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Performance Evaluation of Geothermal Integrated Desalination Double Effect Evaporator (DEE) with or without Steam Jet Ejector with Software Simulation

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ABSTRACT

This work offers an extensive framework for the performance evaluation of Geothermal integrated Double effect evaporator (DEE) with or without steam jet ejector for delivering 1.0 Kg/s freshwater. Utilization of low enthalpy Geothermal energy in numerous applications, including Desalination and their potential incorporation with thermal-based desalination framework is an environmentally friendly solution for water desalination, to satisfaction of worldwide water emergencies. The geothermal integrated Double Effect Evaporator designed by comparing results obtained from manual calculation, Excel and MATLAB/Simulink. So, as to have a good and optimized design, manual, Excel and MTALB/Simulink calculations are approximately the same with a minor difference. Various parameters, which can conceivably change the results of the evaluation were picked to examine their effect on design. These parameters include boiling temperature, Intake seawater temperature, heating steam temperature (Geothermal fluid temperature), feed water quality, quality of Geothermal resources. By changing their values, the detail of our basic model results was assessed

1. INTRODUCTION

Water has always been one of the key requirements of every living system on the earth(Prajapati et al. 2021). In a couple of years, the quality and the proportion of consumable freshwater decrease because of different debasement and climate change (M. Shah, Vaidya, and Sircar 2018). Water on the earth is either present as oceanwater or groundwater and as ice. About 96 - 97% of the earth's water is salty, and the rest is freshwater. Just 1-2% freshwater is available for human activity(Chatterjee and Ray 2014). As per the UNICEF and World Health Organization (WHO) report in 2015, about 2.10 billion people are used water without filtering, and most of this society is living in country regions wherever the low populace (UNESCO-WWAP 2019). As of now, water on the earth has saltiness up to 10,000 ppm. Seawater contains salinity in the range of 36,000 to 46,000 ppm (Kuroda et al. 1987). As per report World Health Organization (WHO), water use for drinking purposes has salinity up to five hundred ppm. For uncommon cases, the salinity goes up to a thousand ppm. Thus, to fulfill the demand for freshwater, we need to go for the desalination of brackish water or seawater (Prajapati et al. 2021). There are different technologies available that can be utilized to treat saline water however, it needs high mechanical or heat energy to operate the desalination unit. For feasible development and water filtration, environmentally friendly energy sources play a critical role when it integrates with the desalination unit. Primary renewable (sustainable) energy sources are geothermal energy, wind energy, solar energy, etc. While the desalination unit worked by using conventional fuel sources, it consumes oil-based products, which in the end extends contamination level (Singhal, Singh, and Kumar Sharma 2018).

Geothermal energy is earth energy, which presents as a hot liquid, known as geofluid (Tzen and Morris 2003). The enthalpy /temperature of geothermal fluid changes from site to site. It depends upon various parameters, for example, the well's rock composition, Geothermal production well depth, and so on (B. Shah et al. 2019; M. Shah, Sircar, Shaikh, et al. 2019; M. Shah, Vaidya, and Sircar 2018). On their temperature, geothermal energy categories as follows, higher enthalpy/temperature geothermal sources with a temperature of more than 200 ^{0}C, mostly found in volcanic zones. High to medium enthalpy/temperature geothermal sources with a temperature range of 130 ^{0}C to 200 ^{0}C and medium to low enthalpy/temperature geothermal sources with temperature under 130 ^{0}C. Medium to low enthalpy/temperature geothermal liquid under 130 ^{0}C temperature utilized as a heating medium for desalination of seawater or brackish water. Geothermal energy has preferences among other renewable energy; (1) it doesn't rely on atmosphere conditions (2), heat flux is consistent since the sun and wind energy rely on both(Prajapati et al. 2021). In a geothermal incorporated desalination system, geofluid could be circulated in two ways directly for heating saline water or indirectly to create power for working RO unit relies upon the enthalpy of geofluid (Loutatidou and Arafat 2015).

El-Dessouky et al. (1999) built up a mathematical model for a single-effect evaporator. The model incorporates energy and mass balance equations. The procedure mathematical model can be used for the investigation of single-effect evaporator (SEE) execution for various value of boiling and heating steam operating condition additionally this model used for analyzing the heat transfer area of condenser and evaporator, the mass flow rate of heating steam required, the amount of cooling water and so on (El-Dessouky and Ettouney 1999).

Ji et al. (2007) developed a mathematical model for examining the performance of the SEE-TVC desalination framework. They investigate the effect of fluctuating parameters like seawater temperature, cooling water mass flow rate (m_{cw}) on performance. The outcomes demonstrated that the efficiency of the desalination framework is higher for the higher design value of cooling water flowrate (m_{cw}) and higher design value of seawater temperature (Ji et al. 2007).

Al-Juwayhel, El-Dessouky, and Ettouney (1997) performed a comparison of 4 types of SEE desalination framework. They created a steady-state mathematical model. The investigation was completed for the comparison of the heat transfer area (sA), performance ratio (PR), power consumption, cooling water flowrate (m_{cw}). They additionally proposed a MATLAB algorithm to tackle a mathematical model optimization issue (Al-Juwayhel, El-Dessouky, and Ettouney 1997).

The present paper describes the modeling and simulation of a geothermal integrated desalination system of Double-effect evaporator (DEE) and Double effect evaporator with steam jet ejector in Excel and MATLAB/Simulink, to analyze the performance of both systems for producing 1.0 Kg/s of freshwater. This research also includes the comparison of some parameters like performance ratio (PR), the mass flowrate of heating steam (m_s), the mass flowrate of cooling water (m_{cw}), etc.

2. GEOTHERMAL INTEGRATED DOUBLE EFFECT EVAPORATOR

2.1. Use of Geothermal Energy in desalination system

Geothermal energy is most promising sources of energy correspondingly as it is an elective environmentally friendly power source. It is accessible as high temperature water or steam under the Earth. The energy from geothermal assets could be used to generate steam power in power plant unit, bathing, heating, in desalination framework as a heating medium, and so on. Geothermal energy present as a hot fluid, known as geofluid, this is the combination of fluid and vapour, present in the Earth's (Gude 2016).

