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SIMULATION STUDY OF REVERSE OSMOSIS DESALINATION SYSTEM POWERED BY COMBINED SOLAR AND WIND POWER PLANTS

OPTIMISATION OF THE DIMENSIONS OF WIND AND SOLAR SUBSYSTEMS

Ph.D THESIS

by

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INTRODUCTION

The problem of fresh water shortage faced by most countries as a result of consumption increase and population growth , where the average daily per person water consumption is in the order of 50 liters in the developing countries and exceeds 500 liters in certain western countries .These figures represent the total average consumption for all activities without distinction

while for the human nutritional purpose the daily requirement is only about 4 to 5 liters per person for cooking and drinking.

This problem led to use desalination process as about 97.5% of the world’s water resources is existed as salt water in the oceans and seas in addition to brackish water in many regions, at the present time a number of large desalination units are already in operation ,most of these units are powered by fossil fuels (oil or gas) either directly for distillation processes or indirectly for processes using semipermeable membranes (electrodialysis or reverse osmosis) among the desalination methods ,the reverse osmosis desalination one has the advantage from the point of view of energy consumption the low energy consumption is a primary reason why reverse osmosis is rapidly becoming the sea water desalination choice.

The energy crisis is one of the most difficult problems faced by different countries, due to the higher prices and limitations of conventional fuels ,a lot of effort is devoted to find competitive alternative energy sources. Among possible alternative energy sources, the solar energy is pollution—free and limitless. Also recent development in wind turbine technology means that wind power can be regarded as a reliable and cost—effective power source for many areas in the world.

The rising energy costs have motivated many countries to turn to renewable energy sources for desalination purposes.

The cost is also the main criterion for the choice of the solar! wind generators dimensioning and there is more than one factor affecting it ,when a reverse osmosis system is powered by combined solar / wind.

Chapter (1) presents the desalination by reverse osmosis in addition to the operation of solar and wind generator.

Chapter (2) presents the simulation results of the main reverse osmosis desalination systems in use

a—One stage (RO1)

b—One stage with recovery turbine (RO1RT)

c—Two stages (R02)

d—Two stages with recovery turbine (RO2RT)

Where :

It also deals with two new designs proposed. These two designs are simulated according to the following models

e—One stage with module connected to the rejectwater (ROll)

f—Two stages with module connected to the rejectwater (R021) where improvement in specific energy and productivity were achieved in addition to the rejectwater reduction compared to

RO1 RO2

Chapter(3) deals with simulation study of reverse osmosis desalination system powered by solar wind and by combined solar —wind power plants where program model was developed to study the following possible designs

a—One stage reverse osmosis system with recovery turbine powered by solar energy with a. battery and a. diesel generator b—One stage reverse osmosis system with recovery turbine powered by wind energy with a battery and a diesel generator c—One stage reverse osmosis system with recovery turbine powered by combined solar – wind energy with a battery and a diesel generator

Also the operation of two new proposed designs was tested

– Reverse osmosis system with n module with constant and a variable pressure

Chapter(4) deals with the problem of optimal dimensions of solar and wind subsystems with objective function ,the cost of potable water .The steepest descent algorithm succeeded to give the solution ,while the variations of the different parameters proved the sensibility of the method.

CHAPTER (1)

REVERSE OSMOSIS DESALINATION SYSTEMS POWERD BY SOLAR AND WIND ENERGY

1.1 THE DESALINATION BY REVERSE OSMOSIS

1.1.1 INTRODUCTION

Water is becoming scarce as consumption increases due to population growth and rising standards of living .The average daily per person water consumption is in the order of 50 liters in the developing countries and exceeds 500 liters in certain western countries. These figures represent the total average consumption for all activities without distinction while for the human nutritional purpose the daily requirement is only about 4 to 5 liters per person for cooking and drinking.

About 97.5%.of the world's water resources is existed as salt water in the oceans and seas.

At the present time a number of large desalination units are already in operation ,most of these units are powered by fossil fuels (oil or gas) either directly for distillation processes or indirectly for processes using semipermeable membranes (electrodialysis or reverse osmosis).

However for a high capacity plant operating with a high plant factor -energy- related costs account for 40 to 50 % of the total cost per cubic meter of fresh water [1].

Energy consumption is one of the important parameters that dictates the choice of the used desalination method and the final unit cost of desalted water.

Many studies were made and proved that reverse osmosis consumes less energy than the other systems [2].

The cost of the consumed energy depends beside the performance of the plant on the quality of Energy [3] ,when compared to freezing or evaporation ,reverse osmosis has the advantage that water can be separated from a solution at near theoretical minimum power requirements without the large energy investment which is required for a change of state [4] .

So low energy consumption is a primary reason why reverse osmosis is rapidly becoming the sea water desalination process of choice. The seawater reverse osmosis process requires only 5 to 7 $\left(Kwh/m^3\right)$ of energy to produce a cubic meter of potable water where it is about 1/2 the energy that is required by conventional distillation [5].

1.1.2 THE BASIC PHENOMENON AND PROCESS DESCRIPTION.

Reverse osmosis(R.O) is a pressure driven separation of water from a brine solution across a membrane the pressure being adequate to overcome osmotic pressure of the saline solution and to provide an economically acceptable flux [6,7] .

The membrane is placed in a cylindrical pressure vessel which must be adequately protected against damage which would be caused by failure or power outage. The cost of membranes is about 25% of the total installations for brackish water and about 35% for seawater [8].

The feed water Fw with concentration *Cf(ppm)* enter the membrane-module with pressure P is split into a permeate flow or product water Pw with concentration *Cp(ppm)* and reject water Rw with concentration Cr(ppm) .

The relationship between product water and feed water is given by a recovery ratio Rr as[8].

$$Y = \frac{Pw}{Fw} \tag{1.1}$$

also the relation between feed and product and reject water in the R.O. system is as

$$Fw = Pw + Rw \tag{1.2}$$

The product water flow through a semi-permeable membrane can be expressed at design operating condition as following [9].

$$Pw = (Lp)(P - \Delta\pi)(A) \tag{1.3}$$

Where *Lp* is the hydrodynamic permeability of the membrane $\left(m^3 / m^2 \cdot psi \cdot hr\right)$.

P is the applied hydrostatic pressure (*psi*).

A is the area of the membrane (*m*^{2}).

$\Delta\pi$ is the difference between the osmotic pressure of the feed $\Delta\pi f$ and product $\Delta\pi p$ water where is calculated by the following relation (*psi*).

$$\Delta\pi = \Delta\pi f - \Delta\pi p \tag{1.4}$$

The salt rejection R is defined [8,10] by the relation.

$$R = \frac{(Cf - Cp)}{Cf} \tag{1 .5}$$

The osmotic pressure of feed water is established by the feed concentration *Cf* and temperature *Tk* it can be expressed by [11,12].

$$\Delta\pi f = \frac{0.0384933(Cf)(Tk)}{\left(1000 - \left(\frac{Cf}{1000}\right)\right)} \tag{1.6}$$

and $\Delta\pi p$ is calculated as follows

$$\Delta\pi\, p = \frac{0.0384933(Cp)(Tk)}{\left(1000 - \left(\frac{Cp}{1000}\right)\right)}$$

(1.7)

There are different methods to correct the equation of product water where in chapter(2) will be exhibited the main features of models dealt with that.

A - FLOW RATE

A R.O. plant is usually designed to produce a certain flow of productwater, low product rate is a sign of fouling and an indication that cleaning is necessary .

A configuration must be operated above min. brine or reject flow rate to prevent concentration polarization, from occurring.

Each stage of an R.O plant is designed to operate at a particular recovery [13] ,if the recovery is more than the design value then the product water quality will be poorer because the salt concentration on the feed /reject side of the membrane increase.

A higher salt concentration increases the salt flux also the increase of the osmotic pressure will reduce the water flux, both result in impaired product water quality [7].

The range of recoveries which have been proposed for various systems has been between (20 & 45)% ,with the lower recoveries being used in smaller systems [4],in other words the reject brine water is between (80 & 55)% of feed water.

No any study deals with this quantity of Reject brine water. As economical problem of brine disposal where is not included in economical estimates [14].

B- EFFECT OF APPLIED PRESSURE

The permeated rate can be increased by increasing the applied pressure

The salt flow through a membrane is defined by.

$$Fs = (B)(Cf - Cp) \tag{1.8}$$

where: Fs- is the salt flux $\left(g/cm^2 \cdot s\right)$.

B- is the salt permeability (cm/s).

Cf-Cp- is the concentration gradient across the membrane $\left(g/cm^2\right)$.

Although none of these parameters is directly affected by a change in the feed pressure [15] there is an indirect effect of pressure on the salt concentration of the product water.

If the pressure reduced, less water permeates the membrane. while the salt flux stays constant ,thus there is more salt per unit volume of product water conversely if the pressure increase more water permeates the membrane, yet the same amount of salt transfer occurs .Thus there is less salt per unit volume of water [16].

The effect of pressure on salt rejection is demonstrated in [17], also the feed pressure results in compaction of the membrane [18] at a particular temperature obtained after operating for time *(t)*.

The effect of pressure on the overall productivity is a result of the sum of the instantaneous productivity and the compaction, usually the productivity at any particular time is greater for high pressure operation than for low pressure operation.

The standard feed pressure for brackish water membranes is nearly 27 bar (400 *psi*) while that of seawater membranes is about 55 bar (800 *psi*) or higher (7].

Operating pressure is there for a major factor in determining reverse osmosis flux [19].

e- EFFECT OF TEMPERATURE

Feed water temperature has several effects on energy requirements ,first the osmotic pressure is directly proportional to the absolute temperature, although this is not a large effect ,because the possible temperature range is small, it is real & tends toward increasing the power requirements as the temperature is increased.

A second effect which is more evident is the increase in the mass transport coefficient (Lp).

There are lower and upper temperature limits imposed on the R.O operation .

The lower limit is zero C^0 for all membranes. and the upper limits depend on the membrane , and are pressure dependent, the current upper temperature limits of (30 to 35) C^0 where established by the membrane manufacturers.

Generally the optimum performance of membrane system is obtained when the feed temperature is (24 to 27) C^0 .So when the typical feed water temperature is low ,a heat exchanger is used to control the feed water temperature [7] Up to 30 C^0 the flux increased with increase in feed temperature but at over 30 the flux decreased with increase in temperature However the flux does not vary significantly at feed temperature between 15 & 50 C^0 this means that a satisfactory flux can be obtained at normal atmospheric temperature [19].

D- EFFECT OF THE FEED CONCENTRATION

In actual operating conditions the feed concentration changes frequently ,it was found that R0 flux decreased with increased feed concentration ,where when the feed concentration increased its osmotic pressure rose but the effective operating pressure decreases so the flux still decreased noticeably [19].

The salt flow is essentially independent of pressure and the permeate quality improves with applied pressure .

The relationship between the water flux and salt flux characteristics of a membrane can have significant effect on the power requirements [4] Salt rejection depend on the salt flux or on the quality in other word depends on the-recovery ratio.

E- CONSUMPTION OF ENERGY

The theoretical energy requirement to separate fresh water from sea water at law recovery is about 0.75 $\left(Kwh/m^3\right)$ this theoretical limit could be approached by an idealized reverse

osmosis device having.

1. perfect membranes able to provide complete salt rejection at working pressure just slightly above the feed Osmosis pressure.
2. Zero concentration polarization.
3. No energy requirement for feed pretreatment and filtration.
4. negligible brine side hydraulic losses.
5. 100% efficient feed pumping.
6. 100% efficient energy recovery from the reject brine.

Real reverse osmosis system depart rather widely from the above idealizations ,in order to achieve high membrane productivity and salt rejection ,typical working pressures for sea water desalination are about 2.5 times the feed osmotic pressure.

Energy losses due to hydraulic friction and pump inefficiencies are substantial [20] .Reverse osmosis process is reversible and the minimum work is required for separation when

the applied pressure approaches the osmotic pressure .Thus for a typical seawater system with an osmotic pressure of 24.8 atm. the energy required to separate one liter of water would be 24,800 cc-atm in more familiar units this amounts to 0.595 $\left(Kwh/m^3\right)$ in this is at an infinitely low permeation rate [4].

The energy consumed by the P.O. process will be mainly used to drive the following pumps [14].

- high pressure pump.
- reject water pump.
- feed water pump.
- product water pump.
- miscellaneous pumps for chemical injection.

The following relations is used to calculate the consumed energy(wh) in P.O. [21].

1-High pressure pump is (H.p.p)

$$Eo=\left[\frac{(c)(P)}{ep}\right]\left(\frac{1}{Y}\right)(Fw) \qquad (1.9)$$

2-Reject water pump is(R.w.p)

$$ERP=\left[\frac{(c)(PR)}{ep}\right]\left(\frac{1}{Y}-1\right)(Rw) \qquad (1.10)$$

3-Feed water pump is(F.w.p)

$$EFP=\left[\frac{(c)(PF)}{ep}\right]\left(\frac{1}{Y}\right)(Fw) \qquad (1.11)$$

4-Product water pump is(P.w.p)

$$EPP=\left[\frac{(c)(PP)}{ep}\right](Pw) \qquad (1.12)$$

c - conversion factor

P , PR , PF , PP , the applied pressure by high, reject, feed, product , pumps respectively *(psi)*

Ep- the efficiency of pump

Miscellaneous pumps for treatment will be not considered for simplicity & unknown specific parameters The load *EL(wh)* in the model is

$$EL=Eo+ERP+EFP+EPP \qquad (1.13)$$

The specific energy SPE(kwh/m) of productwater is

$$SPE=\left(\frac{(EL)(10)^{-3}}{Pw}\right) \qquad (1.14)$$

1.2 SOLAR AND WIND ENERGY

The rising energy costs have motivated many countries to turn to renewable energy sources for desalination purposes [1] . and particular attention is being paid to the consumption of various desalting processes it also results in an increased research effort on the use of renewable energies solar and wind energy[2].

Two demonstration projects were performed using wind or solar power for the energy supply of reverse osmosis desalination units [22].

The world’s first solar-powered sea water reverse osmosis system has been installed and was operating in Jeddah ,Saudi Arabia on the eastern shore of the red sea [23.]

More recently however small experimental genuinely wind-driven units have been run on Suderoog a small Island off the north sea coast of Germany [24].

For location at brownsville, texas.A design concept for a solar desalination plant couples a state of art solar power generation system with a reverse osmosis membrane filtration system Alternating current electric power is generated by an integrated wind & solar energy conversion system. The optional wind / solar ratio is very dependent upon site conditions [25].

A wind and photovoltaic powered reverse osmosis seawater desalination plant with a fresh water production of 150 (m^3 /day) was carried out in Tarifa Cadiz Spain [26].

1.2.1 - SOLAR ENERGY

The energy crisis is one of the most difficult problems faced in different countries, due to the higher prices and limitations of conventional fuels. A lot of effort is devoted to find competitive alternative energy source. Among possible alternative energy sources, the solar energy is the most inexpensive, pollution-free and limitless.

The application of solar energy in different uses has found it’s way successfully in many purposes. The knowledge of the available solar irradiation is valuable for the design and assessment of solar energy system.

Extensive work has been done for determining the total solar insulation on a flat plate surface at any orientation and their optimum tilt in different ways. [27,28,29,30,31].

- SOLAR RADIATION

The solar radiation consists of direct and diffused radiation, and The hourly values of global radiation incident on a tilted surface are calculated as follows 132].

$$Ht = Hbt + Hdt + Hrt \tag{1. 15}$$

Where Hbt Hourly values of direct radiation incident on a tilted surface.

Hdt- Hourly values of diffuse radiation incident on a tilted surface.

Hrt- Hourly values of reflected component incident on a tilted surface.

If we assume that the diffuse and reflected radiation components are isotropic then we can write.

Where Hd is the hourly value of the diffuse component on the horizontal plane.

The direct component on a tilted surface is calculated as the following.

$$Hdt = \frac{1}{2}(Hd)(1+\cos(t)) \tag{1.16}$$

$$Hrt = \frac{1}{2}(H)(rg)(1+\cos(t)) \tag{1.17}$$

H- is the hourly value of the global radiation on a horizontal plane.

Rg- is the ground reflectance.

t- is the tilt angle of the surface toward the horizontal plane.

$$Hbt = (H - Hd)(Rb) \tag{1.18}$$

where *Rb* is the hourly mean tilt factor and defined by the relation

$$Rb = \frac{\cos(z)}{\cos(i)} \tag{1. 19}$$

Where

z- The angle between the incident direct radiation and the normal to the horizontal surface at the mid-point of the hour considered.

i- The angle between the incident direct radiation and the normal to the tilted plane at the mid-point of the hour considered.

The total solar radiation on a tilt surface Ht can be expressed by [33].

$$Ht = (H - Hd)(Rb) + 0.5(Hd)(1 + \cos(t)) + 0.5(H)(rg)(1 - \cos(t))$$

(1.20)

- THE PHOTOVOLTAIC SOLAR CELLS

The growth of research development, and production during the last decade in the area of medium and large scale photovoltaic power generation ,is phenomenal and several factors have emerged during the recent years that place the photovoltaics in a more favourable economic position [34].

The silicon is the most widely used and the best characterized semiconductor material. It is dominating among the semiconductor materials used for photovoltaic energy conversion, and it looks like it will keep this position for many years to come.

Although there exist materials with better photovoltaic properties, silicon is out performing them either because of economic reasons or because of the mastering of its cell technology [35].

-THE EFFICIENCY OF SOLAR CELLS

The efficiency of solar cell is given by:[34]

$$ec = \frac{P\max}{Pin} \tag{1 .21}$$

Where *Pmax* is the maximum power which defined as the following.

$$P\max = (V\max)(\mathrm{Im}\,ax) \tag{1.22}$$

$$P\max = (FF)(Voc)(Ic) \tag{1.23}$$

Vmax- is the maximum voltage.

Imax- is the maximum current.

FF- fill factor.

Voc- open circuit voltage.

Ic- short circuit current.

Pin- the input power is defined as.

Pin =(area of solar cells) . (irradiance)

The maximum power depends on Voc and Ic and FF.

The factors which affect the efficiency are:

-open circuit voltage.

-short circuit current density.

-shunt and series resistance.

-impurities in the silicon.

Again the load resistance in the maximum power point depends on the area of the cell.

The efficiency of solar cell depends mainly on *Ic* ,*Voc* where a large *Ic* is the result of the following factors:

(1) -a total absorption of the light ,which requires.

-a low reflection.

-optical confinement.

(2) -a total collection of the generated carriers, requiring.

-a large diffusion length in both neutral regions.

-a low surface recombination velocity on both surfaces The efficiency of solar cell. decreases if the temperature of cell is more than the *Tr* (reference temperature is taken to be 25 C^0).

The cell temperature Tc is calculated [36,37] according to the relation.

$$Tc = (Tair) + (tc)(It) \tag{1.24}$$

Where *Tair*- the temperature of surrounding air in (C^0).

It- the total radiation incident on a pv module $\left(mw/cm^2\right)$.

Tc- the temperature coefficient equals 0.3 $\left(C^o \cdot cm^2/mw\right)$.

The efficiency of solar cell due to *Tc* becomes.

$$ec = er\left(1 - e\left(Tc - Tr + (tc)(K)\right)\right) \tag{1.25}$$

Where

e- is the loss in efficiency of the solar cell for every degree Celsius of cell temperature (*e* = 0.005).

er- is the efficiency at reference temperature.

and *K* in simple but less accurate[31] is given by the relation $K = 78.76$ $(mw/C^0 .cm^2)$ (1.26).

1.2.2 WIND POWER

Unequal heating of atmosphere and earth surface causes the motion of air masses i.e. wind, meaning that solar energy is transformed into kinetic energy.

Recent development in wind turbine technology means that wind power can be regarded as a reliable and cost-effective power source for many areas of the word [38].

- PHYSICAL-TECHNICAL CHARACTERISTICS

The mean wind speed in the height of interest hz can be determined as.

$$V(h_2) = V(h_1)\left[\frac{h_2}{h_1}\right]^a \qquad (1.27)$$

where

hi- height of measurement hz :height of interest

V(hi)- mean wind speed at height of measurement

V(hz)- mean wind speed to be calculated of the height of interest

a- altitude exponent or Hellmann-exponent (the value of a depends on the surface roughness and thermal stratification).

The energy of motion (kinetic energy) of a moving mass m increases with the square of its velocity *Vf*, according to the formula

$$E = \frac{1}{2}(m)(Vf)^2 \qquad (1.28)$$

Flowing air presents a moving mass.if a volume of air *V* with density d and mass $m=d\ V$, moves with speed *Vf*, then its kinetic energy is.

$$Pin = \frac{1}{2}(d)(Aw)(Vf)^3 \qquad (1.29)$$

Normal air pressure at sea-level about 1 bar and a temperature of 20 C^0 in an air density of 1.225 (kg/m^3).

A wind power plant converts part of the kinetic energy of the air flow into mechanical energy reducing the speed of the air flow.

if we consider an area *A*, which is perpendicular to the air flow then a volume *V* of size

$(V= Aw . Vf . t)$ (*t* is the time) will flow through this area per second. Using eq.(1.29), the power *Pin* is equal.

$$Pin = \frac{1}{2}(d)(Aw)(Vf)^3 \tag{1.30}$$

The maximum power output is

$$P\max = \frac{8}{27}(d)(Aw)(Vf)^3 \tag{1.31}$$

-THE POWER COEFFICIENT (*Cp*)

The maximum theoretical efficiency will be not more than

$$Cp = \frac{P\max}{Pin} = 16/27 = 0.593 \tag{1.32}$$

An ideal wind power plant, operating without losses can convert at most 16/27 of the energy contained in the air flow through its rotor area into mechanical energy [39] .

In this case, the velocity is reduced to a third. However, Eetz's efficiency limit of 16/27 is not, as was often assumed, precisely derivable from conservation laws.

In practice a power coefficient *Cp* is defined, which gives the ratio of mechanical energy obtained and natural energy supplied.

The power output Pro

$$\Pr o = \frac{1}{2}(d)(Cp)(Aw)(Vf)^3 \tag{1.33}$$

For a given aerodynamic design of the blades, the power coefficient *Cp* is essentially a function only of the quotient of velocity *u* of the blade-tips and velocity *v* of the wind.

This quotient is also called the tip speed ratio *(u/v)*.it has been shown [4O] that the rotor power coefficient is nearly independent of wind speed for a machine operating at a constant tip speed ratio.

The power that would be produced by a wind machine is given by

$$\mathrm{P}e = \frac{1}{2}(d)(Ce)(Cp)(Aw)(Vf)^3 \tag{1.34}$$

where *Ce* the efficiency of the conversion of mechanical energy into electrical energy.

The wind velocity at which the production of rated power of the machine is attained is called rated wind speed.

If the rated wind speed is exceeded, the blades can be twisted, or turned out of the wind, so the power coefficient *Cp* is reduced and thus also the power of the rotor *Pro* at the shaft. to the extent that the power *Pe* does not exceed the rated power predetermined by the machine size.

For the start of a wind power plant a definite minimal torque is required the torque at cut-in velocity must be at least as high as this minimum torque.

The torque developed at cut-in velocity is essentially dependent on the wind velocity and on the angle of incidence of the blades.

The optimum angle of incidence at cut-in velocity is considerably larger than the optimal angle of incidence for normal operation. Thus if the angle of incidence can be adjusted by turning the blades around their longitudinal axis, the necessary minimal wind speed required for starting is greatly reduced.

If the technically determined maximum wind velocity vmax is exceeded, the wind power plant is turned off on grounds of safety.

The minimum or cut-in wind velocity is referred to as vmin, the rated wind velocity as *Vrat*,

Depending on the average time. the average wind speed and the characteristics of the machine, the power predicted using the steady state power curve and the average wind speed could differ significantly from the measured value [41].

When techniques and rotational speed are known the power output at the machine can be determined, the predicted power produced would be an average value as given by the following equations[42].

$$Pe = \begin{cases} 0 \Rightarrow if\ (vf \prec V\min) \\ \frac{1}{2}(d)(Ce)(Cp)(Aw)(Vf)^3 \Rightarrow if\ (V\min \le Vf \prec Vrat) \\ \frac{1}{2}(d)(Ce)(Cp)(Aw)(Vrat)^3 \Rightarrow if\ (Vrat \le Vf \le V\max) \\ 0 \Rightarrow if\ (Vf \succ V\max) \end{cases} \tag{1.35}$$

1.2.3 BATTERY

The battery is a device for transforming chemical energy into electrical energy and consists essentially of two plates of different materials immersed in a liquid solution which acts more readily on one plate than on the other.

The magnitude of Electro motive force (e.m.f.) between the two plates depends only upon the material of the plates and on the electrolyte and for a given pair of plates ,it is independent of their area.

The active materials in a battery contain a definite quantity of chemical energy which may be transformed into electrical energy, so that a battery can give a definite number of watt-hours or a definite number of ampere-hours at normal
voltage [43].

If *Eo* is the open-circuit voltage of a battery, *rb* is the internal resistance, and *r* is the resistance of the external circuit, then the current

$$i = \frac{Eo}{rb + r} \tag{1.36}$$

and has a maximum value on short circuit as

$$i = \frac{Eo}{rb} \tag{1.37}$$

If *n* batteries are connected in series then the current.

$$i = \frac{(n)(Eo)}{(n)(rb) + r} \tag{1.38}$$

If *r* is large compared with *(n . rb)* as is usually the case, then the current is approximately proportional to the number of batteries connected in series.

But if n batteries are connected in parallel then the current *i* is

$$i = \frac{(Eo)}{\left(\frac{rb}{n}\right) + r} \tag{1.39}$$

An increase in the number of batteries does not produce any considerable increase in the current as long as *r* is large compared with *(rb/n)*

The usual reason for connecting batteries in parallel is to divide the load and so make the battery last longer.

-THE EFFICIENCY OF BATTERY

The storage efficiency of a battery is dependant on [44].

1. state of charge.
2. Temperature.
3. electrolyte concentration.
4. magnitude of charge and discharge currents.

A reasonably accurate model of a battery can be obtained by fixing some of parameters to their optimal values and by assuming that the energy exchange is within the minimum and maximum limits.

The charge and discharge efficiencies (*ebc* and *ebd*) can then be analyzed in terms of the charge and discharge currents only.

If *Ei* is the energy enters the battery with an average current *ic* during the time interval *dt* then energy stored during *dt* is

$$Ebc = (ebc)(Ei) \tag{1.40}$$

but

$$Ebc = (dc)(Vbo) \tag{1.41}$$

Where *dC* change in stored charge

Vbo nominal battery voltage.

So

$$(ebc)(Ei) = (dc)(Vbo) \tag{1. 42}$$

$$ebc = \frac{(ic)(dt)(Vbo)}{Ei}$$ (1 .43

where: $(ic)(dt) = dc$

also the discharge efficiency

$$ebd = \frac{(ibd)(dt)(Vbo)}{Ebc} \tag{1.44}$$

where output energy from the battery is

$$Ebd = (ibd)(dt)(Vbo) \tag{1.45}$$

The overall efficiency of the battery is the product of *ebc* and ebd

$$eb = (ebc)(ebd) \tag{1 .46}$$

The energy obtained from the battery *Ebd* is smaller than the input energy *Ei* and is expressed by the relation [45,46].

$$Ebd = (eb)(Ei) \tag{1.47}$$

The value of efficiency eb is taken as (eb = 0.85).

CHAPTER (2)

SIMULATION OF DESALINATION SYSTEMS BY REVERSE OSMOSIS

2.1 ONE STAGE REVERSE OSMOSI S SYSTEM

The parameters affecting the operation of R.O system are *Cf, Cp, P. Tk, Y* ,where at design operation condition equ.(1.3) is used to calculate the *Pw* ,but these parameters will be not constants practically at field operation, due that equ.(1.3) will be corrected to be applied with actual parameters and to be able to simulation studies of different designs.

There are different models to correct the equation of product water so in the following will be exhibited the main features of models dealt with this subject and we will simulate these models to construct the suitable model

For simplicity and to recognition will name the models as one, two ,three.

2.1.1 MODEL ONE[8] (M1)

The concentration of the feedwater is gradually increased up to concentration of reject water *Cr* at the end .

