ISSN 2229-5518

Numerical investigation of a reverse osmosis desalination system with cogeneration and renewable energy integration

Y. Aroussy[1], M. Nachtane[1], D.Saifaoui[1], M.Tarfaoui[2]
[1]Renewable Energy Laboratory and dynamic systems University Hassan II Faculty of sciences Aïn chock
[2]Department of Fluid Dynamics, Materials and Structures, ENSTA Bretagne – IRDL/LBMS, 29806 Brest

Aroussy110@gmail.com
mourad.nachtane@gmail.com
ddsaifaoui@gmail.com
m.abidkamy@gmail.com
Bahassi.mehdi@gmail.com

Abstract: At first we will present a numerical simulation of sea water desalination and brackish water reverse osmosis plants with cogeneration in which we will establish the governing equations and solve analytically to validate numerical modeling with different systems based on the mass conservation laws of momentum, energy and the second law of thermodynamics, then we will show the positive impact of renewable energy as a free source to power reverse osmosis.

Keywords:
Desalination, Reverse Osmosis, Cogeneration, Renewable Energy.

Introduction

Water and energy are two inseparable products that govern the life of humanity and civilization develops. The history of mankind shows that water and civilization are two inseparable entities. This is proved by the fact that all great civilizations were developed and thrived near major water sources.
In this context of climatic uncertainties, droughts and water shortages, desalination appears to be one of the most promising solutions to overcome this situation [1].

From seawater or brackish water through special techniques.
So Water is vital for human life. For this reason and to support the human development needs this source increased in a phased manner, particularly in the area of use. In this perspective and to meet these increased water needs, it has become essential research other innovative alternative[2]., such as the invention and construction of units capable of producing safe drinking water from the resources of saline water. This process of salt water treatment, desalination called, involves removing salt brine
Indeed, the largest water reserve of our planet is salt water of the seas and oceans. In this perspective, our project has focused on the study of a power cogeneration system and drinking water by the desalination process based on the Rankin cycle.
This project consists of a performance analysis of three systems described below, combining a reverse osmosis unit (RO) for the production of drinking water and a Rankin cycle which produces mechanical work[3]..
RO subsystem incorporates an energy recovery unit with hydraulic turbine in the second system; while in the third, it incorporates an energy recovery unit based on an exchange.

-First case (system 1): Study simple without cogeneration Rankin.
-Second case (System 2): RO subsystem incorporating a water turbine, coupled with the Rankin cycle.
-Third case (system 3): Sub-RO system, incorporating an energy recovery unit based on an exchange, coupled with the Rankin cycle.
-Fourth case (system 4): gas-steam combined cycle for desalination and electricity generation
-Fifth case (system 5): integration of renewable energy for desalination water sea and producing electricity.

I. RO DESALINATION SYSTEM

The membrane desalting systems include reverse osmosis (RO), where seawater is pressurized against a semipermeable membrane that allows almost pure water to permeate[4]., and not salt. It is mechanically driven by pumping energy. The main problem of the SWRO is the membrane's fouling that required extensive pretreatment to avoid or decrease that fouling. The feed water pressure (Pf) to the membranes is in the range of 60–80 bar (depending on the feed water salinity, and membranes characteristics). The brine leaving the membranes is at about 2 or 3 bar only less than Pf. The energy of this brine can be recovered by energy recovery device (ERD), (e.g. reversed centrifugal pump working as a turbine, Pelton wheel, and pressure exchanger). The specific consumed energy is in the range of 4–6 kW h/m3 depending on the feed water salinity and the type of ERD. The share of RO membrane process is rapidly increasing with the time compared to distillation processes as it consumes much less energy, and thus less cost, see Fig. 1.

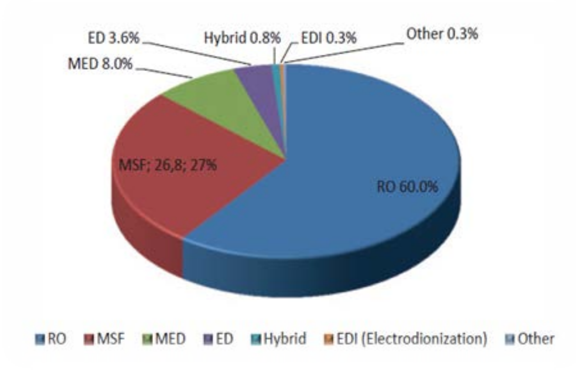


Fig. 1: The trend of increasing use of RO compared to distillation processes.

