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An Improved Mathematical Model for Multi Effect Distillation

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Abstract

Increasing global demand for fresh water is driving research and development of advanced desalination technologies. As a result thermal desalinations types are developed. In this paper, improvements of multi effective desalination are discussed. Thenew mathematical model present the design of areas of feed heaters, stages required areas and flow rates in each effect and its details of flashing and evaporating flows, which use both to produce fresh water. Addition the inlet steam temperature is reduced compared with the traditional designs to reduce the corrosion, fouling in the pipes, maintained cost and running cost for high temperature of inlet steam. Increasing details in the system leads to allowing proper sensitivities to key variables related inputting, operating, and design analysis cogeneration and optimization process, As result of more detailed such as (feedheaters, flashing and boiling distillate every stage)the number of required approximations and assumptions is decreased.

Keywords: MED, desalination, feed heater, mathematical model, optimization.

1. Introduction

The traditional thermal desalination systems are depended on the source of heat to do heat transfer between the pipes and seawater to evaporate the seawater and convert it to fresh water. The source of heat in the traditional systems is Steam, which reach temperature in the first stage at some systems to 120^0C and average operation temperature in the other stages between (110: 90)^{0}C.

The high temperature of steam leads to high initial and running cost to make water boiling additional to periodic maintenance frequently because of the corrosion in the pipes which caused by high concentration of salinity.

New modification is required to reduce the running cost and maintenance with the same performance of production of fresh water, so there are many modifications in the design of materials but the same problem of the running cost is still, and the problem of the corrosion is not effective because the materials need high cost to fabricate it.

To avoid the cracking of water salinity ions at the same size of productivity to safe the performance and reduce the corrosion, new modification by changing the saturated temperature with less inlet steam temperature and less pressure by vacuum the stage pressure, the relation between these conditions (Saturated temperature and pressure). The inlet steam of the system will be from rang 60^0C to 90^0C maximum, the improved model will be designed as inlet steam temperature at 70^0C.

Almost of previous models, determine the distillate water from stage as a package without detail the mounts of flash and vapor separately, the losses of fresh vapor which used as a heat source of the next stage and its active mass flow rates. So it is important to calculate the previous flow rates with the brine and feed heaters to reduce the losses and can easily optimize the system.

2. Mathematical improved model of M.E.D.

A thermal model of an MED system is presented that provides more accurate description of the MED process through relying on fewer assumptions and simplifications.

2.1 Approximations

Several standard engineering approximations are made in this analysis:

- Steady state operation.
- Distillate is pure water (i.e., salinity of product water is 0 P.P.M).
- Exchanger area in the effects is just large enough to condense vapor to saturated liquid(i.e., $x = 0$) at the previous effect's pressure.
- Seawater is an incompressible liquid and the properties are only a function of temperatureand salinity.
- Energy losses to the environment are negligible.
- The overall heat transfer coefficient is averaged over the length of an exchanger.
- The overall heat transfer coefficient in each effect, feed heater, and condenser is a functionof temperature only.