This implies that also the osmotic pressure of feedwater is increased to average value of osmotic pressure where.

$$\Delta\pi\, fb = \left(\Delta\pi\, f\right)\left(\overline{CF}\right) \qquad (2.1)$$

$\Delta\pi\, f$ is calculated by eq.(1.&) and $\left(\overline{CF}\right)$ is the average concentration factor which is efined as

$$\left(\overline{CF}\right) = \frac{\left(1-R\right)^{\left(1-\left(1-Y\right)\right)}}{Y\left(1-R\right)} \qquad (2.2)$$

$$Cp = Cr\left(1-R\right)\left(\overline{CF}\right)$$

$$\Delta\pi\, fb = \left(\Delta\pi\, f\right)\left(\overline{CF}\right)$$

$$Pw = Lp\left(P - \Delta\pi\, fb\right)A$$

$$Pw = \left(\frac{A2}{A1}\right)\left(\frac{TCFA}{TCFS}\right)Pwi$$

Thus $\Delta\pi\, fb$ depends on the recovery Ratio *Y*

$$A2 = \left(Pf - \left(dPfb/2\right) - Pp - \Delta\pi\, fb - \Delta\pi\, p\right)$$

$$A1 = \left(Pfo - \left(dPfbo/2\right) - Ppo - \Delta\pi\, fbo - \Delta\pi\, po\right)$$

and the membrane salt rejection *R* similarly the concentration of productwater *Cp* increases gradually and its value can be calculated using the average concentration factor $\left(\overline{CF}\right)$ where

$$Cp = Cr\left(1-R\right)\left(\overline{CF}\right) \tag{2.3}$$

R is the salt rejection of the given membrane and does not change with the concentration over the concentration ranges normally occurring in an installation.

This model ignores the osmosis pressure of productwater Mrp where the productwater following the equation

$$Pw = Lp\left(P-\Delta\pi\, fb\right)A \tag{2.4}$$

<u>2.1.2 MODEL TWO[11]</u> (M2)

The main equations incorporated with this method are the following 1121

$$Pw = \left(\frac{A2}{A1}\right)\left(\frac{TCFA}{TCFS}\right)Pwi \tag{2.5}$$

Where:

Pw is the actual permeate flow rate

Pwi is the standard permeate flow rate

$$A2 = \left(Pf - \left(dPfb/2\right) - Pp - \Delta\pi\, fb - \Delta\pi\, p\right) \tag{2.6}$$

$$A1 = \left(Pfo - \left(dPfbo/2\right) - Ppo - \Delta\pi\, fbo - \Delta\pi\, po\right) \tag{2.7}$$

Where *A2* is the actual parameters

A1 is the standard parameters

Pf feed pressure, *dPfb/2* bundle pressure drop, *Pp* product pressure $\Delta\pi\, fb$ osmosis pressure for feed, and $\Delta\pi\, p$ Osmosis pressure for product The value of the parameters ended with *o* related to standard conditions

TCFA and *TCFS* are dependent on the type of device (spiral or hollow fiber) and on the membrane type (cellulose acetate, polyamide composite) where for HFF(Bl0)

$$TCF = 1.028^{(Tf-25)} \tag{2.8}$$

and for *FFF(B9)*

$$TCF = 1.030^{(Tf-25)} \tag{2.9}$$

The concentration of the feedwater is gradually increased up to the concentration *Cfb* where is calculated as follows

$$Cfb = \frac{Cf}{Y}Ln\left[\frac{1}{1-Y}\right] \tag{2.10}$$

and the osmotic pressure of feedwater is calculated as follows

$$\Delta\pi\, fb = \frac{0.0384933\left(Cfb\right)\left(Tk\right)}{\left(1000-\left(\frac{Cfb}{1000}\right)\right)} \qquad (2.11)$$

The osmotic pressure of productwater is calculated as follows

$\Delta\pi\, p = 0.01\ (\Delta\pi\, f\ )$ (for seawater). (2.12)

$\Delta\pi\, p = 0.05\ (\Delta\pi\, f\ )$ (for brackish). (2.13)

The concentration of salt in the reject brine is calculated by the relation

$$Cr = \frac{Cf}{\left(1-Y\right)} \qquad (2.11)$$

<u>2.1.3 MODEL THREE [47]</u> (M3)

The design actual membrane productivity can be obtained as follows

$$Pw = \left(PCF\right)\left(TCF\right)\left(MFRC\right)Pwi \qquad (2.15)$$

Where:

Pwi is the permeator capacity at design operating condition.

PCF is pressure correction factor incorporates the pressure.

terms effecting capacity. where be calculated by the following equation [48,49].

$$PCF = \frac{A2}{A1} \qquad (2.16)$$

bundle pressure drops can be estimated [8,26] and *TCF* is the

temperature correction factor is given [24,25] for B10T and B9 permeators by the relation.

$$TCF = 1.030^{(Tf-25)} \qquad (2.\ 17)$$

MFRC the membrane flux retention coefficient is a log function with respect to time ,however the time factor is not significant after the initial flux decline has occurred

The difference in *MFER* values and consequently permeated productivity between third and fifth year of continuous operation is less than two percent [48] due that will be not considered in the simulation

Reverse osmosis systems are designed to produce a specific amount of permeate at the end of the membrane guaranteed life.

Pwi is the initial permeated capacity at design operating conditions

The concentration of salts *Cr* in reject water is calculated 148] by the relation

$$Cr = \frac{Cf}{\left(1-Y\right)} \qquad (2.18)$$

The feed brine concentration for membrane is based on an average [48,49].

$$Cfb = \frac{Cf + Cb}{2} \qquad (2.19)$$

$\Delta\pi\ fb$ can be calculated from equ.(2.11) by replacing *Cfb* from equ. (2.19)

The osmotic pressure of productwater for *B10T & B9* is calculated by (equ.2.12,2.13) respectively [48].

2.1.4 **A PROPOSEL MODEL** (M4)

This model was suggested depending on the past models and practical considerations and taking in the consider the second stage of R.O. so we can note the following points.

- Concentration of product water *Cp* and the Osmosis pressure of product water have consider values.
- Equ.(1.7)A2.1),(2.3) is used to calculate the osmotic pressure.
- Correction factor $\left(\overline{CF}\right)$[18] is used to correct *Cf & Cp*.
- Pressure correction factor *(PCF)* [47.48,49] is used to correct the productivity *Pw*.
- Temperature correction factor *(TCF)* [47,48,49] is used to correct the productivity *Pw*.
- *MFRC* will not consider where the time factor is not as significant after the initial flux has occurred also is used to estimate long-term [7].

Fig. (2.1)-Flow diagram of reverse osmosis system (One stage)

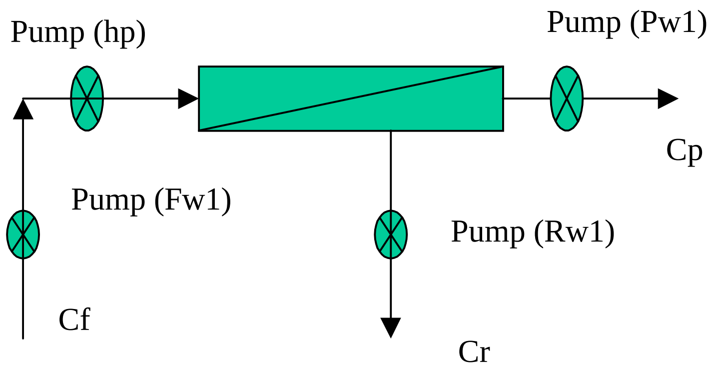


Fig.(2.1)

2.1.5 COMPARATIVE STUDY OF SIMULATION RESULTS

1 - Concentration of salt in feed water *(Cf)*

Fig. (2.2) represents the relation between *Cf* & $(\Delta\pi 1, \Delta\pi 2, \Delta\pi 3, \Delta\pi 4)$.

The simulation results of *Cf* was as

$\Delta\pi 3 > \Delta\pi 2 > \Delta\pi 1 > \Delta\pi 4$

The difference between the upper and lower values ($\Delta\pi 3 - \Delta\pi 4$) are in the range of (8 to 26) *psi*

Fig. (2.3) represents the relation between *Cf & (Pwl ,Pw2 ,Pw3 ,Pw4)*

The simulation results of *Cf* was as

Pw4 > Pw2 > Pw3 > Pwl if (Cf < 26000 ppm) and

Pwl > Pw4 > Pw2 > Pw3 if (Cf > 26000 ppm) Pw2,Pw3,Pw4 is more closely but Pwl converges when *Cf* increases to about 26000 *ppm* to intersect *Pw2,Pw3,Pw4* where *Pw1* diverges after intersection takes place

2- Applied pressure *(P)* psi by the high pump

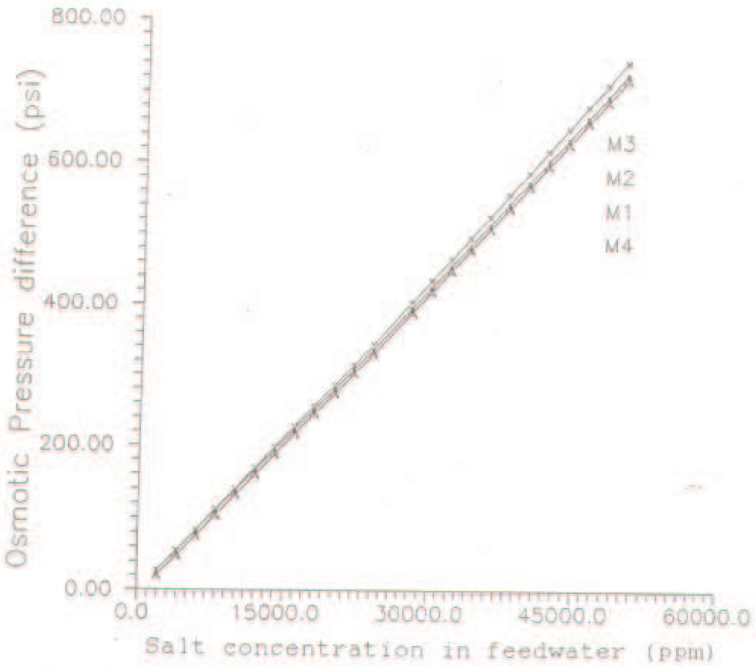

800.00
600.00
400.00
200.00
0.00
Osmotic Pressure difference (psi)
0.0
15000.0
30000.0
45000.0
60000.0
Salt concentration in feedwater (ppm)
M3
M2
M1
M4

Fig.(2.2)

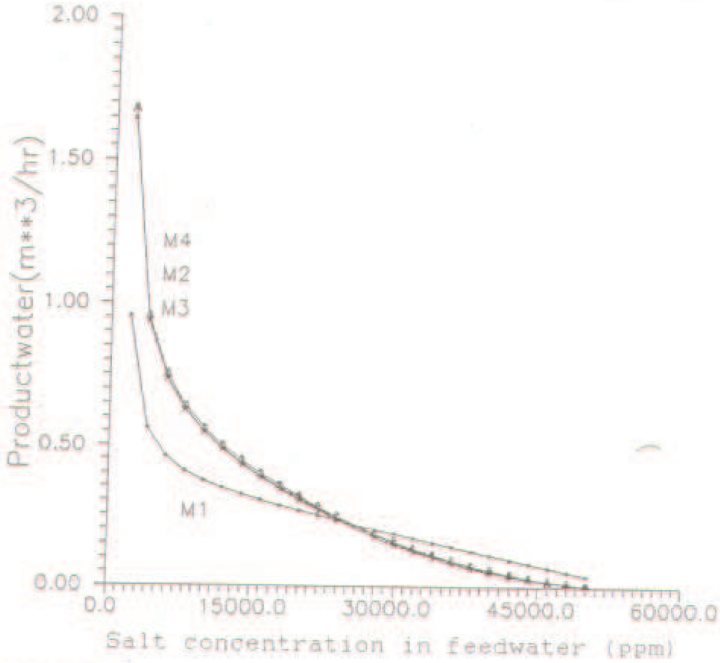

2.00
1.50
1.00
0.50
0.00
Productwater(m**3/hr)
0.0
15000.0
30000.0
45000.0
60000.0
Salt concentration in feedwater (ppm)
M4
M2
M3
M1

Fig.(2.3)

Fig.(2.4) represents the relation between *P & SPE1 ,SPE2 ,SPE3 ,SPE4*.

The output of simulation of *P* is straight line and *SPE* is function of *P* with slop *(SPE/P)* where SPE1 = SPE2 = SPE3 = SPE4

3- Temperature of feed water *(Tk)*

Fig. (2.5) represents the relation between *Tk & Pwl,Pw2,Pw3, Pw4* The output of simulation results of *Tk* was as

Pwl > Pw4 > Pw2 > Pw3 where Pwl linear with negative slope but *Pw2.Pw3,Pw4* are curvatures concave down increase slightly to maximum points near *(Tk2= 330 ,Tk3 = 322 ,Tk4 = 335)* where decrease after that

The linear relation of Pwl results from absence of Temperature correction factor *(TCF)*

4- Recovery Ratio *(Y1)* of the system

Fig.(2.6) represents the relation between $Y \& \Delta\pi 1 , \Delta\pi 2 , \Delta\pi 3 , \Delta\pi 4$ The simulation results of *Y* was as The values of $\Delta\pi 1$,$\Delta\pi 2$,$\Delta\pi 3$,$\Delta\pi 4$ increase when *Y* increase where the relations are not linear and the order of the values are

if $Y1 = 0.1$ then

$\Delta\pi 1 > \Delta\pi 3 > \Delta\pi 2 > \Delta\pi 4$

where $\Delta\pi 1 - \Delta\pi 4 = 6$ *psi*

and if $(0.3 > Y1 > 0.1)$ then

$\Delta\pi 3 > \Delta\pi 1 > \Delta\pi 2 > \Delta\pi 4$ and if $Y1 > 0.3$ then

$\Delta\pi 3 > \Delta\pi 2 > \Delta\pi 1 > \Delta\pi 4$

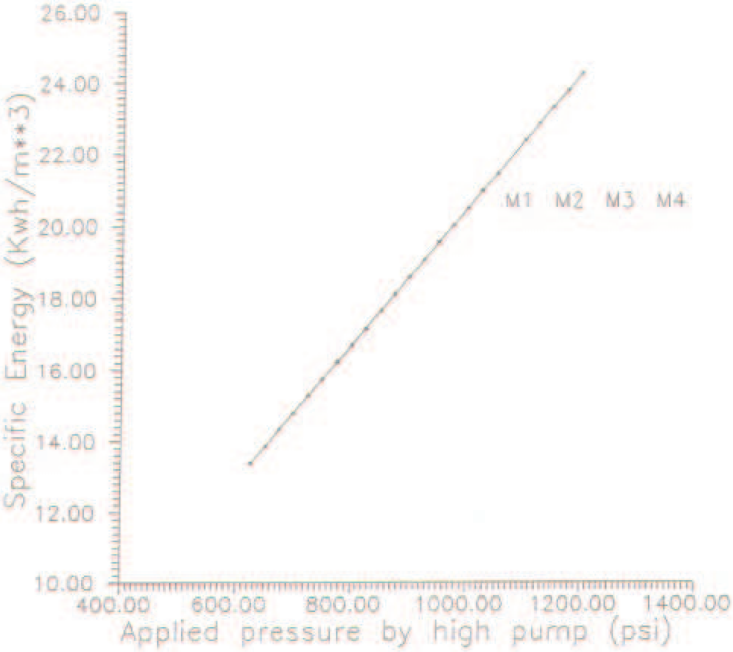
where $\Delta\pi 3 - \Delta\pi 2 = 151$ *psi*

Fig.(2.7) represents the relation between *Y & (Pwl,Pw2,Pw3, Pw4)*

The Output of simulation results of *Y* was as

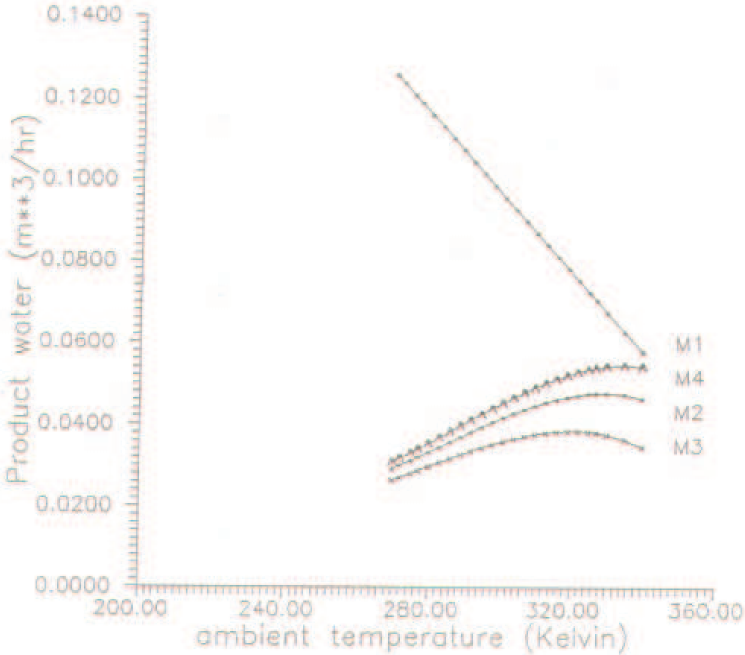
Pw1 > Pw4 > Pw2 > Pw3 where decrease when *Y* increases but *Pw1* concaves down and *Pw2,Pw3,Pw4* are nearly linear for *Y* < 0.5 , *Pw3* fanishs for *Y* > 0.5 but *Pw1 ,Pw2 ,Pw4* fanish for *Y* > 0.62.

Fig.(2.8) represents the relation between *Y & (SPE1,SPE2,SPIE3,SFE4.).*



Specific Energy (Kwh/m**3)
26.00
24.00
22.00
20.00
18.00
16.00
14.00
12.00
10.00
400.00
600.00
800.00
1000.00
1200.00
1400.00
Applied pressure by high pump (psi)
M1 M2 M3 M4

Fig.(2.4)



Product water (m**3/hr)
0.1400
0.1200
0.1000
0.0800
0.0600
0.0400
0.0200
0.0000
200.00
240.00
280.00
320.00
360.00
ambient temperature (Kelvin)
M1
M4
M2
M3

Fig.(2.5)

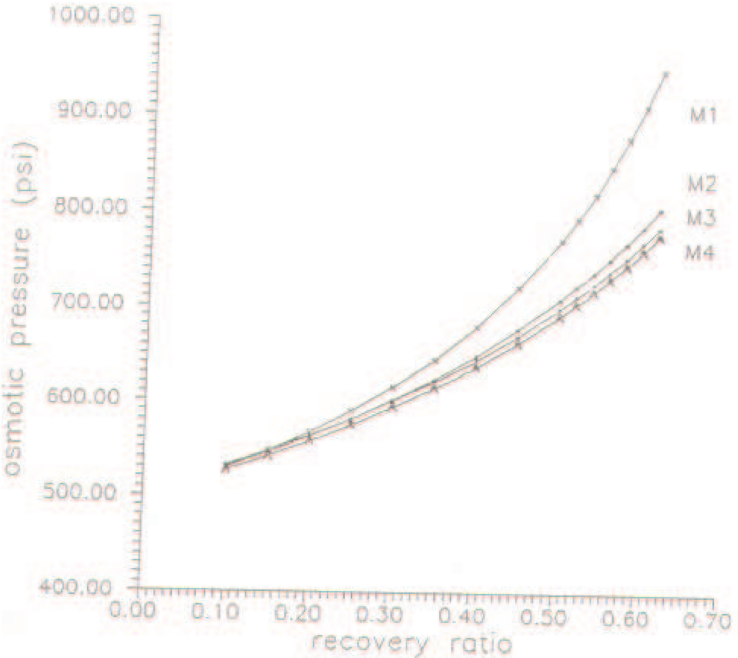

1000.00
900.00
800.00
700.00
600.00
500.00
400.00
osmotic pressure (psi)
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
recovery ratio
M1
M2
M3
M4

Fig.(2.6)

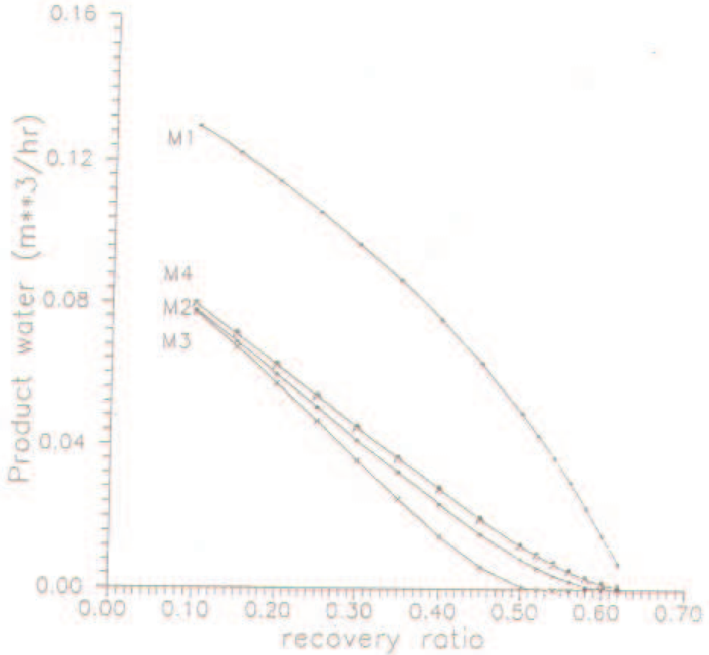

0.16
0.12
0.08
0.04
0.00
Product water (m**3/hr)
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
recovery ratio
M1
M4
M2
M3

Fig.(2.7)

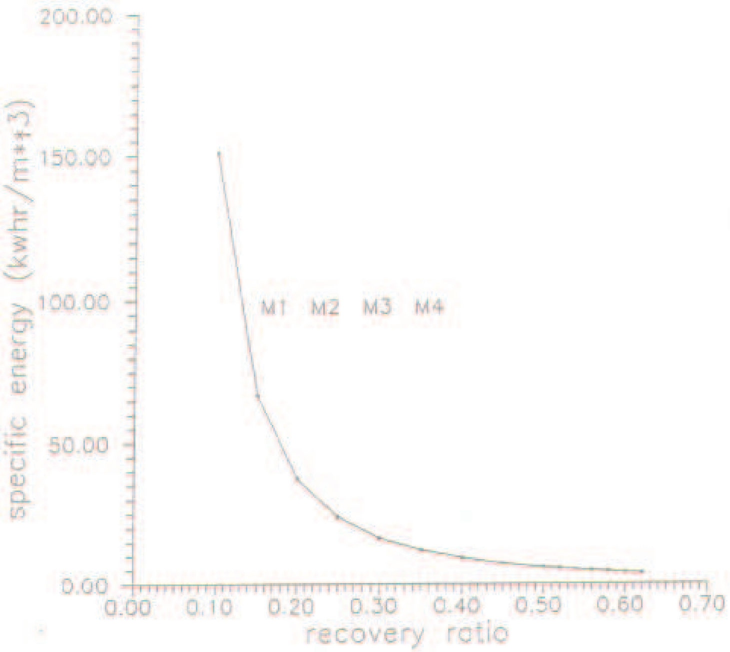

200.00
150.00
100.00
50.00
0.00
specific energy (kwhr/m**3)
M1 M2 M3 M4
0.00 0.10 0.20 0.30 0.40 0.50 0.60 0.70
recovery ratio

Fig.(2.8)

The output of simulation results of Y was as

SPE1 = SPE2 = SPE3 = SPE4 and curve line where the specific energy *SPE* is dependent on *Y* .

where *SPE* is fast decreasing when *Y* decrease from 0.1 to 0.25 and in the range of 0.35 to 0.62 the curve nearly is linear with negative small slope

- the Concentration correction factors

Equ. (2.2) defines the concentration correction factor for model one and from equ.(2.10) is defined the correction factor for model two ,by replacing equ.(2.18) in equ.(2.19) and arrangement the correction factor for model three is

$$CF3 = \frac{(2-Y)}{2(1-Y)} \tag{2.20}$$

CF is function of *Y,Cf,Cp,* but *CF2.CF3*, function of *Y* where for simulation of *Cf* the results resulted from the values of correction factors where

CF3 > CF2 > (CF1 = CF4)

- the osmosis pressure of product water is very small where was as $\Delta\pi p1 = 0$

$\Delta\pi p2 = \Delta\pi p3$ and function of *Cf , Y ,*

$\Delta\pi p4$ is function of *Cp , Cf , Y*

where the max. value of $\Delta\pi p4 < 7$ psi for *Cp* = 500 *ppm.*

- the product water depends on the partial difference of osmosis pressure where *Pw* decreases as $\Delta\pi$ increases for that the output *Pw* of models as was mentioned before *Pw* decreases when *Y* increases where $\Delta\pi$ is function of *Y* fig.(2.6)

In the following simulations , proposed model will be depended due to two points

- is enable to simulate reverse osmosis system has second stage
- is enable to simulate recovered energy and the module connected to the rejectwater

2.2 ONE STAGE REVERSE OSMOSIS SYSTEM WITH RECOVERY TURBINE

In the following, proposed model will be dependent in simulation studies ,where the productwater *(Pw)* from one RO Module is given by equ.(1.3) where the osmosis pressure difference is calculated by equs.(1.6) ,(2.1) ,(2.2) ,(1.7) ,(2.2) ,(2.3)

when designing a reverse osmosis plant using any membrane permeated, it is necessary to correct the membrane productivity from standard conditions to actual design conditions The correction process include corrections for operating pressure and temperature [47]

The pressure correction factor *PCF* can be calculated using the equ.(2.16) [48,49] ,while the values of parameters related to standard conditions are given by membrane manufacturers while bundle pressure drops *(dp)* can be estimated [7,50] bundle pressure drop at actual conditions of 15 *(psi)* and 6 *(psi)* are assumed for B10T and B9 permeated respectively

Instantaneous capacity of the permeated is affected by the feedwater temperature ,the temperature correction factor for both B10T & B9 permeated is estimated by equ.(2.17) [48,49]

The productwater given by eq. (1.3) will be corrected by the correction factors *TCF & PCF* so The product water by one module during one hour $\left(m^3/hr\right)$ is

$$Pw1 = Lp\left(Po1 - \Delta\pi 1\right)\left(A1\right)\left(TCF\right)\left(PCF\right) \tag{2.21}$$

Pol :The applied pressure in first stage (RO1) *(psi).*

$\Delta\pi 1$:The osmosis pressure difference in (ROl) *(psi).*

$$Lp = 1.9\times10^{-8}\left[1.04^{(90-100\times R1)}\right]\times3600 \qquad \left(m^3/psi\cdot m^2\cdot hr\right)$$

A1 :the area of the membrane in the module *(* m^2 *)*

The feed water is calculated as the following:

$$Fw1 = \frac{Pw1}{Y1} \tag{2. 22}$$

and the recovery water is calculated from the relation

$$Rw1 = Pw1\left[\frac{1-Y1}{Y1}\right] \tag{2.23}$$

In reverse osmosis unit ,brine rejection takes place at a pressure near the supply pressure (applied pressure) and at a flow rate between 70% and 90% of the supply sea water flow [51].

Hydroturbines and impuls turbines are two devices that have been used in industry for the past 20 years or more to recover energy from high pressure process steams, the efficiency for these devices range from 75% to 85% [6].

Most reverse osmosis systems have no provision for reject brine energy recovery resulting in gross inefficiency since the reject brine flow represents most of the energy applied to the feed pumps ,in order to obtain much improved efficiency a family of positive displacement energy recovery pumps has been developed for reverse osmosis system in the product capacity range from 1 liter/hour ,for the smallest manual desalinators used in life rafts up to 100 $\left(m^3/day\right)$ for heavy duty desalination plants.

These reciprocating pumps combine feed pumping and brine energy recovery functions in each cylinder [52].

The max. feed to reject pressure drop of spiral-wound element is (8-12 *psi*) less than one bar per element and (40-60 *psi*)per six element pressure vessel but the pressure drop through a hollow fiber may be high as (50 *psi*) about (3.5 *bar*) ,without mechanical problems ,however it is good practice to keep the pressure drop below (25 *psi*) less than (2 *bar*) for both configurations [7].

Fig.(3.1) illustrates the system with recovery turbine connected to the rejectwater where the recovered energy is calculated from the following relation.

The energy available for recovery from the reject brine can be estimated using the relation

$$RE = c\left(Po1 - dp\right)et\left(\frac{1}{Y1} - 1\right)Rw1 \qquad (2.\ 24)$$

dp is the fluid pressure loss through R.O. (psi) *et* is the efficiency of recovery turbine.

The Load *(wh)* when Recovery Turbine connected to the system.

$$ELR = EL - RE \qquad (2\ .25)$$

and the specific energy SPER $\left(Kwh/m^3\right)$ is

$$SPER = ELR \times 10^{-3} / Pw1 \qquad (2.26)$$

EL The Load in the system without recovery turbine (see ch.2.)