II. Geometric and Mathematical Formulation

Desalination technology can be regarded as a system whose input is the saline water. This water requires an amount of energy to separate it into brine (often called the concentrate) and in pure water .This amount of energy depends on the characteristics of the saline water and on the technology used.

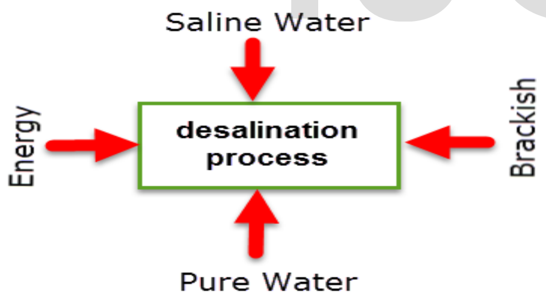


Fig. 2: desalination system modeling

A. Operating Principle of Reverse Osmosis

To produce drinking water from sea water, we resorted to desalination system based on reverse osmosis. The latter consists of a water purification system containing materials in solution through a filtering system very end that lets only the water molecules[6]..

This system mainly consists of a semi-permeable membrane filter, placed between two compartments containing different salinity solutions (see diagram below).

On the other hand, osmosis is a natural phenomenon which involves the migration of water from the less concentrated solution to more concentrated solution, ie osmotic flow. It should be emphasized that this flow through the membrane will stop naturally as the system reaches equilibrium. It is said that equilibrium is reached when the difference in height is equivalent to the osmotic pressure, which corresponds to equal concentrations on both sides of the membrane[5]..

Moreover, when applying a pressure higher than the osmotic pressure to the more concentrated solution, the water flow goes in the opposite direction of the osmotic flow, that is to say in the most concentrated solution to the least solution concentrated: the reverse osmosis phenomenon.

On its part, the feed solution is injected into the membrane by means of pumps. For powering the system is coupled with the Rankin cycle which provides the simultaneous production of thermal energy and mechanical energy; This is called cogeneration.

On the one hand, the mechanical energy generated by a turbine or a motor is converted into electrical energy and second, the thermal energy from the heat recovery condenser (through exchangers) is used to heat seawater.

Cogeneration has many attractions other than the mere provision of electricity and heat. This is indeed one of the most effective ways of generating electricity with a smaller volume of emissions and waste.

B. Cogeneration System

On the other hand, thermal power generation is not very effective if we cannot recover the waste heat from the power plant. Thus, for the recovery of these, it increases the overall plant efficiency by getting more useful energy per unit of fuel burned. To this end, it fills more needs rejecting less heat, fewer greenhouse gases and fewer pollutants[7]..

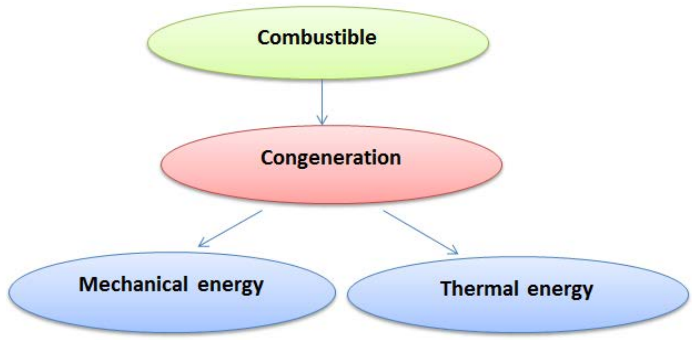


Fig .3: Diagram of a cogeneration system.

C. Hypotheses:

During this study will be considered the following assumptions:

Steady;

ISSN 2229-5518

The change in kinetic energy and potential energy flows are negligible;

The fluid at the inlet of the hydraulic pump must be a compressed liquid which confirms the selection of the heat supplied to the boiler;

The temperature T5 and pressure P5 of saline water at the entrance of the system are considered the reference conditions, and are considered also as ambient conditions;

The losses have been neglected.

-m1 = m2 = m3 = m4 = M: the flow rate of fluid circulating in the Rankin cycle;

-M5 = M6 = M7 = M: the salt water feed rate;

-M10 = M11: the flow of rejected brine;

-M9=M10 = M: e the flow of water produced;

- r1 = M9 / ṁ: permeate recovery rate;

- r2 = M10 / ṁ: the rejection rate of the brine;

-r3 = M / m: the mass ratio between the pure water flow rate in

-the Rankin cycle and the saline feed water flow rate;

-The temperature of the sea water is assumed equal to 15 ° C;

-For lack of data at the output of the reverse osmosis system, they were considered the following values: T9 = T10 = 20 ° C and T11 = 15 ° C.

