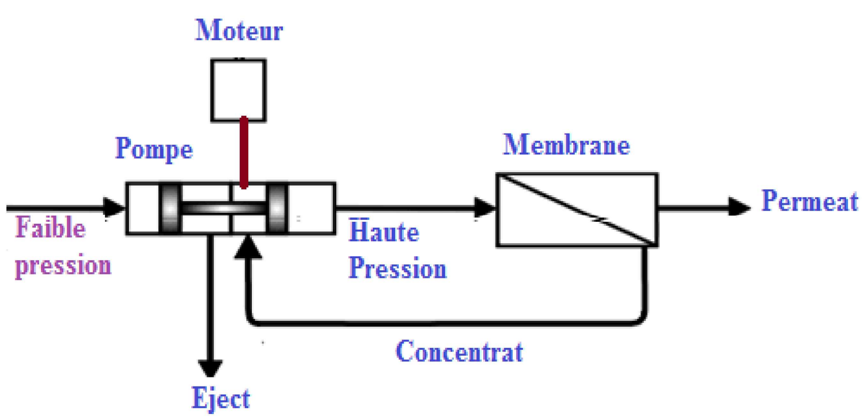

Fig. 5: Reverse osmosis system principle provided by Clark pump

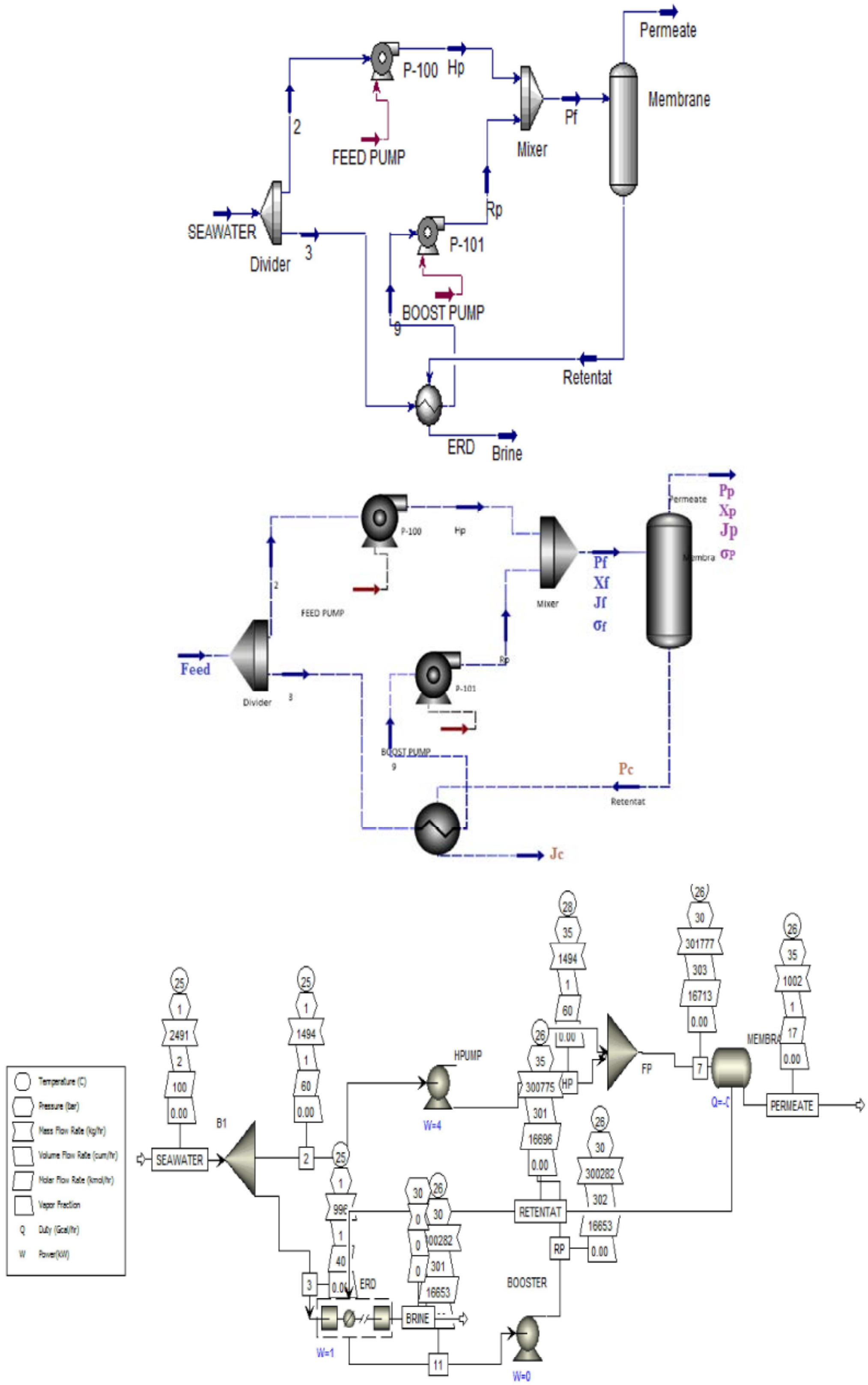

Fig. 6: Simulation of reverse osmosis model under Aspen Plus

Table 1: PV characteristics in function of Junction temperature.

Junction temperature (°C)	Irradiance (W/m^2)	I_{max}(A)	V_{max}(V)	P_{max}(W)	R_s(Ù)
35	400	2	40	80	0.85
45	600	3	40	120	0.82
55	800	4	40	160	0.76
65	1000	5	40	200	0.72

Table 2: Heat and material balance under Aspen Plus.

Heat and Material Balance Table										
Stream ID		S2	S3	S4	S5	SEAWATER	PF	PERMEATE	RETENTAT	BRINE
From		B1	B1	B2	B3		B4	B6	B6	B7
To		B2	B3	B4	B4	B1	B6		B7	
Phase		LIQUID	LIQUID	LIQUID	LIQUID	LIQUID	LIQUID	LIQUID	LIQUID	LIQUID
Substream: MIXED										
Mole Flow	kmol/hr									
WATER		.9064153	.6042769	.9064153	.6042769	1.510692	1.510692	1.496335	.0143572	.0143572
NACL		.1862724	.1241816	.1862724	.1241816	.3104539	.3104539	2.13294E-5	.3104328	.3104328
Total Flow	kmol/hr	1.092688	.7284584	1.092688	.7284584	1.821146	1.821146	1.496356	.3247901	.3247901
Total Flow	kg/hr	27.21554	18.14369	27.21554	18.14369	45.35924	45.35924	26.95813	18.40111	18.40111
Total Flow	l/min	.3733822	.2489214	.3733905	.2491098	.6223036	.6226716	.4533349	.1870208	.1870208
Temperature	K	298.1500	298.1500	298.2284	300.8087	298.1500	300.2282	301.1500	301.1500	301.1500
Pressure	atm	5.921540	5.921540	13.22766	88.43989	5.921540	13.22766	64.15000	64.15000	64.14531