2.2 Numerical model for the improved MED.

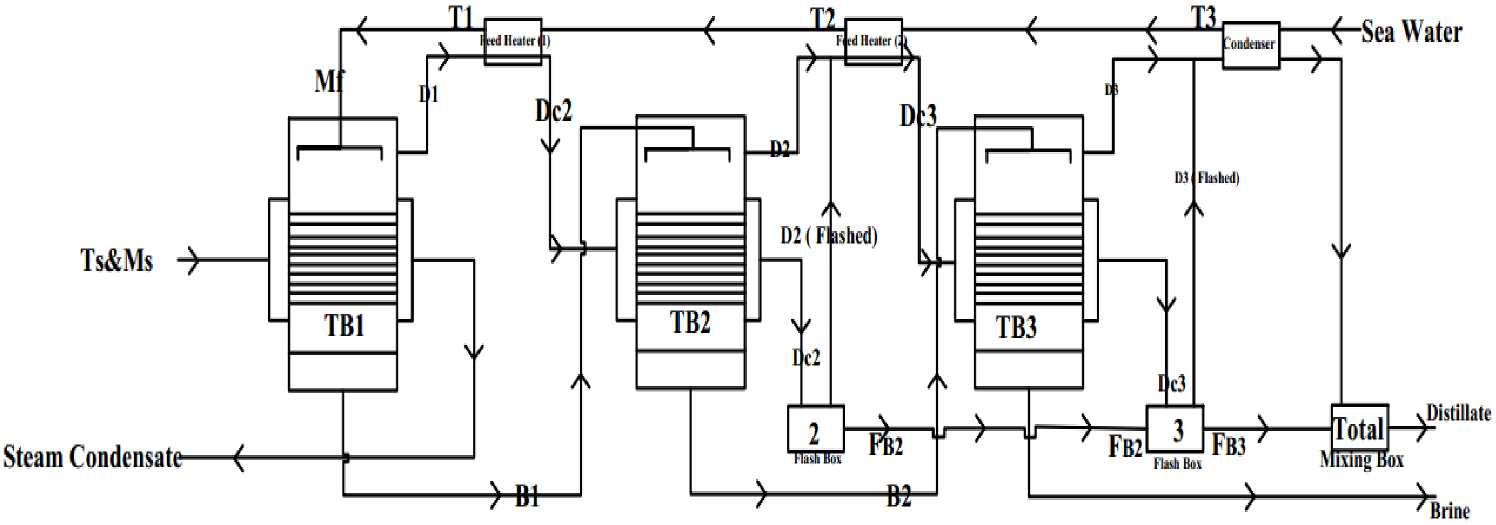


Figure1: Schematic of multi evaporation desalination.

The flow rates of brine leaving effect number (3) and feed seawater are obtained from equations

$B_n = \frac{Xf * Md}{Xn - Xf}$ **(1)**

$M_F = Md + Bn$ **(2)**

Temperature drop every stage $=(T_s - T_3)/n$ **(3)**

From BUCK equation to determine every stage's saturated pressure

$P=0.61121 \exp[[18.678 - \frac{T}{234.5}][\frac{T}{257.14+T}]]$ **(4)**

The latent heat value different stages is given by:

$H_{Fg}= 2499.5698 - 2.20486\ T - \frac{2.304}{10^3} * T^2$ **(5)**

The thermal load in all effects is assumed constant so:

$Q_1=Q_2=Q_3$ **(6)**

$Q_{stage}= M_s*H_s = D_{c2}*H_2 = D_{c3}*H_3$ **(7)**

<u>For first effect</u>

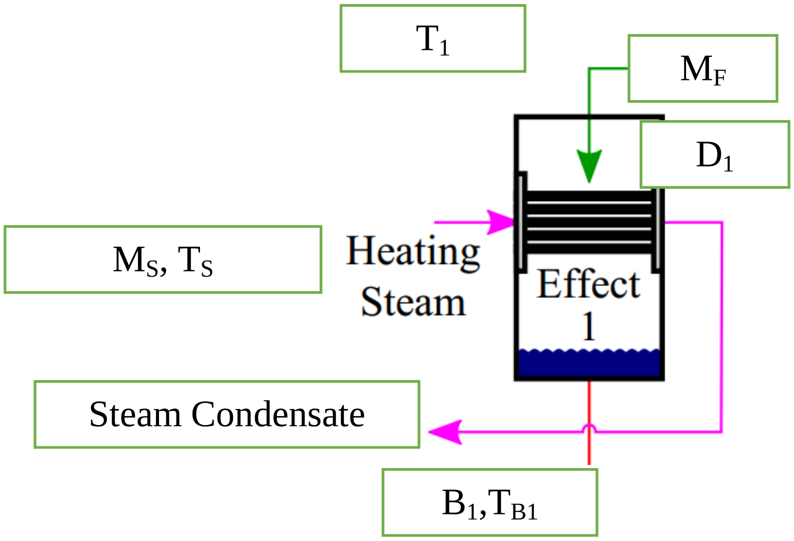


Figure 2: The first stage details.

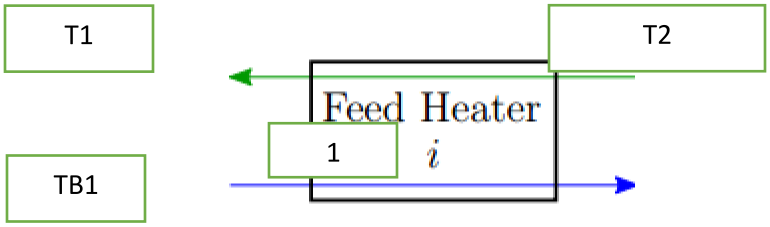
<u>Energy balance of first stage gives</u>

$Q=Ms*Hs$ **(8)**

$(M_s*H_s)+(M_F*C_P*T_1) = (B_1*C_{P1}*T_{B1}) + (D_1*H_{fg1})$ **(9)**

The mass flow rate of steam required is equal to the amount of vapor that must condense in the first effect.

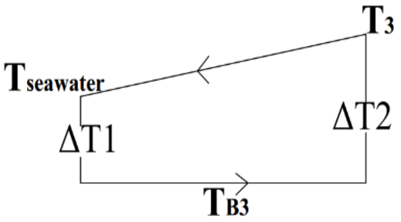
$M_S= M_{D1}$ **(10)**

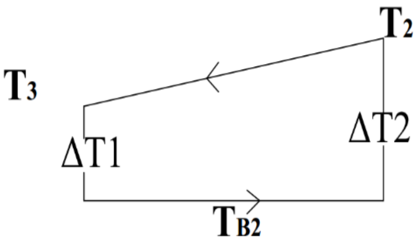


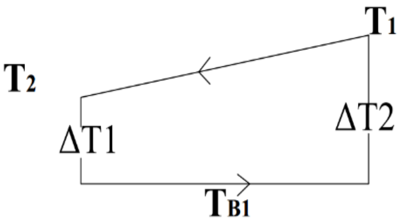
$$\Delta M_1 = \frac{Mf * Cp * [T1 - T2]}{Hfg1 * B1} \qquad \textbf{(11)}$$