Extraction of geothermal heat from the earth's crust by utilizing two well (M. Shah et al. 2018),

1. Geothermal generation/production well and
2. Injection well

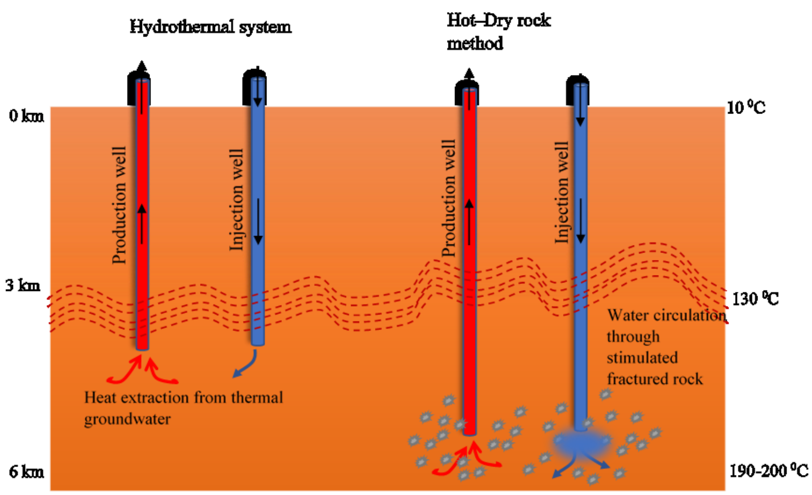


Fig. 1. Geothermal fluid extraction method (Abdelkareem et al. 2018)

(Fig. 1.) shows that the geothermal fluid extracted through production well. According to geochemistry, the portion of geofluid could be utilized as a heating medium in many areas directly or indirectly (M. Shah, Vaidya, and Sircar 2018). After the utilization of geothermal liquid directly or indirectly further, it reinjected through the injection well. Submersible pumps fitted at the geothermal production well. The geothermal fluid contains many microelements, micropollutants and metal most of the cases which is present in high concentration it includes Na+, CO^{3-}, Ca^{2+}, Mg^{2+}, K^{+}, HCO^{3-},CO_2 and Hg, Zn, Pb, Fe, Cu, Boron, cadmium (Cd), arsenic, nickel (Ni), and silica (Si) respectively. The heat energy of geothermal resources is varying from site to site. It depends upon various factors it includes geothermal well productivity, the temperature of geothermal liquid, rock structure, and accessibility of geofluid (M. Shah et al. 2018; M. Shah, Sircar, Varsada, et al. 2019)

There is no need of thermal storage when the system operated by utilizing geothermal heat energy such as steam power generation, desalination system etc. (Fig. 2.) depicts a simplified schematic of a conventional geothermal driven Double effect evaporator (DEE) system to treat saline water. Depending on the geothermal chemistry, the system can either be directly heated by geofluid as shown in the (fig. 3 & 4) or indirectly via a secondary heating medium cycle (e.g. Organic Rankine Cycle (ORC)) to manage contamination problems and scaling (Gude 2016; Gude, Nirmalakhandan, and Deng 2010). In this case, the system is directly heated by low enthalpy geofluid which has a temperature of less than 130 ^{0}C.

Assumption and Mathematical Model

The following assumptions are made to drive a low enthalpy geothermal integrated desalination model (Al-Najem, Darwish, and Youssef 1997).

- Steady-state operating condition.
- The distillate is pure water.
- Thermodynamic losses to the environment are negligible.
- The losses due to Non-Equilibrium Allowance (NEA) is negligible.
- Assumed a constant value of heat capacity.

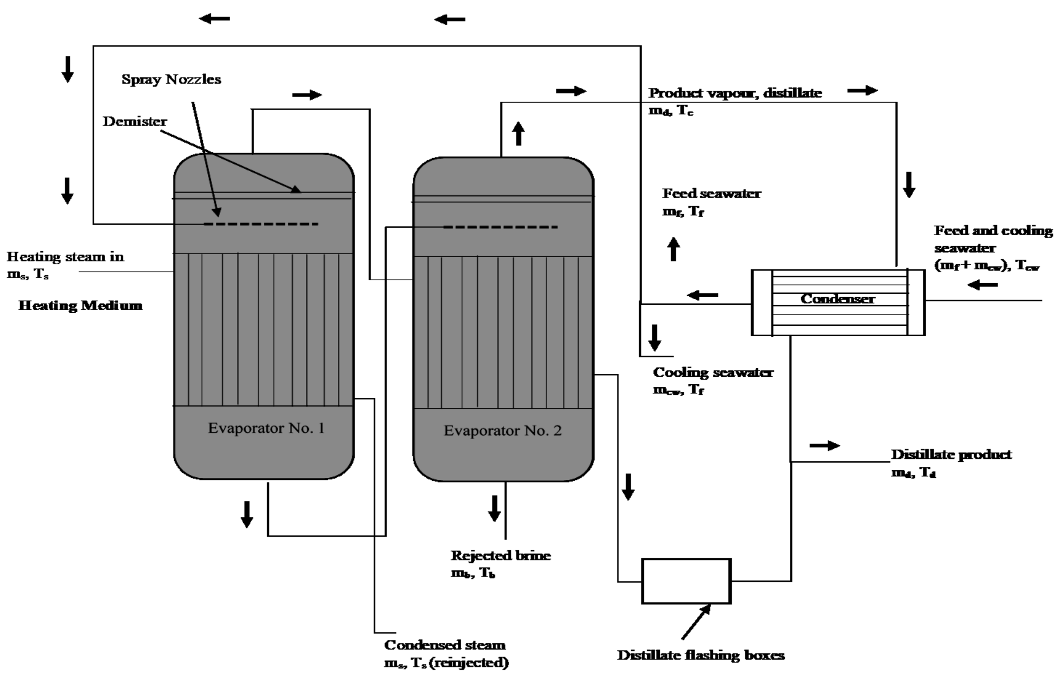


FIG. 2. Double Effect Evaporator (DEE) for desalination system (El-Dessouky and Ettouney 1999).