2.2.1 COMPARATIVE STUDY OF SIMULATION RESULTS

Programs was installed in Fortran language to simulate the two designs in Fig. (2.1) & Fig. (2.9).

Fig.(2.9) Flow diagram of reverse osmosis system (One stage) with recovery turbine (R.T)

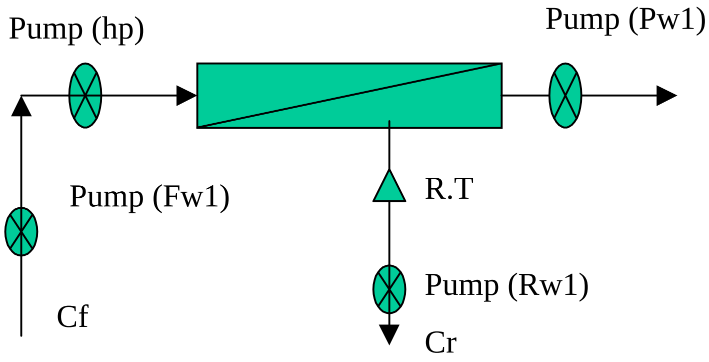


Fig.(2.9)

The following results was mentioned from simulation

-The productwater *(Pwl)* decreases when *(Cf)* increases where *Pw1=0* when the osmosis pressure ($\Delta\pi1 > Po1$) as a result feedwater *(Fw1)* & rejectwater *(Rw1)* decreases and fanishes when (*Pw1*=0) .fig.(2.10)

- Fig.(2.11) represents the relation between *Cf & (SPE)* where the specific energy depends on *(Cf)*

—Fig.(2.12) is seen the relation between *(Pa1 & Pw1,Rw1,Fw1)* from second degree where this comes from the correction factor *(PCF)* in equ. (2.35).

(Pwl = 0 .Rwl = 0 ,Fwl = 0). if ($\Delta\pi1$ = Po1) so we can estimate the real value of ($\Delta\pi1$) from the fig.

(Pw1) increases if *(Po1)* increases but *(Fw1 & Rw1)* increase quickly more than *(Pw1)* that means more reject of water *(Rw1)*.

—Fig.(2.13) represents the relation between *(Po1 & R1)* where the applied pressure *(Po1)* increases if

(Cf) increases but the salt rejection *(Ri)* jumps from (0.75) to (0.95) when *(P01)* increases to *(400 psi)* but in the range of *(P01 > 400)* the salt rejection *(R1)* increases mach slowly as straight line with small slop

1-The specific energy is function of *(Po1)* where is linear intersects the y-axis at value represents the consumed energy by the other pumps.

From fig, (2.14) we note the *(SPE)* increases more slightly than *(SPER)* where the recovered energy increases as *(Po1)* increases so the *(SPER)* relative to *(SPE)* decreases as *(Po1)* increases where the value *(SPE - SPER)* is decreased if *(Po1)* increased where *(RE)* is increased.

2-Fig.(2.15) represents the effect of *(Tk)* on the *(Pw1)* where *(Pw1 ,Rw1, Fw1)* are increased if *(Tk)* increases to value near *(Tk = 335)* where *(Pwl ,Rwl, Fwl)* decreases if *(Tk>335).*

This behavior of *(Tk)* arises from the effect of correction factor *(TCF)* equ.(2.34) in this range of temperature but when *(Tk > 235)* then arises the effect of osmosis pressure ($\Delta\pi 1$) where is directly proportion to *(Tk)* which is decreased the *(Pw1)* that is not seen when *(Tk< 335).*

-Fig.(2.16) represents the relation between *(Tk & Po1)* where when *(Tk)* increases *(Po1)* decreases but there is limitation for the maximum of *(Tk)* related to the characteristic of the membrane.

-Fig. (2.17)represents the relation between *(Tk & SPE)* where is some energy will be saved if *(Tk)* is increased and the system produces constant fresh water.

-fig.(2.18) is shown the effect of *(Y1)* on *(Pw1,Rw1,Fw1)* where *(Pw1)* is decreased as *(Y1)* increases with nearly -ve slope line but *(Fw1,Rw1)* are curvature decrease quickly when *(Y1)* increases up to (3.3) but in the range of *(Y1 > 0.3) (Fw1,Rw1)* decrease slightly.

-Recovery ratio *(Y1)* is one of the important parameters has effect on the operation and consumed energy in the reverse osmosis system where the *(SPE,SPER)* decrease fastly if *(Y1 < 0.3)* and decrease more slightly if *(Y1 > 0.3)* fig. (2.19).

-the recovered energy by the recovery turbine (R.T) decreases if *(Y1)* increases to the state becomes the (R.T.) is useless where *(SPE = SPER) if (Y1 > 0.5)* but if *(Y1 < 0.4)* then reasonable energy will be saved.

It is important to operate with *(Y1 > 0.3)* for two points:

-to save energy.

-to save water especially the brackish water and money.

-fig.(2.20) represents the effect of (Cp1) on *(Fw1,Pw1,Rw1).*

where are curvatures increase when *(Cp1)* increases that results from the decreasing of the osmosis pressure difference ($\Delta\pi 1$)

-Fig. (2.21) represents the relation between *(Cpl & SPE)* where the *(SPE)* is function of *(Cp1)* and *(SPE)* decreases if *(Cp1)* increases.

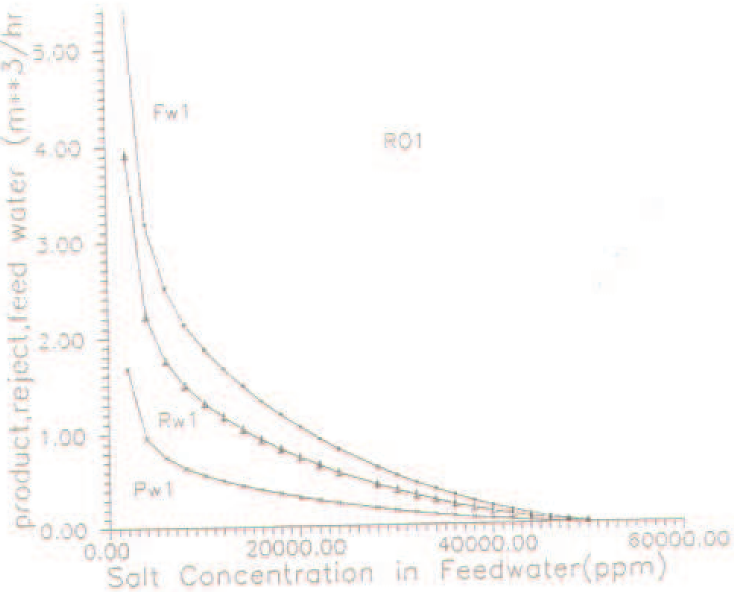


Fig.(2.10)

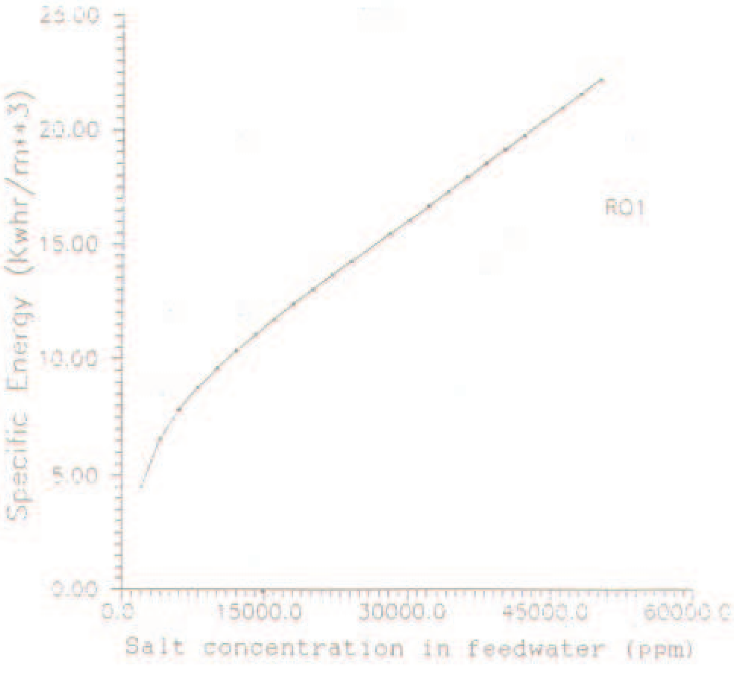


Fig.(2.11)

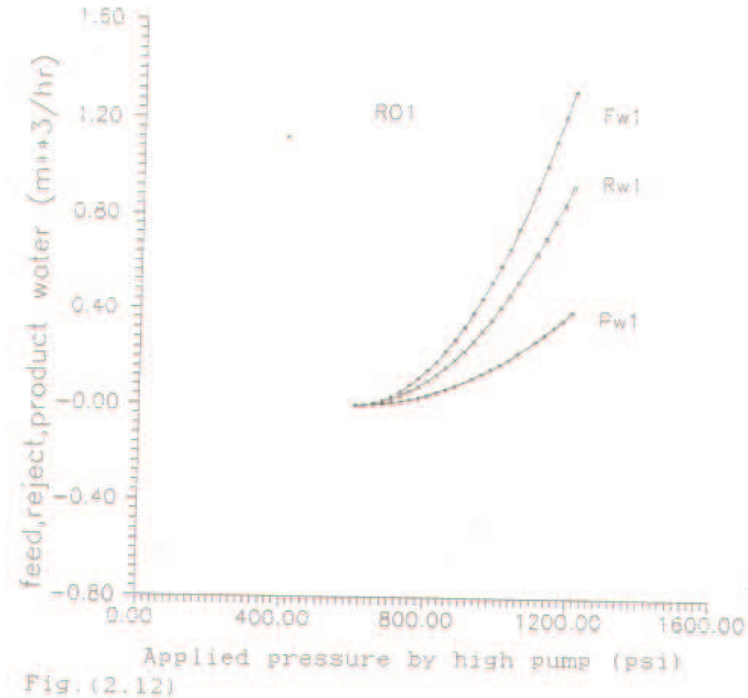


Fig.(2.12)

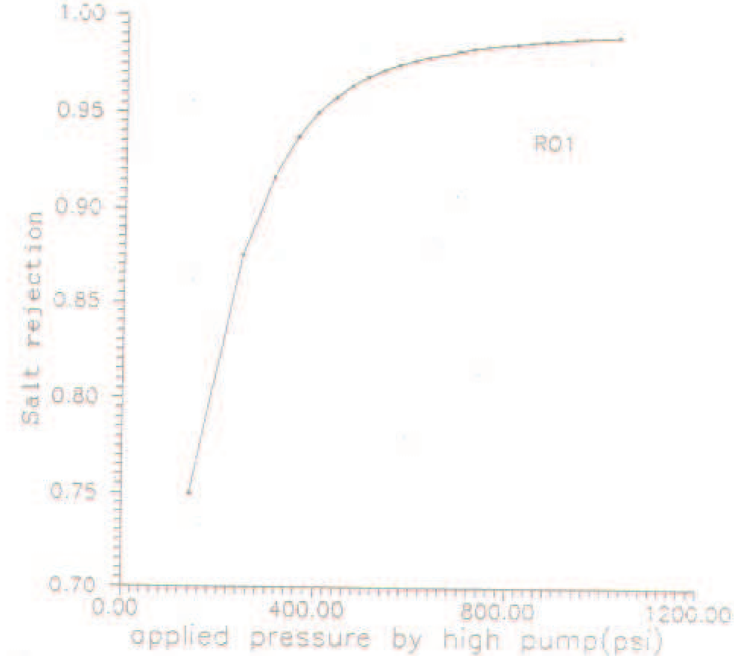


Fig.(2.13)

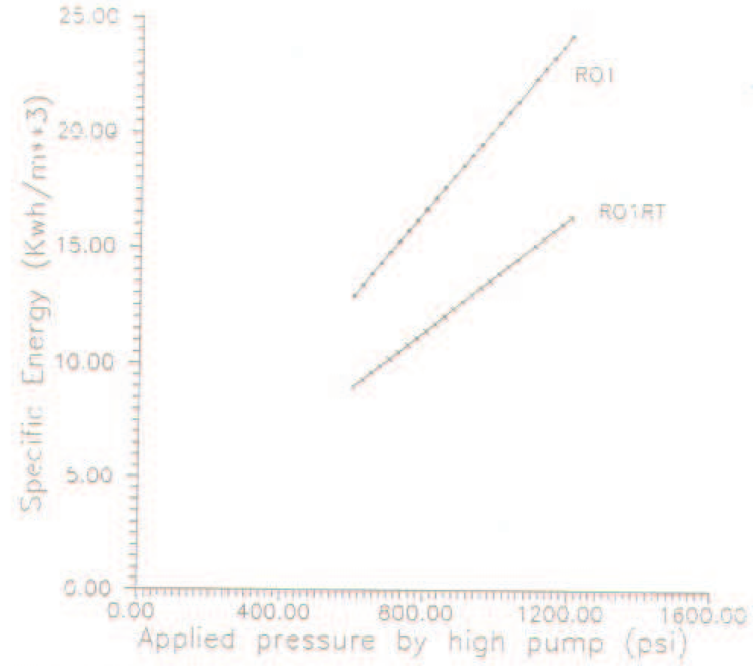


Fig. (2.14)

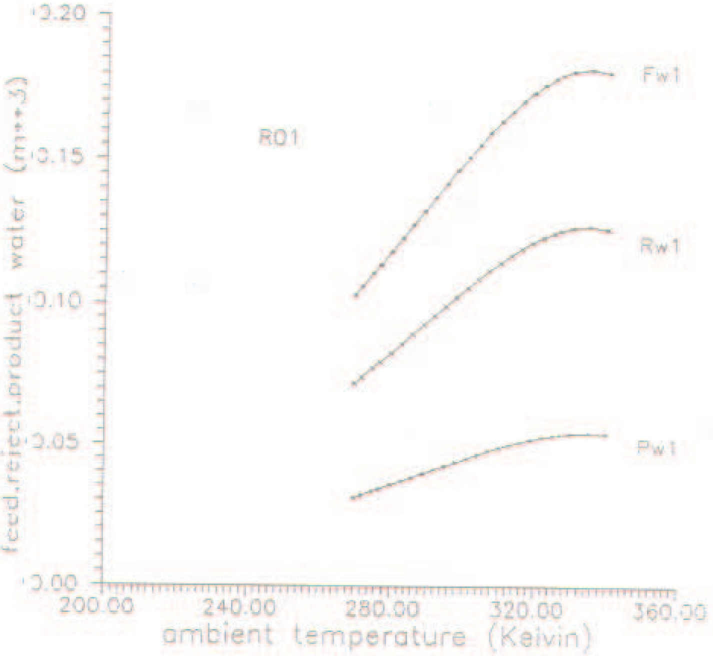


Fig. (2.15)

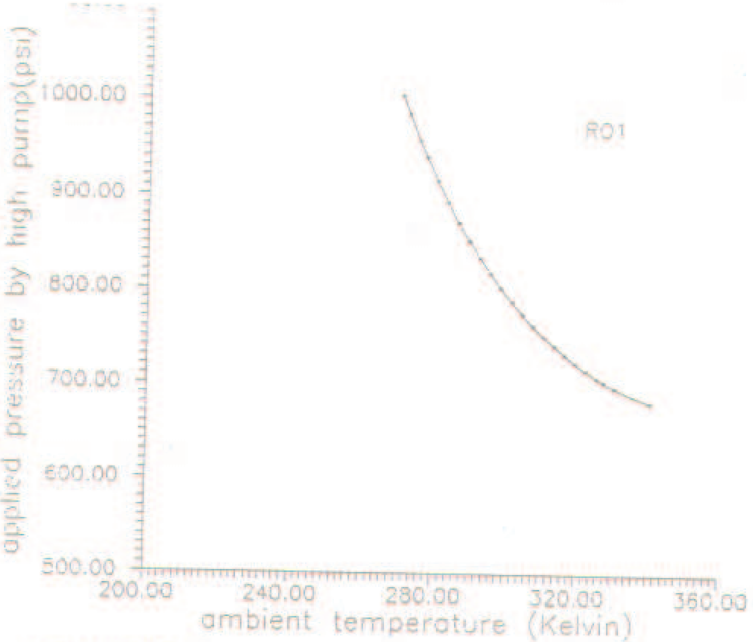


Fig.(2.16)

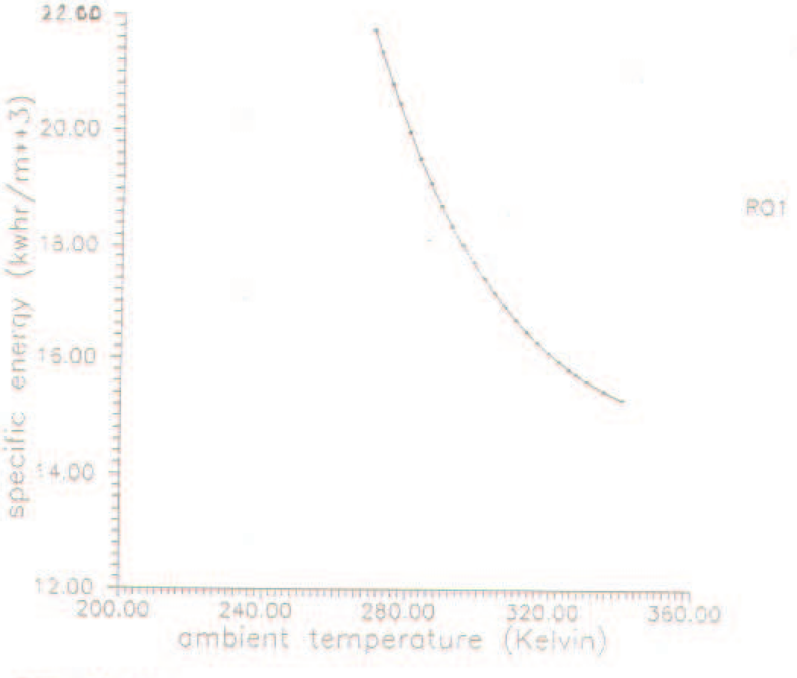


Fig.(2.17)

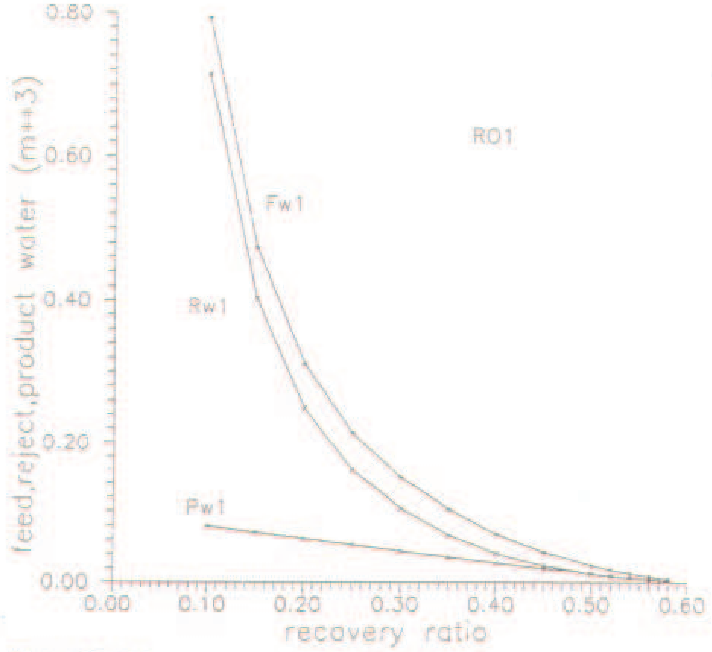


Fig.(2.18)

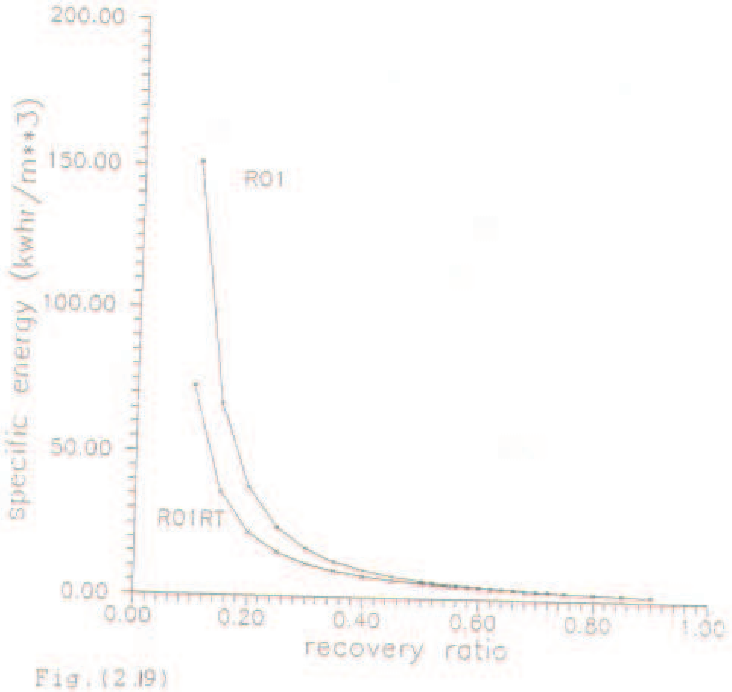


Fig.(2.19)

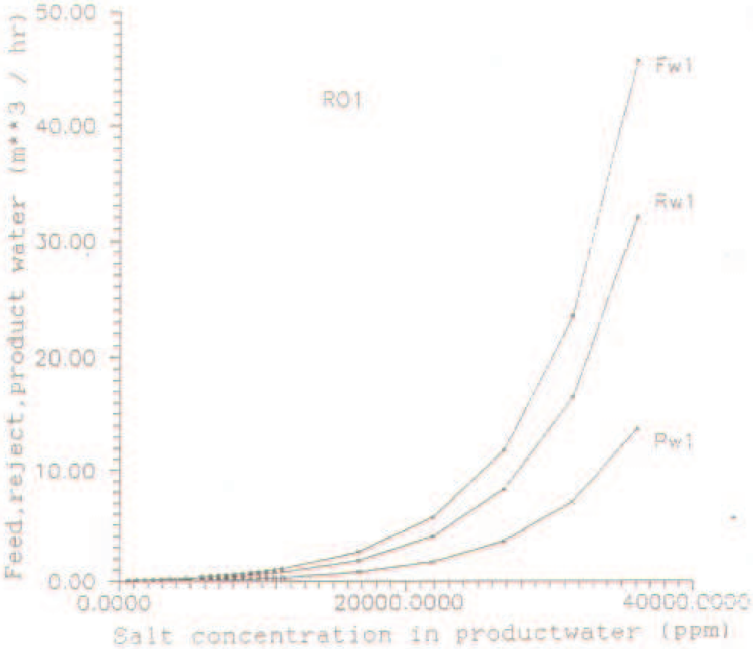


Fig.(2.20)

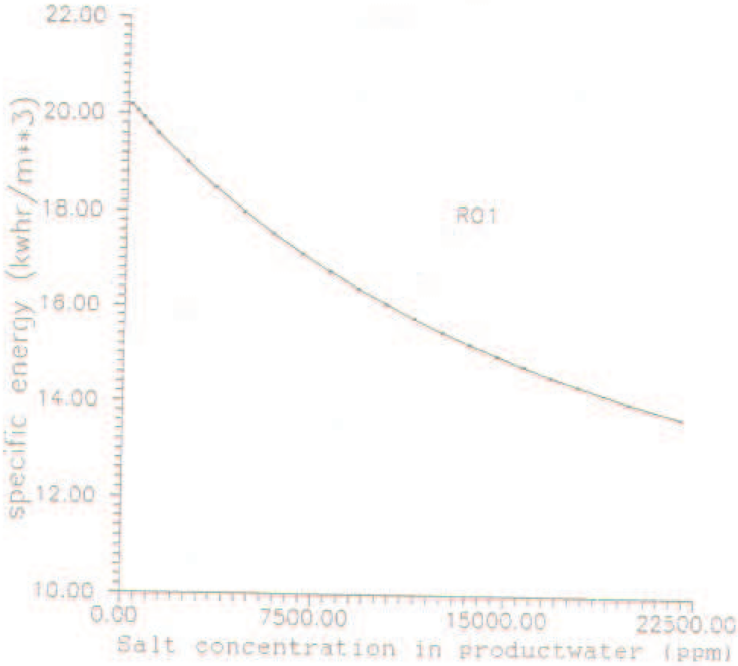


Fig.(2.21)

2.3 TWO STAGES REVERSE OSMOSIS SYSTEM WITH AND WITHOUT RECOVERY TURBINE

2.3.1 THE OPERATION OF REVERSE OSMOSIS IN TWO STAGES

Although the single stage seawater units have been built they are often limited to low water recoveries. In order to have a satisfactory permeate quality and recovery, the second stage unit has been used to treat all or part of the permeate from the first stage The second stage unit is the same as would be used for a brackish water having similar characteristics [4,6,53].

The feedwater is pumped from the source by feed water pump (F.W.P) and is pressurized to pressure *(P)* by the high pressure pump (h.p.pl) into the module where the feedwater *(Fw1)* is split into productwater *(Pw1)* and rejectwater *(Rw1)* in first stage *(Po1)* .

The productwater *(Pw1)* is pressurized by the second high pressure pump (h.p.p2) to be as the feedwater for the second stage *(Po2)* where also is split into productwater *(Pw2)* and rejectwater *(Rw2)*

Fig. (2.22) Flow diagram of reverse osmosis system (two stage) and fig(2.23) represents flow diagram of reverse osmosis two stage with recovery turbine (R.T).

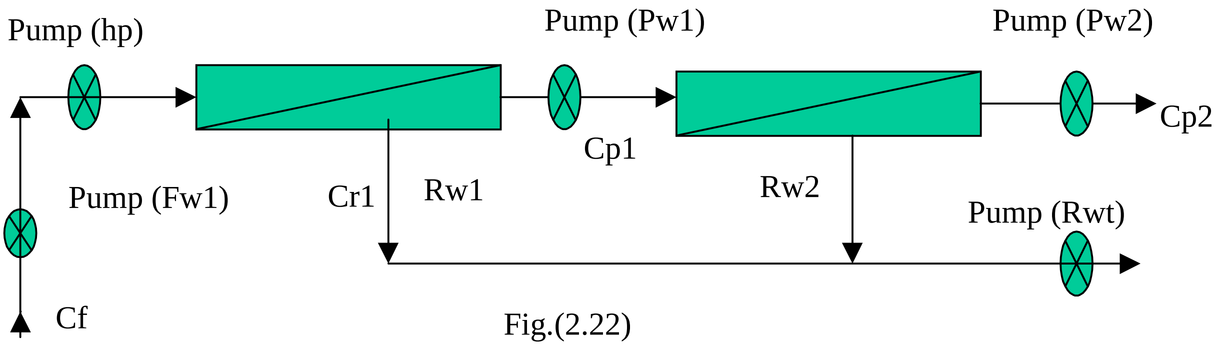


Fig.(2.22)

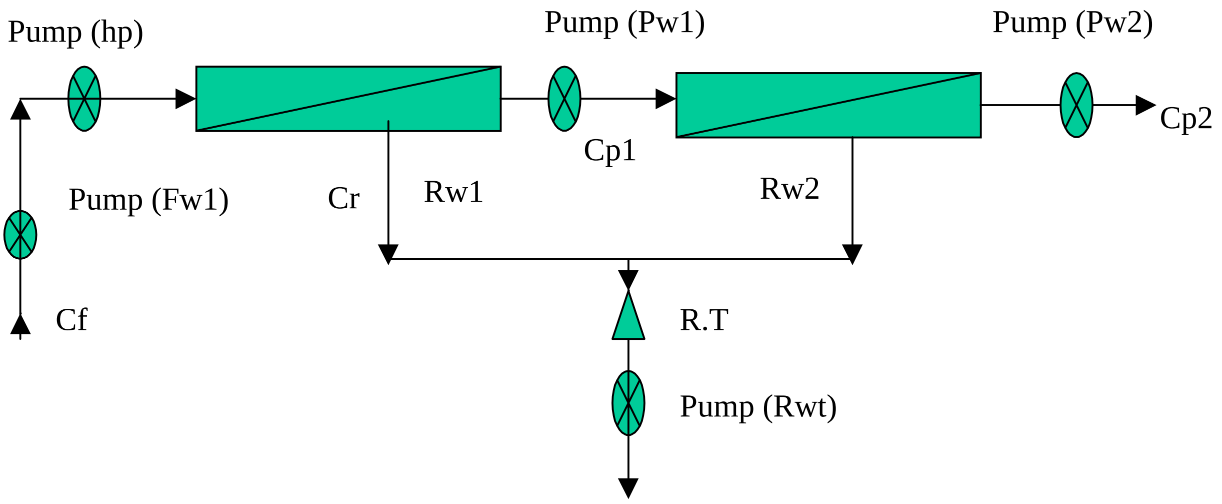


Fig.(2.23)

In the following will be exhibited the relations between the first and second stage and the energy consumed in the two designs.