Vapor Frac		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Liquid Frac		1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
Solid Frac		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Enthalpy	cal/mol	-74502.69	-74502.69	-74496.65	-74400.33	-74502.69	-74458.12	-68641.94	-1.0147E+5	-1.0147E+5
Enthalpy	cal/gm	-2991.238	-2991.238	-2990.996	-2987.129	-2991.238	-2989.449	-3810.085	-1791.083	-1791.083
Enthalpy	cal/sec	-22613.38	-15075.59	-22611.55	-15054.87	-37688.97	-37666.42	-28531.33	-9154.978	-9154.979
Entropy	cal/mol-K	-38.97260	-38.97260	-38.96877	-38.81560	-38.97260	-38.84001	-39.94605	-27.85542	-27.85542
Entropy	cal/gm-K	-1.564726	-1.564726	-1.564573	-1.558423	-1.564726	-1.559403	-2.217272	-.4916640	-.4916640
Density	mol/cc	.0487743	.0487743	.0487732	.0487374	.0487743	.0487455	.0550129	.0289442	.0289442
Density	gm/cc	1.214821	1.214821	1.214794	1.213902	1.214821	1.214103	.9911046	1.639845	1.639845
Average MW		24.90697	24.90697	24.90697	24.90697	24.90697	24.90697	18.01586	56.65540	56.65540
Liq Vol 60F	l/min	.3662107	.2441405	.3662107	.2441405	.6103512	.6103512	.4501581	.1601932	.1601932

Sun Tracking Automatization: The aim for automatization is to extend interval of benefit from solar radiations by exploiting photovoltaic effect. Thereon, we use appropriate programmable microprocessor and photo resistors as sensors to detect optimal position in the way to get maximal power during the day. We illustrate it in Fig. 4 [16, 17].