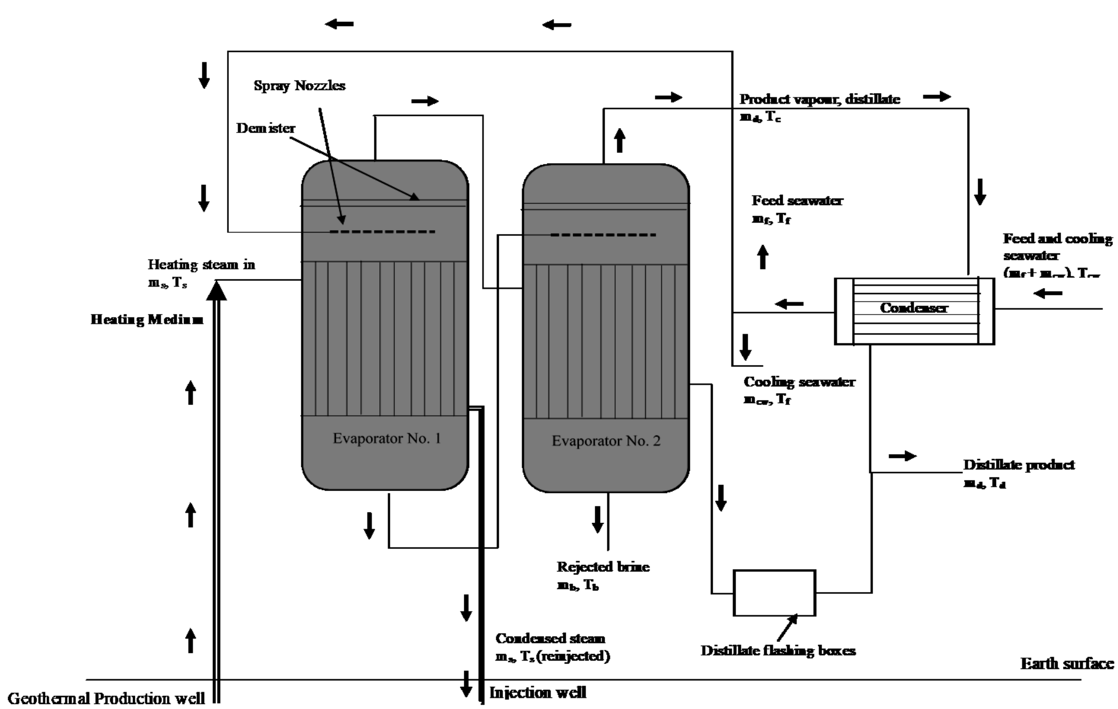


FIG. 3. Geothermal integrated Double Effect Evaporator (DEE) desalination system (El-Dessouky and Ettouney 1999; Gude 2016).

As shown in (fig. 3.) feed seawater (m_f) with (x_f) concentration and cooling water (m_{cw}) at a temperature (T_{cw}) is entered into the condenser/preheater where it exchanges heat with vapour produced in the evaporator and the temperature rises from (T_{cw}) to (T_f). Feed seawater leaves the condenser/preheater unit at temperature (T_f). The portion of cooling water is further sent back to sea. The importance of cooling water (m_{cw}) is to remove excess heat to enter the system by heating steam. The heating of feed seawater from (T_{cw}) to (T_f) in condenser/preheater is primally to increase the system's performance. The vapour produced in the evaporator is to be used to heat the seawater inside the preheater. Before the seawater or feed, water enters into the evaporator is passed through the primary treatment where the feed seawater is filtered and chemically treated. The primary treatment is essential because to prevent scale formation and foaming in the evaporator (El-Dessouky et al. 1998, 2002).

After all, the feed water is sprayed in the first evaporator using a spray nozzle at the top, where it directly contacts with tubes. In this case, heating steam utilized low enthalpy geothermal heat energy, which has a temperature of less than 130 ^{0}C provides sensible and latent heat for water evaporation. Finally, the feedwater temperature (T_f) is increased to the boiling temperature (T_b). Now, Due to the effect of Boiling Point Elevation (BPE), the temperature of vapour (T_v) produced in the evaporator is lower than the boiling temperature (T_b) and also the temperature of condenser vapour (T_d) is less than the temperature of generated steam (T_v) due to the demister (El-Dessouky et al. 2002). Now the vapour product from the first effect is utilized as a heating medium in the second effect. Finally, vapour from the second evaporator sent to the condenser where seawater was used as a coolant. New freshwater is consistently collecting in the tank by using a pump then it will circulate through the water pipeline from the desalination plant(Prajapati et al. 2021). The brine is rejected from the evaporator's bottom. After using heat from the geothermal fluid to the evaporator (desalination system), the reinjection of this geofluid into the earth by utilizing injection well (M. Shah, Sircar, Shaikh, et al. 2019).

3. METHODOLOGY

3.1. Design of DEE and DSEwith Steam Jet Ejector in Microsoft Excel & Matlab/Simulink

Microsoft Excel is a spreadsheet program that is utilized to record and analyze numerical data. Now, the following set of specifications (Input data) used for the solution of a geothermal integrated desalination system (DEE and DEE with steam jet ejector) in Microsoft Excel and MATLAB/Simulink(Nafey, Sharaf, and García-Rodríguez 2010).

m_d	1	(kg/s)
T_b	50-90	(^{0}C)
T_{cw}	25	(^{0}C)
T_f	calculated	(^{0}C)
T_s	60-130	(^{0}C)
X_f	36000	(ppm)
X_b	60000	(ppm)
Cp	4.21	(KJ/kg ^{0}C)
Cpv	1.88	(KJ/kg ^{0}C)
Cr	2-4	
η	0.9	
P	300	Kg/m^3
V	1.8	m/s
L	0.1	m
δ_w	0.28	mm

Table. 1. Input data

MATLAB/Simulink is a universally useful software program for dynamic frameworks (Nafey, Sharaf, and García-Rodríguez 2010). This program has been chosen to make the undertaking of Geothermal integrated desalination system modeling & simulation since it offers magnificent execution characteristics for structuring algorithms. The User can easily build models using different Library Blocks or changing a current model. For demonstrating, MATLAB/Simulink gives a GUI for making models as block diagrams, using click-and-drag mouse activities(Nafey, Fath, and Mabrouk 2006). With this GUI, the user can draw the models comparatively as it would with a pencil and paper. Simulink incorporates an exhaustive block library of Sources, Sinks, Nonlinear and Linear components, User-Defined Functions and Connectors. The User can likewise modify and make his blocks. (fig. 6) shows the Library Browser, user can build models by copying blocks from a library into a work area (Nafey, Fath, and Mabrouk 2006).

