Effect of Desalination Plant Performance on Water Cost in Dual-Purpose Plant for Production of Water and Electricity

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ABSTRACT

The cost of water produced by seawater desalination is the main factor affecting the usage of desalination technology, not only in Egypt but also in many other countries with limited resources of water. Researches are made to improve desalination technology were carried out to enhance the performance of the desalination plants and reducing its cost in order to attain minimum water cost produced. In arid regions dual purpose plants are built to provide both electricity for direct consumption and low-pressure steam that used as an energy source to the desalination plants. In this paper; a cost analysis study has been carried out to estimate the capital and running costs for desalination plants using steam generated from power plants as a source of energy through back pressure turbine. Energy cost allocation method is used to determine the cost of water produced. The effect of the desalination unit characteristics on the amount of water and electricity produced are discussed. Also the effect of changing both: Top Brine Temperature and Performance Ratio on energy cost, capital cost and fresh water cost produced as well as the electricity cost are investigated.

INTRODUCTION

The demand for water is usually associated with a similar demand for electricity, many co-generation plants were built to provide both products. From the thermodynamics and economic point of view, these co-generation plants are the more energy efficient means of fuel resource utilization. That is the reason for combining seawater desalination plant with power station in integrated co-production plants (dual purpose plant) in which high pressure steam is used to produce electricity and low pressure exhaust steam from the turbine serve as heat source for desalination process.

In the dual-purpose plant; how to allocate the total expenses of the plant between water and electricity produced is the major concept in the pricing these products.

It is difficult to have a single standard to determine the actual production cost of water and electricity and consequently provide a basis for pricing both of them, but there are many methods and procedures for cost allocation between water and electricity production.

In the present study, a cost allocation method based on energy prorating are presented and applied for typical dual-purpose plant comprising steam power plant and multi stage flash desalination unit at different design and operating conditions.

COSTING METHODS:

For a single plant dividing the production expenditure (capital. fuel, and operation and maintenance costs) by the annual production output can arrive at the unit cost.

In dual-purpose plant that have two final products, water and electricity, the unit cost estimate for each product is more difficult. There are several approaches used in the dual –purpose plants each yielding a unit cost for each product [1,2,3].

Cost allocation approach is one of these approaches in which the annual expenditure for the whole plant is allocated to both products. This approach can be split into two methods.

First the credit method. It consists in attributing to one of the products as a priori value and obtaining the cost of the other by difference.

Second the cost prorating method, consist in dividing the total production cost according to a given set of rules entailing in general a sharing of this benefit between the two products.

Various prorating methods are used for dividing the annual cost of dual-purpose plant between the two products, such as:

- Prorating in the basis of the total costs of single purpose alternative plant.
- Prorating in the basis of available energy or exergy.
- Prorating in the basis of power generated, this method is used in the present work to evaluate the water and electric unit cost, which are produced from dual-purpose plant.

POWER COST ALLOCATED METHOD

This method consist in breaking down the annual costs of the common sections of the dual-purpose plants is proportion to the amount of the actual electrical power delivered to the grid and the reduction of the amount of power which could have been generated by a power only station with the same power plant [4].

It is necessary, therefore, to establish the ratio of the grid power ***Pb*** produced by the dual-purpose plant to the grid power generated by the same steam plant in case of stand alone station ***Pc***. The proportion of the common cost items attributable to electricity is then given by the ratio

$$F_E = Pb/Pc.$$

The power consumed by the desalination unit is equal to:

$$Pd = Pc-Pb$$

Where ***Pd*** comprises the thermal energy delivered to desalination unit plus electrical power for auxiliary desalination equipment. The proportion of the common cost items attributable to water is then given by the ratio

$$F_W = Pd / Pc = (Pc-Pb) / Pc$$

COST OF WATER AND ELECTRICITY

In cost allocation method the capital and operating costs for each component are charged directly to the product produced by that component.

The turbine, condenser and generator expenses are allocated to the generation of electrical power since the main purpose of these components is to produce mechanical power or electricity.

The expenses of the desalination plant are allocated totally to the production of water.

Expenses of all other common components of the power plant, i.e., steam generator, dearator, feed water pump, and feed water heaters beside foundation, buildings, and laboratories are appointed between electricity and water according to the energy consumed by each product.