Where H_{FGB1} at $T = T_{B1} - \Delta T_{Losses}$

Energy balance of feed heater gives







For N-effect

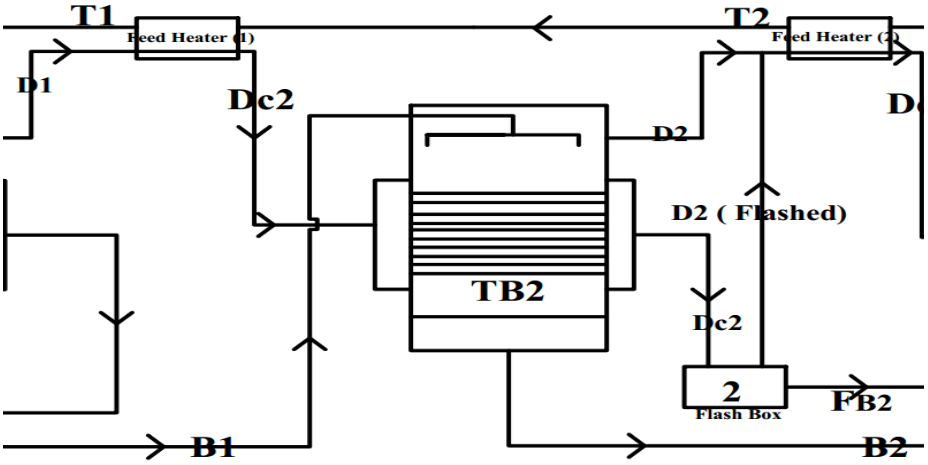
$$U_n * A_n * \Delta T_{Log} = M_f * C_P * \Delta T \qquad \textbf{(12)}$$

$$\text{Where } \Delta T = (T_N + T_{N-1})/2 \qquad \textbf{(13)}$$

For all effects

$$\Delta T_{Log} = \frac{\Delta T1 - \Delta T2}{Ln\left(\frac{\Delta T1}{\Delta T2}\right)} \qquad \textbf{(14)}$$

For second effect



Energy balance gives

$$[(B_1 * C_p * (T_{B1} - \Delta T_{Losses})] + ((D_1 - \Delta M_1) * H_{FG2}) = (B_2 * C_p * T_{B2}) + (D_2 * Hg_{B2}) \qquad \textbf{(15)}$$

$$D_2 = \frac{B1 * Cp1 * (TB1 - \Delta T) + ((D1 - \Delta M1) * Hfg2) - B2 * Cp * TB2}{Hfg2} \qquad \textbf{(16)}$$

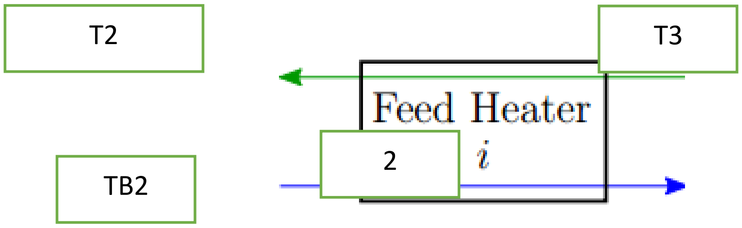
$$D_2 = D_{2Flashing} + D_{2Boiling} \qquad \textbf{(17)}$$