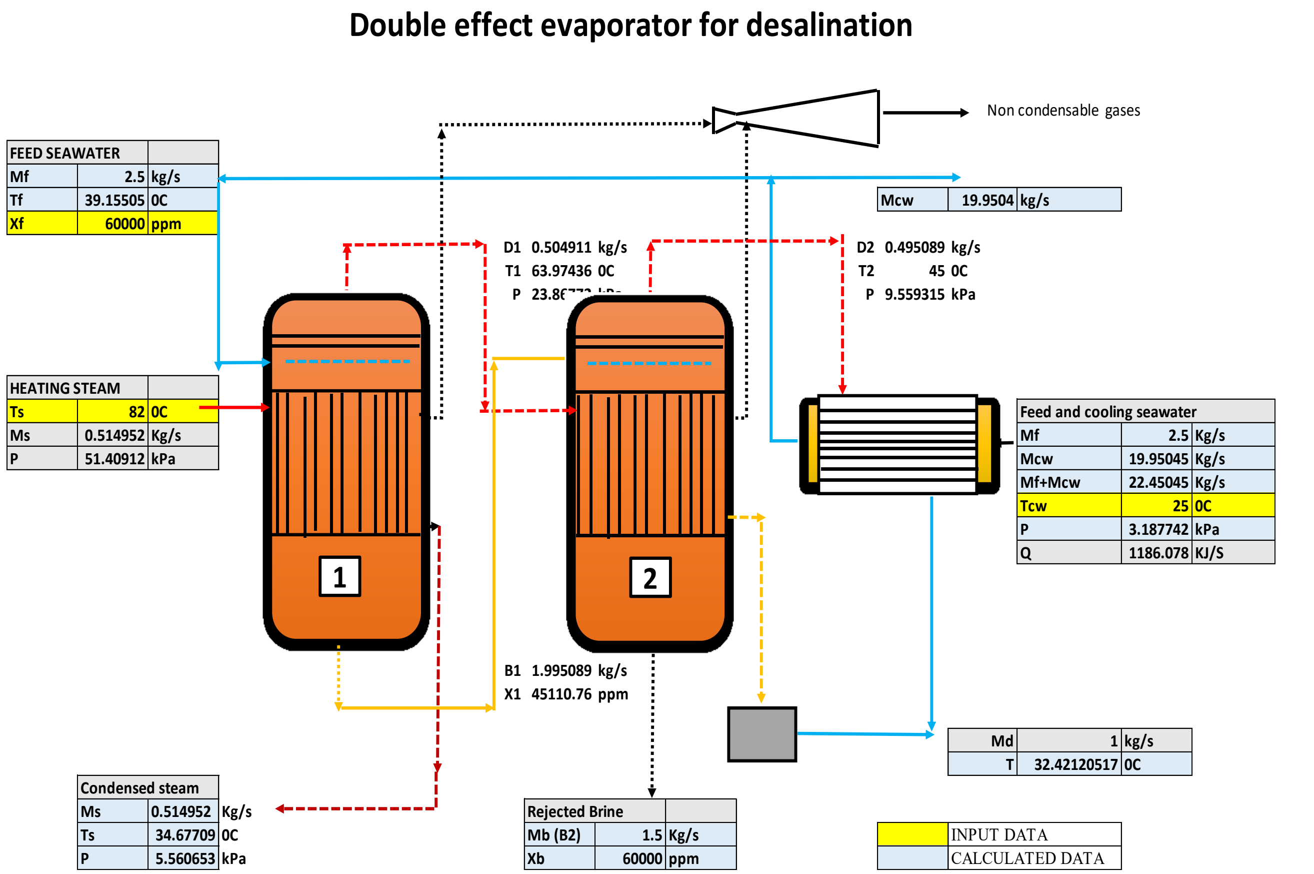


Fig. 4. Double effect evaporator desalination system in Microsoft Excel.