The total expenditure for the generation of electricity C_{ET} are arrived at by summing up the capital and operating costs C_E of the turbine and generator plus a portion of the total expenses C_C of the common component of the power system. This portion F_E is the ratio between the actual electricity provided to grid and the electricity supposed to be obtained when no desalination unit is exist (stand-alone power plant).

$$C_{ET} = C_E + F_E * C_C$$

Similarly the total expenditure to produce water C_{WT} are arrived at by summing up the cost of the desalination unit C_W, and it's share from the total expenses C_C of the common components .

$$C_{WT} = C_W + F_W * C_C$$

CONFIGURATIONS CONSIDERED

The flow diagram of the dual-purpose plant considered in this study with back pressure turbine mode is shown in Fig.1.

The nominal power of the steam power plant is 80 MW coupled with desalination units with water capacity ranging from 33,000 to 85,000 m^3/d, of a Multi Stage Flash (MSF) type according the desalination unit performance.

The steam is supplied to the turbine rated at 81.94 kg/s and throttle conditions of 60 bar, 485 ^0C. Four steam extraction points are provided in the back pressure turbine to supply steam to the feed water heaters, dearator and the desalination unit.

The dual-purpose plant is assumed to be base load for both electricity and water.

In the MSF unit the steam supplied into the brine heater to heat the brine to it's maximum temperature top brine temperature.

For allover the plant the state properties of the inlet and outlet streams that shown in Fig.1 such as temperature, pressure, enthalpy, entropy, and mass flow rate are determined.

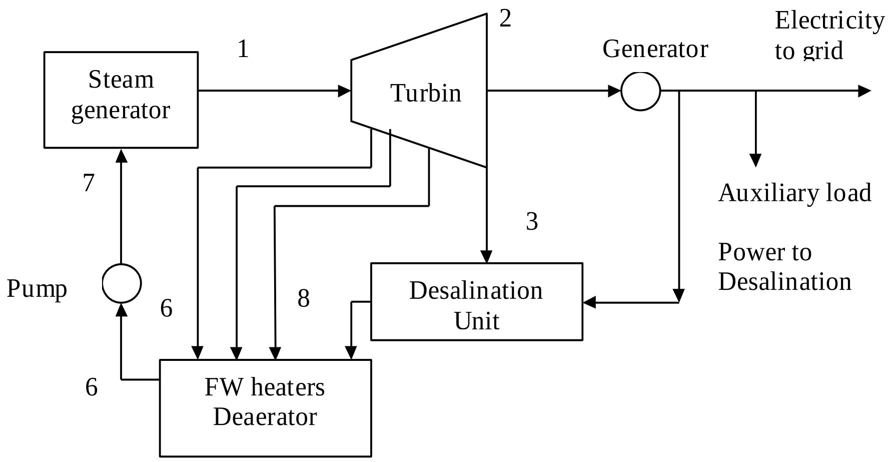


Fig. 1 schematic diagram of dual purpose plant with back pressure

Energy balance is carried out for boiler, back pressure turbine, desalination evaporator, preheater, and boiler feed pump in he following modes:

1. Stand-alone power plant.
2. Dual-purpose plant (power plant + Desalination unit).

For the MSF process different top brine temperature are studied 120^oC, 105 ^oC, 95^oC, 85 ^oC, and 75 ^oC, with different performance ratios ranging 5 to 12.

After allowing for pressure drop losses through the steam supply system and desalination plant inlet steam control valve, the temperature required for the back pressure turbine is estimated to be 124 ^oC, 109 ^oC, 99 ^oC, 89 ^oC, and 79 ^oC with its corresponding pressure [5].

CAPITAL AND RUNNING COSTS

Capital costs for power and desalination plants considered are based on recent tender prices for similar co-generation plants [6,7,8]

Capital cost of the power plant consists of:

1 Capital cost of power plant concern producing electricity

The specific capital cost for power plant (including turbine, condenser, and generator) is taken to be $ 600 /kW of the nominal power.

2. Cost of steam generator, feed water heater, dearator, pumps and common facilities such as foundation, buildings, laboratories …etc.

The specific cost of steam generator and common facilities such as foundation and buildings is taken o .35 Million $/MW.

Capital cost of the desalination plant consists of:

1. cost of desalination unit

Specific capital cost of (Capital cost per m^3) for a reference MSF unit (C_r) is considered to be 1800 $/$m^3$/d [9].

The capital cost is estimated from the following equation

Sp. Cost = F1* F2 C_r

Where

F1= Performance ratio correction factor = (PR/reference performance ratio)$^{.45}$

F2 = unit capacity factor

= 0.7 + 0.3[reference unit capacity/unit capacity]$^{1/2}$ [9]

Reference unit: capacity = 24000 m^3/d, performance ratio = 7.