A - SECOND STAGE

The productwater (Pwl) in the first stage (P01) has the Concentration (Cpl) will be the feedwater for the second stage where the productwater (Pw2) is calculated from the following equation.

$$Pw2 = Lp\left(Po2 - \Delta\pi 2\right)\left(A2\right)\left(TCF\right)\left(PCF2\right) \qquad (2.26)$$

Where *Lp* is the hydrodynamic permeability of the membrane

Po2 is the applied pressure by the high pressure pump2*(psi)*

A2 is the Area of membrane in the module(R.0.2)

$\Delta\pi 2$ is the difference between the feed and product osmosis pressure in the second stage

PCF2:The Pressure Correction Factor for the second stage

see (2—2) for $\Delta\pi 2$, *PCF2*

The feedwater (Fw2=Pw1) to (Ro2) $\left(m^3/hr\right)$ is

$Fw2 = Pw1 = Pw2/Y2$ (2. 27)

and the rejectwater *(Pw2)* is calculated from the relation

$Rw2 = Pwl - Pw2$ (2. 28)

in term of Pw2 & Y2, Rw2 becomes as follows

$$Rw2 = Pw2\left[\frac{1-Y2}{Y2}\right] \qquad (2.\ 29)$$

B — THE CONSUMED ENERGY IN THE SYSTEM -

-The load in the system fig. (2.22)

$EL = ERP+EFP+EPP+Eo1+Eo2$ (2.30)

Eo1, EFP , are calculated by equ.(1.9),(1.11)

- The consumed energy in the high pressure pump2 *(wh)*

$$Eo2 = \left[\frac{(c)(Po2)}{ep}\right]\left(\frac{1}{Y2}\right)\left(Pw1\right) \qquad (2.31)$$

- The consumed energy in the reject pump *(wh)*

$$ERP = \left[\frac{(c)(PR)}{ep}\right]\left(\frac{1}{Yt}-1\right)\left(Rwt\right) \qquad (2.32)$$

- The consumed energy in the product pump *(wh)*

$$EPP = \left[\frac{(c)(PP)}{ep} \right] (Pwt) \qquad (2.33)$$

where

$Yt = (Y1)(Y2)$ (2.34)

$Y2$ - The Recovery Ratio of The second stage (R02).

Pwt- The productwater of the system $(Pwt = Pw2)$.

Rwt- The rejectwater of the system

where

$Rwt = Rwl + Rw2$ (2.35)

- The specific energy in the system $\left(Kwh/m^3 \right)$

$$SPE = \left(\frac{(EL)(10)^{-3}}{Pwt} \right) \qquad (2.\ 36)$$

2.3.2 TWO STAGES REVERSE OSMOSIS SYSTEM WITH RECOVERD TURBINE

Fig.(2.23) illustrates the system with Recovery Turbine connected to the rejectwater where the Recovered energy is calculated from the following.

$$RE = c\left(Po1 - dp \right) et \left(\frac{1}{Yt} - 1 \right) Rwt \qquad (2.37)$$

and the specific energy $\left(Kwh/m^3 \right)$

$$SPER = \left(\frac{(ELR)(10)^{-3}}{Pwt} \right) \qquad (2.37)$$

2.3.3 SIMULATION RESULTS

The following results was mentioned from simulation of Reverse Osmosis System (Two stages) without Recovery Turbine fig. (2.22) and with Recovery Turbine fig. (2.23).

In the range of *(Cf < 6000 ppm)* the specific energy decreases about *(2 kwh)* but in the range of *(6000 to 50000 ppm)* the specific energy decreases just about *(1 kwh).*

The Recovery Turbine (R.T.) recoveries sensible energy fig. (2.24) where more than *(5 kwh)* is saved.

The specific energy is function of *(Po1)* fig.(2.25) for the two designs where is direct proportion straight line has +ve. slope The (R.T.) saves about *(4 to 9 Kwh)* in the range from *(600 to 1200 psi)* where the recovered energy increases if *(Po1)* increases .

The specific energy effected by (Yl) where the $(SPE,SPER)$ decrease vastly when $(Yt < 0.25)$ where $Yt = (Y1)\ (Y2)$ but for $(Yt > 0.25)$ the $(SPE.SPER)$ decrease more slightly also the recovered energy decreases to the state becomes the (R.T) not useful where for $(Yt > 0.3)$ the two curves become too much closed fig.(2.26).

The specific energy decreases when $(Cp2)$ increases this effect results from the second stage where when $(Cp2)$ increases the applied pressure $(Po2)$ will decreases and due that $(SPE,SPER)$ will decrease as it has seen in fig.(2.27).

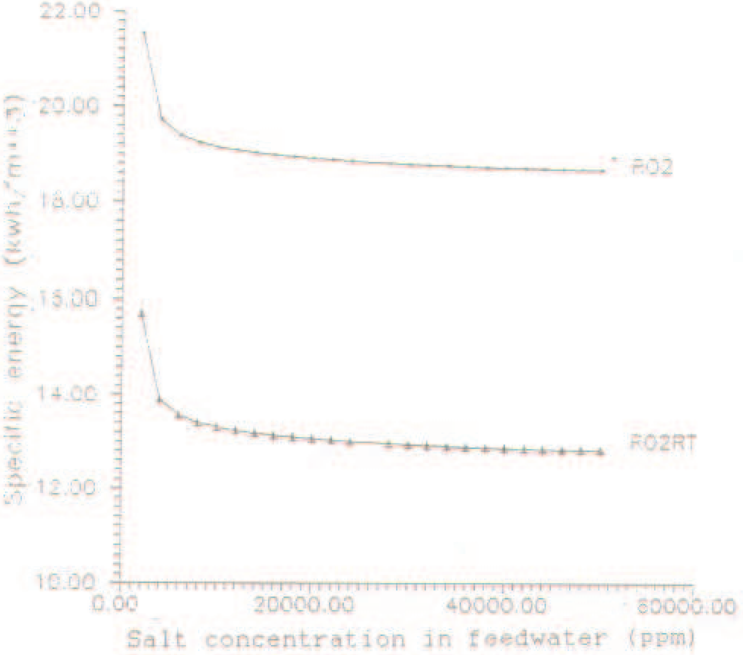


Fig.(2.24)

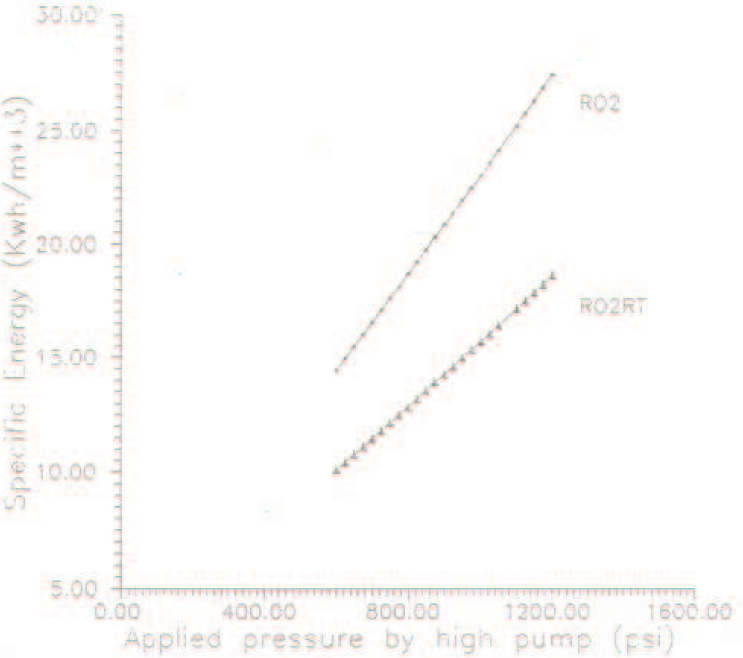


Fig.(2.25)

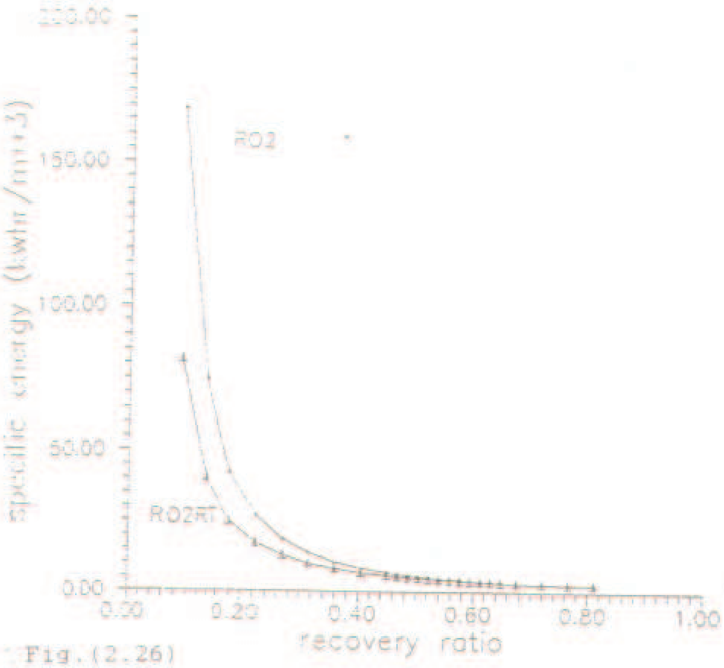


Fig.(2.26)

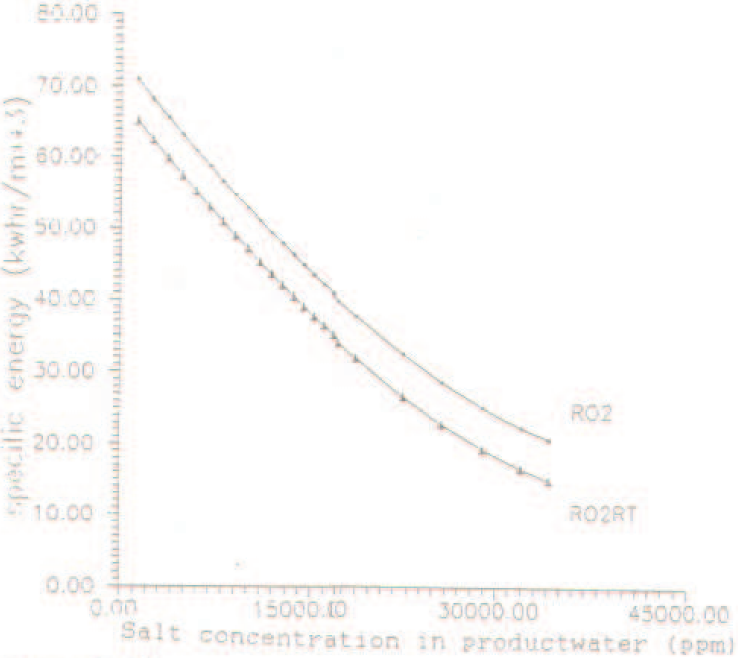


Fig.(2.27)

2.4- ONE STAGE REVERSE OSMOSIS SYSTEM WITH MODULE CONNECTED TO REJECT WATER

2.4.1 REJECT WATER (Rw)

The reverse osmosis system is usually designed to produce a certain flow of productwater *(Pw)* .

A low product rate is a sign of fouling and an indication that cleaning is necessary .

A configuration must be operated above minimum brine or reject flow rate to prevent concentration polarization from occurring.

The range of recoveries which have been proposed for various systems has been between (10 & 45) % with the lower recoveries being used in smaller system [5] in other words the reject water is between (55 & 90) % of feed water.

Reverse osmosis system is consider as the most system consumes water for that Kuwait was not keen on to carry on a large scale brackish water desalination mainly to save the brackish water source which is considered to be a main source for blending distilled water produced by Multistage effect (NSF) plants in addition to the unsolved problems of brine disposal [3]

In Reverse Osmosis System the reject water takes place at a pressure near the supply pressure (applied pressure

A- DESCRIPTION OF THE SYSTEM

The feed water *(Fw1)* with salt concentration *(Cf)* and Pressure *(Po1)* is split into a product water *(Pw1)* with concentration *(Cp1)* and Pressure less than (10 *psi*) [15] and the reject water *(Rwl)* with concentration *(Cr1)* and Pressure near applied Pressure *(Po1)* since the reject water represents most of the energy applied to the feed pumps.

In this design the reject water Rwl from RO1 is the feed water for the second stage fig. (2.28)

Fig. (2.28) Flow diagram of Reverse Osmosis system (One stage) with module connected to the

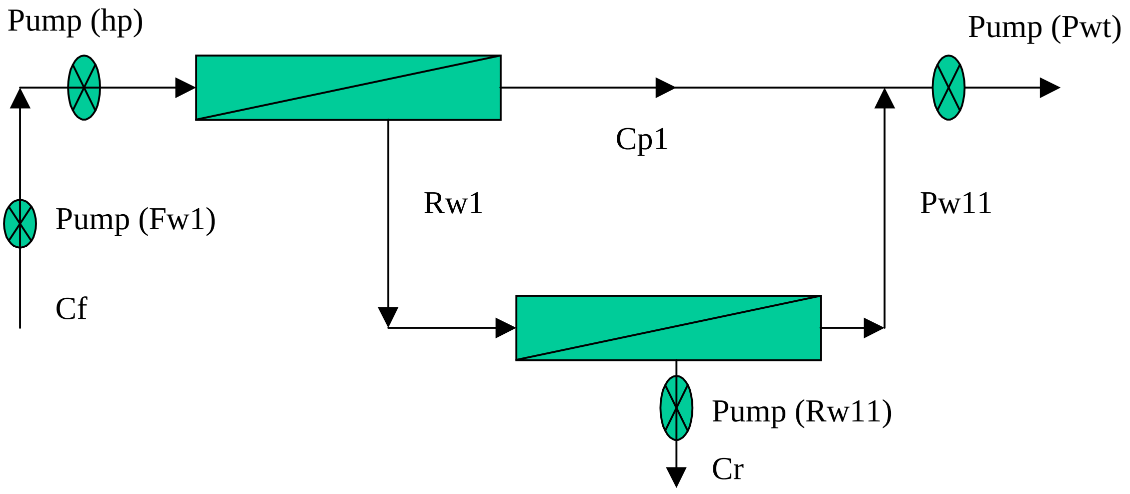


Fig.(2.28)

The product water Pwll is calculated from the following relation when no any external pressure.

$$Pw11 = Lp\left(P11 - \Delta\pi 11\right)\left(A11\right)\left(TCF\right)\left(PCF11\right) \qquad (2.27)$$

where *P11*- The pressure in the reject water by (RO1) *(psi).*

$$P11 = Po1 - dp \qquad (2.28)$$

and *dp*- The loss pressure in (RO1).

A11- The Area of membrane in the second module.

PCF11- The Pressure Correction Factor for the second module where is calculated by the relation.

$$PCF11 = 0.002129\left(P11 - \left(dp/2\right)\right) - Pp11 - \Delta\pi f11 + \Delta\pi p11 \qquad (2.29)$$

where

Pp11 - the Pressure in productwater *(Pw11)*

$\Delta\pi f11$- The reverse osmosis pressure of the feedwater is calculated from the

$$\Delta\pi f11 = \frac{0.0384933\left(Cr1\right)\left(Tk\right)}{\left(1000 - \left(\frac{Cr1}{1000}\right)\right)} \qquad (2.30)$$

$\Delta\pi p11$- The reverse osmosis pressure of the productwater is calculated from the

$$\Delta\pi p11 = \frac{0.0384933\left(Cp11\right)\left(Tk\right)}{\left(1000 - \left(\frac{Cp11}{1000}\right)\right)} \qquad (2.31)$$

$\Delta\pi 11$- The reverse osmosis pressure of the feedwater

$$\Delta\pi 11 = \Delta\pi f11 - \Delta\pi p11 \qquad (2.32)$$

Cr1- The concentration of salts in the feedwater to the second module is calculated from the relation

$$Cr1 = \frac{\left(Cf - Cp\right)}{\left(1 - Y\right)} \qquad (2\ 33)$$

Cp11- The concentration of salts in the productwater by second module

R11 -The rejected salts by the membrane is calculated from the relation

$$R11 = \frac{Cr1 + Cp11}{Cr1} \qquad (2.34)$$

The recovery ratio of the second module is expressed as

$$Y11 = \frac{Pw11}{Rw1} \qquad (2.35)$$

and the reject water from the system is

$$Rw11 = Rw1 - Pw11 \qquad (2.36)$$

and the product water from the system is

$$Pwt = Pw1 + Pw11 \tag{2.37}$$

So the Recovery Ratio of the system RO11 is calculated as

$$Yt = \frac{Pwt}{Fw1} \tag{2.38}$$

The salt Concentration in the Pwt of the system RO11 is

$$Cpt = \frac{(Cp1)(Pw1) + (Cp11)(Pw11)}{(Pw1 + Pw11)} \tag{2.39}$$

B - THE CONSUMED ENERGY BY THE SYSTEM

The load in the system is as follows

$$EL = Eo + ERP + EFP + EPP1 \tag{2.40}$$

EFP, Eo1 are the same of RO1 see chap.(1) ,*ERP & EPP* are calculated by the following relation

ERP- The consumed energy in the reject pump *(wh)*

$$ERP = \left[\frac{(c)(PR)}{ep}\right]\left(\frac{1}{Y11} - 1\right)(Fw1 - Pwt) \tag{2.41}$$

ERP- The consumed energy in the product pump *(wh)*

$$EPP = \left[\frac{(c)(PP)}{ep}\right](Pwt) \tag{2.42}$$

The specifice energy of the system $\left(Kwh/m^3\right)$

$$SPEt = EL \times 10^{-3} / Pwt \tag{2.43}$$

2.4.2 SIMULATION RESULTS

A program was installed in Fortran Language to simulate the design in fig.(2.28), where the simulation of design RO1 was performed in this design in addition to of simulation of the Concentration of salt in productwater of the second stage *(Cp11).*

The specific energy of the design is function of *(Cf)* fig. (2.29) where significance improvement achieved in the range from (2000 to 46000)*ppm* for brackish and sea water this improvement is from the connected module to the reject water from first stage where is used here the pressure in the rejectwater *(Po1—dp)* directly to produce water without any additional energy or change in the state of energy

fig. (2.30) represents the relation between the applied pressure *(Po1)* and the specific energy.

The straight line is for one module ($Po1$) and the curve is for the design Rol.

The second module starts when ($Po1-dp > \Delta\pi 11$) where the specific energy of the system decreases to the minimum value when ($Po1$) nearly (950 *psi*) for this simulation.

In the range of increasing in temperature of feedwater from (0 to 54 C^0) the specific energy increases from minimum to value equaled to (*SPE*) of one module and decreases when ($Tk > 54\ C^0$).
for sea water ($Cf = 42000\ ppm$).

The effect of (*Tk*) is very low when brackish water is using as is seen in fig. (2.31) the lower curve when ($Cf = 8000\ ppm$).

The specific energy in the design is less than design one module when ($Y1 < 0.35$) where the meet point is function of (*Cr*) where for low concentration of (*Cf*) the specific energy is lower and the meet point takes place for higher (*Y1*) as is shown in fig, (2.32) where the lower curve is for ($Cf = 4000\ ppm$).

The second module is operating if ($Y1 <$ *meet point*) and the energy will be saved but *for* ($Y1 >$ *meet point*) the design returns to one stage.

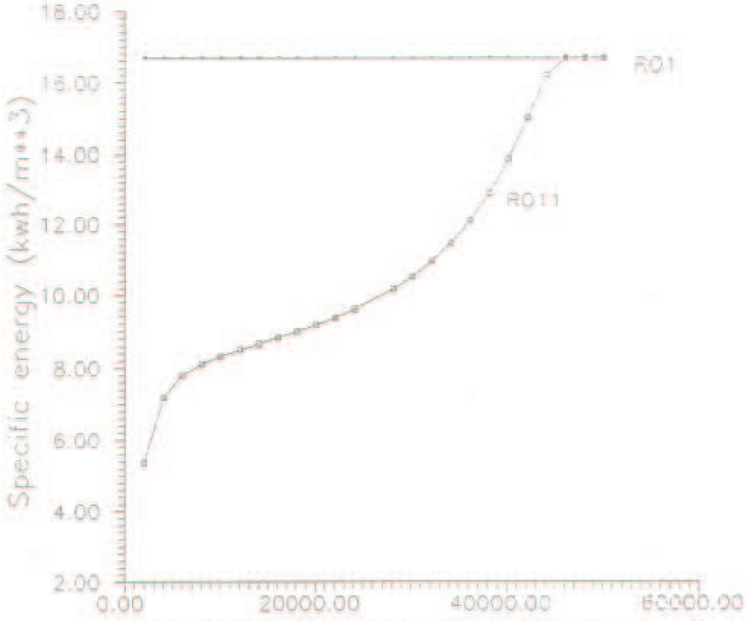


Fig.(2.29)

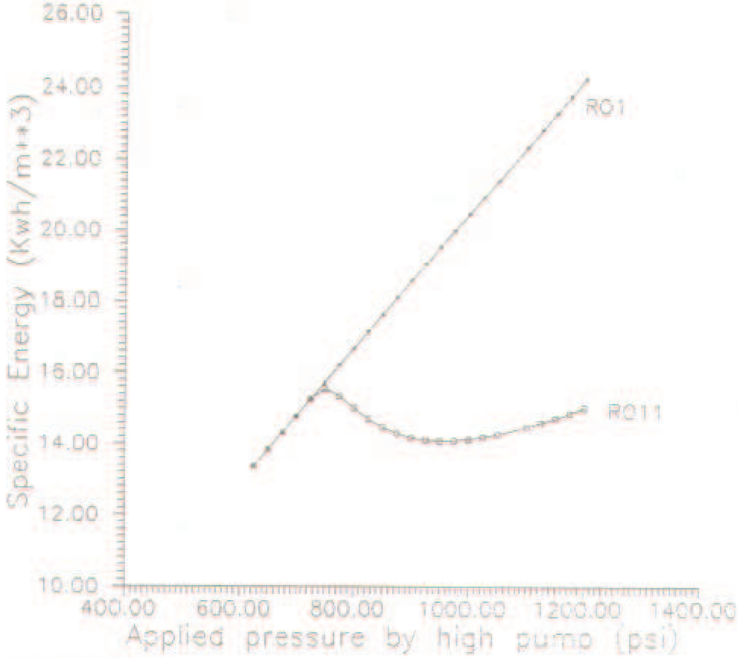


Fig.(2.30)

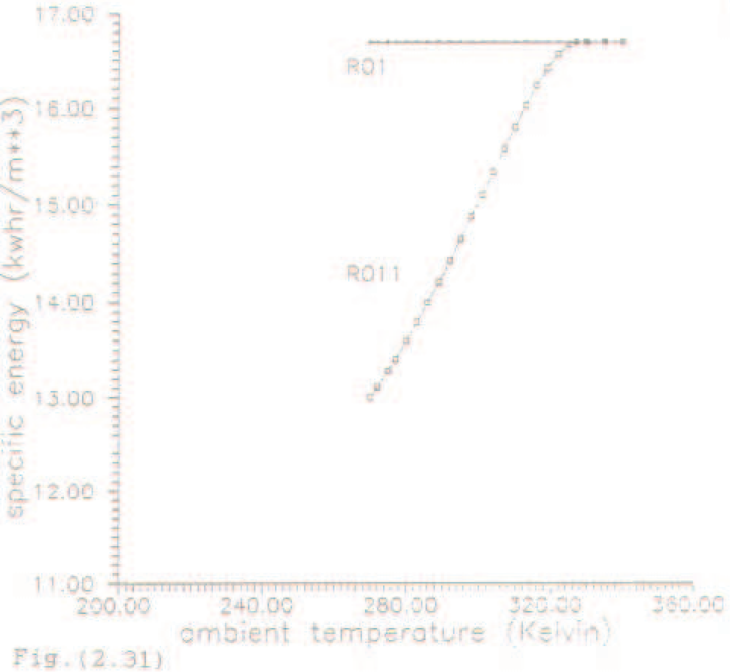


Fig.(2.31)

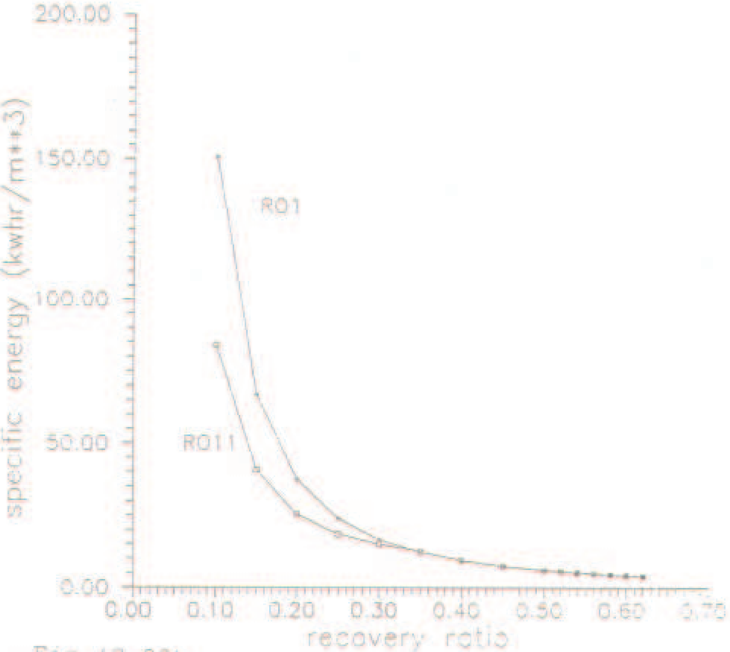


Fig.(2.32)

2.5 Two **STAGES REVERSE OSMOSIS SYSTEM WITH MODUL CONNECTED TO REJECT WATER**

2.5.1 DESCRIPTION CF THE SYSTEM

This System is compound of three modules Fig. (2.33) One is connected to the productwater *(Pw1)* of First stage and the second module is connected to rejectwater *(Rw1)* of the first module.

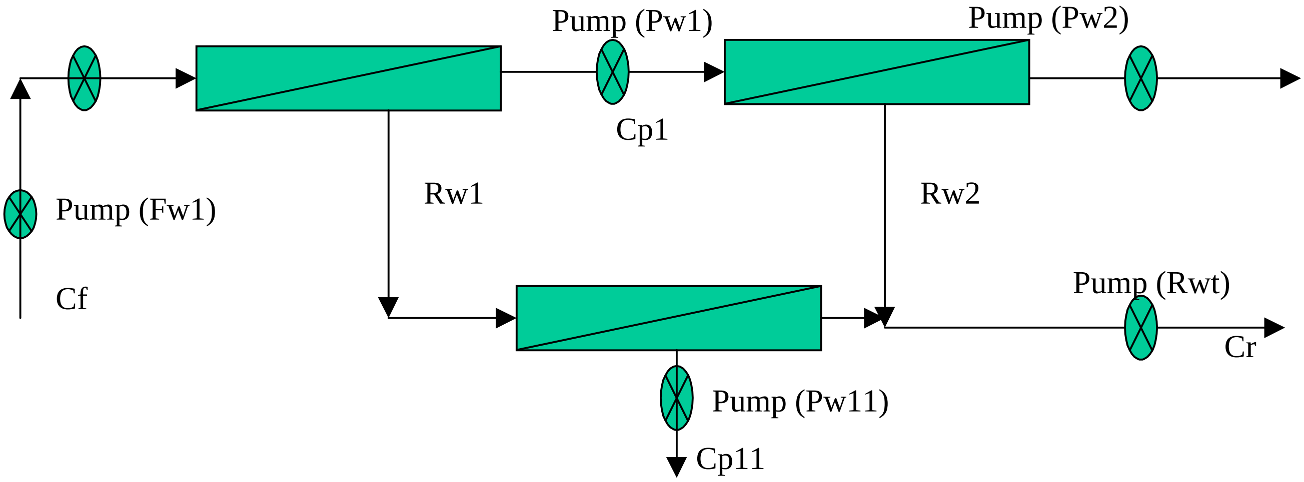


Fig.(2.33)

(see the operation of (RO1) . (R02) , (RO11))

The reject water from the system is

$$Rwt = Rw11 + Rw2 \qquad (2.44)$$

and the product water from the system as

$$Pwt = Pw2 + Pw11 \qquad (2.45)$$

So the recovery ratio of the system is calculated as

$$Ys = \frac{Pwt}{Fw1} \qquad (2.46)$$

The salt Concentration in the Pwt of the system is

$$Cpt = \frac{(Cp2)(Pw2) + (Cp11)(Pw11)}{Pwt} \qquad (2.47)$$

2.5.2 THE CONSUMED ENERGY BY THE SYSTEM

The load in the system is

$$EL = RP + EFP + EPP1 + Eo1 + Eo2 \qquad (2.48)$$

For *EFP Eo1* , *Eo2* see chap.(l) (2-2) , (2-3)

ERP is calculated by the relation

$$ERP = \left[\frac{(c)(PR)}{ep}\right]\left(\frac{1}{Ys} - 1\right)(Rwt) \qquad (2.49)$$

EPP as calculated by the relation

$$EPP = \left[\frac{(c)(PP)}{ep}\right](Pwt) \qquad (2.50)$$

The specific energy in the system

$$SPE = \left(\frac{(EL)(10)^{-3}}{Pw}\right) \qquad (2.51)$$

2.5.3 SIMULATION RESULTS

The program was installed in Fortran Language to simulate the design P012 where the following simulation was performed.