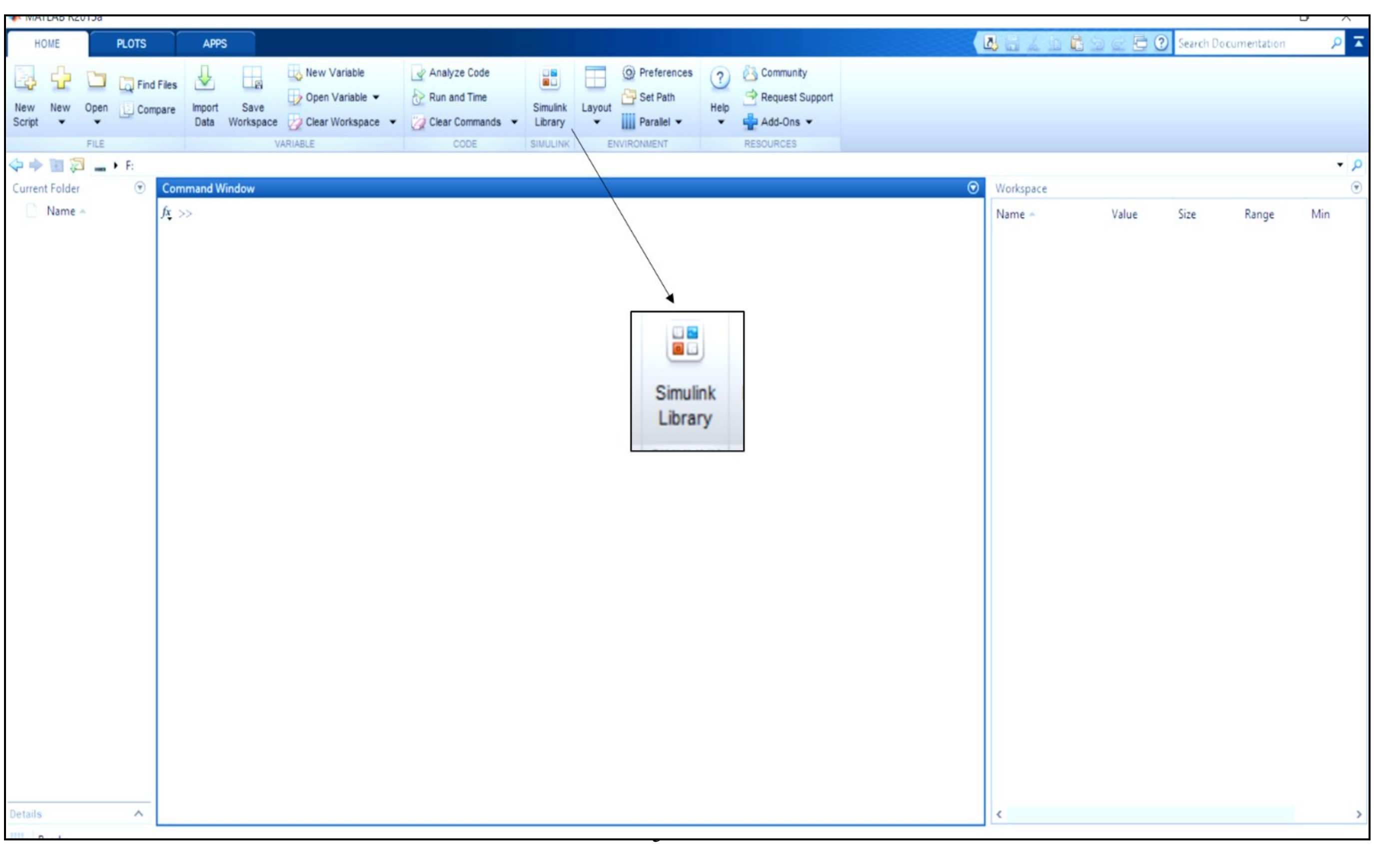


FIG 5. Location of Simulink library in MATLAB (Nafey, Fath, and Mabrouk 2006).

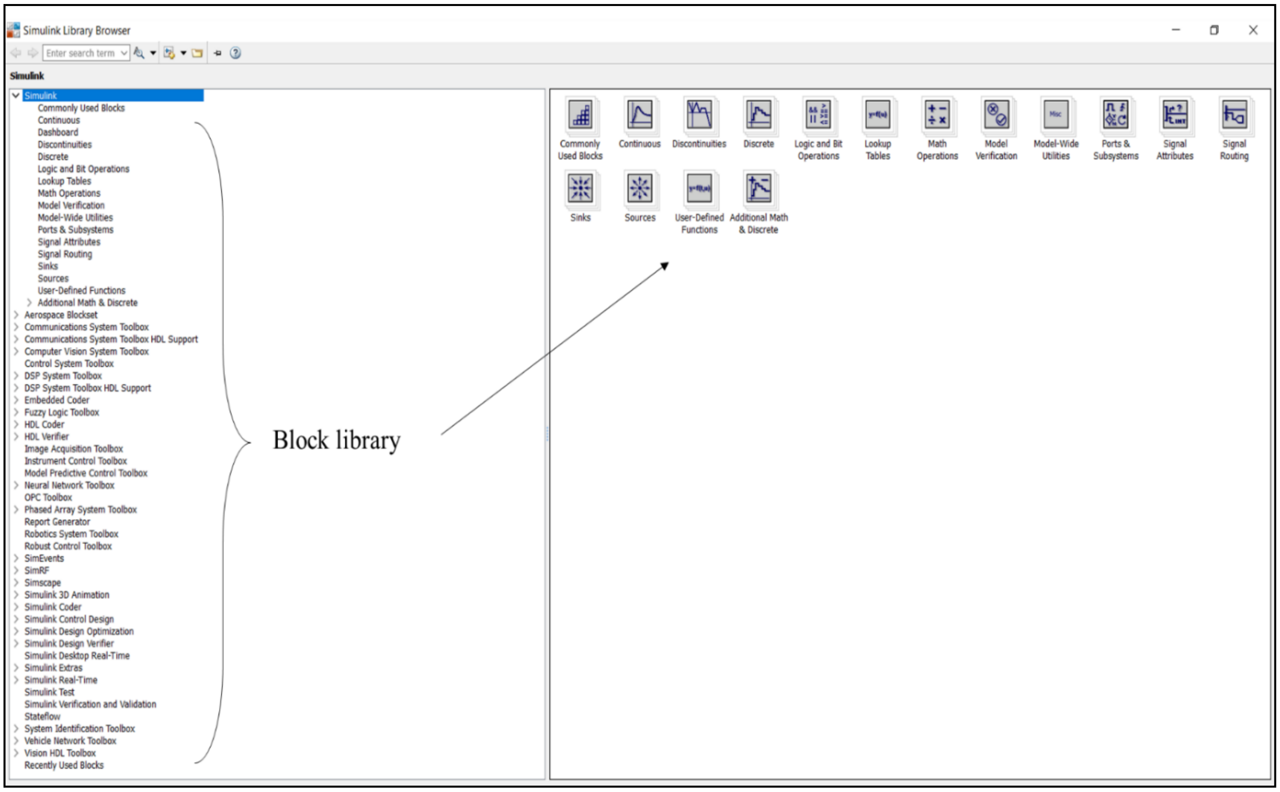


Fig. 6. Simulink library browser with different blocks (Nafey, Fath, and Mabrouk 2006).