2. The cost of seawater intake and outfall to the desalination plant is taken 300 $/$m^3$/d.

3. The cost of the backup heat source is 375$/$m^3$/d .

Annual amortization is calculated from the plant life time and discount rate as the inverse of the present worth equation;

$$Amortization = Total\,Capital\,\cos t \frac{r}{1+(1+r)^{-n}}$$

where n plant life times, y

r discount rate

The desalination and power plant capital and operating costs are based on the following operating conditions:-

Power plant load factor	85%
Desalination unit load factor	85%
Plant life time	20 Year
Discounts rate	10% p.a.

The running costs for power plant includes:

1 Variable operating and maintenance factor = 12.807$/kW/year

2 Fixed operating and maintenance factor = 8.69$/kW/year.

3 Fuel cost = 0.3 Million $/MW/year (based on 18$ per barrel).

The running costs for desalination unit includes:

1. The electrical power consumed by the desalination unit depends on its rated capacity, and performance ratio [9,10].
2. The operating and maintenance cost = 0.1725$m^3/d [8].

RESULTS AND DISCUSSION

The main technical parameters for the dual-purpose plant at different top brine temperature are listed in Table 1. The effects of the performance ratio on the technical parameters of the dual- purpose plant are listed in Table 2.

Table 1 Technical parameters for dual purpose plant for various **TBT**.

Desalination Plant				
Maximum Brine Temperature, ^{o}C.	120	105	95	75
Performance Ratio	12	12	12	12
LP steam flow to desalination unit, kg/s	80.49	79.56	78.26	75.79
Pressure, bar	1.8	1.433	1.013	0.047
Temperature, ^{o}C.	124	109	99	79
Thermal energy input to desalination, MW.	179	177	174	167
Desalination plant production, m3/d.	**83,456**	**82,487**	**81,139**	**78,586**
Power plant				
Thermal energy input, MW.	233	233	233	233
Steam flow to turbine, kg/s.	81.94	81.94	81.94	81.94
Pressure, bar	60	60	60	60
Temperature, ^{o}C.	485	485	485	485
Power from turbine with desalination unit, MW	54.23	56.67	59.62	67.05
Power lost by turbo generator, MW.	1.08	1.13	1.19	1.34
Power plant auxiliary load, MW.	2.658	2.78	2.92	3.29
Net electricity output, MW.	50.49	52.8	55.50	62.43
Power consumed by desalination process, MW	24.89	22.62	19.87	12.95
Elec. Power to desalination equipment, MW	11.47	11.34	11.16	10.81
Pd Total desalination power, MW	36.36	33.96	31.03	23.76

Pb	Power to grid, MW	39.02	41.42	44.35	51.62
Pc	Power form stand alone power Unit, MW	75.38	75.38	75.38	75.38
	F_E	.518	.550	.588	.685
	F_W	.482	.450	.412	.366

Table 2 Technical parameters for dual purpose plant for different **PR.**

Desalination Plant				
Maximum Brine Temperature, ^oC.	105	105	105	105
Performance Ratio	5	7	9	12
LP steam to desalination unit, kg/s	79.56	79.56	79.56	79.56
Pressure, bar	1.433	1.433	1.433	1.433
Temperature, ^oC.	109	109	109	109
Energy input to desalination, MW.	177	177	177	177
Desalination plant production, m3/d.	**34,369**	**48,117**	**61,865**	**82,487**
Power Plant				
Power from turbine, MW	56.67	56.67	56.67	56.67
Power lost by turbo generator, MW	1.13	1.13	1.13	1.13
Power plant auxiliary load, MW.	2.777	2.777	2.777	2.777
Net electricity output, MW.	52.76	52.76	52.76	52.76
Power consumed by desalination process, MW	22.62	22.62	22.62	22.62
Electrical power to desalination auxiliaries, MW.	6.02	7.82	9.28	11.34
Pd Total desalination power, MW	28.64	30.44	31.90	33.96
Pb Power to grid, MW.	46.75	44.94	43.48	41.42
Pc Power for stand alone power Unit, MW	75.38	75.38	75.38	75.38
F_E	.620	.596	.577	.549
F_W	.379	.404	.423	.451

As shown from Table 1 increasing the top brine temperature increasing the water production and consequently the power to the grid is decreased. But for the same top brine temperature it is shown from Table 2 that increasing the performance ratio increases water production with a slight decrease in the power delivered to the grid due to increasing the electrical power for auxiliary system.