The consumption of energy in the design increases quickly when *(Cf)* increases from *(2000 - 4000 ppm)* but for the range *(4000-46000 ppm)* the consumption increases slightly where intersects the specific energy line of one module at a point near *(43000 ppm)* and for *(Cf > 46000)* the module (ROll) becomes unable to produce water where *(Po1-dp <* $\Delta\pi 11$*)* so from fig. (2.34) .

$SPET < SPE$ *if* $Cf < 43000$ *ppm and*

$SPET > SPE$ *if* $Cf > 43000$ *ppm*

Fig.(2.35) illustrates the behavior of the design when the applied pressure increases where is shown

if (Pol < 720 psi) then (RO11) does not operate because *(Po1-dp <* $\Delta\pi 11$*)* Then the consumption of energy increases but

if (Pol > 720 psi) then *(SPET)* decreases to its minimum value when *(Po1> 975 psi)* but increases for *(Po1 > 975)*

if (Po1 < 790 psi) then (SPE < SPET) but

if (Po1 > 790 psi) then (SPE > SPET) where the point *(Po1 = 790 psi)* is intersect point

The consumption of energy of the design is function of temperature *(Tk)* where

if (Tk < $305\ k^0$ *) then (SPET < SPE)*

elseif (Tk > $305\ k^0$*) then (SPET > SPE)*

elseif (Tk = $305\ k^0$ *) then (SPET = SPE)*

if (Tk < $330\ k^0$ *) then (SPET)* is considered nearly direct proportion but for *(Tk >* $330\ k^0$ *) then (SPET)* nearly independent of *(Tk)* fig. (2.36).

The specific energy is inverse proportion function to *(Y1)* where

if (Y1< 0.3) then (SPET< SPE)

elseif (Y1 = 0.3) then (SPET = SPE)

else if (Y1 > 0.3) then (SPET > SPE) & (Po1 -dp < $\Delta\pi 11$*)* where (ROll) is out of operation fig.(2.37).

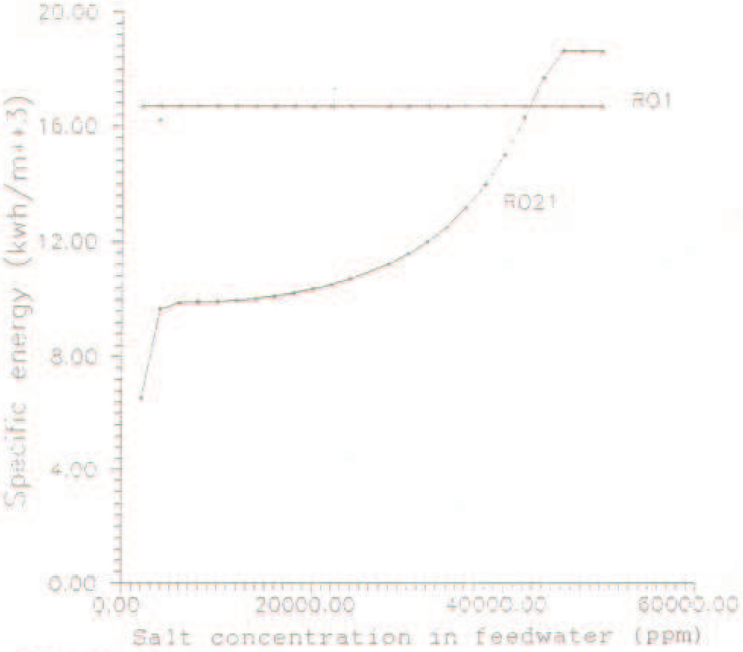


Fig.(2.34)

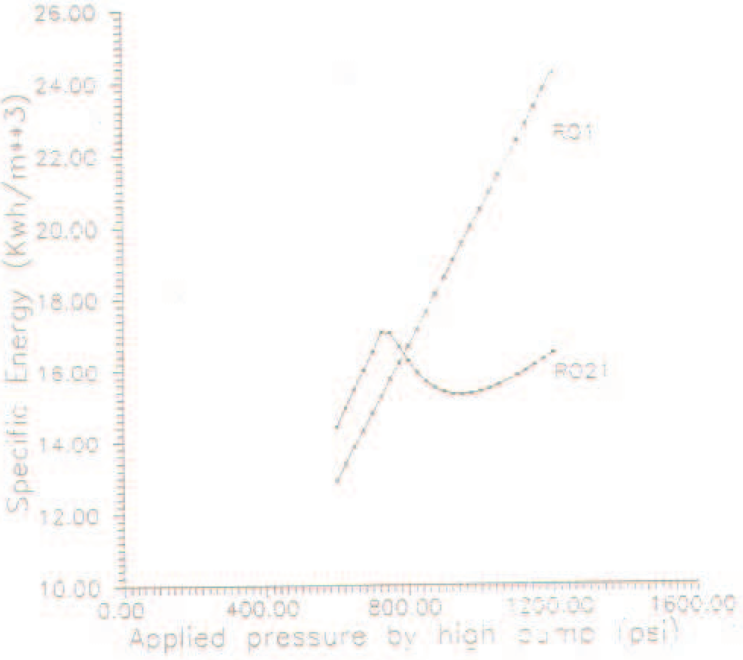


Fig.(2.35)

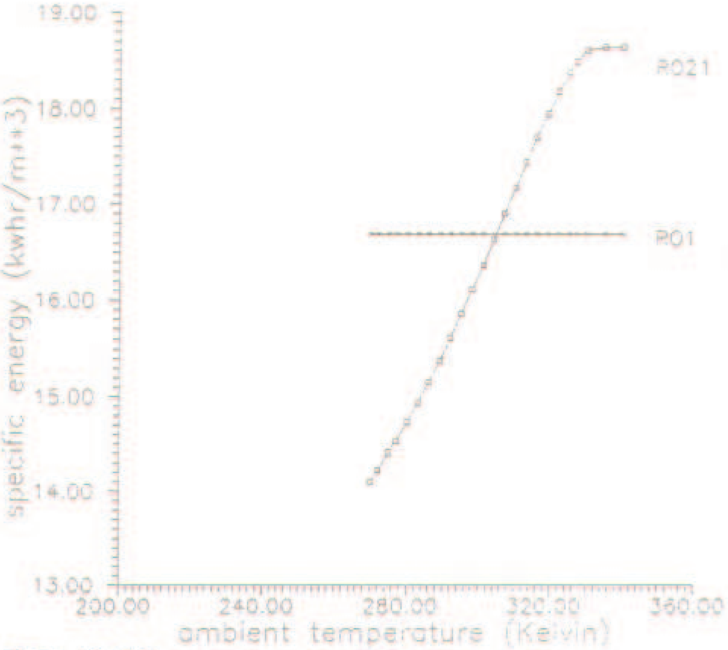


Fig.(2.36)

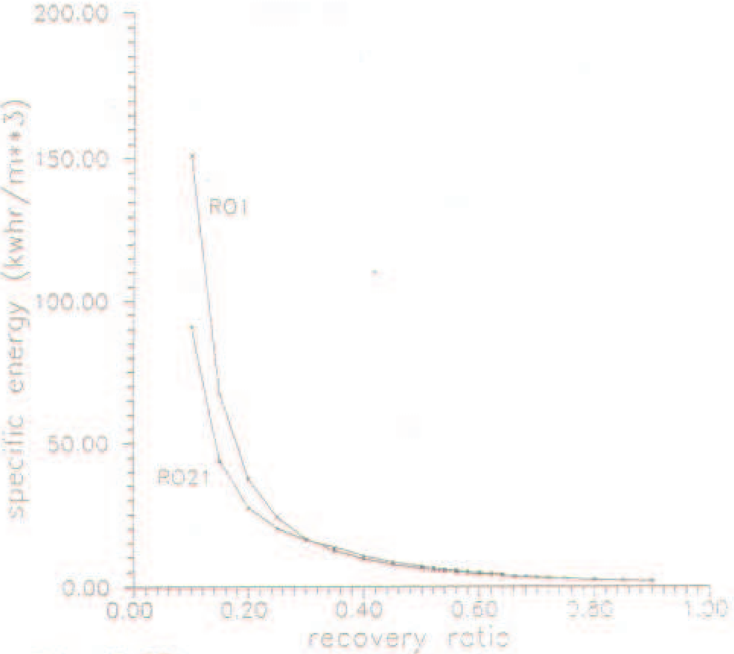


Fig.(2.37)

2.6 REVERSE OSMOSIS SYSTEMS WITH RECYCLING OF REJECTWATER

2.6.1 DESCRIPTION OF THE METHOD

As we have seen the range of recoveries which have been proposed for various systems has been between (10 & 45) % with the lower recoveries being used in smaller system 175],in other words the reject water is between (55 & 90) % of feed water.

In this work will be exhibited the simulation of designs illustrated in figs.(2.38—41) where was minimized the rejectwater and as result was minimized the specific energy and the chemical treatment.

The rejectwater is recycled to be as a part of the feedwater where the concentration of feedwater will increase up to controlled values of Concentration of brine in feed & reject water so the feedwater from the source when the rejectwater is recycled is equal to the productwater value where.

$Fw = Pw + Rw$, and

$Fw = Fwr + Rwr$, if is recycled where

$Fwr = Pw$

$Rw = 0$, if is recycled

so the value of rejectwater *(Rw)* depends on the controlled value and on the Concentration of brine in the feedwater *(Cf)*where is calculated from the relation

$$Cpt = \frac{(Cr)(Rw) + (Cf)(Pw)}{Rw + Pw} \qquad \text{if is recycled}$$

and the Concentration in Prductewater *(Cp)* is calculated from the relation

$$Cp = Cfr\,(1 - R)\,CF \qquad \text{if is recycled}$$

Fig. (2.38) Flow diagram of reverse osmosis system (one stage) with recovery turbine (R.T) and recycle the rejectwater.

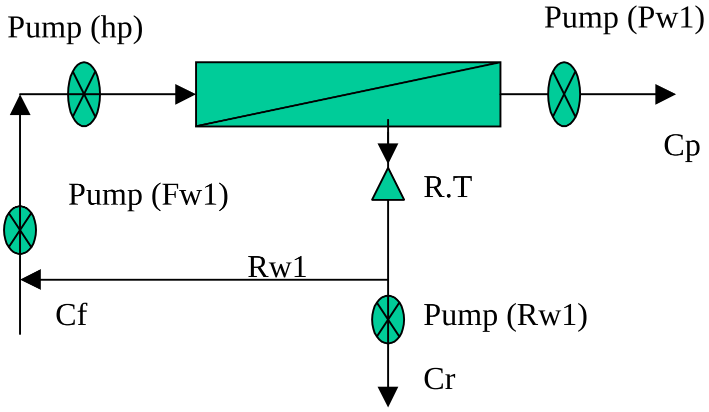


Fig.(2.38)

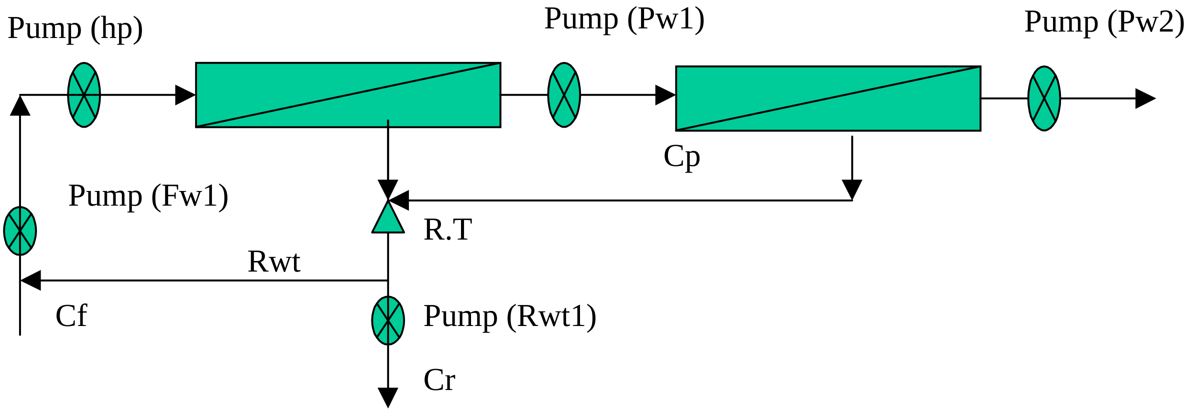


Fig.(2.39)

Fig. (2.39) Flow diagram of reverse osmosis system (Two stage) with recovery turbine (R.T) and recycle the rejectwater.

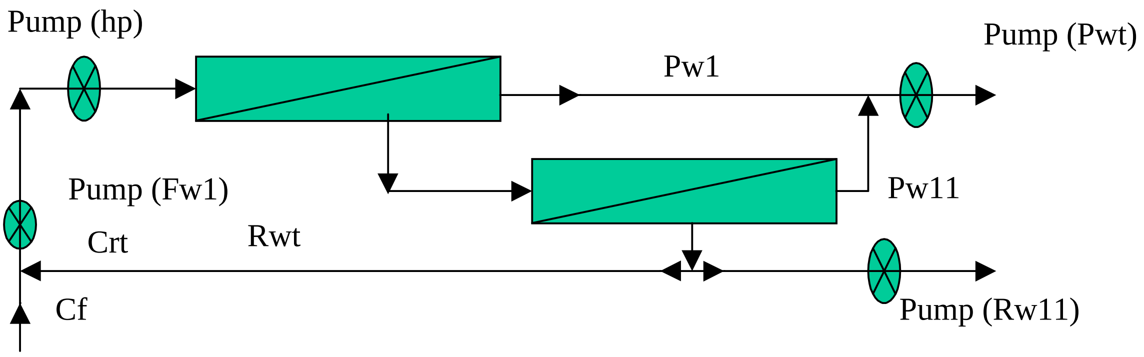


Fig.(2.40)

Fig. (2.40) Flow diagram of reverse osmosis system (One stage)

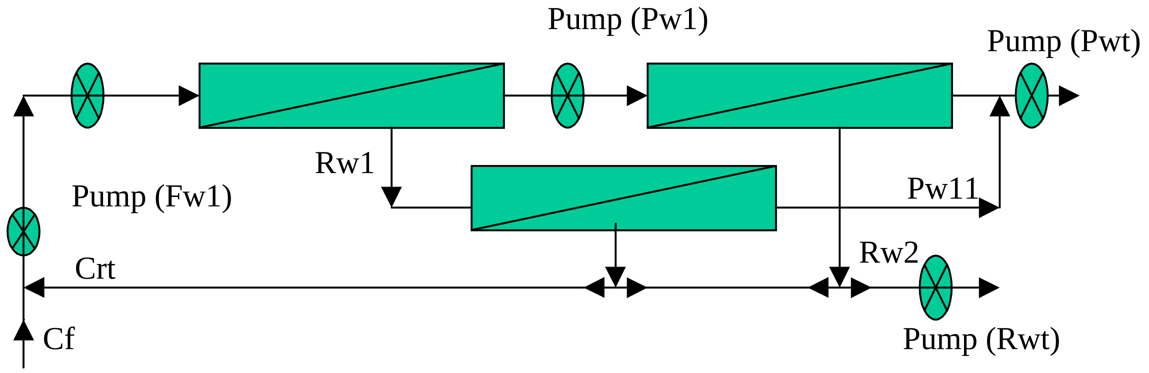


Fig.(2.41)

Fig. (2.41) Flow diagram of reverse osmosis system (two stage) with module connected to the rejectwater and recycle the rejectwater

2.6.2 SIMULATION RESULTS

The programs were installed in Fortran Language to simulate the designs in figs.(2.38-41) where same condition was applied in run ,brackish water was supposed *(Cf = 4000 ppm).*

A - EFFECT OF RECYCLING ON SALT CONCENTRATION IN FEEDWATER

Fig. (2.42) represents the increase in Concentration of salts in feedwater due to recycling the rejectwater. for the applied control the maximum Concentration of salts in feedwater in the designs was about.

10000 ppm for the design RO1 after 4 hours
20000 ppm for the design RO2 after 7 hours
30000 ppm for the design RO11 after 5 hours
560000 ppm for the design R021 after 7 hours

B - EFFECT OF RECYCLING ON SPECIFIC ENERGY

Fig. (2.43) represents the increase in Concentration of salts in feedwater due to recycling the rejectwater and it’s effecting on the specific energy of the designs.

The specific energy is constant in RO1 but increase in the other’s designs where specific energy of *(RO11 < RO21 < PO1 < RO2) if (Cf < 30000 ppm)* or in 5 hours.

Fig. (2.44) represents the relation between the specific energy and the Concentration of salts in productwater where as is showed.

(RO11 < RO21 < RO1 < RO2) if (Cp < 760 ppm)
(RO11 < RO1 < RO21 < RO2) if (Cp < 900 ppm)
(RO11 < RO1 < RO2 < P021) if (Cp > 900 ppm)

c - EFFECT OF RECYCLING ON PRODUCTWATER

Fig.(2.45) is showing the effect of time or Iteration on the productwater where the productwater of the designs is as following.

(RO11> RO21 > RO1 > R02) if (Iteration < 4.5 hours) but
(RO11 < RO21 < RO2) after 4.5 hours

D - EFFECT OF RECYCLING ON REJECTWATER

Fig. (2.46) is shown the effect of recycling on the rejectwater, where the rejectwater in the designs as the following order.

(RO11= RO21 < RO1 < R02) if (Iteration <=2 hours) but
(RO11< RO21 < RO1 < R02) if (Iteration >2 hours)
RO11 and RO21 have small deference in 5 hours Iteration.

2.6.3 DISCUSSION

The design Fig.(2.40) was the best during 4 hours Iteration and the applied condition or control where in this case the Reverse Osmosis System will dispatch the brine water ones every 4 hours then return to start from beginning in other words the system starts with initial values of *(Cf)* and *(Cp)* and increases every time up where when the condition *(Cp = 1000 ppm)* is touched then the system dispatches the brine water or rejectwater and Cp in the productwater will be about 750 (ppm) and the specific energy about 4 $\left(Kwh/m^3\right)$.

For this simulation about (20%) just dispatch from the rejectwater of the system

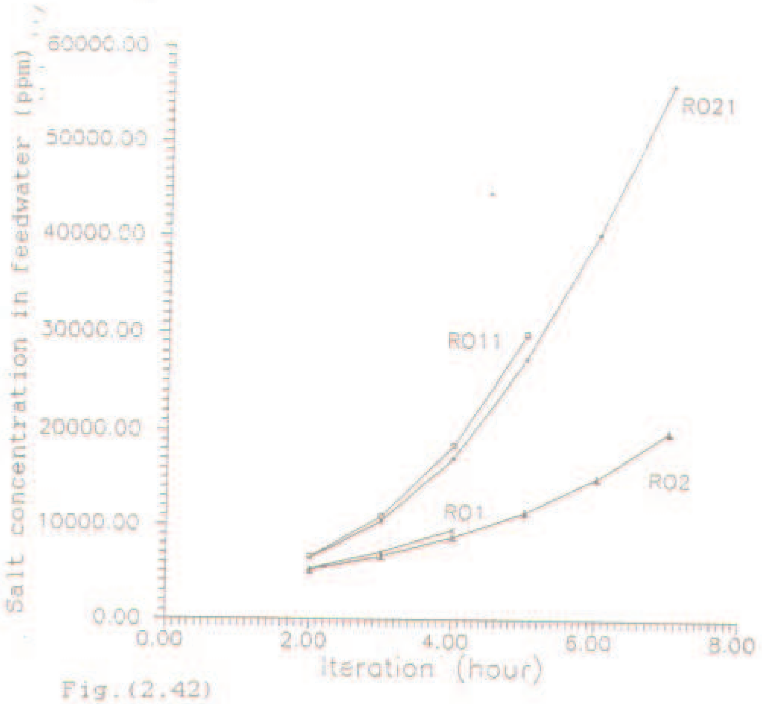


Fig.(2.42)

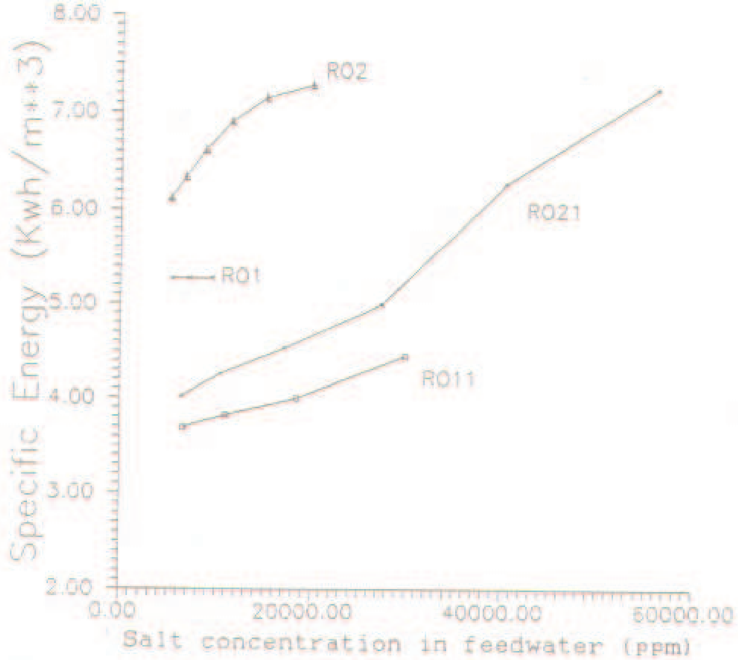


Fig.(2.43)

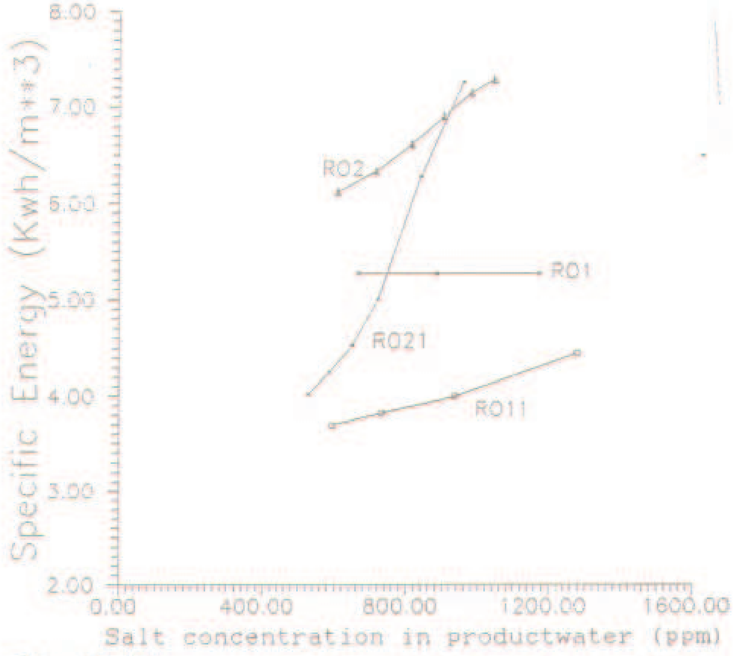


Fig.(2.44)

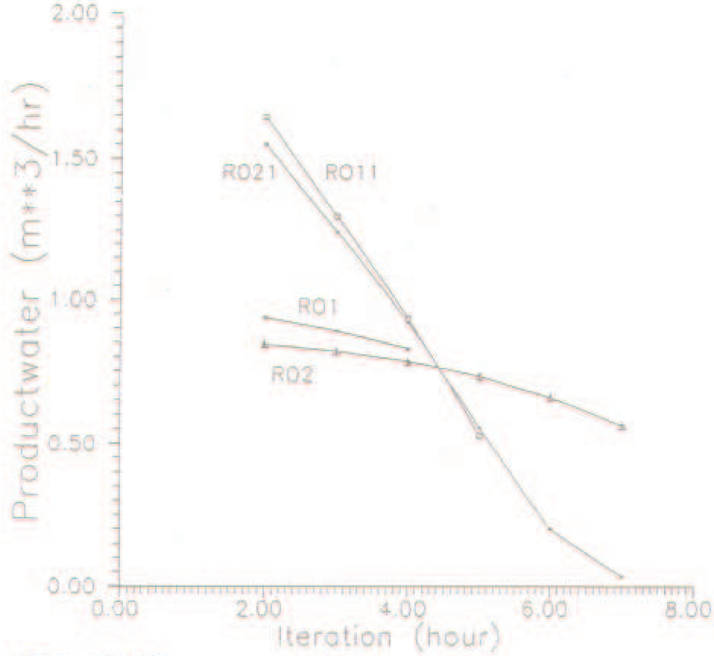
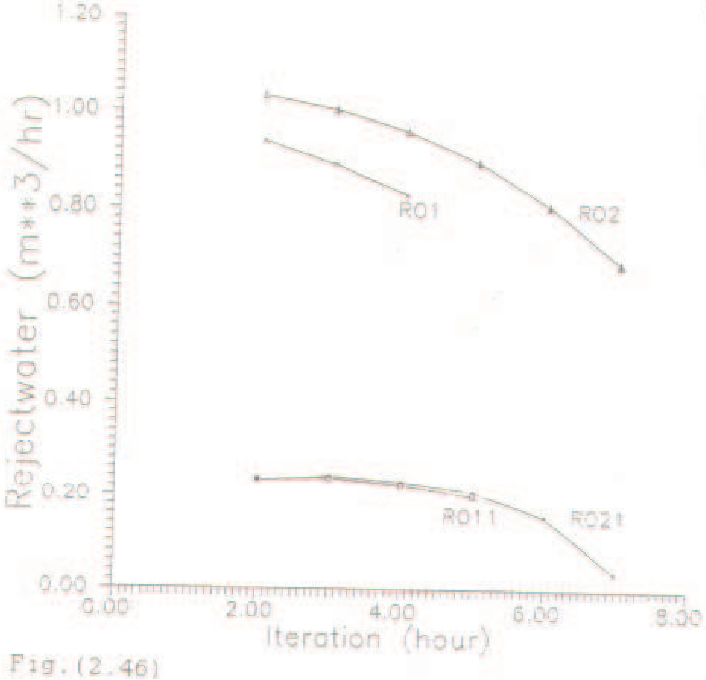


Fig.(2.45)



1.20
1.00
0.80
0.60
0.40
0.20
0.00
Rejectwater (m**3/hr)
RO1
RO2
RO11
RO21
0.00
2.00
4.00
6.00
8.00
Iteration (hour)

Fig.(2.46)

CHAPTER(3)

SIMULATION STUDY OF REVERSE OSMOSIS DESALINATION SYSTEM POWERED BY COMBINED SOLAR AND WIND POWER PLANTS

3.1 INTRODUCTION

The shortage of fresh water and The rising energy costs have motivted many countries to turn to renewable energy sources for desalination purposes [1].

Few papers dealt with solar and wind energy in spite of water desalination by wind & solar power is very attractive due to possibility of overcoming the energy supply discontinuity by storing the fresh water and because water desalination is particularly needed in remote areas of devolping countries where in many cases are favourable conditions for the utilization of wind and solar energy. [22,23,51,38,52].

A wind and photovoltaic powered reverse osmosis seawater desalination plant with a fresh water production of $150\left(m^3/day\right)$ was carried out [25].