Results Test of PV: We note that PV intensity current relies to solar irradiance during the day, but thanks to automatic following the power is important for each junction temperature. Therefore, we resume some examples in the given Table.

Reverse Osmosis System: This phenomenon is biologic in origin; otherwise, we use it for seawater desalination basing on membrane processes. Indeed, to desalinate by membrane we reach osmotic pressure to separate water molecules from saline water. We build our private system referring to the principle of Clark pump as given by Fig. 5 [18, 19, 20].

Modelization and Simulation: Many parameters are varying during desalination process so, it reflects the performances of our system. We make obvious distinction by a developed model under Aspen Plus which which is powerful for system building especially talking about desalination and hydraulic processes. Our model is given in the Fig. 6:

Table 3: Reverse osmosis performances of innovative pump.

P(W)	Jp(L/h)	SEC(KWh/m3)	MPE(%)	Pf(bar)	R(%)	σp(μS/cm)	G(%)
192	34	5.65	40.00	20	8	644	6
210	37	5.68	43.75	24	12	616	13
236	43	5.49	49.17	28	15	595	17
264	48	5.50	55.00	33	18	574	23
287	51	5.63	59.79	37	21	553	28
300	54	5.56	62.50	41	24	532	31
314	57	5.51	65.42	45	27	511	34
330	60	5.50	68.75	48	32	476	38