D. RANKIN CYCLE

After a brief description of the Rankin cycle, they will be studied and analyzed successively the following systems: the simple Rankin cycle cogeneration without, then with the Rankin CHP without thermal coupling and finally Rankin with cogeneration and thermal coupling.

We performed the calculated three first case based on the Rankin cycle :

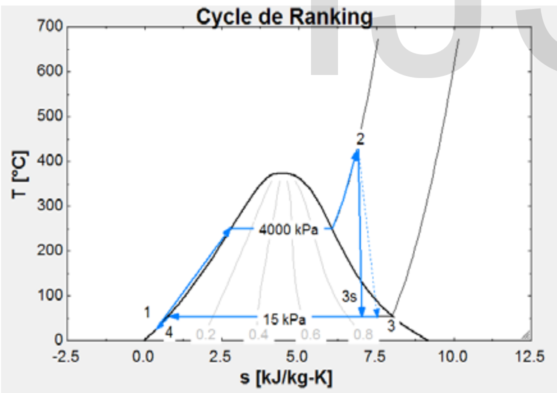
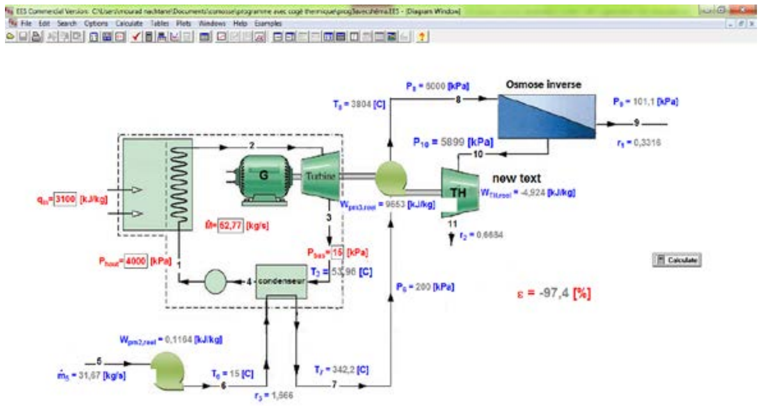


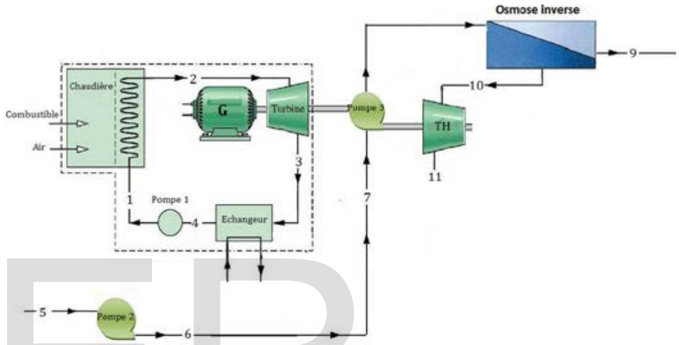
Fig. 4: T-S diagram of the Rankin cycle

III. SIMULATION OF SYSTEM

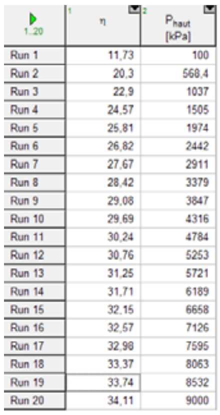


IV. RESULTS:

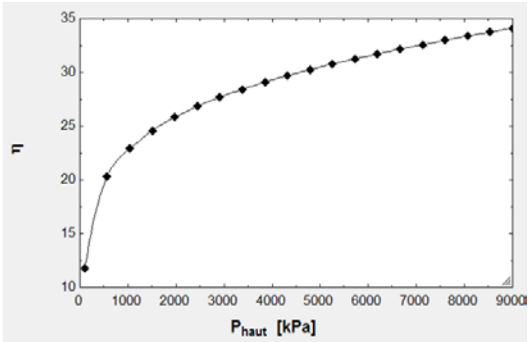
A. *First Case : Rankin cycle without cogeneration*



