Utilization of exhaust waste heat from power plants for sea water desalination

Ghanim Kadhem Sada**
Mechanical Engineering Department
University of Al Mustansiriya
Baghdad - IRAQ
Ghanimkadhim@yahoo.com

Lina Ismail Jassim
Mechanical Engineering Department
University of Al Mustansiriya
Baghdad - IRAQ
linajassim@yahoo.com

Abstract

The international demand of water increased compared to the available water resources due torecent development water resources for different uses. In many areas especially in Arabian Gulf Areas, a shortage of portable water. This study deals with design a model to combine the multi effect desalination water (MED) with the steam power plant. Using the exhaust waste heat of the power plant to heat the sea water. The model has been based upon various heat and mass transfer equations. Taking in consideration all requirements of making available safe drinking water for requirement. The waste heat of the exhaust gases of power plant is captured before exhausting it to the atmosphere and transferred to salty water. The temperature of salty water rise to level 90C to130C. This is ideal temperature for desalination in multiple effect distillation MED plant. The hot salty water then passes through a flash into the evaporator then condenses on the condenser tube bank, and internal heat recovery is achieved by transferring its heat of condensation to the sea water feed that is thus being preheated.

In this study selective an exist steam power plants, combine with MED to produce 1000 m^3/day to15000 m^3/day drinking water from salty water.

The cost of combine MED desalination with power plant was compared with the exist desalination methods, the study show that this system less cost than the other methods of desalination.

The model is useful in sizing various components, power plant chimney heat exchanger, evaporation and condensation chambers of desalination plant and useful to find out plant output for various combinations of design parameters. The basic motivation for this research and development is to propose a choice of technical options, based on the use of power plant energy, which could be sustainable and at same time economically. The lowest costs with the multi effect desalination (MED) plants are obtained by utilizing virtually free waste heat of power plant.

Key worlds: *Steam power plant, Waste heat utilization, low cost desalination, MED system*

**** Corresponding author**

الخلاصــــــة

نتيجة لشحة المياه الصالحة للشرب في منطقة الشرق الاوسط وخاصة منطقة الخليج العربي. تضمن هذا البحث تصميم نموذج لتقطير مياه البحر المالحة للحصول على ماء صالح للشرب باستخدام الحرارة المطروحة من محطات الطاقة الكهربائية لتسخين المياه المالحة، وهذا النموذج يشمل تصميم مجموعة مبادلات حرارية اللازمة لعملية التقطير تتكون المنظومة من مدخنة محطة الطاقة الكهربائية والمبخر والمقطر ومجمعين للملح والماء المقطر، علما ان هذه المنظومة تنتج ما يقارب ١٠٠٠ متر مكعب الى ١٥٠٠٠ متر مكعب ماء صالح للشرب. وتعتبر تلك طريقة اقتصادية للحصول على ماء الشرب مقارنة بتكلفة محطات تحلية المياه.

1. Introduction

Water desalination is a process that separates water from a saline water solution. The natural water cycle is the best and most prevalent example of water desalination. Ocean waters evaporate due to solar heating and atmospheric influences; the vapor consisting mostly of fresh water (because of the negligible volatility of the salts at these temperatures) rises buoyantly and condenses into clouds in the cooler atmospheric regions, is transported across the sky by cloud motion, and is eventually deposited back on the earth surface as fresh water rain, snow, and hail. The global freshwater supply from this natural cycle is ample, but many regions on Earth do not receive an adequate share. Population growth, rapidly increasing demand for fresh water, and increasing contamination of the available natural fresh water resources render water desalination increasingly attractive. Water desalination has grown over the last four decades to an output of about 20 million m^3 of fresh water per day, by about 10,000 sizeable land-based water desalination plants.

Many ways are available for separating water from a saline water solution. The oldest and still prevalent desalination process is distillation. The evaporation of the solution is effected by the addition of heat or by lowering of its vapor pressure, and condensation of these vapors on a cold surface produces fresh water. The three dominant distillation processes are multistage flash (MSF), multieffect (ME), and vapor compression (VC). Until the early 1980s the MSF process was prevalent for desalination. Now membrane processes, especially reverse osmosis (RO), are economical enough to have taken about one third of the market. In all membrane processes separation occurs due to the selective nature of the permeability of a membrane, which permits, under the influence of an external driving force, the passage of either water or salt ions but not of both. The driving force may be pressure (as in RO), electric potential (as in electro dialysis, ED), or heat (as in membrane distillation, MD). A process used for low-salinity solutions is the well-known ion exchange (IE), in which salt ions are preferentially adsorbed onto a material that has the required selective adsorption property and thus reduce the salinity of the water in the solution [1].