The effect of performance ratio on water production and electricity delivered to the grid is shown in Fig. 2.

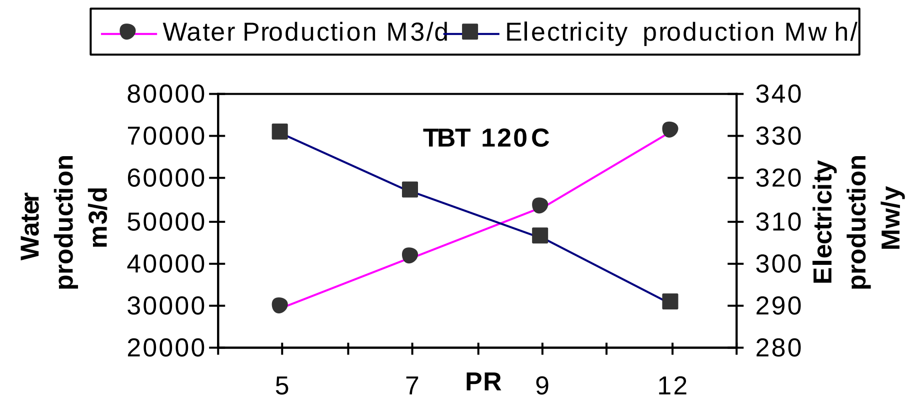


Fig. 2 Effect of PR on water & electricity production.

It is obvious that increasing the performance ratio results in increasing the water production and decreasing the electrical to the grid.

Fig. 3 shows the effect of top brine temperature on water production and electricity delivered to the grid.

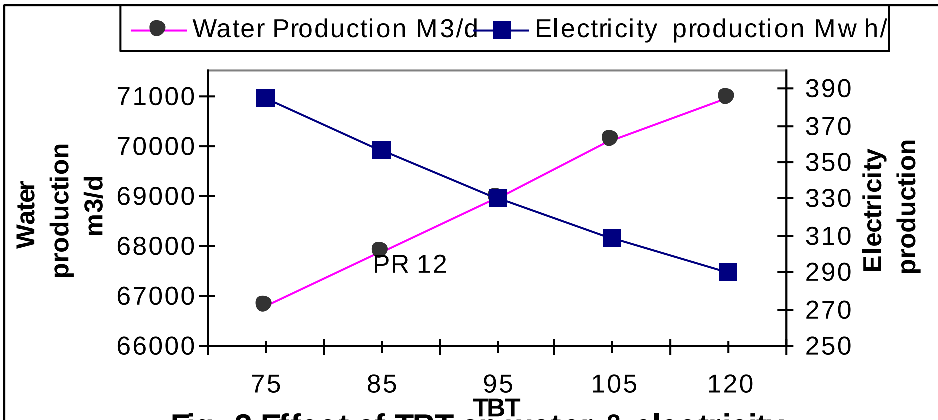


Fig. 3 Effect of TBT on water & electricity production

It is clear from Fig.4 that the increase in water production due to the variation in performance ratio is more significant than the variation of top brine temperature.

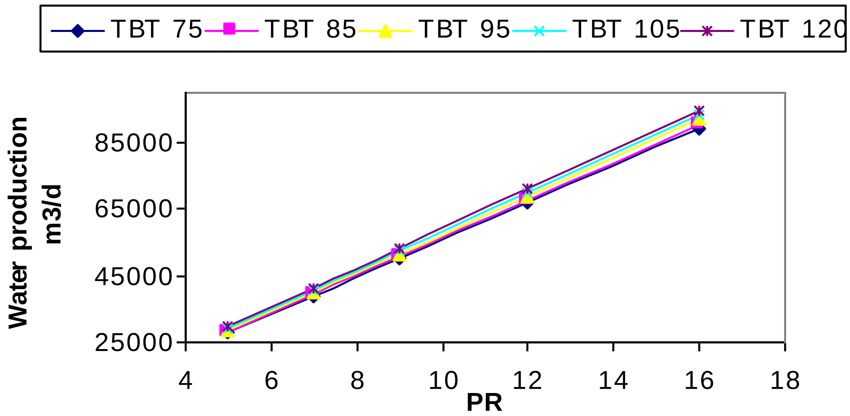
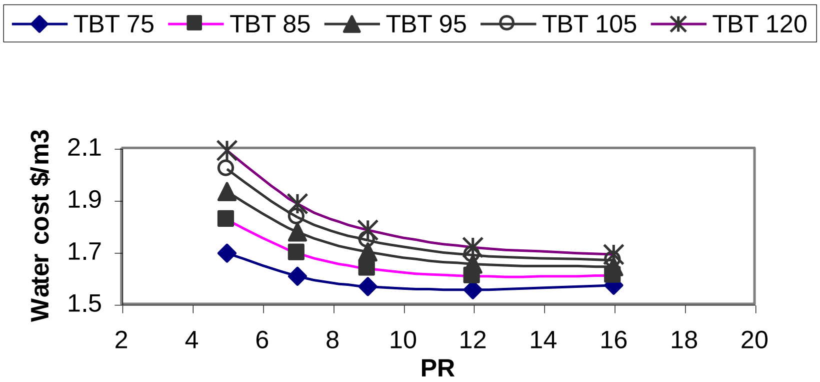