Fig. 7: Pump conception and electric converion

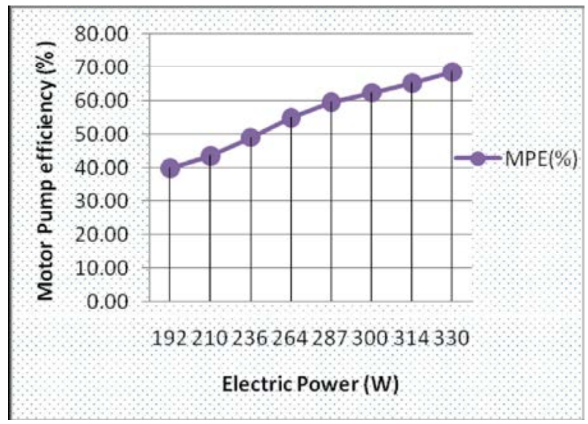

Fig. 10: Evolution of motor pump efficiency

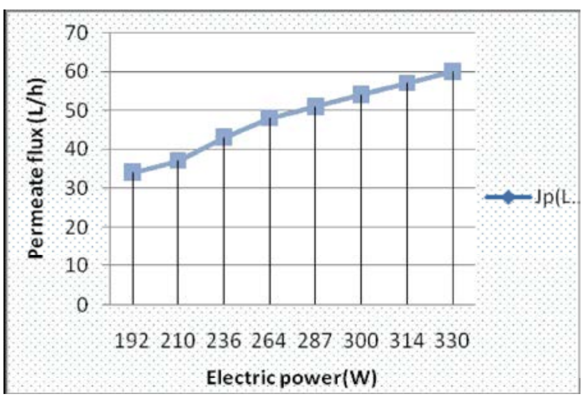

Fig. 8: Permeate flow with consumption

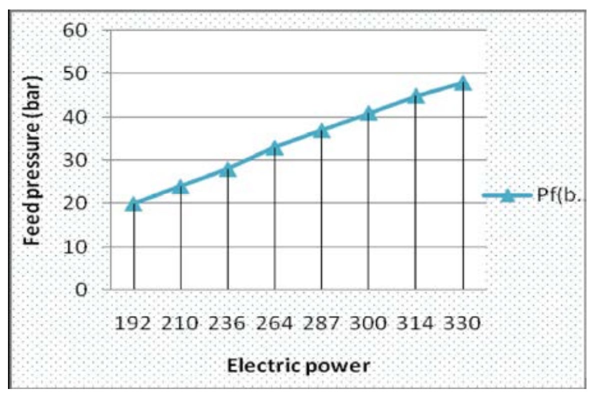

Fig. 11: Feed pressure variation in function of power

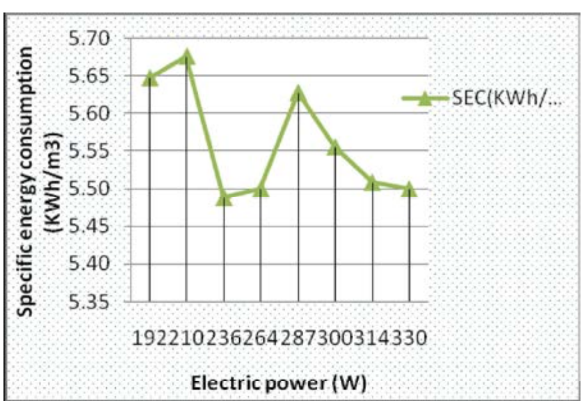

Fig. 9: Specific energy for different powers

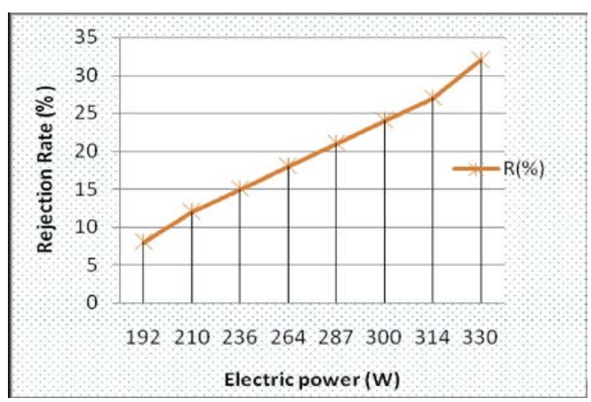

Fig. 12: Evolution of salt rejection rate

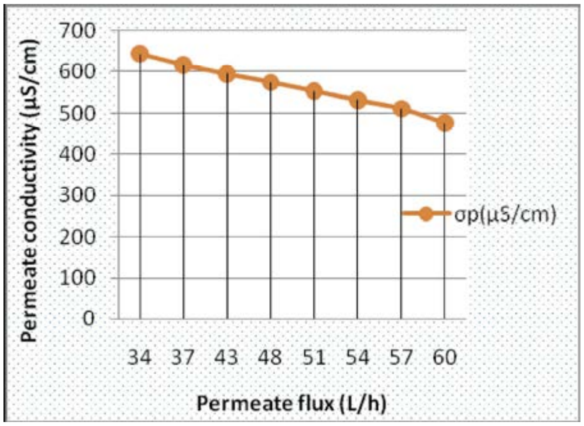

Fig. 13: Performance of desalination for various power.

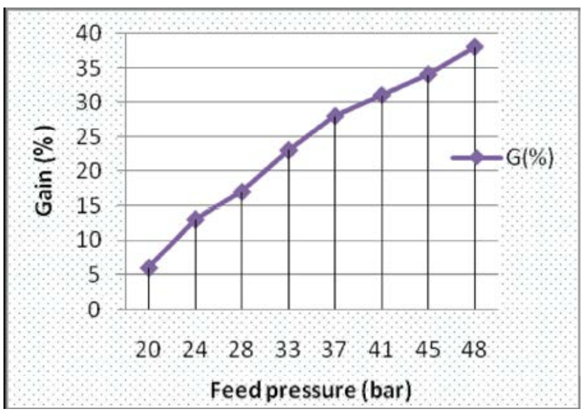

Fig. 14: Gain rate in function of feed pressure

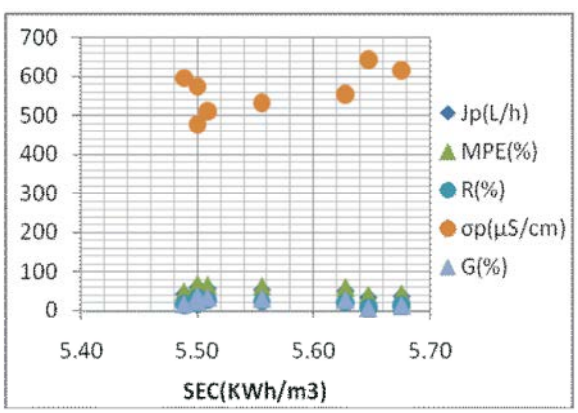

Fig. 15: Performances with specific consumption.