The Battery is an important part of Solar and Wind power plants as a storage system when excess energy is attained or to supply the system by power when no energy from solar and wind where the capacity is chosen to cover three days operation [53,54,55,56,57, 58,59].

The problems of shortage of drink water and high cost of energy in Greece are possible to overcome and to be faced due to favourable winds and solar energy in many sits of Greece espcially in the islands.

This paper presents the simulation model of Reverse Osmosis System operated by wind or solar or both energy in Greece island kythons where the combined of renewable energy sources has been applied there [160].

The Load in the system mainly is used to operate the pumps in the system this Load is consumed to produce the Productwater.

Fig. (3.1) represents the block diagram of the reverse osmosis *system* of one stage with recovery turbine (R.T) combined to wind generator ,solar cells ,batteries ,diesel generator ,control of power and main pumps.

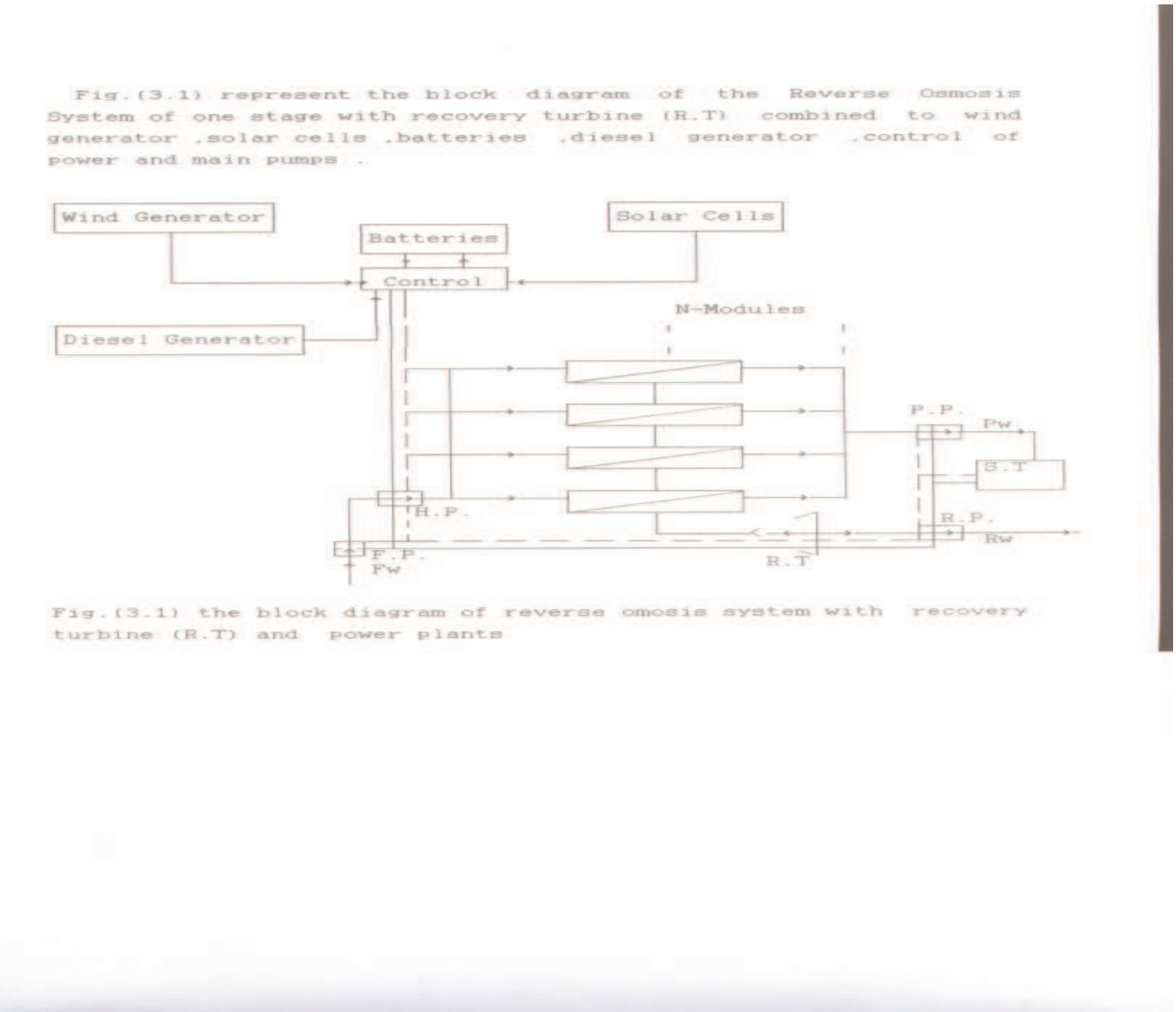


Fig.(3.1) represent the block diagram of the Reverse Osmosis System of one stage with recovery turbine (R.T) combined to wind generator ,solar cells ,batteries ,diesel generator ,control of power and main pumps .

Fig.(3.1) the block diagram of reverse omosis system with recovery turbine (R.T) and power plants

Fig. (3.1) the block diagram of reverse osmosis system with recovery turbine (R.T) and power plants.

The power mainly is consumed in Feed pump ,High pump ,Product pump ,Reject pump and some power is used in treatment this power will be not considered due to its small quantity compared to the other pumps so we can write [14,21].

$$EL = Eo + EPP + ERP + EFP \qquad (3.1)$$

Where

EL- The Load in system per hour *(kwh)*

Eo- The Load in High Pump per hour *(kwh)*

EPP-The Load in Product Pump per hour *(kwh)*

ERP-The Load in Reject Pump per hour *(kwh)*

EFP- The Load in Feed Pump per hour *(kwh)*

In case the System connected to Recovery Turbine the Load will be as the following

$ELR = EL - RE$ (3.2)

Where

ELR- The Load with Recovery Turbine *(kwh).*

RE -The Recovered Energy *(kwh).*

The Load is consumed to produce the requirement of Productwater each hour where denotes as $Pw\left(m^3/hr\right)$

The Load is function of the parameters and characteristics of water in the regions system and the characteristics of Reverse Osmosis System .the product water across the membrane is given by [17] is corrected by Temperature, Pressure Correction Factors *TCF & PCF* [47,48,49].

The hourly energy. balance when Reverse Osmosis combined to solar and wind power plants is written as follows.

$$NL\left(k, I\right) = ELR - Aw \times WE\left(k, I\right) - Av \times SEc\left(k, I\right) \qquad (3.3)$$

Where

ELR , Aw , Av were defined before

k - The number of day

I - The hour in the day

$NL(k,I)$ -The net load per hour *(kwh)*

$WE(k,I)$-The power produced by wind machine $\left(Kwh/m^2\right)$

$SEc(k,I)$-The power produced by photovoltaic system $\left(Kwh/m^2\right)$

Computation of *NL(k,I)* will denote the operation of the system where there are three cases Fig. (3.2).

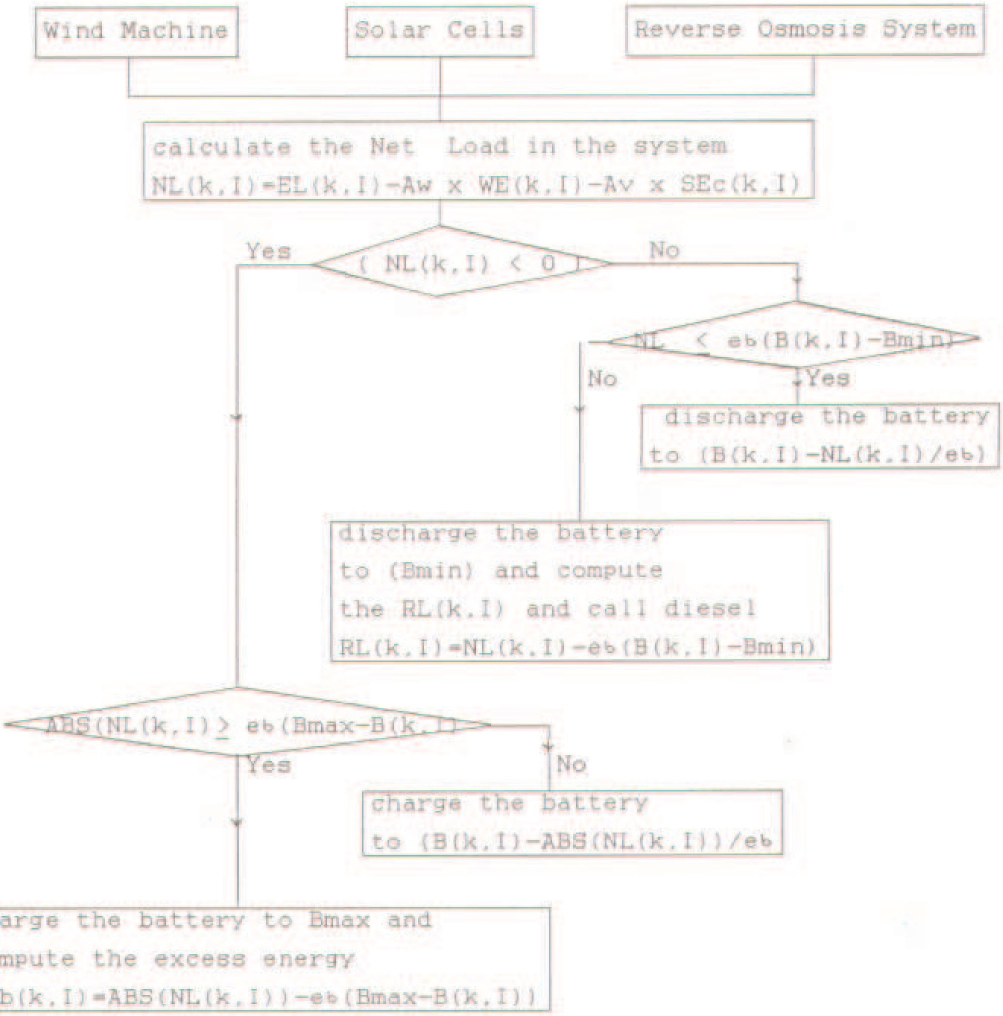


Fig.(3.2) Possible operation of the system each hour

1-If NL(k,I)<0 then the Reverse Osmosis System operates by wind and solar energy only and there is an excess of energy more than requirment and the excess of energy will be directed to charge the battery upon the capacity of battery will have two possible ways where a- *If* $Abs\ (NL(k,I)) < eb(Bmax-Bmin)$ *then* the battery will be charged to

$(B(k,I) + (Abs(NL(k,I))))$ *else*

b- *If* $(Abs\ NL(k,I) > eb(Bmax — Bmin))$ *then* the battery will be charged to *Bmax* and there excess of energy where

$$ENb(k,I)=Aw(WE(k,I))+Av(SEc(k,I))-EL-eb(Bmax-B(k,.I)) \tag{3.4}$$

where

eb - The efficiency of battery.

$B(k,I)$- The current level of the power stored in the battery (kwh).

$ENb(k,I)$- the excess of energy *(kwh)* after achieve the Load and charging the battery to *Bmax*.

2- *If* $(NL(k,I) = 0)$ then equation (3.3) reduces to

$$EL = Aw\ (WE(k,I)) + Av\ (SEc\ (k,I)) \tag{3.5}$$

that means the System operates directly by wind and solar energy, where the Load is covered and no contribution from battery or diesel.

3- *If* $(NL(k,I) > 0)$ then the Load is bigger than energy from wind and solar and needs contribution of energy to maintain the operation of the system to produce the requirement of productwater and the second step depends on the following condition.

a- *If* $(NL(k,I) < eb(B(k,I) — Bmin))$ then the battery will be discharged to $(B(k,I) — NL(k,I)/eb)$ to recover the Load

b- *If* $(NL(k,I) > eb(B(k,I) — Bmin)$ then the battery will be discharged to Bmin and remains residual load where is computed by the relation.

$$RL(K,I) = NL(k,I) - eb(B(k,I) — Bmin) \tag{3.6}$$

The Residual Load will be produced by diesel generator to maintain the operation of the system.

The program consists of the following parts.

1- main program to calculate the time operation of Solar. Wind, Battery and diesel generator yearly for small and high capacity of productwater 0.715-14.3 $\left(m^3/hr\right)$ with plant factor 100% operation (8760 *hr*) yearly.

2- Simulation program for Reverse Osmosis System as subroutine to evaluate the Load in the system for the required of drink water hourly and yearly to provided the main program with the required load.

3- Simulation program for Wind Energy System as subroutine to evaluate the power each hour for one year attained from wind.

4- Simulation program for Solar Energy System as subroutine to evaluate the power each hour for one year attained from solar.

5- Simulation program for Battery System as subroutine to evaluate the state of energy and the current level of battery each hour and time abundance of energy i.e. the energy excess the load and battery the time charge and discharge and time operation of diesel generator to achieve the load in the system.

3.2 ONE STAGE REVERSE OSMOSIS SYSTEM WITH RECOVERY TURBINE POWERED BY SOLAR ENERGY

The simulation model was developed to simulate reverse osmosis operated by (Photovoltaic power-diesel).

The data and parameters used in the simulation program are the real hourly data of the year 1982 for global solar radiation on horizontal surface of Kythnos Island in Greece each case was performed for 20 Reverse Osmosis Systems with different Productwater from 0.715-14.3 $\left(m^3/hr\right)$ where the time operation was calculated hourly and yearly for each subsystem.

Fig. (3.3) shows the hourly load of 20 plants and time operation of diesel *(T-diesel)* in case Reverse Osmosis System connected to Photovoltaic System and Battery.

We also defined the time operation of system by solar *(T-solar)*

-Time abund. (T-abund.) when attains excess energy more than load and energy requirement to charge the battery to *Bmax* eq(5).

-Time charge *(T-charge)* when the energy more than loud and less than load and *eb(Bmax-B(k,I)).*

-Time discharge *(T-discharge)* when the energy less than load.

Time diesel is the time operation of diesel generator when the solar energy not enough and the battery was drained to Bmin.

(T-abund.) + (T-charge) + (T-discharge) = 8760 - (T-diesel).

Where

(T-solar) = 8760 - (T-diesel).

In Fig. (3.4) the productwater yearly and time percent of diesel ,solar required to each system to operate for one year.

The optimum specific energy was attained for productwater 4.37 $\left(m^3/hr\right)$ and (37.46 %) energy from diesel.

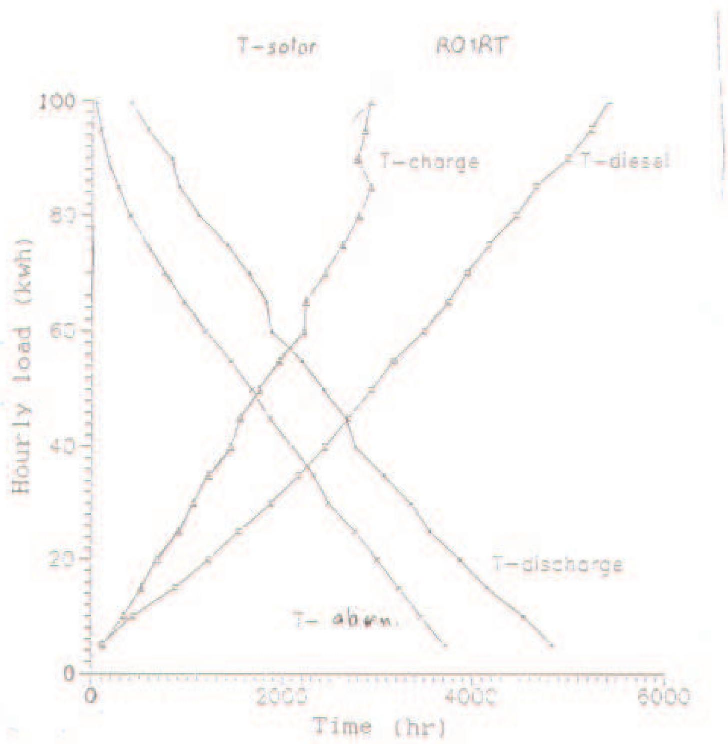

T-solar
RO1RT
100
80
60
40
20
0
Hourly load (kwh)
T-charge
T-diesel
T-discharge
T- abern.
0
2000
4000
6000
Time (hr)

Fig.(3.3)

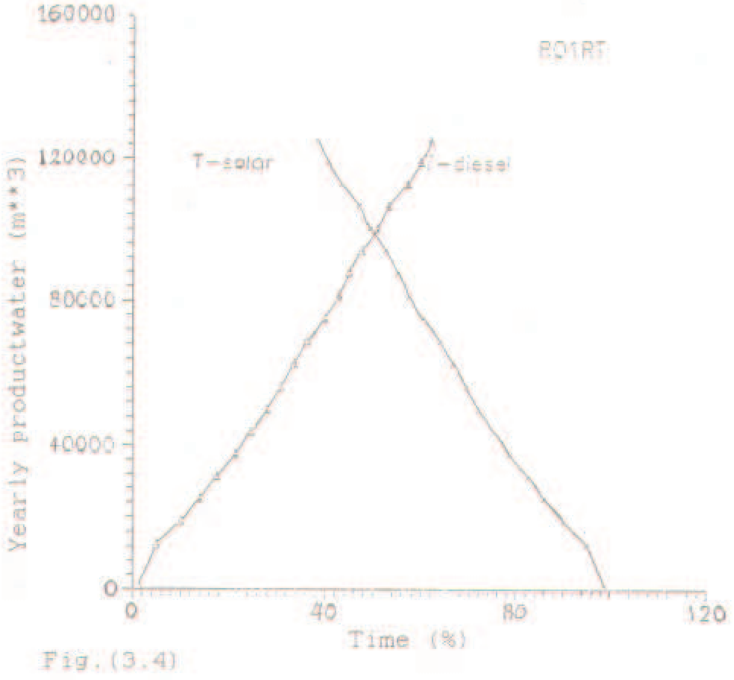

160000
120000
80000
40000
0
Yearly productwater (m**3)
RO1RT
T-solar
T-diesel
0
40
80
120
Time (%)

Fig.(3.4)

3.3 ONE STAGE REVERSE OSMOSIS SYSTEM WITH RECOVERY TURBINE POWERED BY WIND ENERGY

The Simulation model was developed to simulate Reverse Osmosis operated by (Wind power - diesel).

The data and parameters used in the simulation program are the real hourly data of the year 1982 for wind speed of Kythnos Island in Greece.

Each case was performed for 20 Reverse Osmosis Systems with different Productwater from 0.715-14.3 $\left(m^3/hr\right)$ where the time operation was calculated hourly and yearly for each subsystem.

Fig. (3.5) shows the hourly load of 20 plants and time operation of diesel *(T-diesel)* in case Reverse Osmosis System connected to Wind machine System and Battery.

We also defined the time operation of system by wind *(T-wind).*

-Time abund. *(T-abund.)* when attains excess energy more than load and energy requirement to charge the battery to *Bmax* eq(5)

-Time charge *(T-charge)* when the energy more than loud and less than load and *eb(Bmax-B(k,I))*

-Time discharge *(T-discharge)* when the energy less than load.

Time diesel is the time operation of diesel generator when the wind energy not enough and the battery was drained to *Bmin.*

(T-abund.) + (T-charge) + (T-discharge) = 8760 - (T-diesel).

Where

(T-wind) = 8760 - (T-diesel).

In Fig. (3.6) the productwater yearly and time percent of diesel ,wind required to each system to operate for one year.

The optimum specific energy was attained for productwater 12.54 $\left(m^3/hr\right)$ and (49.36 %) energy from diesel.

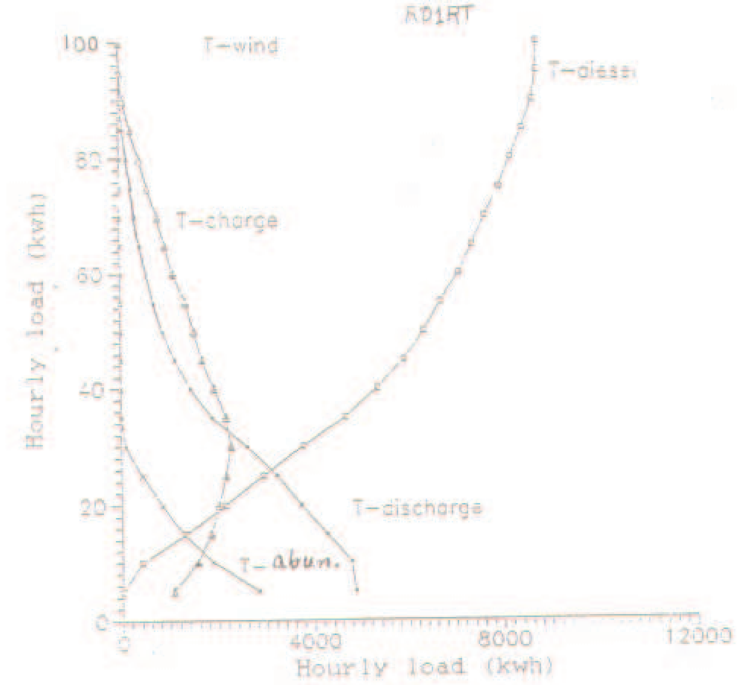

RO1RT
T-wind
T-diesel
T-charge
T-discharge
T-abun.
Hourly load (kwh)
100
80
60
40
20
0
0
4000
8000
12000
Hourly load (kwh)

Fig.(3.5)

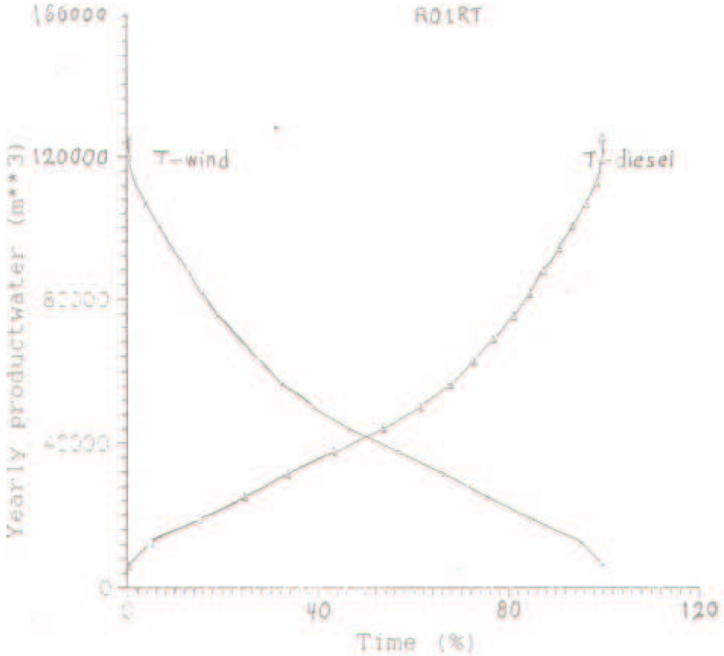

RO1RT
T-wind
T-diesel
Yearly productwater (m**3)
160000
120000
80000
40000
0
0
40
80
120
Time (%)

Fig.(3.6)

3.4. ONE STAGE REVERSE OSMOSIS SYSTEM WITH RECOVERY TURBINE POWERED BY COMBINED SOLAR AND WIND ENERGY

The Simulation model was developed to simulate Reverse Osmosis operated by (Solar-Wind Power - diesel).

The data and parameters used in the simulation program are the real hourly data of the year 1982 for Wind speed of Kythnos Island in Greece.

Each case was performed for 20 Reverse Osmosis Systems with different Productwater from 0.715-14.3 $\left(m^3/hr\right)$ where the time operation was calculated hourly and yearly for each subsystem.

Fig. (3.7) shows the hourly load of 20 plants and time operation of diesel *(T-diesel)* in case Reverse Osmosis System connected to Wind machine System and Battery.

We also defined the time operation of system by Solar-Wind *(T-Solar-Wind).*

-Time abund. *(T-abund.)* when attains excess energy more than load and energy requirement to charge the battery to Bmax eq(5).

-Time charge *(T-charge)* when the energy more than loud and less than load and *eb(Emax -B(k,I)).*

-Time discharge *(T-discharge)* when the energy less than load.

Time diesel is the time operation of diesel generator when the Solar-Wind energy not enough and the battery was drained to *Bmin.*

(T-abund.) + (T-charge) + (T-discharge) = 8760 - (T-diesel).

Where

(T-Solar-Wind) = 8760 - (T-diesel).

In Fig. (3.8) the productwater yearly and time percent of diesel ,Solar-Wind required to each system to operate for one year.

The optimum specific energy was attained for productwater 16.71 $\left(m^3/hr\right)$ and (45.59 %) energy from diesel.

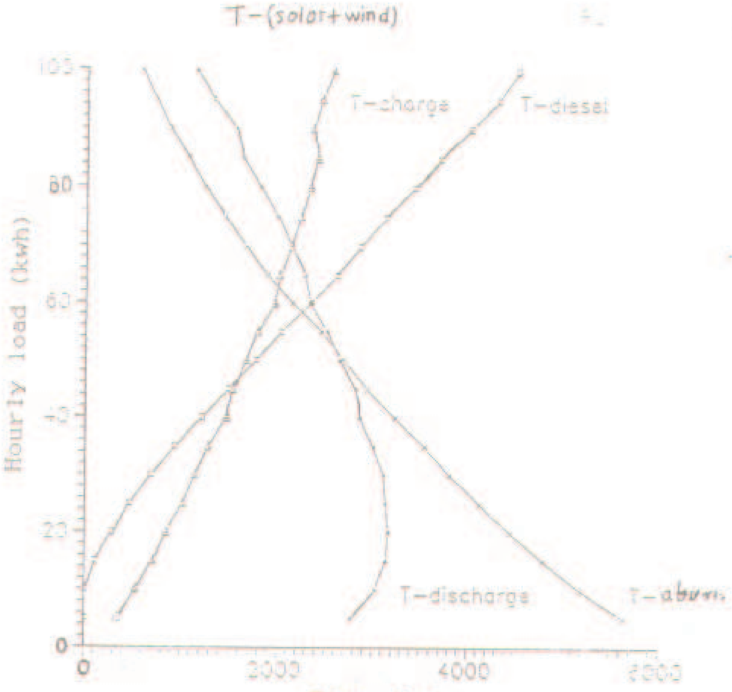

T-(solar+wind)
100
80
60
40
20
0
Hourly load (kwh)
T-charge
T-diesel
T-discharge
T-abvm.
0
2000
4000
6000
Time (hr)

Fig.(3.7)

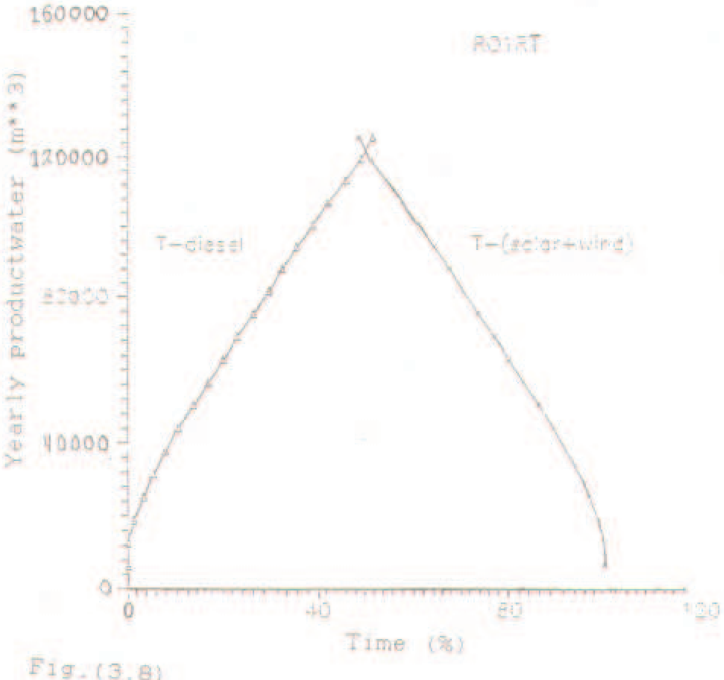

160000
120000
80000
40000
0
RO1RT
Yearly productwater (m**3)
T-diesel
T-(solar+wind)
0
40
80
120
Time (%)

Fig.(3.8)

3.5 SIMULATION RESULTS

The simulation was performed for 20 Reverse Osmosis plants where the gradient of Productwater *(Pw)* from plant to other was adjusted as

Pw = Pw1 (N . 10) where *N =(1 up 20)* and *Pw1* is the Productwater of one module.