Corrado [2] used waste heat steam from different process steam in power plant where MSF/MED plants performance ratio and production were optimized.

Kamali and mohebinia [3] used parametric optimization method to increase GOR value of MED-TVC systems. The program is used to provide engineers a cost effective tools for designing, developing and optimizing the thermal desalination plants.

Our study deals with the design a model to combine the multi effect desalination water (MED) with the steam power plant. Utilizing the exhaust waste heat of the steam power plant to heat the sea water. The model is included the design parameters of heat exchanger in chimney of power plant, evaporator and condenser. A primary objective in the Heat Exchanger Design (HED) is the estimation of the minimum heat transfer area required for a given heat duty.

The cost of desalted water is comprised of the capital cost of the plant, the cost of the energy needed for the process, and the cost of operation and maintenance staff and supplies. In large seawater desalination plants the cost of water is about $1.4 to $2/m, dropping to less than $1/m for desalting brackish water.

A methodology for assessing the economic viability of desalination in comparison with other water supply methods is described by Kasper and Lior [4]. Desalination plants are relatively simple to operate, and progress toward advanced controls and automation is gradually reducing operation expenses.

The useful of waste heat of exhaust gases of power plant to heat the salt water by heat exchanger at the chimney is presented. This hot water passing through evaporator which exposed to under vacuum to get vapor at saturated temperature, at this low pressure the salt separates from water. This vapor condensate when it contacts the vertical banks tubes at temperature less than vapor saturated temperature. This condensate vapor flows down the tubes under the action of gravity. The presence of a liquid film over the tubes drains down to get drinking water. This system produces 1000 m^3/day to 15000 m^3/day drinking water from salty water.

The relative effect of the cost of the energy on the cost of the fresh water produced depends on local conditions, and is up to one half of the total.

2. Desalination system

The multi effect desalination system was coupled to the chimney of the power plant, is shown in Fig.1. The sea water is pumped to condenser, at condenser the salty water is preheated by internal heat recovery from condensation. The water vapor during Passage through a vertical tubes bank, which arranged in a staggered, the temperature of salt water inside condenser is increased, and after that goes to the chimney of steam power plant, at chimney the hot gases passing through a series of bank tubes heat exchanger. The waste heat of the exhaust gases is captured before exhausting it to the atmosphere and transferred to incoming salty water to rise its temperature to 100 C, and then the hot salty water evaporated at low pressure in a flush evaporation chamber, so the evaporation process is used to separate the salt from hot water. The salt then collects in a tank, and the vapor passing over vertical tubes bank condenser to condensate out side the tubes bank. This desalination system (MED) coupled to steam power plant could be produces about 1000 m^3 /day to 15000 m^3 / day.