$D_{2Flashing} = \mathbf{B_1} * \mathbf{C_p} * \frac{TB2-TB'1}{Hfg2}$ **(18)**

$H_{FG2:}$ Enthalpy of flashing flow rate at $T = T_{B2}$

$D_{2Boiling} = D_{2\ Total} - D_{2Flashing}$ **(19)**

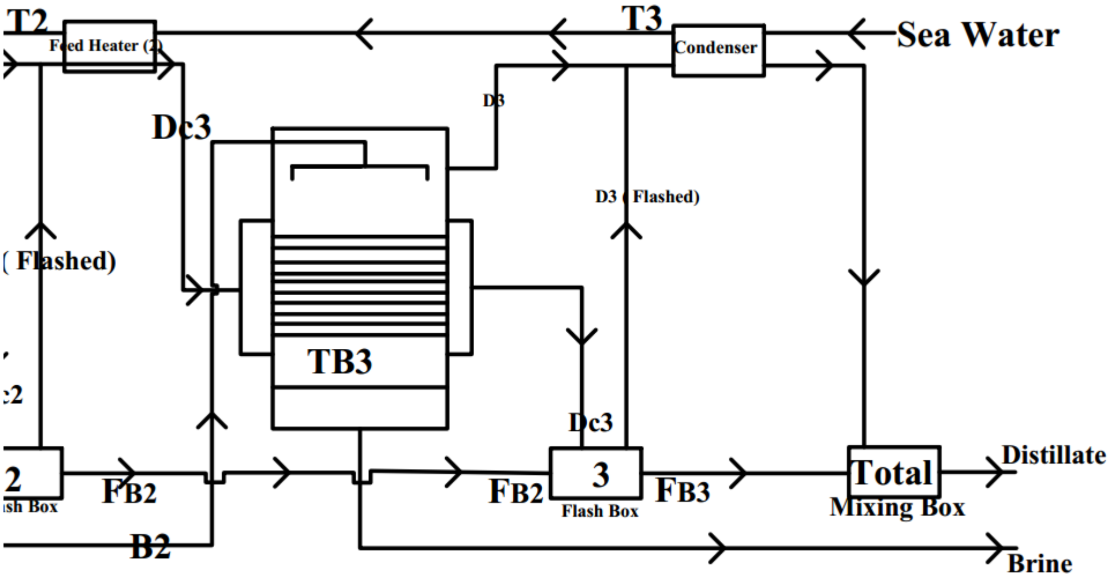
$B_2 = B_1 - D_2$ **(20)**



$\Delta M_2 = \frac{Mf*Cp*[T2-T3]}{HfgB2}$ **(21)**

Where H_{FGB2} at $T = T_{B2} - \Delta T_{Losses}$

For third effect



Energy balance gives

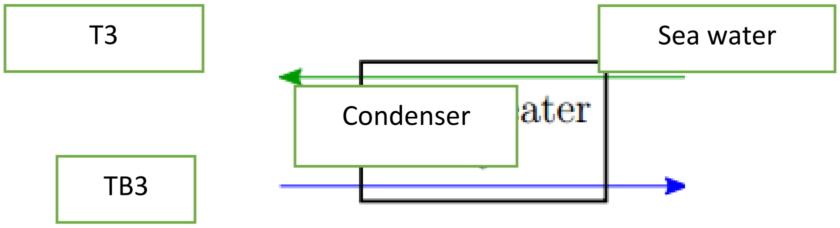
$[(B_2*C_p*(T_{B2}-\Delta T_{Losses})] + ((D_2-\Delta M_2* H_{FGB3}) = (B_3*C_p*T_{B3}) + (D_3*H_{GB3})$**(22)**

$D_{3Flashing} = \mathbf{B_2} * \mathbf{C_p} * \frac{TB3-TB'2}{HfgB3}$ **(23)**

$H_{FGB3:}$ Enthalpy of flashing flow rate at $T = T_{B3}$

$D_{3Boiling} = D_3 - D_{3Flashing}$ **(24)**

$B_3 = B_2 - D_3$ **(25)**



$$\Delta M_3 = \frac{Mf * Cp * [T3 - Tseawater\ ]}{HfgB3} \qquad \textbf{(26)}$$

Where H_{FGB3}at $T = T_{B3} - \Delta T_{Losses}$

3. Summary of the mathematical model equations.

From Previous, modeling the summary of equations can be writer as function of number of stage (I or N) with the next stage (I+1) or (N+1) and pervious stage (I-1) or (N-1) to simplify the model as shown:

- Temperature drop per stage:

$$\Delta T_B = \frac{Ts - TB(N)}{N} \qquad \textbf{(27)}$$

- Feed water drop per stage:

$$\Delta T_W = \frac{Tw(1) - Tw(N)}{N} \qquad \textbf{(28)}$$

<u>For first stage:</u>

$$\text{Assume } M_S = 1.1 * D_{(1)} \qquad \textbf{(29)}$$

- First stage temperature:

$$T_{B(1)} = T_S - \Delta T_B \qquad \textbf{(30)}$$

- Desalination due to boiling effect:

$$D_{B(1)} = D_{(1)} - D_{f(1)} = D_{(1)} = \frac{MF * CP * (Tw(1) - TB(1))}{HFG(1) - (TB(1) * CP) - 1.1 * HS} \qquad \textbf{(31)}$$

- Desalination due to flashing effect:

$$D_{f(1)} = 0 \qquad \textbf{(32)}$$

- Brine flow rate at first stage:

$$B_{(1)} = M_F - D_{(1)} \qquad \textbf{(32)}$$

- Condensation flow rate:

$$D_{C(1)} = M_S \qquad \textbf{(33)}$$

- Steam enthalpy:

$$H_S = 2499.5698 - (2.20486 * T_S) - \frac{2.304 * Ts * Ts}{1000} \qquad \textbf{(34)}$$