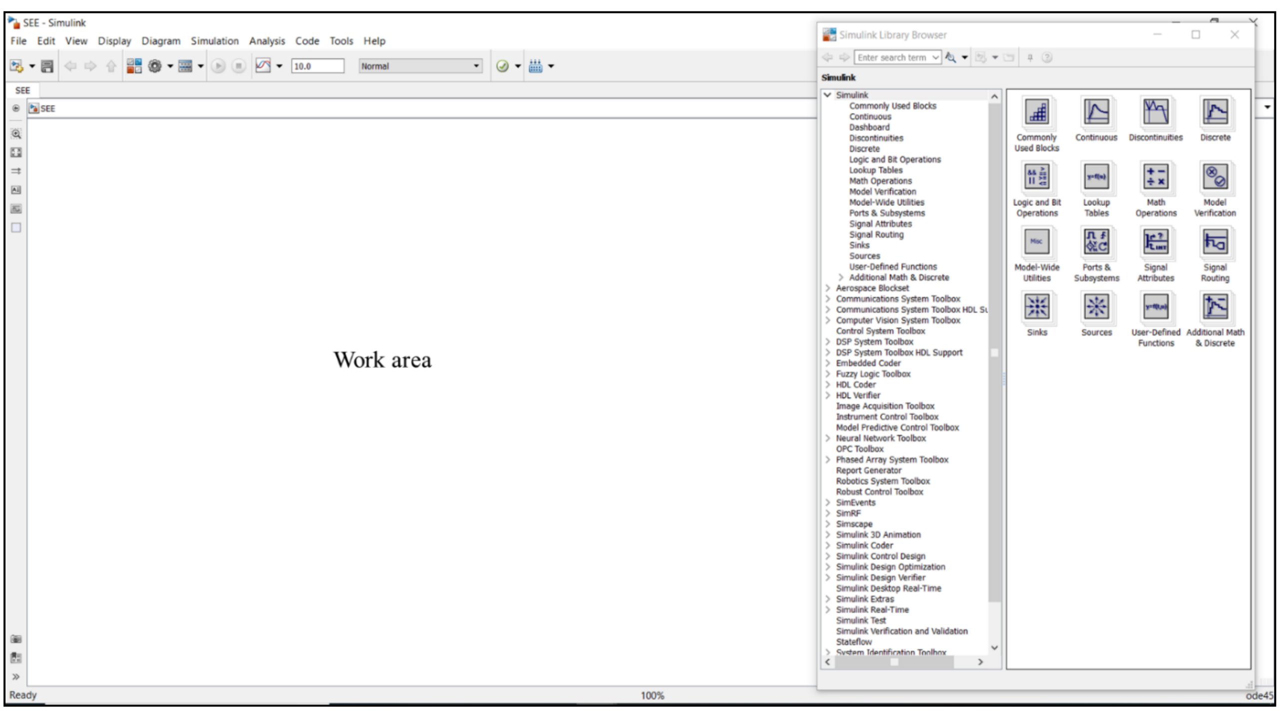


Fig. 7. Work area for drawing model using different blocks (Nafey, Sharaf, and García-Rodríguez 2010).

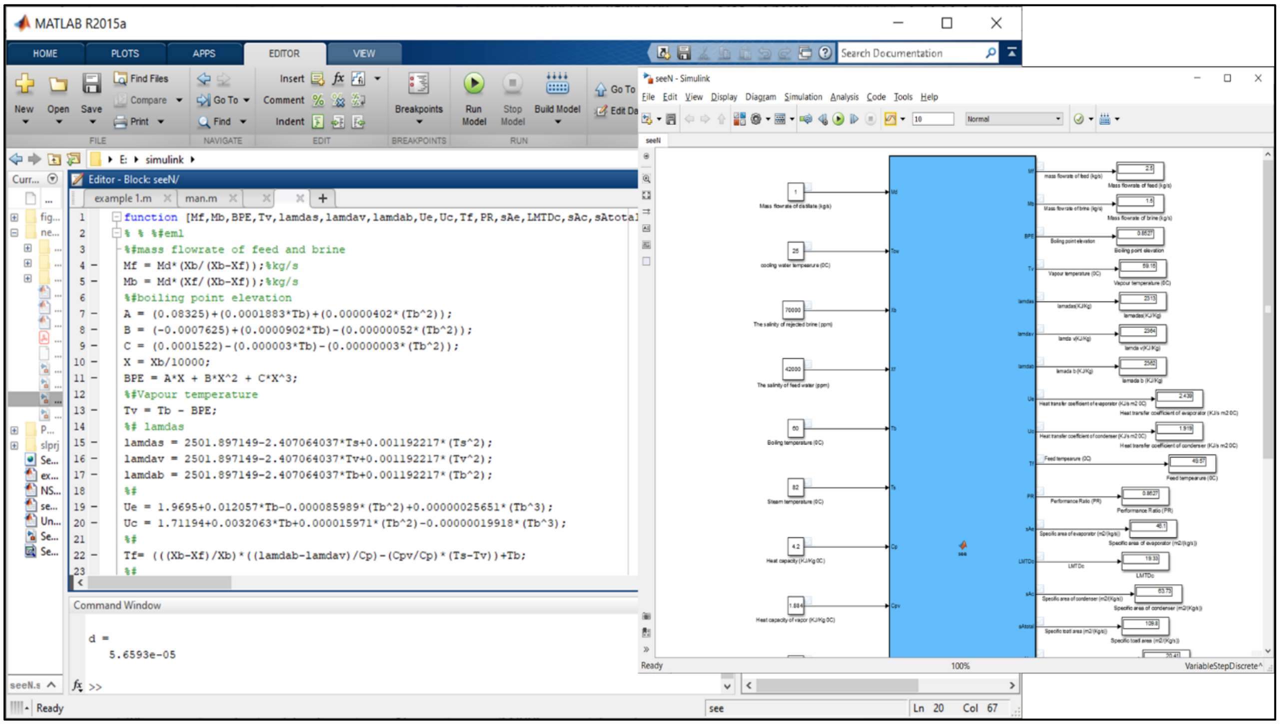


Fig. 8. MATLAB/Simulink program and block diagram for Dingle effect evaporator (DEE).