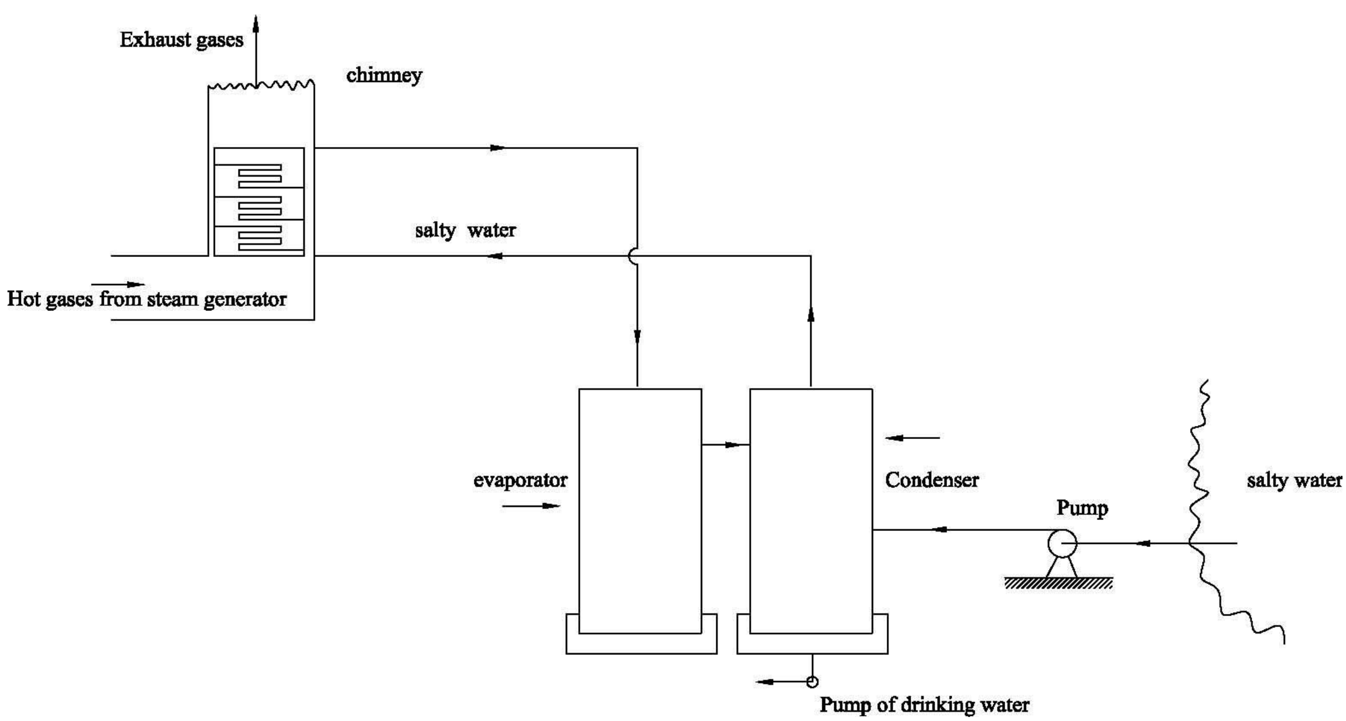


Fig. 1. Schematic diagram of The Multi effect desalination system (MED) coupled to steam power plant.

3. Mathematical model

3-1 Heat exchanger in chimney

To design heat exchanger of tubular type which arranged in staggered arrangement, there are some parameters should be calculated such as tube size (diameter and length), number of tubes. All these parameters are based on computing the heat exchange surface area through the mean logarithm temperature difference approach.
The heat reject from hot gas in chimney of steam power plant is given as:

$$Q = \dot{m}_g . C_{Pg} . (T_{gin} - T_{gout}) \qquad (1)$$

The heat gain by salty water is given as:

$$Q = \dot{m}_{sw} . C_{Pw} . (T_{w2} - T_{w1}) \qquad (2)$$

So the heat surface area of Heat Exchanger is given as:

$$A_s = \frac{Q}{U.LMTD.f} \qquad (3)$$

The overall heat transfer coefficient is computed through the following equations.

$$U = \frac{1}{\frac{1}{h_o A_o} + \frac{\ln\left(r_o / r_i\right)}{2\pi.K.l} + \frac{1}{h_i A_i}} \qquad (4)$$

The tube side heat transfer coefficient h_i is computed according to the flow regime, resorting to the following correlations [5]:

$$h_i = \frac{K}{d_i}\left[4.364 + \frac{0.086\left(\mathrm{Re}\,\mathrm{Pr}\frac{d_i}{l}\right)^{1.33}}{1 + .1\mathrm{Pr}\left(\mathrm{Re}\frac{d_i}{l}\right)^{.83}}\right] \qquad (\mathrm{Re} < 2300) \qquad (5)$$

Fully developed turbulent and transition flow (Re > 2300) [6]:

$$h_i = \frac{K}{d_i}\left[\frac{\frac{\xi}{8}(\mathrm{Re} - 1000)\mathrm{Pr}}{1 + 12.7\sqrt{\frac{\xi}{8}}\left(\mathrm{Pr}^{2/3} - 1\right)}\left[1 + \left(\frac{d_i}{l}\right)^{2/3}\right]\right] \qquad (6)$$

Where,

$$\xi = \frac{1}{(1.82 \log \mathrm{Re} - 1.64)^2}$$

The shell side heat transfer coefficient h_o is computed as follows [7]:

$$h_o = \frac{K}{d_o}\left[0.3 + \sqrt{Nu_{lam}^2 + Nu_{turb}^2}\right] \tag{7}$$

Where,

$$Nu_{lam} = .664\sqrt{\mathrm{Re}}\sqrt[3]{\mathrm{Pr}}$$

$$Nu_{turb} = \frac{0.037\,\mathrm{Re}^{0.8}\,\mathrm{Pr}}{1 + 2.443\,\mathrm{Re}^{-0.1}\left(\mathrm{Pr}^{2/3} - 1\right)}$$