Fig .4 Effect of PR on water production.

The capital and running cost for different top brine temperature and performance ratio are listed in Table 3

Table 3 Capital & Running costs of dual purpose plants

Power Plant			
Turbine, generator & condenser cost, million $		48	
C_E Levelized capital cost, million $/Y		**5.63**	
Variable O & M cost, million $/Y		1.02	
Fixed O & M cost, million $/Y		0.69	
Energy cost, million $/Y		24	
Steam generator with common facilities million $/Y		3.28	
Cc		**29.01**	
Desalination unit			
TBT	120	120	95
PR	12	9	9
Unit capital cost, million $	164	111.7	105.9
Seawater intake & out fall, million $	25	18.78	17.68
Backup heat source, million $	31	23.4	22.10
Capital cost Amortization, million $/Y	25.97	18.07	17.57
O & M cost, million $/Y	4.47	3.36	3.25
Cw	**30.44**	**21.43**	**20.82**
Water production m3/d	**83,450**	**62,587**	**60,634**
Electricity production MW	**39**	**41.1**	**46.31**
Total Expenses for producing electricity, million $/Y	20.65	21.46	26.26
Electricity Cost, $/kW hr	**0.071**	**0.07**	**0.066**
Total Expenses for producing water, million $/Y	44.43	34.63	28.65
Water cost, $/m3	**1.71**	**1.783**	**1.57**



Fig, 5 Effect of PR on water cost.

Fig.5 and Fig.6 show the effect of performance ratio and top brine temperature on water cost respectively. The optimum performance ratio for minimum water cost is around 10-12, where the water cost may reach as minimum as 1.55 $\$/m^3$, and as shown in Fig.6, increasing top brine temperature increases the water cost.