Fig.(3.3) shows the results of simulations the R.O.Systems operated by Photovoltaic System and Battery where the yearly time operation by solar and diesel and time abund. ,time charge and time discharge of battery yearly for each R.O.System was calculated also.

Fig.(3.4) is the time percent of time operation of diesel and solar relative to productwater per year where

T-diesel increase from (1.2 - 61.8) % for productwater from (17.18 - 343.5) $\left(m^3/hr\right)$

Fig.(3.5) shows the results of simulations the R.O.Systems operated by Wind System and Battery where the yearly time operation by wind and diesel and time abund. ,time charge and time discharge of battery yearly for each R.O.System was calculated also

Fig. (3.6) is the time percent of time operation of diesel and wind relative to productwater per year where

T-diesel increase from (0 - 100) % for productwater from (17.18 - 343.5) $\left(m^3/hr\right)$

Fig. (3.7) shows the results of simulations the R.O.Systems operated by Solar-Wind System and Battery where the yearly time operation by Solar-Wind and diesel and time abund. ,time charge and time discharge of battery yearly for each R.O.System was calculated also

Fig. (3.8) is the time percent of time operation of diesel and Solar-Wind relative to productwater per year where

T-diesel increase from (0 - 51.4) 56 for productwater from (17.18 - 343.5) $\left(m^3/hr\right)$

3.6 Discussion

The problems of shortage of fresh water and rising energy costs are possible to be solved by Reverse Osmosis System operated by solar or wind or by combined solar and wind.

Wind System is more efficient for productwater less than 35$\left(m^3/hr\right)$and solar system is more efficient when productwater more than 35 $\left(m^3/hr\right)$ where for productwater 343.2 $\left(m^3/day\right)$ *T-diesel* is 100% in wind system and just 61.8% in solar system.

The combination of solar and wind energy enhanced the productivity and time operation by solar and wind where

T-diesel was decreased to (51.4%) compared to (61.8%) in solar and (100%) in wind system for the same productwater (343.2 $\left(m^3/day \right)$.

The system operated by solar energy is more stable than system operated by wind energy

The combination of solar and wind energy where is possible enhances the productivity and reduce *T-diesel* and give stability to the system.

The policy of operation and size of battery and load of system effect on the *T-diesel* and possible to be removed for special design where for our simulation it is possible to remove diesel generator if the plant factor is (0.9) and the load (34.92 kwh) ie 108 $\left(m^3/day \right)$ or less.

The optimum specific energy was attained at certain value for each power plant of poductwater.

Reverse Osmosis Parameters System

Concentration of salt in feedwater (Cf) = 30000 ppm

Concentration of salt in Productwater (Cp1) =500 ppm

Feedwater Temperature (Tk) = 300 k

Recovery Ratio (Y1) = 0.4

Membrane Area in module (Am1)= 10 m^2

Operating pressure (Po1) = 800 psi

Pump efficiency (ep) = 0.9

Turbine efficiency (et) = 0.9

Specific energy consumption (spe) = 6.97 $\left(Kwh/m^3 \right)$

Wind Machine Parameters

Rotor swept area (Aw) = 528.5 m^2

Cut-in speed (Vmin)= 3 m/s

Rated speed (Vr) = 11.1 m/s

Cut-out speed (Vmax) = 24 m/s

Wind generator efficiency (Cp) =0.25

Photovoltaic tai c Parameters

Area of photovoltaic cells (Av) = 1200 m^2

inclind angle (Ai) = $37^o 25'$

Conversion efficiency (ec) = 0.08

Battery Parameters

Maximum level (Bmax) = 600 kwh

Minimum level (Bmin) = 120 kwh

Battery efficiency (eb) = 0.8

3.7 ONE STAGE REVERSE OSMOSIS SYSTEM WITH N MODULES POWERED BY COMBINED SOLAR AND WIND POWER PLANTS

3.7.1 DESCRIPTION OF THE SYSTEM

Few works have been published about Reverse Osmosis Systems R.O.S. operate with constant pressure by solar or wind energy.

These works use batteries to maintain a constant pressure in case the Energy is less than requirement to the system or to store the Energy in case more than requirement.

The Batteries represent the main part in the system and big obstruction faces the wide application in arid areas of the world due to high part of cost and drain of money which increases the cost of the Productwater by this way.

Up to date all the modules start and stop together with constant pressure that means the need to many batteries to maintain operation of the system in case no enough energy from solar and wind so we can estimate the maximum capacity of Batteries with simple calculation as

Maximum capacity of Batt.=(Consumption Energy in One Module) x

(Numbers of Modules in the System).

also that depends on the policy of system's operation and demand of water.

Two programs was installed to simulate the two possible operations of design Fig. (3.1)
by one generate.

A - OPERATION WITH CONSTANT PRESSURE

In this operation the Modules operate one pressure Po so when the energy is enough to first Module will start in other words.

if $(P < Po)$ then the system not operate and there (Eab) not enough to operate one module and it is less energy of module (Em) where the energy needed to start (ELs) where

$Em = Eab + ELs$ and

if $(Eab= 0)$ then $(Em = Els)$ that means no solar or wind energy so the energy that may be obtained is $(Eab<Em)$ Or $(Eab=0)$ and the energy that may be needed is

$ELs = Em - Eab$

if $(Eat = 0)$ then $(ELs = Em)$

The System will operate under the pressure control as the following *if* $(P < Po)$ then the energy not enough to operation

if $(P >= Po \ \& \ P< 2Po)$ then one Module operates

if $(P > 2Po \ \& \ P< 3Po)$ then two Modules operate The system may be controlled by the general condition

if $(P > Npo \ \& \ P< (N-1(Po))$ then N Modules operate The maximum energy (Eab) that may be stored is less than (Em) and

the maximum energy (ELs) that may be needed is equal to (Em) if one or N Modules operate so the capacity of the Batteries is minimized to be Less or Equal (Em) the energy of One module

B - OPERATION WITH VARIABLE PRESSURE

In this operation the Modules operate one by one with variable pressure $(Pmax \ \& \ Pmin)$ where

$(P <= Pmax \ \& \ P >= Pmin)$

so when the energy is enough to generate Prnin then the first Module will start in other words

if $(P < Pmin)$ then the system not operate and there is energy (Eab) not enough to operate one module and it is less than the energy of module $(Emin)$ where the energy needed to start one module (ELs) where

$Emin = Eab + ELs$ and

if $(Eab = 0)$ *then* $(Emin = Els)$.

that means no solar or wind energy so the energy that may be obtained is

$(Eab<Emin)$ *Or* $(Eab=0)$.

and the energy that may be needed is

$ELs = Emin - Eab$

$(ELs = Emin)$ *if* $(Eab = 0)$

The System will operate under the pressure control as the following

if $(P < Prnin)$ *then* the energy not enough to operation

if $(P >= Pmin \ \& \ P < Pmax)$ *then* one Module operates

if $(P > Pmax \ \& < Pmax+Pmin)$ *then* one Module operates

if $(P >= Pmax+Pmin \ \& \ P <= 2Pmax)$ *then* two Modules operate

if $(P > 2Pmax \ \& \ P < 2Pmax+Pmin)$ *then* two Modules operate

The system may be controlled by the general condittion

if $(P >= (N-1)Pmax+Pmin \ \& < (N)Pmax)$ *then* N Modules operate

The maximum energy (Eab) that may be stored is less than $(Emin)$ and the maximum energy (ELs) that may be needed is equal to $(Emin)$ if one or N Modules operate so the capacity of the Batteries is minimized to be Less or Equal $(Emin)$ the required energy to start one module

3.7.2 SIMULATION RESULTS

In this simulation was supposed sea water of high salinity as a Feedwater and sunny windy region to provide the system with the solar and wind energy

Fig. (3.12) represents the relation between the energy and the number of Modules that operate in two designs so for same energy and time the numbers of Modules under operation when the system operates with variable pressure is less than the Modules in the system when operates with constant pressure and the difference in number of Modules increase if the energy increases as is shown in Fig. (3.12) where about 12 Modules will be under operation in design operates with constant pressure subtend to 1 Module operates at maximum state in other words

if $(P < Prnin)$ *then* No any Module operates in the two designs

if $(P > Pmin \ \& \ P < Po)$ *then* design with constant pressure not operates but 1 Module operates in the other design.

if $(P = Pmax)$ *then* 1 Module operates in variable option and 12 Module in constant option

Fig.(3.13) is shown the difference in number of Modules at the same time between the two designs where we can note that in variable option the system operates earlier than in constant option and at high energy we need huge numbers of Modules in constant option but in variable option few numbers of Modules is needed that means minimization about 12 times the basic cost if the system operates with variable pressure.

Fig. (3.14) represents the relation between the required energy ELs to operate one Module in the two designs where ELs in variable option is very small that means small capacity of battery need but in constant option ELs is equal to Em in other words.

$ELs = 0.8\ kwh$ in constant option but

$ELs = 0.044\ kwh$ in variable option

In the present Reverse Osmosis system combined with solar and wind energy the capacity of batteries for full operation is.

$ELs = N$ *(number of Modules in the system) x ELs (in constant opt.)*

that means huge number of batteries is needed in the present systems which leads to high cost of the productwater

Fig. (3.15) is shown the relation between Eab and time for the two designs where in variable option Eab is vary small where at maximum value

$Eab < Emin = 0.044\ kwh$ that means small battery is needed but in constant option

$Eab < ELs = 0.8\ kwh$ must be the capacity of battery

Fig. (3.16) is shown the Productwater in constant option is less than the productwater in variable option in the first 4 hours but at high energy the total productwater in constant option is more than the productwater in variable option &xt the Productwater per Module in variable option is much more than in constant option when the system operates at maximum state

In Fig.(3.17) the Rejectwater in constant option is more than in variable option

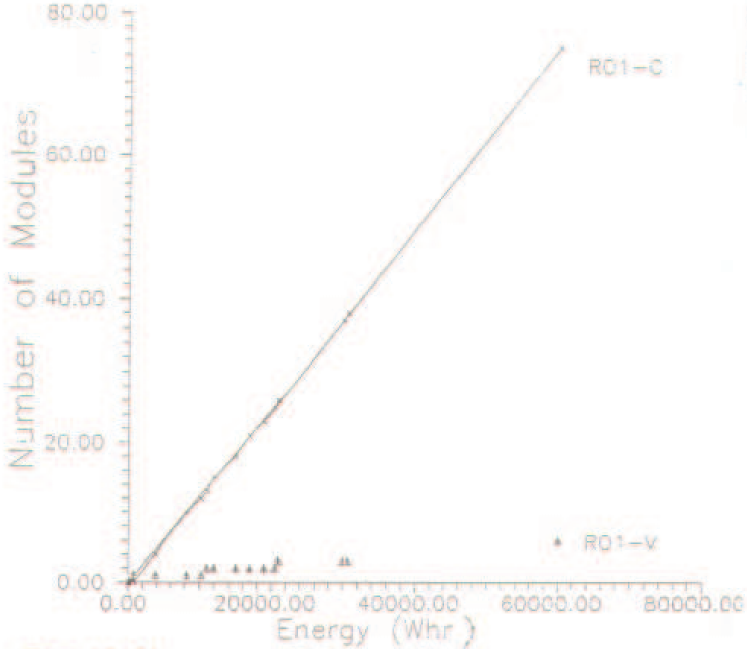


Fig.(3.9)

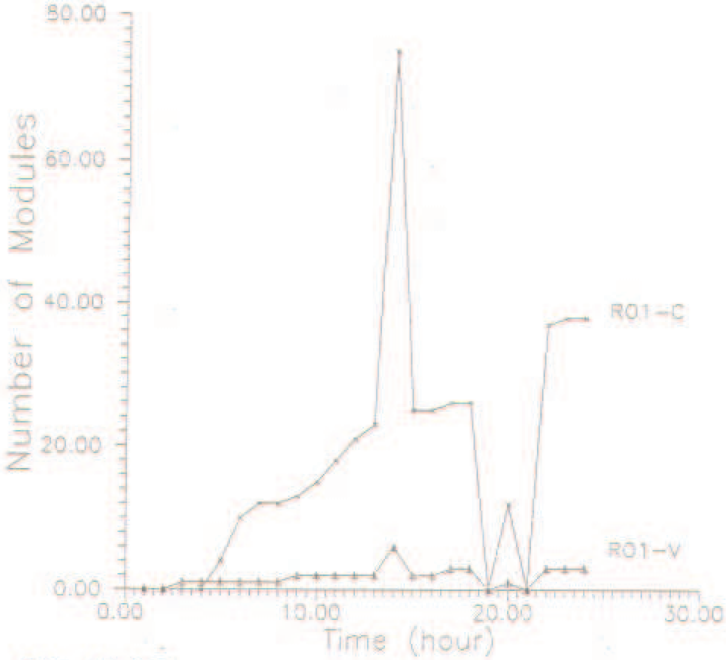


Fig.(3.10)

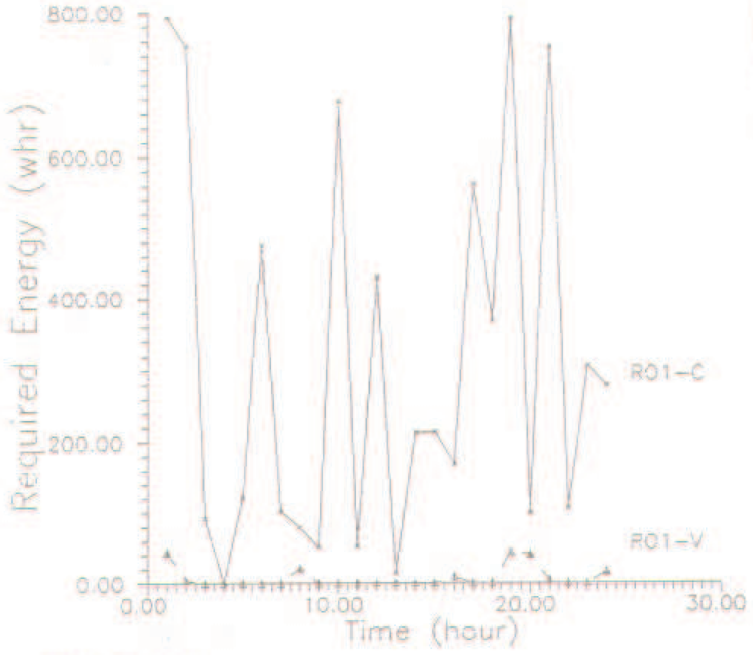


Fig.(3.11)

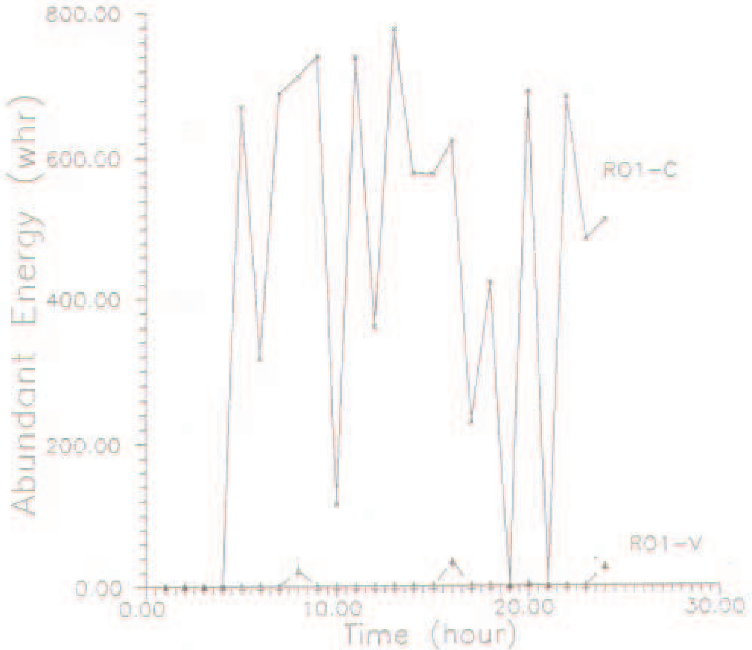


Fig.(3.12)

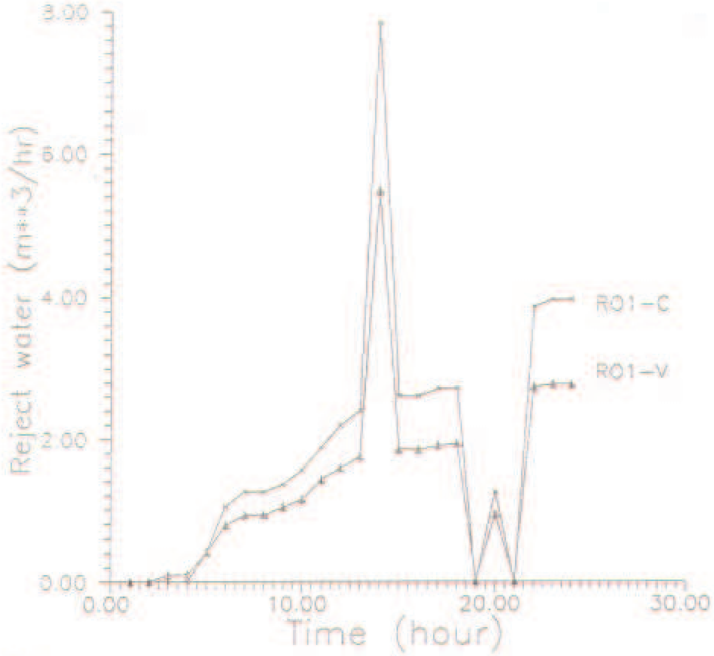


Fig.(3.13)

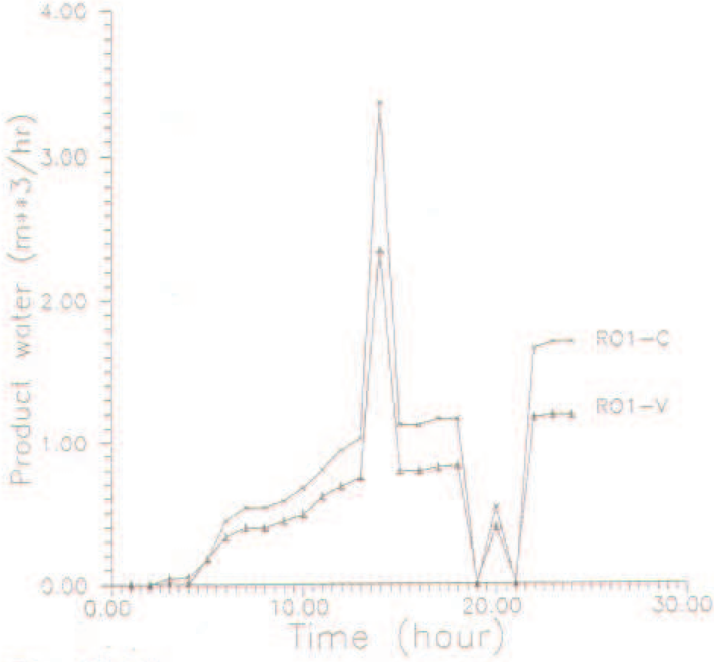


Fig.(3.14)

37.3 **DISCUSSOIN**

The following points are mentioned From this simulation

1- Variable option is more economic than constant option where less Modules are used and minimum energy is stored or required to start a module where it is possible to remove the battery from the system.

2- Huge numbers of Module is used in constant option and number of batteries to store the abundant energy.

3-Huge number of Batteries and Modules are used in the present systems where the Modules operate all together with constant pressure.

4-more attention must be paid to the control system to enhance the orientation forward wide applications of Reverse Osmosis System combined with solar and wind energy.

CHAPTER (4)

OPTIMIZATION OF THE DIMENSIONS OF WIND AND SOLAR SUBSYSTEMS

4.1 DISCRIPTI0N OF THE OPTIMIZATION PROBLEMS

The cost is one of the main criterions stand behind the decision of any application or development in fields of life , the decision is easy to be taken when one factor is affecting in the system , to light this point will discuss the problem of combined wind, solar and diesel power to operate reverse osmosis system.

When a region has limited potable water and is surrounded by saline water ,in addition to favorable solar ,wind energy or both where the conditions of combined desalination system with such energies are satisfied ,arise the problem of optimum sizes of the power subsystems such solar ,wind ,storage systems and fuel or main grid.

The works have been published about reverse osmosis system combined to wind and solar energy are classified as the following plants.

1-Reverse osmosis desalination system (wind energy)
2-Reverse osmosis desalination system (solar energy)
3-Reverse osmosis desalination system (wind energy,diesel ,main grid)
4-Reverse osmosis desalination system (solar energy,diesel ,main grid)
5-Reverse osmosis desalination system (wind energy,solar energy)
6-Reverse osmosis desalination system (wind energy,solar energy,diesel ,main grid)

In modes 1,2,5, the battery is necessary to maintain the operation of the system for days in case no energy from wind and solar [53,54,55,56,57,58,59].

Few papers concerned with the combined wind and solar power plant from view the technique of optimization [60,61,62].

No one say how the size of subsystems (wind ,solar)energy, battery are chosen to achieve the operation of the system with minimum cost for a requirement Load (Productwater).

In this work will be optimized two reverse osmosis desalination systems RO1, RO1RT with recovery turbine combined to solar ,wind ,batteries ,diesel systems see fig. (3.1)

To find the optimum sizes of wind machines ,of photovoltaic conversion system and the capacity of a battery storage system for a combined power plant with Reverse Osmosis System ,the minimization of the total life-cycle cost of the power plants systems is the criterion to obtain the optimum parameters of the system for requirement of productwater.

The total life-cycle cost is taken as yearly cost where is expressed as following

$$Z=(C1)(Aw)+(C2)(Av)+(C3)(Bmax)+(C4)(RLt) \qquad (4.1)$$

where

Z - The total cost per year of power plants *($)*

C1 - The cost of rotor swept area per m^2 *($/$m^2$)*

C2 - The cost of photovoltaic panels per m^2 *($/$m^2$)*

C3 - The cost of installed capacity per kwh *($/kwh)*

C4 - The cost of residual load per kwh *($/kwh)*

Aw - The rotor swept area *(*m^2*)*

Av - The area of photovoltaic panels *(*m^2*)*

Bmax- The maximum capacity of the battery *(kwh).*

RLt - The total residual load per year *(kwh).*

The residual load is an implicit function of the dimension parameters and its costs where we can write *RLt(Aw,Av,Bmax,C1,C2,C3,C4).*

4.2 NON LINEAR PROGRAMING

The total cost of power plants Z is function of Aw Av . Bmax. and which transcribe into nonlinear programming problems of the form

$$\min\left\{ f^{o}(z) \middle| f^{i}(z) \leq 0, 1 = 1, 2, ..., m, Rz - b = 0 \right\}$$

where $f^i : R^n \to R^1$ are convex function , R is a matrix , and b is a vector of appropriate dimensions

The function *(Z)* to be minimized under the operational constraints included in the simulation model the partial derivatives of *(Z)* relative to *(Aw , Av , Bmax)* when a combined system is designed for a sunny, windy regions ,will take the form

$$\frac{\partial Z}{\partial Aw} = \frac{\partial\left(C1 \times Aw\right)}{\partial Aw} + \frac{\partial\left(C4 \times RL\right)}{\partial Aw} \leq 0$$

$$\frac{\partial Z}{\partial Av} = \frac{\partial\left(C2 \times Av\right)}{\partial Av} + \frac{\partial\left(C4 \times RL\right)}{\partial Av} \leq 0$$

$$\frac{\partial Z}{\partial B\max} = \frac{\partial\left(C1 \times B\max\right)}{\partial B\max} + \frac{\partial\left(C4 \times RL\right)}{\partial B\max} \leq 0$$

where we know that

$$\frac{\partial\left(C1\times Aw\right)}{\partial Aw} > 0,\ldots\frac{\partial\left(C4\times RL\right)}{\partial Aw} \leq 0$$
$$\frac{\partial\left(C1\times Av\right)}{\partial Av} > 0,\ldots\frac{\partial\left(C4\times RL\right)}{\partial Av} \leq 0$$
$$\frac{\partial\left(C1\times B\max\right)}{\partial B\max} > 0,\ldots\frac{\partial\left(C4\times RL\right)}{\partial B\max} \leq 0$$

The partial derivatives of the residual load relative to size change in power subsystems will increase if sizes of power plants increase and tend to *0* ,when *Aw Av Bmax* becomes largerThe minimum of the total cost *Z* will achieve for the points *(Awo, Avo, Bmaxo)* if

$$\frac{\partial Z}{\partial Aw} = \frac{\partial Z}{\partial Av} = \frac{\partial Z}{\partial B\max} = 0$$

and the Hessian matrix of the objective function is always +ve definite where

$$\frac{\partial^2 Z}{\partial Aw^2} > 0,\ldots\frac{\partial^2 Z}{\partial Av^2} > 0,\ldots\frac{\partial^2 Z}{\partial B\max} > 0,$$

Steepest descent algorithm is one of the earliest algorithm to be used for function minimization.

The problem is considered as the form

$$\left\{f^{o}\left(z\right)\middle|z \in R^{n}\right\}$$

where $f^{o} : R^{n} \rightarrow R^{1}$ is at least once continuously differentiable The highly precise calculation of the derivatives of the function

and its value , may be quite costly in terms of computer time ,and one may therefor wish to avoid it for as long as possible in an iterative process for solving the problem

there are basically two types of algorithms for solving the problem which avoid or reduce the calculation of derivatives of the function

-The first type derives from methods such as steepest descent or Newton-Raphson ,and approximates derivatives with finite differences ,the precision of the approximation being progressively increased as one approaches a solution of the problem

-The second type is modified steepest descent algorithm that is conceptually independent of derivative calculations which avoid either partly or completely the calculation of derivatives of function

Second type was used to find the minimum cost of power plants combined to RO1 ,RO1RT systems and the optimal size of each power plant shares in the desalination system to produce the required of drink water

The outline of the algorithm is as the following

Notations: $X_j = (Aw, Av, B\max)_j$ at iteration j , $\Delta X = (\Delta Aw, \Delta Av, \Delta B\max)$

Data : $a_1 = 0.5, \ldots a_2 = 0.05, \ldots \varepsilon_o = 10, \ldots \beta_1 = 5, \ldots \beta_2 = 0.5, \ldots \gamma = 3.$

```
Step 0    :Set $J = 0, \ldots \varepsilon = \varepsilon_o$

Step 1    :Compute $h_j(\varepsilon, X_j) = -\frac{1}{\varepsilon}\left[Z\left(X_j + \varepsilon \cdot \Delta X\right) - Z\left(X_j\right)\right]$
Step 2    :Compute $\Delta(\varepsilon, X_j) = Z\left[X_j + \beta_1 \cdot \varepsilon \cdot h_j(\varepsilon, X_j)\right] - Z\left(X_j\right)$
              if $\Delta\left(\varepsilon, X_j\right) \geq 0$ then
                  $\varepsilon = \varepsilon / 2$
                  go to step1
              else
Step 3    :Set $\mu = \gamma$ and compute
Step 3.1  : $f\left(\mu, X_j, h_j\right) = Z\left[X_j + \mu \cdot h_j(\varepsilon, X_j)\right] - Z\left(X_j\right)$
Step 3.2  : $\Theta\left(\mu, X_j\right) = f\left(\mu, X_j, h_j\right) - \mu \cdot a_1\left[h_j\left(\varepsilon, X_j\right)\right]^2$
Step 3.3  :if ( $\Theta\left(\mu, X_j\right) \succ 0$ ) then
                  $\mu = \beta_2 \cdot \mu$
                  go to step 3.1
              else
                  $\lambda = \mu$
Step 4    :if ( $f\left(\lambda, X_j, h_j\right) \leq -a_2 \cdot \varepsilon$ ) then
                  $X_{j+1} = X_j + \lambda \cdot h_j(\varepsilon, X_j)$
                  $J = J + 1$
                  go to step 1
              else
                  $X^* = X_j$
                  Stop
```

4.3 OPTIMIZATION MODEL

The Load in the system mainly is used to operate the pumps in the system this Load is consumed to produce the Productwater

The strategic aim of the desalination system is to produce the requirement drink water and quality with minimum cost.