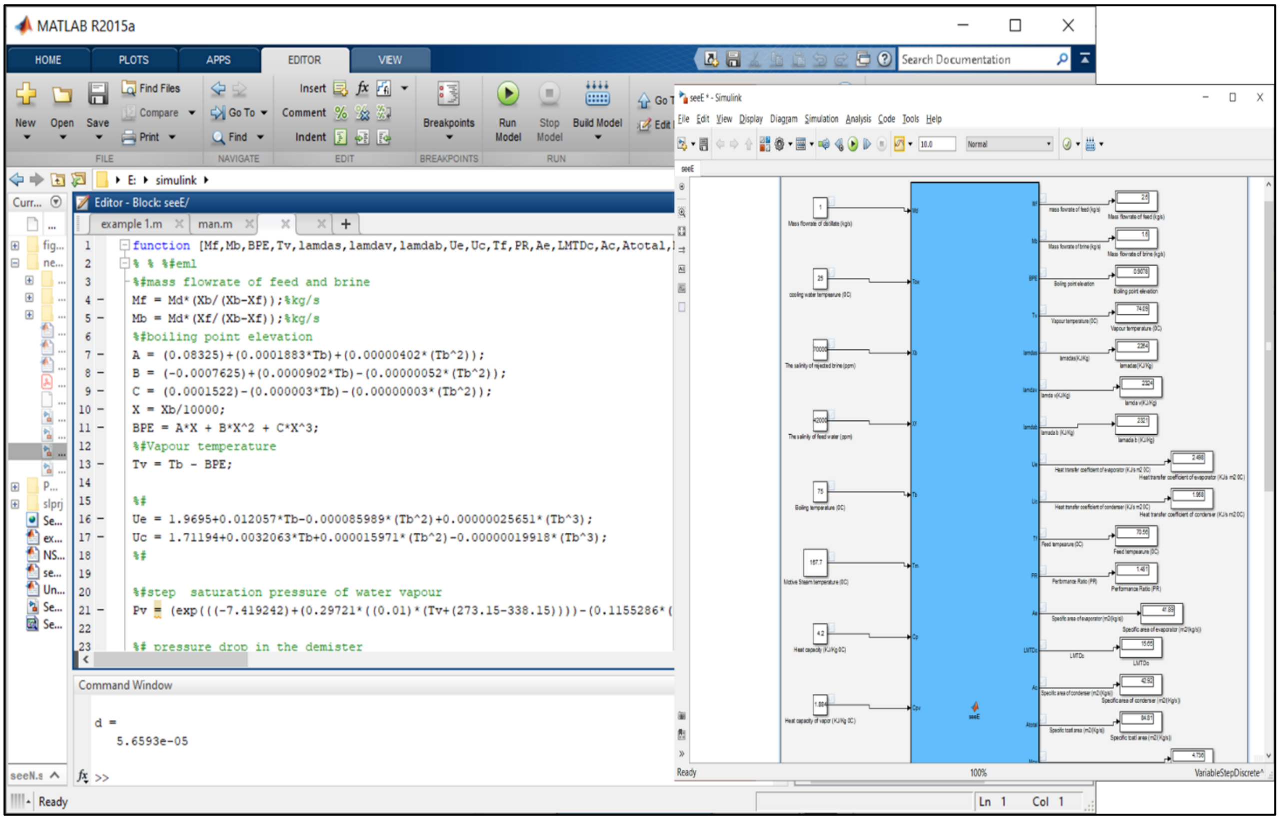
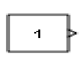
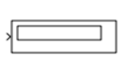


Fig. 9. MATLAB/Simulink program and block diagram for Double effect evaporator with a steam jet ejector model.

Following Library Blocks are used in the model (Nafey, Fath, and Mabrouk 2006),

No.	Name of Block	Symbol	Location of Block	Use in Model
1	Constant		Simulink/ Sources/constant	Generate constant value
2	User-Defined Functions		Simulink/ User-Defined Functions	Apply specified expression to input
3	Display		Simulink/ Sinks/Display	Show the value of input

5. RESUSLT AND DISCUSSION

The performance of geothermal integrated Double Effect Evaporator (DEE) and Double Effect Evaporator (DEE) with steam jet ejector system described as follows,

(fig. 10-14) and (Table 2.) For the different value of boiling temperature (T_b), heating steam temperature (geofluid temperature) (T_s) and cooling water temperature (T_{cw}), analyzed the performance of Double-effect evaporator in terms of specific heat transfer area (sA), performance ratio (PR), the cooling water flowrate (m_{cw}).

N	2							
T_n	**40**	**50**	**40**	**50**	**40**	**50**	**40**	**50**
T_b	**PR**		**M_{cw}**		**M_s**		**sA**	
75	1.944	1.959	21.7113	11.4	0.5143	0.51045	172.79	219.08
80	1.9361	1.9508	23.083	11.77	0.5165	0.51229	151.27	165.3
85	1.9278	1.9426	24.63	12.16	0.5187	0.5147	135.66	139.8
90	1.9195	1.934255	26.39	12.576	0.52095	0.5169	123.622	122.98
100	1.9026	1.9172	30.8	13.48	0.5255	0.5215	106.611	100.93

Table 2. Parameters analysis at different value of boiling temperature (Tb) and last effect temperature (Tn)