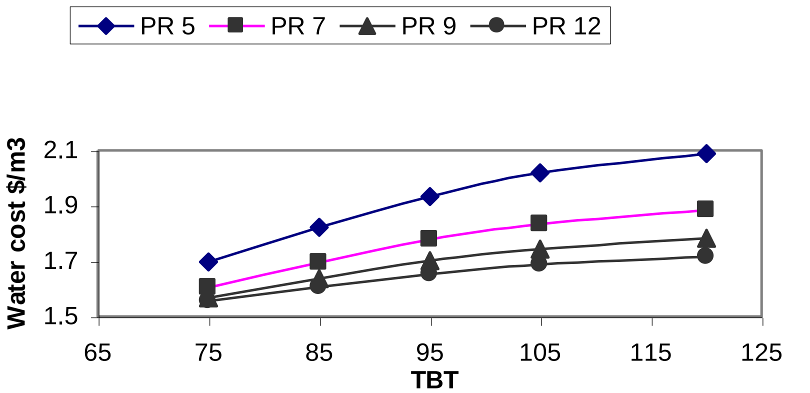


Fig. 6 Effect of TBT on water cost

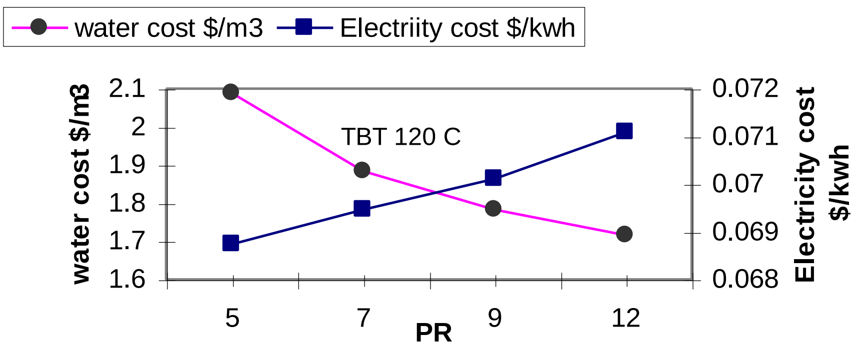


Fig. 7 Effect of PR on water & electricity cost

The effect of top brine temperature and performance ratio on electricity cost is shown in Fig. 7 and 8, as performance ratio increases from 5 to 12 the water cost decreases from 2 to 1.5 $\$/m^3$ while electricity cost increases from 6.5

to 7.1 cent, as increasing top brine temperature results increasing in water and electricity costs.

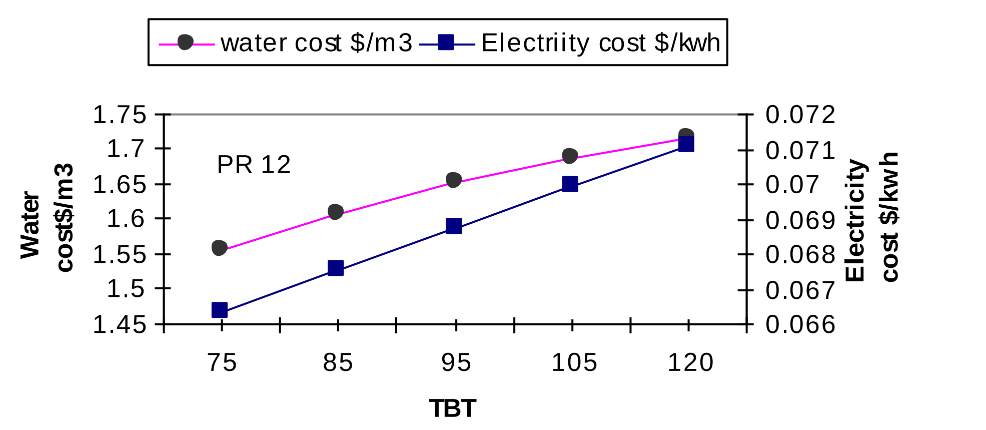


Fig .8 Effect of TBT on water and electricity cost.

Fig. 9 is a break down water cost, it is clear that increasing the performance ratio increases the capital cost on the other hand decreasing the energy costs. In this figure the energy cost includes the heat energy delivered to desalination unit plus electricity for auxiliary of the desalination plant.

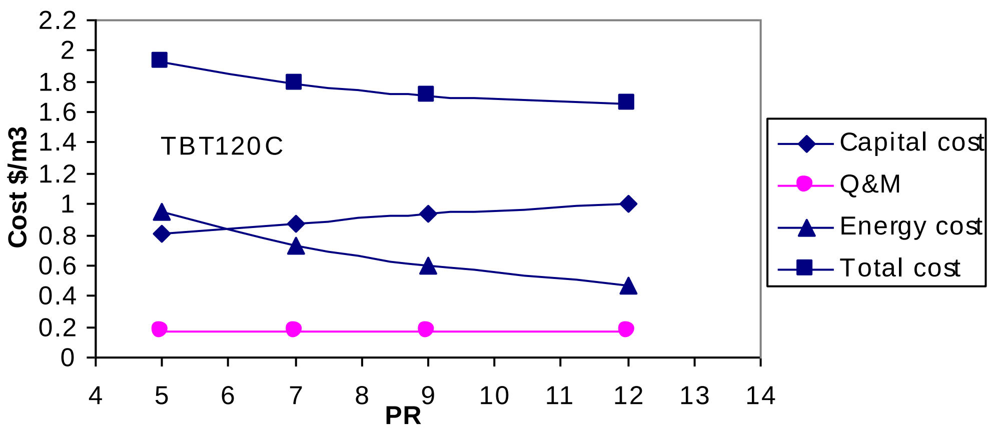


Fig .9 Effect of PR on the break dowen water cost

It is observed that the capital and energy costs represent the major fraction of the water cost around 40% for each operating and maintenance cost may reach 10-20% of the water cost.

In general the specific water from a duel purpose plant ranging from 1.55 to 2$ per m^3 according to the plant performance ratio and top brine temperature.

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