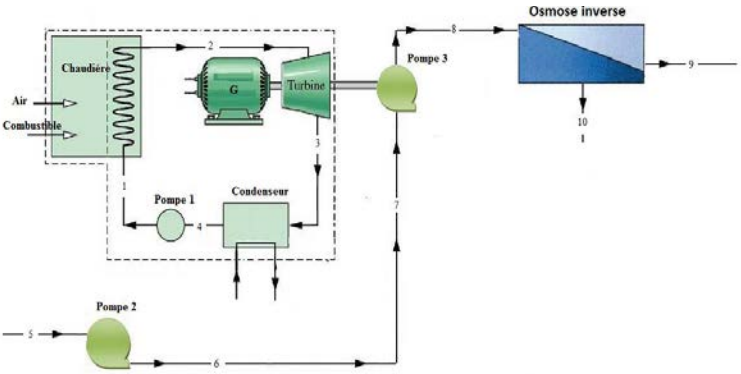
It is observed with increasing high pressure; augment the efficiency to a value equal to 34%. It is therefore deduced that one must have a high pressure at the steam generator.



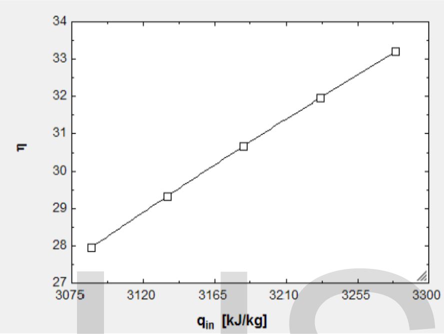
1..20	η	P_{haut} [kPa]
Run 1	11,73	100
Run 2	20,3	568,4
Run 3	22,9	1037
Run 4	24,57	1505
Run 5	25,81	1974
Run 6	26,82	2442
Run 7	27,67	2911
Run 8	28,42	3379
Run 9	29,08	3847
Run 10	29,69	4316
Run 11	30,24	4784
Run 12	30,76	5253
Run 13	31,25	5721
Run 14	31,71	6189
Run 15	32,15	6658
Run 16	32,57	7126
Run 17	32,98	7595
Run 18	33,37	8063
Run 19	33,74	8532
Run 20	34,11	9000



B. *Second Case : Rankin with cogeneration without thermal coupling:*

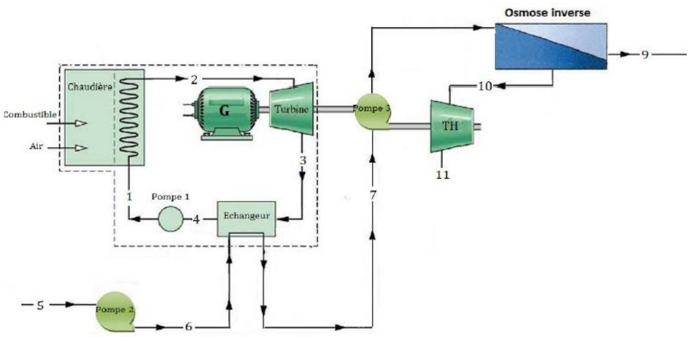


1..20	q_{in} [kJ/kg]	η
Run 1	3087	27.95
Run 2	3135	29.33
Run 3	3183	30.66
Run 4	3231	31.95
Run 5	3279	33.21