<u>For stage 2 to N</u>

- Stage temperature:

$$T_{B(I)} = T_{B(I-1)} - \Delta T_B \qquad \textbf{(35)}$$

- Feed water temperature:

$$T_{w(I)} = T_{w(I-1)} - \Delta T_W \qquad \textbf{(36)}$$

- Brine flow rate at last stage:

$$B_{(N)} = \frac{Xf(1) * Md}{XB(N) - XF(1)} \qquad \textbf{(37)}$$

- Feed water:

$$M_F = M_D + B_{(N)} \qquad \textbf{(38)}$$

- Enthalpy of (seawater / Condensation water)

$$H_{FG(I)} = 2499.5698 - (2.20486 * T_{B(I)}) - \frac{2.304 * TB(I) * TB(I)}{1000} \qquad \textbf{(39)}$$

- Desalination water due to flashing effect:

$$D_{f(I)} = \frac{DC(I) * (HFGD(I-1)) - (CP * TB(I))}{HFG(I)} \qquad \textbf{(40)}$$

- Desalination water due to boiling effect:

$$D_{B(I)} = \frac{(DC(I) * (HFGD(I-1) - HFG(I))) + (B(I-1) * CP * (TB(I-1) - TB(I)))}{HFG(I) - (TB(I) * CP)} \qquad \textbf{(41)}$$

- Total desalinate water

$$D_{(I)} = D_{f(I)} + D_{B(I)} \qquad \textbf{(42)}$$

- Brine flow rate per stage:

$$B_{(I)} = B_{(I-1)} - D_{B(I)} \qquad \textbf{(43)}$$

- Over all heat transfer coefficient:

$$U_{(I)} = (1939.1 + 1.40562 * T_{w(I)}) - (0.0207525 * T_{w(I)}^2) + (0.0023186 * Tw_{(I)}^3) \qquad \textbf{(45)}$$

- Evaporating losses in the feed heater:

$$\Delta_{M(I)} = \frac{MF * CP * \Delta TW}{HFGD(I)} \qquad \textbf{(46)}$$

- Condensation water in the stage to next:

$$D_{C(I)} = D_{(I-1)} - D_{M(I-1)} \qquad \textbf{(47)}$$

- Saturation pressure in the stage:

$$P_{(I)} = 0.61121 \exp[\,[18.678 - \frac{T(I)}{234.5}][\frac{T(I)}{257.14 + T(I)}]] \qquad \textbf{(48)}$$

- Area of feed heater per stage:

$$A_{FeedHeatr(N)} = \frac{Mf * CP * \Delta T}{Un * \Delta TLog} \qquad \textbf{(49)}$$

- Performance ratio

$$P.R = \frac{MD}{Ms} \qquad \textbf{(50)}$$

<u>4. Results and Comparison of performance elements between the traditional and modification steam temperature.</u>

As resultof analyze system to many components such as (Feed Heaters, Flashing boxes, Condensation water per stage and water losses in feed heater). The modification model generate new modification results, which compared to other models from the literature [6].

From mathematical modeling between the traditional and modification of steam temperature, the results can be determining the extent of the effect of this amendment.