3-2 Condenser design

The condenser is constructed of vertical tubes arranged in staggered. The condensation occurs when the temperature of a vapor is reduced below its saturation temperature. This is usually done by bringing the vapor into contact with a solid surface whose temperature is below the saturation temperature of the vapor. For calculating the heat gain to sea water is given as:

$$Q = \dot{m}_{sw}.C_{Pw}.(T_{w2} - T_{w1}) \tag{8}$$

And to calculate the heat rejected by condensation the fallowing equation is used:

$$Q = \dot{m}_{cond}.h_{fg} \tag{9}$$

So to calculate the amount of distilled water is calculated as fallows:

$$\dot{m}_{cond} = \frac{Q}{h_{fg}} \tag{10}$$

The heat surface area of condenser is determined as fallowing:

$$A_s = \frac{Q}{U.LMTD.f} \tag{11}$$

$$A_s = \pi.L.D \tag{12}$$

Nusselt equation is used for determining the overall heat transfer coefficient. So the average heat transfer coefficient for vertical tubes bank [8].

$$h_{vertN,tubes} = 1.76\left(\frac{K_l^3 \rho_l^2 g}{\mu_l^2}\right)^{1/3} \mathrm{Re}^{-1/3} \tag{13}$$

When Re≤1800

$$h_{vertN,tubes} = 0.0077\left(\frac{K_l^3 \rho_l^2 g}{\mu_l^2}\right)^{1/3} \mathrm{Re}^{0.4} \tag{14}$$

When Re≥1800

The surface area for all tubes in condenser is:

$$A_s = N_{total}.\pi.D_{cond}.L_{t.cond} \tag{15}$$

Where: $N_{total} = N.l_c$

4. The results and Discussion

The results of combination of steam power plant and MED produced about 1000-15000 m^3/day drinking water from salty water are shown in table (1) and Fig.2. These results obtained from mathematical and computer models which are found in flow chart diagram.
Table (1) shown the different powers of steam power plants with masses of distilled water. So these powers at different exhaust gases mass flow rate. Fig.1 shown the relationship between exhaust heat and the distilled water, the amount of condensation water is depend on the amount of waste heat from power plant, and the waste heat from steam power plant increased with increase of power generation. Note from Fig.1 that large distilled quantities could be achieved with large steam power plant.

Table (1). The Amount of distilled water by combination of power plant and multi effect desalination process.

Exhaust heat from power plants (Kw)	Salty water (m^3/day)	Distilled water (m^3/day)
13720	5616	836.055
27440	11232	1672.11
41160	16934.4	2521.03
54880	22550.4	3357.08
68600	28166.4	4193.14
82320	33868.8	5042.05
96040	39484.8	5878.11
109760	45100.8	6714.16
123480	50803.2	7563.08
137200	56419.2	8399.14
150920	62035.2	9235.19
164640	67737.6	10084.1
178360	73353.6	10920.2
192080	78969.6	11756.2
205800	84672	12605.1
219520	90288	13441.2
233240	95904	14277.2
246960	101606	15126.2
260680	107222	15962.2

Table (2) presents the most important design parameter of chimney heat exchanger including area of heat exchanger in chimney of steam power plants. Table (2) clarifies the power of steam power plant limits the area of heat exchanger. Note from table (2) that heating surface area decrease with the power of steam power plant decreased.

Table (2). Surface area of heat exchanger in chimney of different power plants

Exhaust heat from power plants (Kw)	Area of heat exchanger in chimney (m^2)
13720	1347.14
27440	1765.44
41160	2084.24
54880	2355.2
68600	2597.07
82320	2819.02
96040	3026.31
109760	3222.29
123480	3409.22
137200	3588.73
150920	3762
164640	3929.95
178360	4093.3
192080	4252.63
205800	4408.39
219520	4560.98
233240	4710.73
246960	4857.89
260680	5002.71
274400	5145.39