No problem when the system operate by diesel or main grids due to steady power supplied to the system but in case the system operates by solar or wind energy there is necessity to use the optimum size of subsystem shared in supplying power to achieve the Load with minimum cost

The equation (4.1) is used to compare the triplets *(Aw,Av,Bmax)* where for each triplets will generate a value of *RLt* this energy is supposed to be provided by diesel generator to achieve the Load in the Reverse Osmosis System to produce the required of productwater for each Load there is one triplets give a minimum

see chapter (3) for the operation of system and the possible operation each hour fig. (3.1)

The strategic aim of this work is to maintain the operation of the Reverse Osmosis System to produce the required of drink water

in the consumption's area with minimum cost of the subsystem shared in the power plants .to achieve this purpose a Simulation program was developed to optimize the subsystem's sizes combined in the power plants

The program consists of the following parts

1-main program depends on a gradient-type method with a finite differences of approximate derivatives and modification of steepest descent algorithm [63,64] with some conditions and suitable steps length calculation to increase the efficiency of program and keep the operation in logic calculation to find the optimal sizes of subsystem.

2-Simulation program for Reverse Osmosis System as subroutine to evaluate the Load in the system for the required of drink water hourly and yearly, to provided the main program with the required load

3-Simulation program for Wind Energy System as subroutine to evaluate the power each hour for one year attained from wind.

4-Simulation program for Solar Energy System as subroutine to evaluate the power each hour for one year attained from solar.

5-Simulation program for Battery System as subroutine to evaluate the state of energy and the current level of battery each hour and the Residual load hourly and yearly.

6-Simulation program for cost as subroutine to calculate the cost of the power plant per year where the minimum cost is the criterion to obtaining the optimum parameters of the system after finite iterations.

The data and parameters used in the simulation program are the real hourly data of the year 1982 for global solar radiation on horizontal surface and for wind speed of Kythnos Island in Greece.

The simulation program is run hour by hour for one year where relative minimum is found for the sizes of *(Aw,Av,Bmax,RLt)* each iteration and after a limited number of iterations the optimization technique allows the global minimum cost to be found for the optimal sizes of *(Aw,Av,Bmax,RLt).*

Second program was developed to check the global minimum and the optimum sizes of *(Aw,Av,Bmax,RLt)* where it depends on computational technique as main program and the programs mentioned in 2,3,4,5,6

For each parameter of the triplets *(Aw,Av,Bmax)* the program was run around the optimal value where the global minimum and the optimum values were verified.

The effect of Load also was simulated where Reverse Osmosis System with Recovery Turbine was verified.

4.4 APPLICATION

4.4.1 ONE STAGE REVERSE OSMOSIS SYSTEM WITHOUT RECOVERY TURBINE POWERED BY COMBINED SOLAR AND WIND ENERGY

The reverse osmosis system was supposed to produce 7.15 $\left(m^3/hr\right)$ human consumption from sea water with salinity *(36000 ppm)* and the recovery ratio *(Y=0.4)* . see the operation of one stage without recovery turbine chapter (2) , also see one stage reverse osmosis system with recovery turbine powered by combined solar and wind energy chapter (3).

4.4.2 ONE STAGE REVERSE OSMOSIS SYSTEM WITH RECOVERY TURBINE POWERED BY COMBINED SOLAR AND WIND ENERGY

see the operation of one stage with recovery turbine chapter (2) also see one stage reverse osmosis system with recovery turbine powered by combined solar and wind energy chapter (3).

To keeping the photovoltaic system in the power plant new costs was supposed to study the effect of the parameters on the optimum values where for each parameter the simulation program was run.

4.5 RESULTS

The figures (4.1-3) are seen the optimum values of *(Aw ,Av ,Bmax)* and the subtended minimum cost for RO1 reverse osmosis system without recovery turbine and RO1RT reverse osmosis system with recovery turbine due to the market cost.

Figures (4.4-6) show the optimal values of *(Aw ,Av , Bmax)* when Recovery Turbine connected to the system due prospective costs.

Table(4.1) Optimization results obtained from the simulation of two reverse osmosis systems one stage

RO1 & RO1RT with recovery turbine.

R.O.S.	*Aw (m^2)*	*(dAw) %*	*Av(m^2)*	*(dAv)%*	*Bmax(Kwh)*	*(dBmax)*	*Z(\$)*	*(dZ)%*
RO1	861		0.0		2752		770900	
RO1RT	640	-25.6	0.0	0.0	2040	-25.8	571200	-25.9

C1= 350 (\$/m^2),C2= 200 (\$/m^2),C3= 70 (\$/kwh) ,C4= 3 (\$/kwh)

The recovery turbine improved the system where decreased the optimal values and the cost about 26% table(4.1)

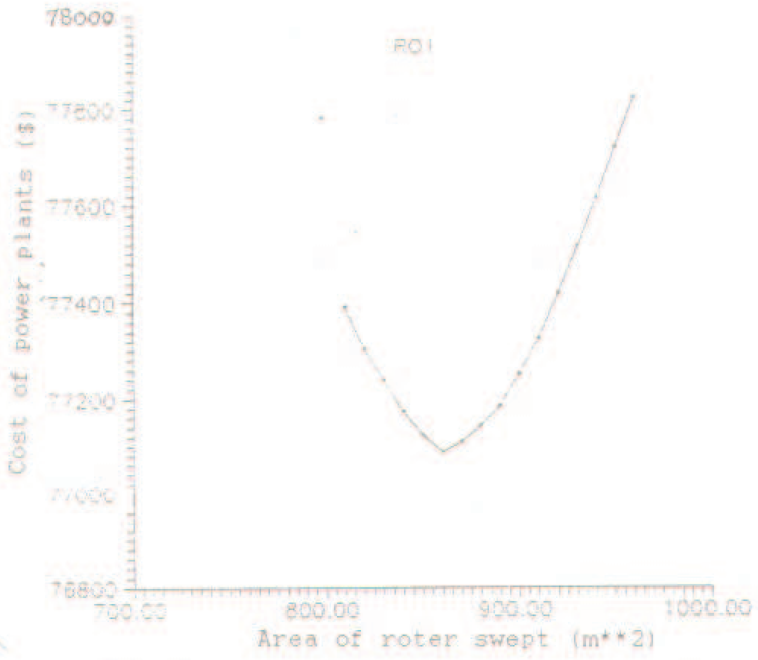

RO1
Cost of power plants ($)
78000
77800
77600
77400
77200
77000
76800
700.00
800.00
900.00
1000.00
Area of roter swept (m**2)

Fig.(4.1)

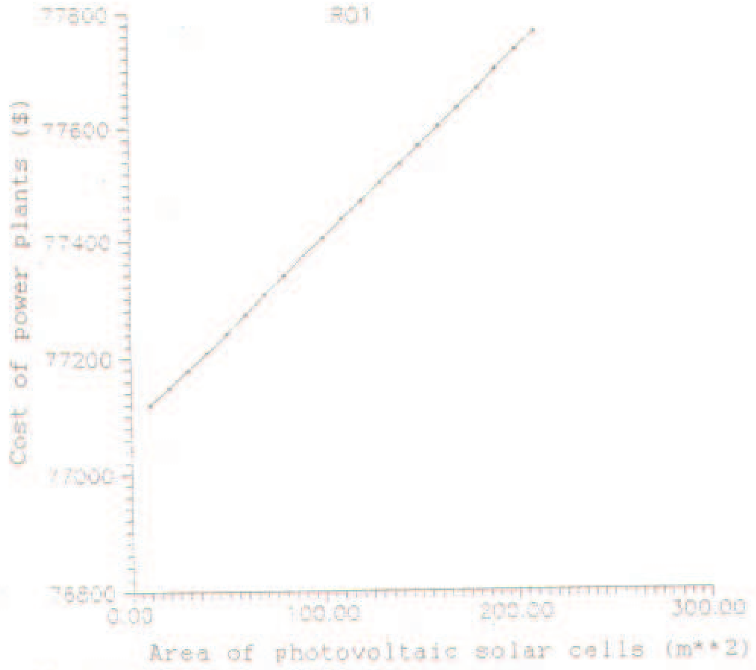

RO1
Cost of power plants ($)
77800
77600
77400
77200
77000
76800
0.00
100.00
200.00
300.00
Area of photovoltaic solar cells (m**2)

Fig.(4.2)

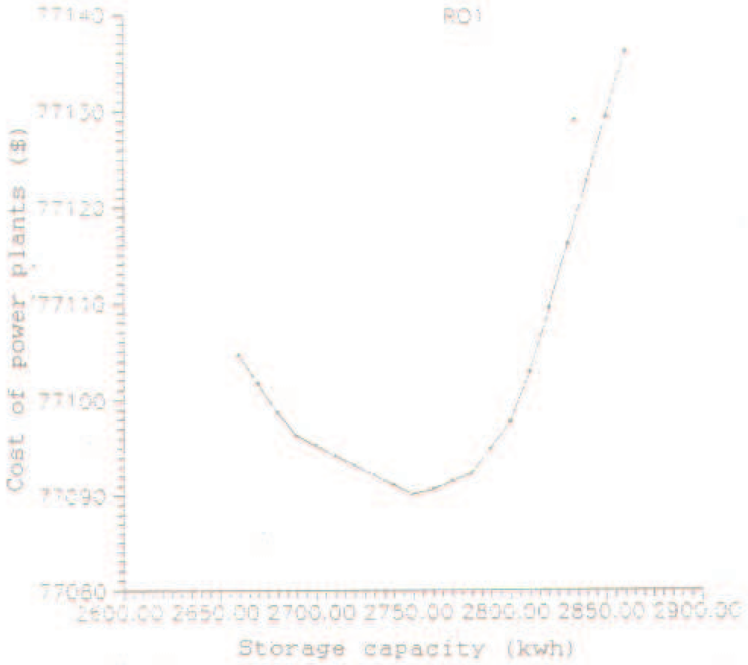

RO1
77140
77130
77120
77110
77100
77090
77080
Cost of power plants ($)
2600.00
2650.00
2700.00
2750.00
2800.00
2850.00
2900.00
Storage capacity (kwh)

Fig.(4.3)

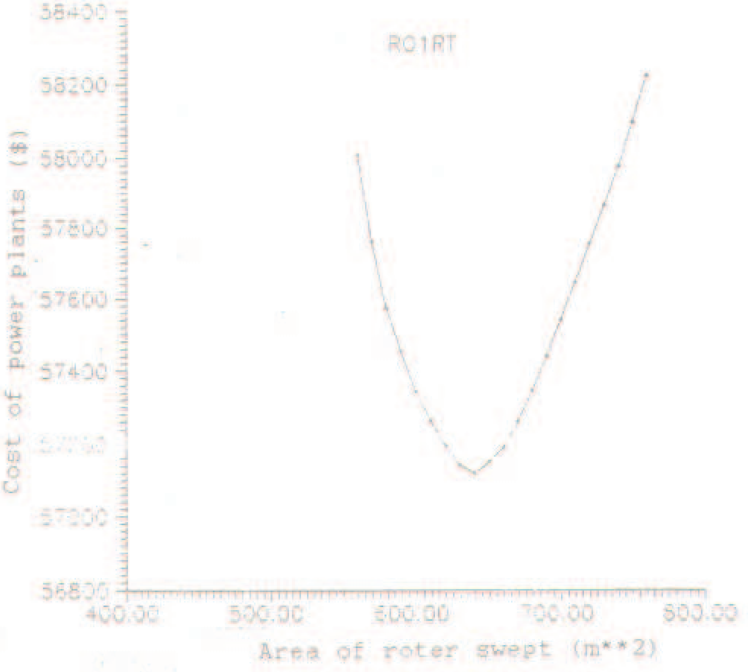

RO1RT
58400
58200
58000
57800
57600
57400
57200
57000
56800
Cost of power plants ($)
400.00
500.00
600.00
700.00
800.00
Area of roter swept (m**2)

Fig.(4.4)

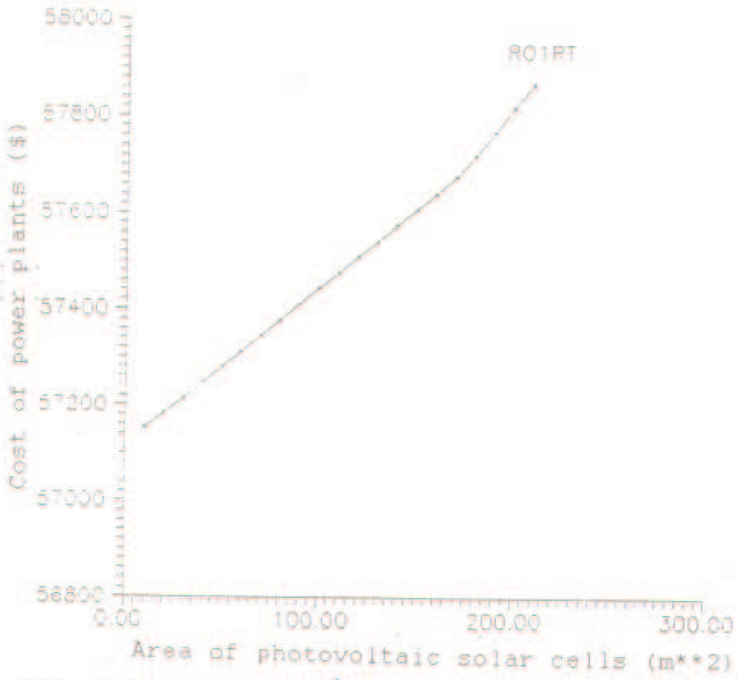

R01RT
Cost of power plants ($)
58000
57800
57600
57400
57200
57000
56800
0.00
100.00
200.00
300.00
Area of photovoltaic solar cells (m**2)

Fig.(4.5)

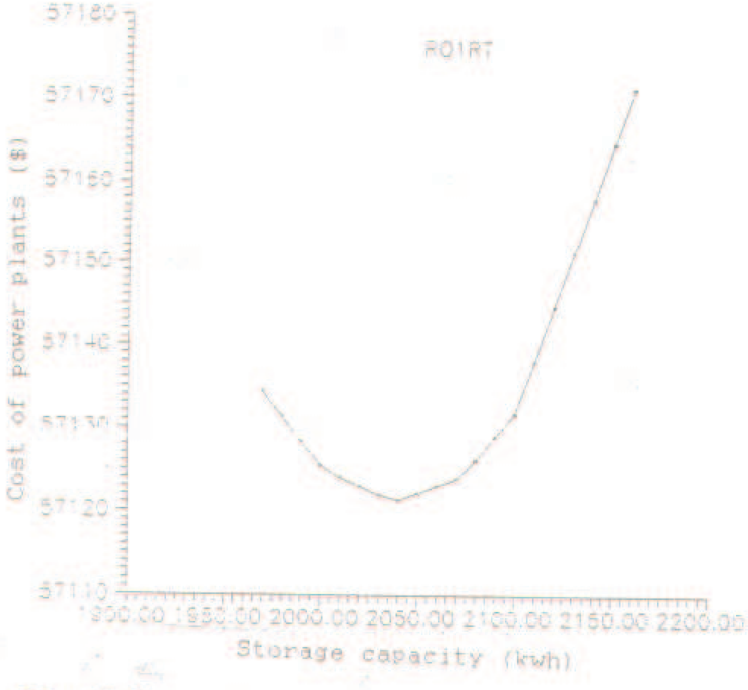

R01RT
Cost of power plants ($)
57180
57170
57160
57150
57140
57130
57120
57110
1900.00
1950.00
2000.00
2050.00
2100.00
2150.00
2200.00
Storage capacity (kwh)

Fig.(4.6)

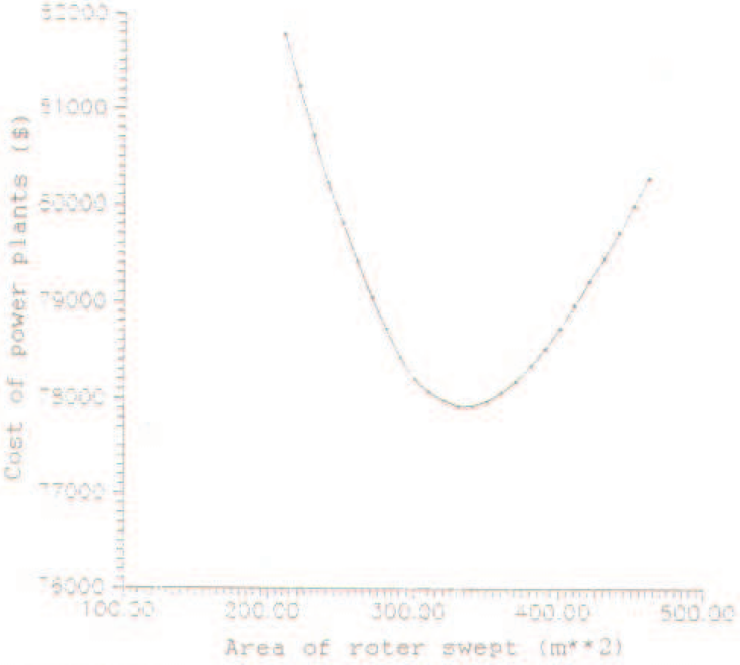

82000
81000
80000
79000
78000
77000
76000
Cost of power plants ($)
100.00
200.00
300.00
400.00
500.00
Area of roter swept (m**2)

Fig.(4.7)

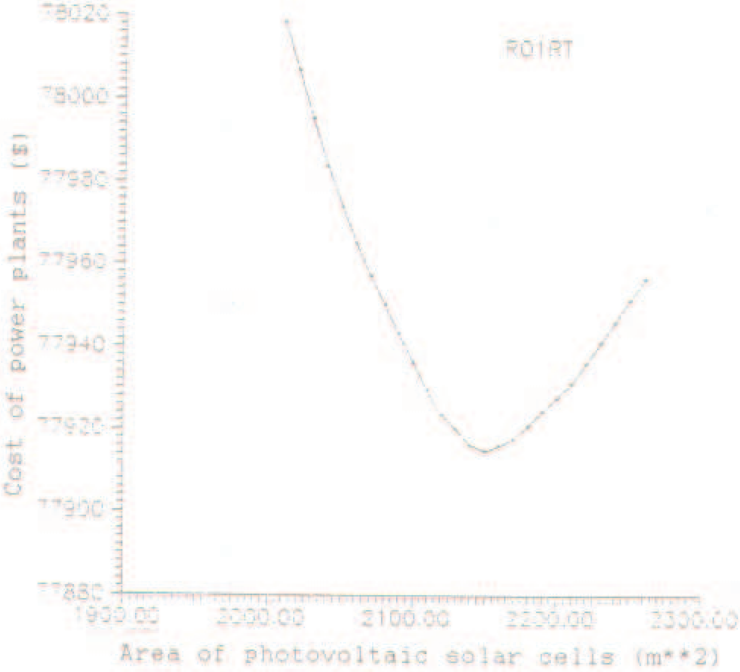

78020
78000
77980
77960
77940
77920
77900
77880
Cost of power plants ($)
R01RT
1900.00
2000.00
2100.00
2200.00
2300.00
Area of photovoltaic solar cells (m**2)

Fig.(4.8)

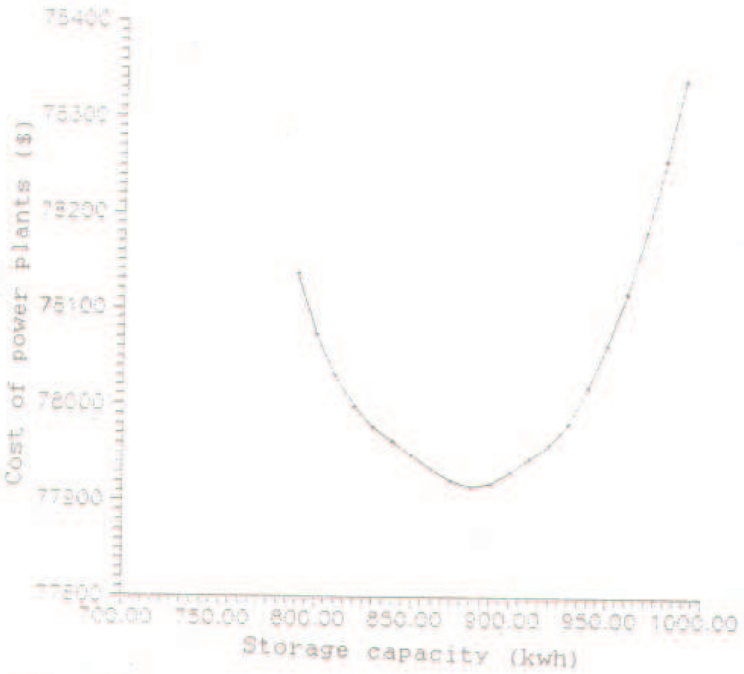

78400
78300
78200
78100
78000
77900
77800
Cost of power plants ($)
700.00
750.00
800.00
850.00
900.00
950.00
1000.00
Storage capacity (kwh)

Fig.(4.9)

4.6 SENSITIVITY ANALYSES

To study the effect of each parameter on the performance of the system and on the optimal values of the parameters the optimization program was run for each parameter where *Cl ,C2 ,C3* were decreased 30% and *C4 ,WE(k,I),SEc(k,I)* increased 30%.

Table (4.2) is shown the results and the effect of each parameter on the optimization and costs ,where we can say there are interrelations among the parameters and the cost of the system is function of *(Cl ,C2 .C3 ,C4 ,WE(k.I) ,SEc(k,I))* ,also the optimum values are function of *(Cl ,C2 ,C3 ,C4,WE(k,I) ,SEc(k,I)).*

Table(4.2) Optimization results obtained from the simulation of the Reverse Osmosis System One Stage RO1RT with Recovery Turbine for the parameters *(C1,C2,C3,C4,SE,WE).*

R.O.S.	*Aw* (m^2)	*(dAw) %*	*Av*(m^2)	*(dAv)%*	*Bmax(Kwh)*	*(dBmax)*	*Z($)*	*(dZ)%*
RO1RT	333	0.0	2149	0.0	884	0.0	77915	0.0
C1-30%	387	+16.2	1969	-8.3	874	-1.1	72533	-6.9
C2-30%	300	-10.0	2778	+29.2	899	+1.7	70456	-9.6
C3-30%	335	+0.6	2188	+1.8	961	+8.7	72352	-7.1
C4+30%	332	-0.4	2474	+15	968	+9.5	83725	+7.5
SE+30%	293	-12	2143	-0.3	900	+1.8	72346	-7.1
WE+30%	283	-15	2143	-0.3	899	+1.7	73907	-5.1

Table(4.3) Optimization results of the yearly diesel consumption and yearly time operation of diesel generator ,obtained from the simulation of the Reverse Osmosis System One Stage RO1RT with Recovery Turbine for the parameters *(C1,C2,C3,C4,SE,WE).*

C1= 50 ($/m²),C2= 10 ($/m²),C3= 20 ($/kwh) ,C4=0.5 ($/kwh)

R.O.S.	*RLt(Kwh)*	*(dRLt) %*	*td(hr)*	*(dtd)%*
RO1RT	44133	0.0	1124	0.0
C1-30%	43638	+1.1	1111	-1.2
C2-30%	36026	-18.0	922	-18
C3-30%	40721	+7.7	1033	-8
C4+30%	35400	-19.8	894	-20.5
SE+30%	36579	-17.1	932	-17
WE+30%	40712	-7.7	1044	-7.1

4.7 Discussion

The photovoltaic system has removed from the power plant for the two designs of reverse osmosis systems. This result comes from the high cost of photovoltaic system relative to the other systems and the low of solar energy in the region.

The maximum effect was attained by decreasing the cost of photovoltaic system where global minimum was decreased by *(10%)* due to *(-30%)* in *(C2)* but when Solar Energy increased *(30%)* the global minimum cost decreased *(7%).*

Inspite of this save in diesel we found the global cost increased about *(7.5%)* as a result of increasing *(15%)* in *(Av)* and *(9.5%)* in *(Bmax)* to maintain the operation of the system with minimum cost.

The increasing in diesel price about 30% raised the global cost about *(7.5%).*

In general we can write as results the following

Z =f (C1 ,C2,C3,C4,WE(k,I) ,SEc(k,I)).

Aw=f (Cl ,C2,WE(k,I) ,SEc(k,I)).

where *(dAw)* is small about *(1%)* due to *(30%)* change in

Av=f(C3 ,C4 ,C4).

where *(dAv)* is less than *(2%)* and less than *(1%)* due to *(30%)* change in *(C3)* and solar ,wind energy in respectively.

Bmax=f(C3 ,C4)

where *(dBmax)* is less than *(2%)* due to *(30%)* change in remains parameters.

Table (4.3) shows the effect of parameters on the diesel consumption and operating time of diesel generator where low effect of *(C1)* and high effect of *(C4)* but the practical effect comes from the solar energy and price of photovoltaic where about *(18%)* of diesel or *(18%)* of generators time operation was saved.

4.8 GENERAL CONCLUSIONS -PROSPECTIVES

This work presents first the simulation results of the main Reverse Osmosis Desalination Systems in use

- One stage (RO1).
- One stage with recovery turbine (RO1RT).
- Two stages (RO2).
- Two stages with recovery turbine (RO2RT).

It also deals with two new designs proposed .These two designs are simulated according to the following models.

- One stage with module connected to the rejectwater (RO11).
- Two stages with module connected to the rejectwater (RO21).

where improvement in specific energy and productivity were achieved in addition to the rejectwater reduction compared to the system RO1, RO2, RO1RT, RO2RT.

The main conclusions obtained are

1. Significant quantity of energy can be saved by the use of recovery turbine in PO1RT, RO2PT compared to RO1 , RO2.
2. The use of second stage increases the consumption of energy in the system as in RO2 compared to RO1 and RO21 compared to RO11.
3. The system RO11 proved to be the one with less energy consumption, higher water productivity and rejectwater reduction.

As concern as the RO21 it presents similarly high productivity and reduction of rejectwater ,although the energy consumption increases comparing to the systems RO11 and RO1RT when the system operates at high pressure for sea and brackish water

The design RO11 proved the best compared to RO1RT, RO2RT, RO21 when feedwater is recycled ,where rejectwater was reduced to just (20%) in RO11.

Second this work presents the simulation results for reverse osmosis desalination systems powered by combined solar and wind power plants for the following cases

- One stage reverse osmosis system with recovery turbine.
- One stage reverse osmosis system with n modules under constant and variable pressure.

The conclusion obtained from this work are:

The system powered by solar energy is more stable than the one powered by wind energy

The combined use of solar and wind energy enhances the productivity reducing the diesel consumption.

The policy of operation and the size of the battery effects on the diesel consumption which is possible to be removed for special design where the power factor is (0.9) and the product water up to 108 (m^2/day).

The operation of the system with variable pressure is more economic than constant pressure as less modules are used and minimum energy is stored or required to start a module and it is possible to remove the battery from the system.

More attention must be paid to the control system to enhance the orientation forward wide applications of Reverse Osmosis System powered by combined with solar and wind energy.

The problem of determining the optimal size of the three components (Solar cells, Wind generator ,Battery) has been formulated for an autonomous system and for an integrated system with an auxiliary electricity generator such diesel units .In spite of the implicit nature of the criterion as a function of the sizes ,the computational technique is efficient and easy to use .It can be applied to any set of local data as help in conceiving a combined plant

The numerical values obtained in this work are relative to the kythnos for which the meteorological data were available .They should only be considered as an illustrative example since the evaluated cost values could not be accurately determined ,The difficulty of a priori cost/benefit analysis arises from the fact that the photovoltaic equipment has not yet been mass produced and that the two renewable energy production systems are still at an experimental level ABut the economic analysis is nevertheless a convenient way to the design of a coherent combined system.

The simulation program has proved that the minimum cost is attained when optimal values of active size of *(Aw ,Av ,Bmax)* and power from diesel or other source are used.

The steepest descent algorithm succeeded to give solution ,while the variations of the different parameters proved the sensibility of the method.

In case that the reverse osmosis system is powered only by wind energy ,the use of recovery turbine in reverse osmosis system reduced each of the optimal size of rotor swept battery and as result the cost about (26%).

The variation of optimum cost for variation of the sizes of subsystems around the optimum sizes was about (1%).

The efficiency of the subsystems as well as the parameters of reverse osmosis system affect on the optimum cost of the power plant.

The design RO11, RO21 is possible to be operated as two lines of productwater ,the productwater for drink from first stage in RO11 and second stage in RO21 ,while the productwater from the module connected to rejectwater to be used in other activities (cleaning ,irrigation) with acceptable salinity ,where drinking and cooking per person represents (10%) in development countries and (1%) in certain western countries from the water consumption.

Intelligent control is required to improve the operation of ROll R021 powered by combined solar and wind energy , when the rejectwater is recycled ,and operates with variable pressure.

These two designs need more study to find the best choice for two lines of productwater and the optimal choice in arid regions when the rejectwater is less than a fix tenths of (m^2/day), where it is obvious we enter into direct rivalry with the conventional solar stills ,not as solution of brine disposal only ,but as desalination system will add more productwater with low salinity less than (50 ppm).

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