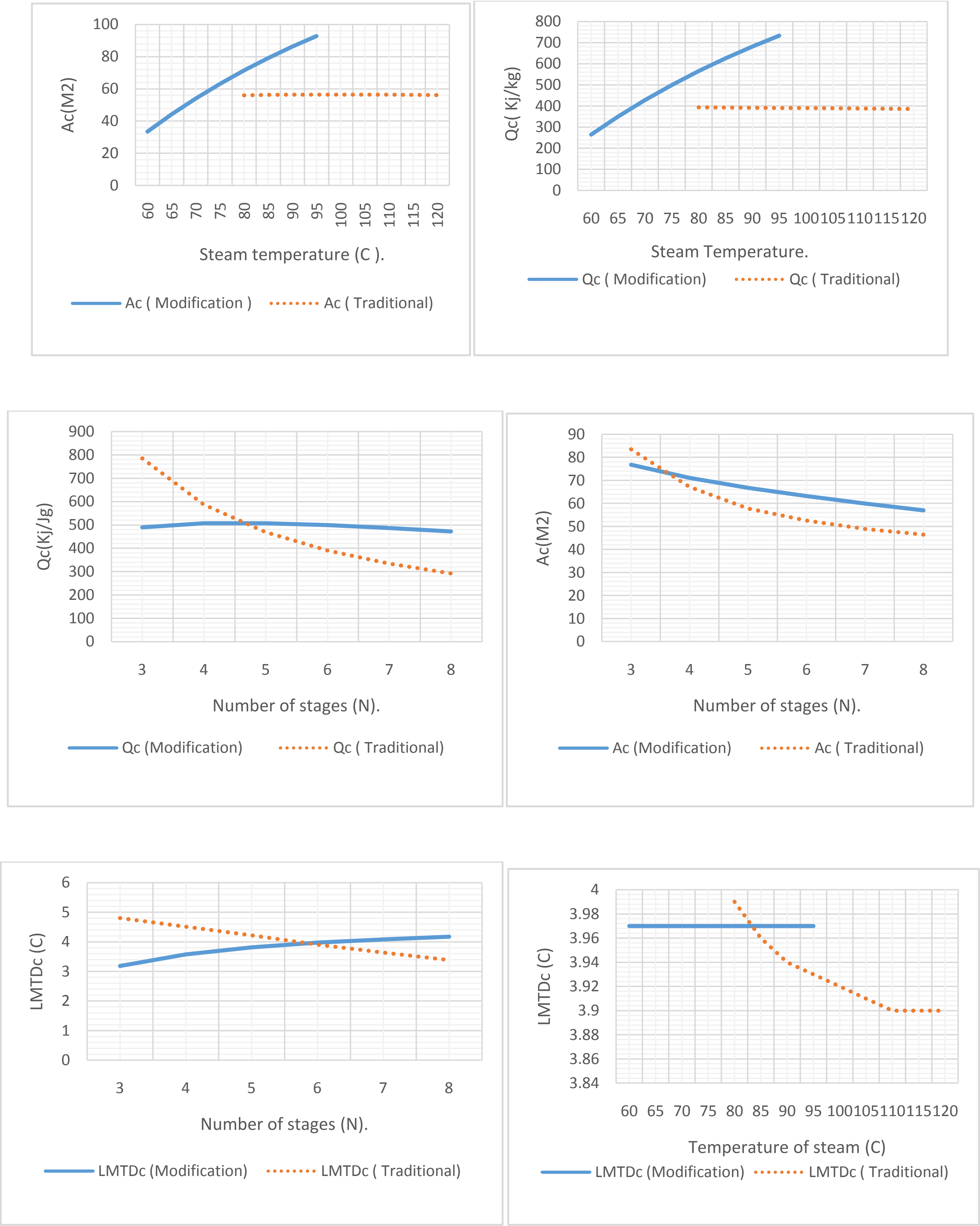


Figure 1: Comparison between traditional and modification condenser parameters.