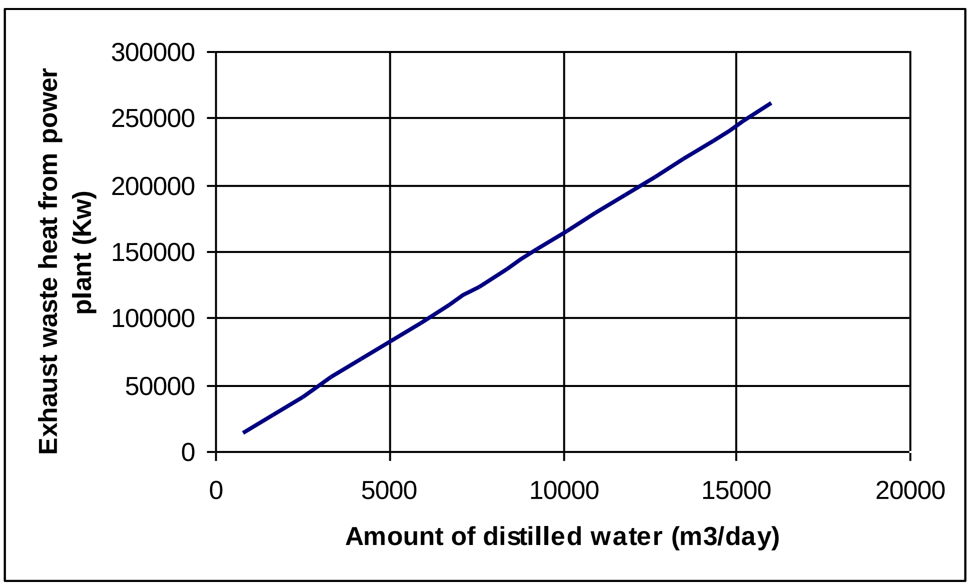


Fig.2. Exhaust heat from power plants against the amount of distilled water

Table (3). Area of condenser at variable heat rejected by condensation.

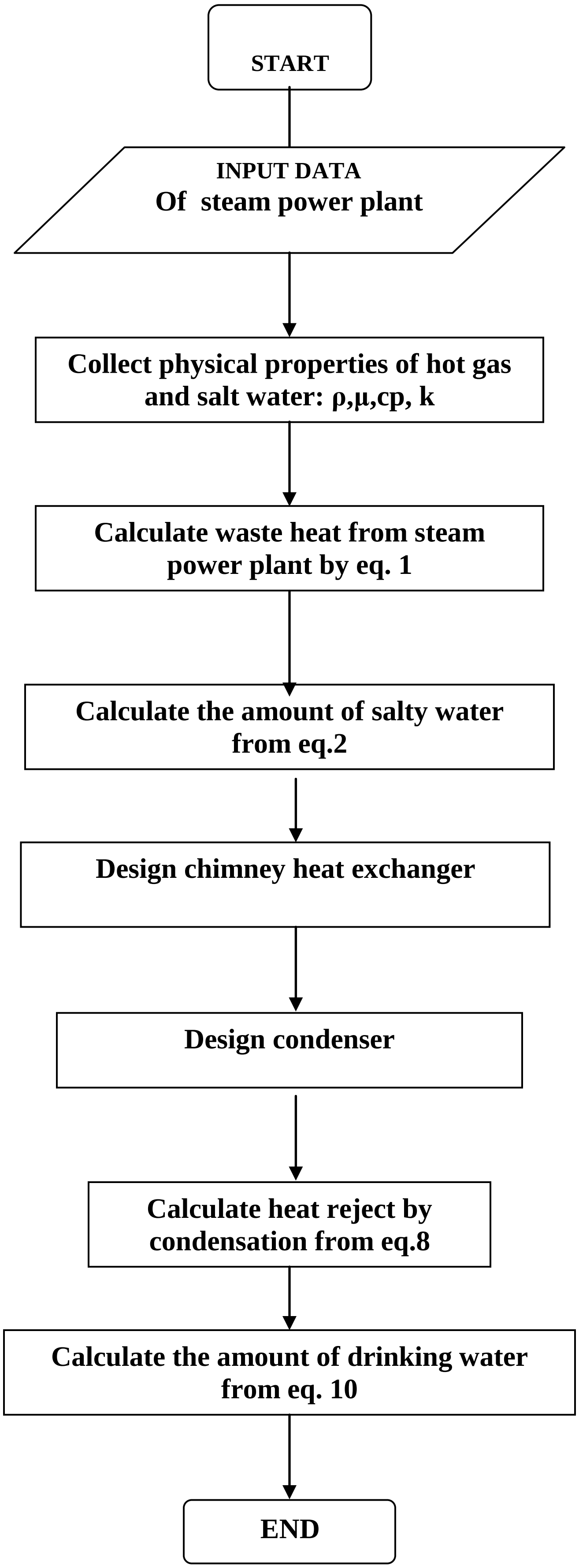
Heat rejected by condensation (Kw)	Area of condenser (m^2)
21892	301.658
43784	586.274
65676	871.742
87568	1151
109460	1429.04
131689	1710.44
153581	1986.88
175473	2262.77
197365	2542.43
219257	2817.47
241149	3092.17
263378	3370.79
285270	3644.93
307162	3918.84
329054	4196.76
350946	4470.27
373174	4743.6
395066	5020.98
416958	5294.01
438850	5566.9

The condenser design parameter found in table (3). We notice the area of condenser is limited by the rate of condensation of water vapor. The temperature of condensation salt water is dependent upon the saturated pressure.