System Interconnections: The system presents various factors which are based on flow and energy conservation. Above all, recycling of concentrate ensures energy recuperation under pressure gradient. We use many references to build interconnections [21, 22, 23, 24].

$$P_F = P_P + P_C \quad (6)$$

$$J_F.P_F = J_P.P_p + J_C.P_C \quad (7)$$

$$J_P = V_P/\Delta t \quad (8)$$

$$SEC = U.I / J_P \quad (9)$$

$$MPE = U.I/ P_{max} \quad (10)$$

$$R=1-X_P/X_F \quad (11)$$

$$JC = R.\ JF \quad (12)$$

$$G = Pc.Jc / P_F.J_F \quad (14)$$

$$\sigma_P = \sigma_F.\ (1-R) \quad (15)$$

Pump Fabrication: The core of this work is to fabricate a new pump that benefits from double movement. In fact, old pumps work in one direction or we implement a few pumps for one process. Thereon, we consume more energy. The developed pump is a powerful technique thanks to low consumption and working in both directions. The efficiency increases in comparison to other systems of reverse osmosis processes. The recuperation of concentrate minimizes the mechanic energy above we choose adequate motor working in optimal function point. We illustrate the fabricated pump in given Fig. 8 that works using solar energy as renewable one. The conversion is required to feed pump motor via PV panel.

Experimental Results: Based on recycling of concentrate and changing the power of feed using a varistor we resume the results in the provided Table. The developed pump has promising haracteristics after results analyzing. The specific energy consumption varies in (5, 5-5, 7 KWh/m^3) which is a wonderful result (less than 8KWh/m^3) in comparison to other systems. Moreover, the distillate quantity obtained is accepted with the average of (45 L/h). The shape and geometry of fabricated pump contribute in energy reducing and boost the process of concentrate recycling to minimize mechanic energy. The gain improves to reach 35% for 45 (bar) of feed pressure, we ensure the osmostic pressure for wide range of membranes. The distillate conductivity decreases from (700 ìS/cm) to reach (500ìS/cm) it also responds to the limit permitted by the world organization of health. The exploitation of solar power ensures good efficiency and rejection rate extending to reach (40%). We remark low losses of pressure for developed pump along with implementation of solar energy then it deserves to be qualified as solution of fresh water shortage especially that we applicate it for seawater which it recovers important area in our planet.

CONCLUSIONS

Thanks to this innovative pump and implementation of solar energy, this work is a promising alternative among membrane processes of desalination. The pump doesn't require a lot of energy and it recuperates a part of its consumption from concentrate recycling. The performances constitute defiance especially that it concerns vital element of life. Seawater desalination has confirmed to resolve the fresh water shortage by adopting similar solutions in different countries around the world. The benefit of photovoltaic effect is a crucial and suitable way for costs reduction of such systems.

ACKNOWLEDGEMENTS

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Nomenclature:

E_s: Solar irradiance (W/m^2).
I_{sc}: C.C current (A).
I_{ph}: Photo-current of cellular (A).
I_d: Diode current (A).
I_r: Shunt resistor current (A).
I_0: Saturation current (A).
q: Electron charge ($1,6\ 10^{-19}$C).
K: Boltzmann constant ($1.38\ 10^{-38}$J/K).
n: Ideality factor ($1<n<5$).
T: Junction temperature (K).
σF : Feed conductivity (µS/cm).
σP : Permeate conductivity (µS/cm).
J_F : Feed flux (L/h).
P_F: Feed pressure (bar).
X_F: Feed salinity (g/L).
U: Applicated voltage (V).
I: Applicated current intensity (A).
P_P: Permeate pressure (bar).
P_C: Concentrate pressure (bar).
J_P: Permeate flux (L/h).
P: Power (W).

Nomenclature:

X_P: Concentration du permeat g/L.
Δt : Time of desalination process (h).
X_C : Concentration du concentrâtg/L.
P_H: High pressure of pump (bar)
J_C: Concentrate flux (L/h).
R: Rejection rate (%).
m_p: Permeate mass (Kg).
S_m: Membrane area (cm2).
MPE: Motor pump efficiency (%)
SEC: Specific energy consumption (KWh/m^3)
G: Gain (%)

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