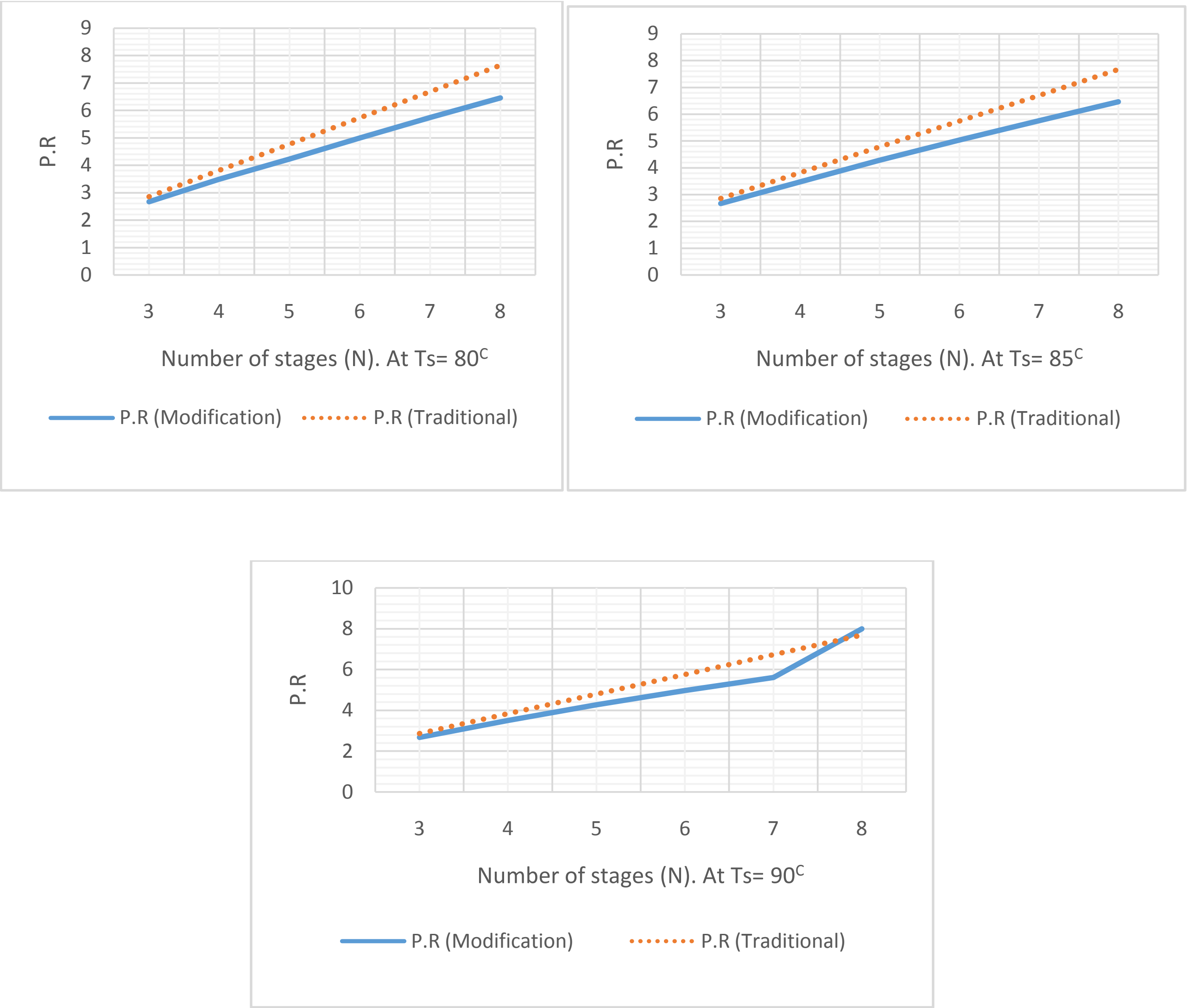
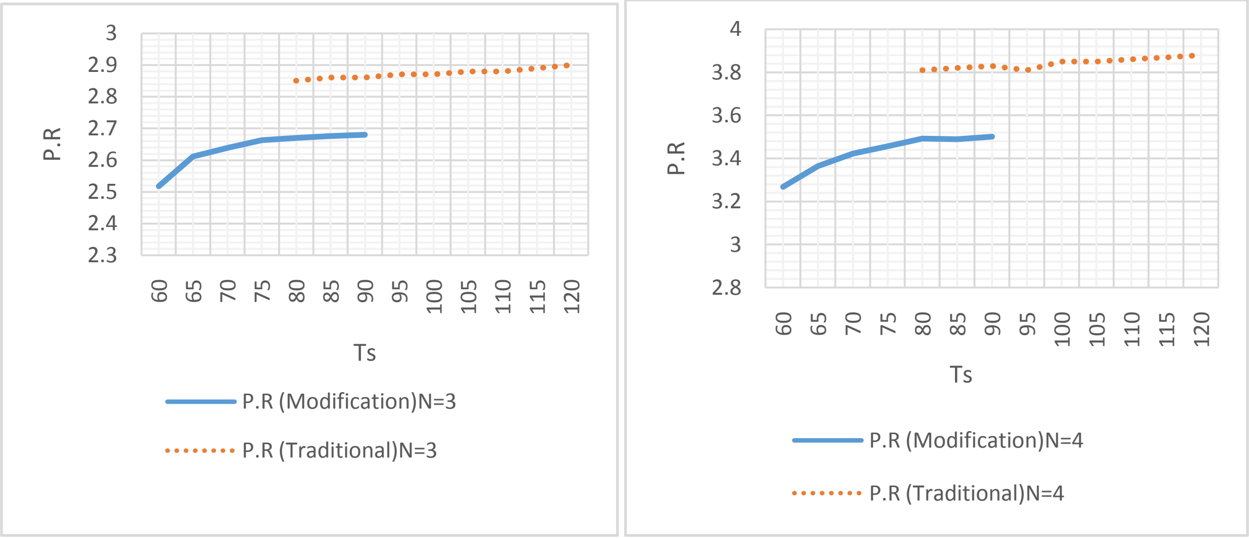


Figure 2: Comparison between traditional and modification P.R with number of stages at constant steam temperature.