5. Conclusions

The combine MED desalination with power plant system having much higher efficiency and results in significant energy savings, that is economic desalination costs. The lowest costs with the multi effect desalination (MED) plants are obtained by utilizing virtually free waste heat of power plant. This method can be used in the Middle East area, and every where when the steam power plant available. In this case the power plant could be producing both electricity and water. The high fuel cost involved in vaporizing salt water can be reduced by using the free exhaust waste heat from steam power plants.

The method used produced tool for design and construction Desalination water system, which tool is covered all the parameters such as heat exchanger in chimney exhaust gas of power plant, evaporator, and condenser with axillaries. Chimney heat exchanger made of stainless steel alloys because of is significantly high corrosion resistant and high thermal conductivity, and the range of operation conditions at heat exchanger in chimney are 50 C to 100 C, the temperatures of salty water inside tubular heat exchanger, and the temperatures of exhaust gas are 250 C to 160 C.
At evaporator chamber, the hot salty water expanded to under vacuum pressure about 0.9 bar, evaporated occur and the salt separate from hot water. The vapor passing over vertical tube banks condenser, hence condensation take place.


START
INPUT DATA
Of steam power plant
Collect physical properties of hot gas and salt water: ρ,μ,cp, k
Calculate waste heat from steam power plant by eq. 1
Calculate the amount of salty water from eq.2
Design chimney heat exchanger
Design condenser
Calculate heat reject by condensation from eq.8
Calculate the amount of drinking water from eq. 10
END

Flow chart diagram

List of Symbols

Cp: specific heat capacity at constant pressure	KJ/kg.K
D, d: diameter	m
f: correction factor	
g :gravitational acceleration	m/s^2
h: mean heat transfer coefficient	W/m.K
h_{fg}: enthalpy of evaporation	KJ/kg
K: thermal conductivity	W/m.K
L: length	m
LMTD: mean logarithm temperature difference	
m : mass flow rate	kg/s
Q: heat rejected	KW
T: temperature	K
U: overall heat transfer coefficient	$W/m^2.K$
μ: Dynamic viscosity	m/s^2
$\rho =$ Density	kg/m^3

Subscripts

c: condenser
g: gas
i: inside
l: liquid
o: outside
s: saturation
sw: salt water
w: water

Dimensionless numbers

Nu: mean Nusselt number
Pr :Prandtl number
Re :Reynolds number

6. References

1. Frank K., and K. Timmerhaus, 2000, ***"The CRC Handbook of Thermal Engineering"***, CRC. Press LLC.

2. Corrado S., 2000***" Utilisation of power plant waste heat steams to enhance efficiency in thermal Desalination"***,Desalination. No. Vol.222 ,pp.592-595.

3. Kamali R.K., and S. Mohebinia, 2008, ***"Experience of design and optimization of multi effects desalination System in Iran"***, Desalination, Vol. 222, pp 639-645.

4. Kasper S and Lior N. 1979, ***"A methodology for comparing water desalination to competitive Fresh water transportation and treatment"***, Desalination,Vol. 30, pp.541-552.

5. Stephan K, 1959, ***"Warmeubergang und druckabafll bei nicht ausgebelideter laminarstromung in Rohren und ebenen spalten"***, Chem. Ing. Tech. Vol. 31, pp.773-778.

6. Petukhov, 1970***,"Heat transfer and friction in turbulent pipe flow with variable physical properties",*** Adv. Heat Transfer, Vol. 6, pp.503-565.

7. Gnielinski V,1975***,"Berechnung mittlerer warme und stoffubergangsko effizientent an laminar und Turbulent uberstromten eizelkorpern mit hilife einer einheitlichen gleichung"***. Forschugim inngnieurwesen, Vol.41, pp.145-153.

8. Necati M, 1988, ***"Heat transfer"***, McGraw-Hill, New York.