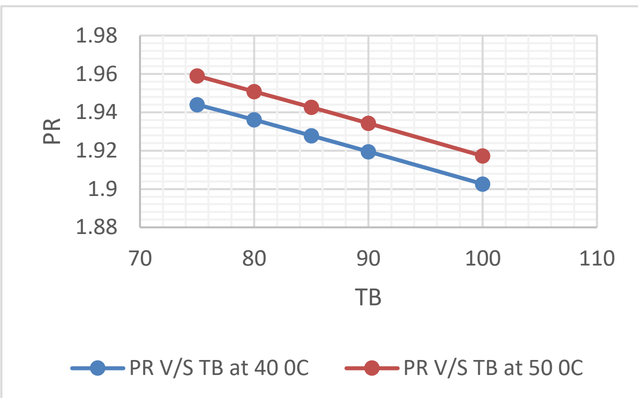


Fig. 10. Performance ration v/s Boiling temperature

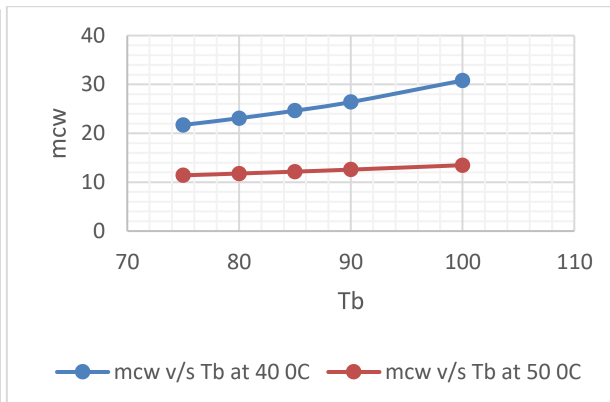


Fig. 11. Mass flowrate of cooling water v/s Boiling temperature

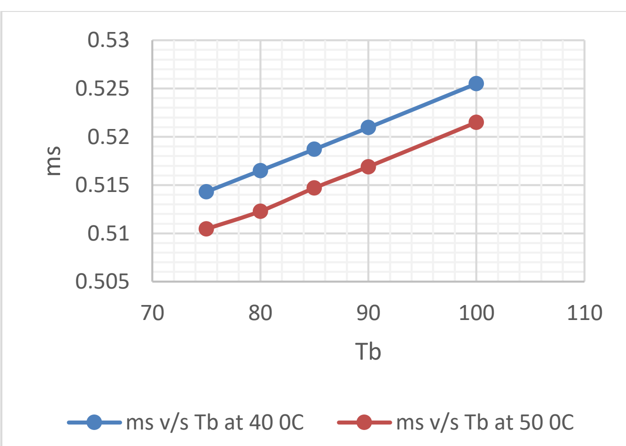


Fig. 12 Mass flowrate of heating steam (Geothermal liquid) v/s Boiling temperature

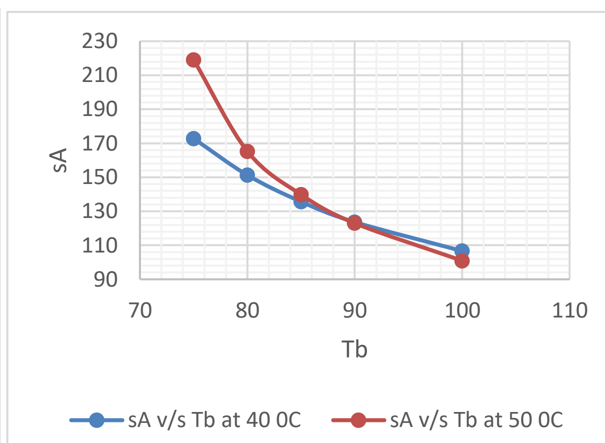


Fig. 13. Specific area v/s Boiling temperature

6. CONCLUSION

This work presents a steady-state modeling and analysis of Double-effect evaporator (DEE) & Double effect evaporator with steam jet ejector using Excel and MATLAB/Simulink for geothermal integrated desalination system. By comparing results obtained from manual calculation, Excel and MATLAB/Simulink are approximately the same with a minor difference. So, as to have a good and optimized design. The performance of geothermal integrated Double effect evaporator and Double effect evaporator with steam jet ejector system described as follows, Various parameters, which can conceivably change the results of the evaluation were picked to examine their effect on design. For the different value of boiling temperature (T_b), heating steam temperature (geofluid temperature) (T_s) and cooling water temperature (T_{cw}), motive steam pressure (P_m), compressor ratio (Cr) analyzed the performance of double-effect evaporator in terms of Specific Heat Transfer Area (sA), Performance Ratio (PR), the Cooling Water Flowrate (m_{cw}). The output from the simulation shows that the performance ratio for DEE without a steam jet ejector is always less than two, and the performance ratio for DEE with a steam jet ejector is greater than two. At low boiling temperature and high motive steam pressure, a higher performance ratio is obtained. With increasing in T_b (boiling temperature) and P_m (motive steam pressure) the PR (performance ratio) is decreased because the vapor pressure increases with increasing temperature.

The specific heat transfer area (sA) is increases with increasing boiling temperature (T_b) and heating steam temperature (T_s). In addition, it will decrease with increasing boiling temperature (T_b) and decreasing in cooling water temperature (T_{cw}). The specific cooling water flowrate is decreasing with increases in boiling temperature. In addition, it will change with both boiling temperature and compression ratio. The model and simulation will be useful in later effect for the simulation in MATLAB/Simulink for a geothermal integrated desalination system.

APPENDIX

Data and Result for DEE in Microsoft Excel

No. of effect N	2	
X (salt weight percentage)	6%	
X_b	60000	ppm
X_f	36000	ppm
M_d	1	Kg/s
M_f	2.5	
M_b	1.5	
Cp	4.2	KJ/Kg ^{0}C
T_c	647.5	K
Feed temp. T_f	39.15505	^{0}C
Vapor Temp. in last effect T_n	45	^{0}C
Cooling water Temp. T_{cw}	25	^{0}C
Steam temp. T_s	82	^{0}C
PR	1.941928	
Total temp. drop across the effect	37	^{0}C
Overall heat transfer coefficient factor	0.95	
Overall heat transfer coefficient U_1	2.4	KW/m^2 ^{0}C
Overall heat transfer coefficient for condenser U_c	1.75	KW/m^2 ^{0}C
P_c	22089	kPa
T_c	647.286	K
Saturation pressure of water vapour, P_1	23.90667	kPa
Pressure drop in Demister	389.5614	Pa/m
pressure drop in Demister	0.038956	kPa
Vapour pressure past the Demister, P_1	23.86772	kPa
Saturation temp. T_1	63.9467	^{0}C
Saturation pressure of water vapour, P_2	9.598271	kPa
pressure drop in Demister	389.5614	Pa/m
pressure drop in Demister	0.038956	kPa
Vapour pressure past the Demister, P_2	9.559315	kPa
Saturation temp. T_2	44.89008	^{0}C
Heat capacity of the vapor, C_{pv}	1.884	KJ/Kg ^{0}C
λb at T_1	2349.085	KJ/Kg
λd at T_2	2395.685	KJ/Kg
feed temp. T_f	39.15505	^{0}C

Outlet temp. of heating steam T_o	34.67709	^0C

NOMENCLATURE:

RO	Reverse Osmosis
MD	Membrane Distillation
ED	Electrodialysis
MED	Multiple Effect Distillation
MSF	Multi-Stage Flash
TDS	Total Dissolved Solid
TVC	Thermal Vapour Compressor
PV	Photo-Voltaic

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