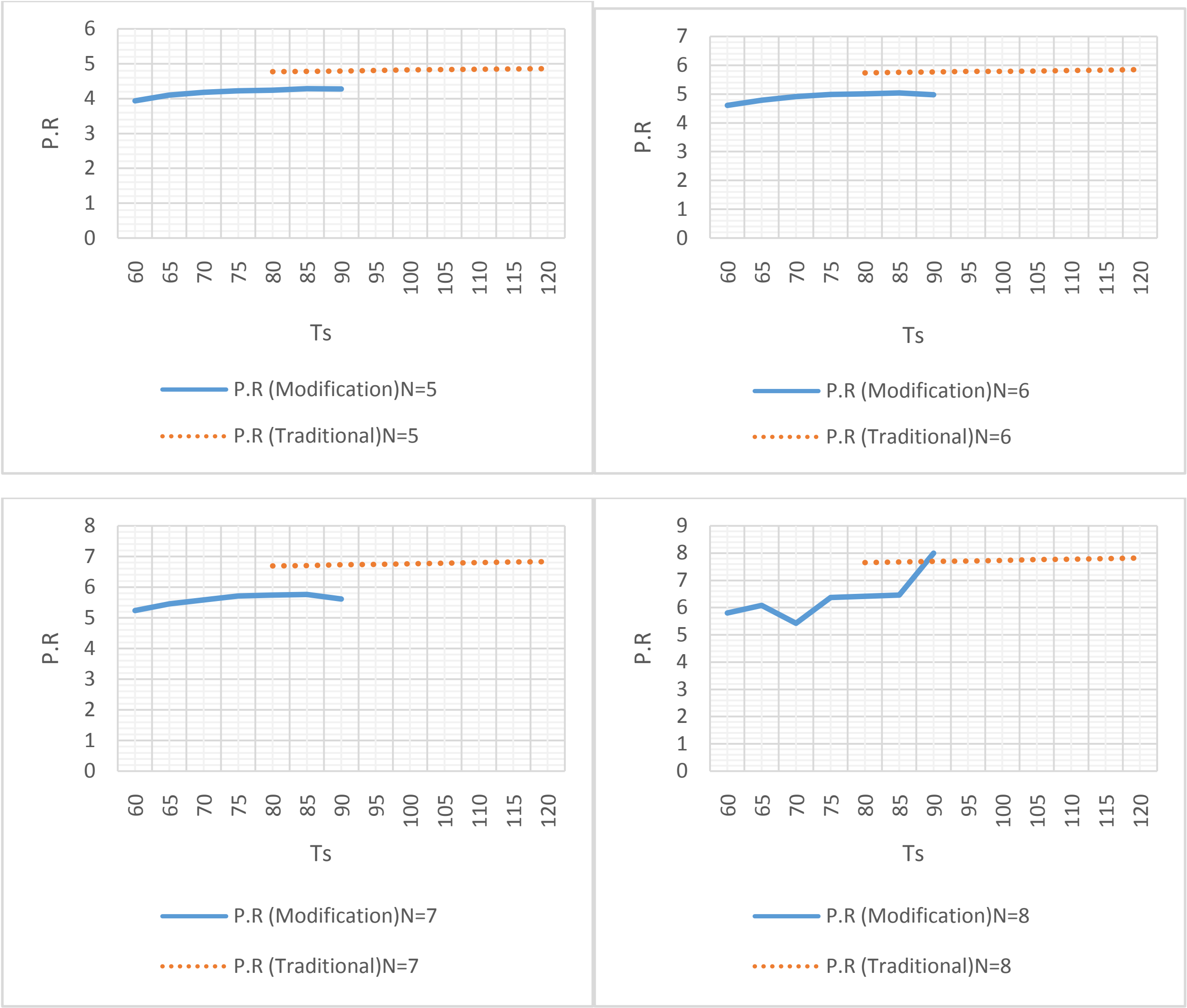


Figure 3: Comparison between traditional and modification P.R In-let steam temperature at constant number of effects.

4. Conclusion.

The difference between system parameters such as (P.R,Qc, In-let Steam Temp., N, LMTD$_{C}$, A$_{C}$) is appeared due to the new modification design parameters.

Table1: Comparison between the traditional design and modification parameters.

	Traditional design	Modification design
In-Let steam	From (100:120)^{C}	From (60:90)^{C}
Overall heat coefficient in effects.	Decrease as constant ratio.	Change from stage to other as shown from equation (45)
Stage (Effect)	Calculate as package	Divide to: 1-Feed Heater. 2-Effect. 3-Flash box.
Losses in the feed heater (Evaporation water).	Neglect.	Take into account as shown from equation (46)
Desalinate water in effect	Package.	Divide to: 1- Boiling water. 2-Flashing water.

NOMENCLATURES

Symbols

$A_{(N)\text{Feed Heater}}$	Area of feed heater	$[M^2]$
B_N	Brine flow rate.	[Kg/Sec]
C_P	Specific heat at constant pressure	[J/Kg.K]
D_C	Condensation water per stage	[Kg/Sec]
D_N	Total desalination flow rate per stage	[Kg/Sec]
D_F	Desalination water of flashing process	[Kg/Sec]
D_B	Desalination water of boiling process	[Kg/Sec]
F_{BN}	Exit water from flash box	[Kg/Sec]
H_{FGN}	Latent heat per stage	[KJ/Kg]
H_{FGS}	Latent heat of steam	[KJ/Kg]
M_D	Desalination mass flow rate	[Kg/Sec]
M_F	Feed water flow rate	[Kg/Sec]
M_S	Steam mass flow rate	[Kg/Sec]
N	Number of stage	
P_N	Saturated pressure per stage	[Kpa]
Q	Thermal load	[KJ]
T_{BN}	Effect temperature	$[^{C}]$
T_S	Steam temperature	$[^{C}]$
T_{WN}	Temperature of inlet seawater	$[^{C}]$
U_N	Over all heat coefficient	$[Kw/m^2.C]$
X_F	Concentration of feed salinity	[P.P.M]
X_N	Concentration of stage salinity	[P.P.M]

Greek Symbols

ΔM	Water losses in the feed heater	[Kg/Sec]
ΔT_N	Deference temperature in stage.	[C]
ΔT_{Losses}	Temperature losses.	[C]
ΔT_{WN}	Deference temperature in the feed heater.	[C]

Abbreviations

M.E.D	Multi Effective desalination
P.P.M	Practical per million
F.F	Forward feed
LMTD	log mean temperature difference

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