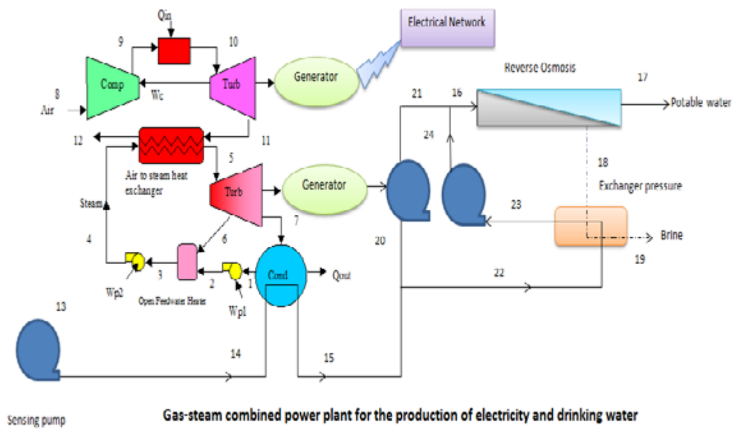


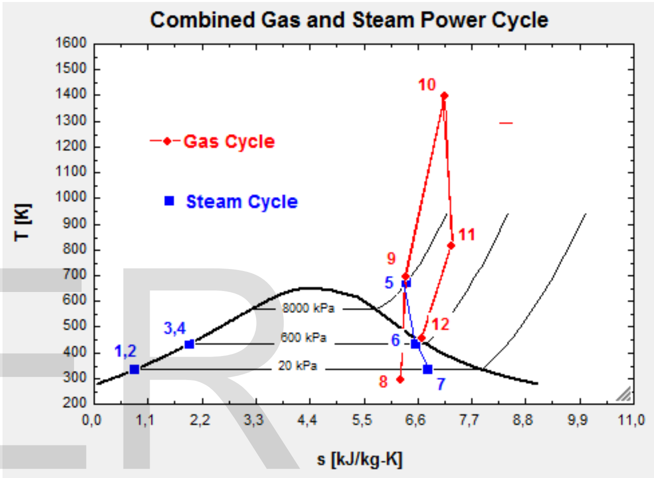
The yield increases with increasing the q in energy, to have a decent return; we must choose the value of the energy entering in the combustion chamber.

C. *Third Case : Rankin with cogeneration and thermal coupling:*



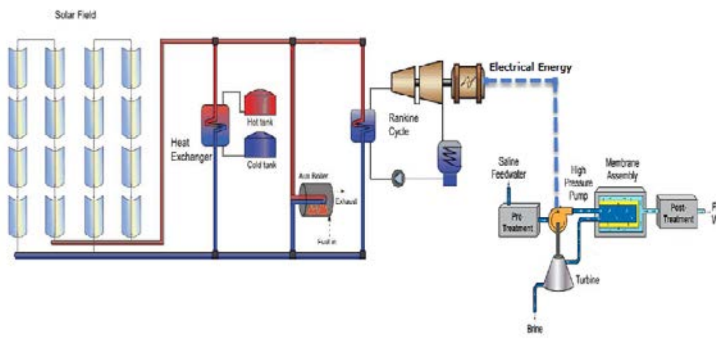
D. *fourth case : gas-steam combined cycle for desalination and electricity generation :*





E. *Fifth case (system 5): integration of renewable energy for desalination water sea and producing electricity.*

In this part analyzed different kinds of desalination systems combined with renewable energy sources such as solar energy. In order to select the best solar desalination-integrated system, it is important to understand its minimum energy requirements, energy recovery and major exergy destruction processes. thermodynamic analysis and modeling of the desalination system is the key to understanding the integration of a desalination system with renewable energy sources.



for the power block, and a lower levelized cost of electricity (LCOE). Second, storage makes it possible to extend the delivery of electricity to cover the broadest period of peak demand and highest electricity prices. In the extreme, this might ultimately enable CSP to function as baseload power[8].. Third, the timing of peak electricity generation can be shifted away from the time of peak solar insolation to better match peak demand, even with limited storage capacity.

Conclusion

From the study of the cogeneration of power and water by reverse osmosis with hydraulic turbine, it was possible to under draw the following conclusion:
The thermal coupling has a large effect on the energy efficiency of water cogeneration systems and power. It allows increasing the temperature at the reverse osmosis system which in turn increases the amount of drinking water produced.

- Thus, this research project allows for financial and environmental benefits as follows:

The production of drinking water through seawater desalination system is a viable and effective solution to address the problem of lack of drinking water in some regions of the Kingdom and also cope with the pollution water in others.

- The economics of energy at the exchanger by reusing waste energy to preheat the seawater before entering the reverse osmosis system.

REFERENCE

[1]. O. Sow, Analyse thermodynamique d'un système de dessalement par distillation avec apport solaire. Recherche des conditions optimales de fonctionnement en regime variable, thèse de doctorat Université de Valenciennes, 2004, p. 195.

[2]. Cengel-Boles-Lacroix : Thermodynamique une approche pragmatique pages (495-496).

[3]. Bouzayani Nawfel /Avril 2006 : Analyse exégétique de systèmes de cogénération de puissance et d'eau par osmose inverse avec turbine hydraulique ou échangeur de pression.

[4]. M. Smith and R. Shaw, Desalination. WEDC Loughborough University Leicestershire,

[5]. O.L.V. Sallangos, Operating experience of the Dhekelia seawater desalination plant using an innovative energy recovery system, Desalination,173 (2005) 91–102.

[6]. M.A. Darwish, A. Darwish, Solar cogeneration powerdesalting plant with assisted fuel, Desalin. Water Treat. 52 (2014) 9–26.

[7]. Y. Cerci, Exergy analysis of a reverse osmosis desalination plant in California, Desalination, 142 (2002)257–266.
[8]. S. Saleem, A. ul Asar, Analysis & Design of Parabolic Trough Solar Thermal Power Plant for Typical Sites of
.