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A simulator for thermal desalination processes

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Abstract

A computer package has been developed for design and simulation of thermal desalination processes. This was motivated by the unavailability of such packages in the literature or on a commercial scale. The package includes models for various systems of single effect evaporation (SEE), multistage flash (MSF), and multi effect evaporation (MEE). The MSF systems include brine circulation, brine mixing, once through, and thermal vapor compression. The MEE configurations include parallel and forward feed systems. The SEE and MEE systems include stand-alone and vapor compression units. Vapor compression systems include mechanical, thermal, absorption, and adsorption heat pumps. All models are based on a well developed set of materials and energy balance equations as well as correlations for evaluation of physical properties, heat transfer coefficient, and thermodynamic losses. All mathematical models have been developed and previously tested and validated by the authors against available industrial and literature data. All models generate the design and simulation variables which have the strongest effect on the unit product cost. These include the thermal performance ratio, the specific heat transfer area, the conversion ratio, the specific power consumption, and the specific flow rate of cooling water. The computer package includes displays for process design, rating, flow charting, performance calculations, help files, and graphing of process schematics and performance curves. The package allows for parameter selection, printing of forms and data files, and selection of parameters for performance charts. The package performs checks on parameter range and prevents pinch conditions in various heat exchange processes. The package has been tested in a number of undergraduate, graduate, and training classes and is found simple to use and provides fast and accurate results.

Keywords: Simulator; Thermal desalination

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1. Introduction

The desalination industry is the lifeline for several countries and zones around the world, especially the Gulf countries, southern California, and the Caribbean islands. The industry has expanded considerably since inception in the early 1950s. The limited number of the early production units, the fully immersed type evaporators, had a very poor overall performance (Temperley, 1997). Operation of such unit was plagued by scale formation, excessive corrosion, and high frequency of tube failure. The units were operated for periods of less than 4 weeks, followed by a similar period for cleaning and maintenance. Since then, various developments have been achieved in system design, construction, operation, and control, where use of alloy materials and special chemicals allows for plant operating factors close to 90% (El-Dessouky et al., 1999a).

Today, thermal desalination processes account for more than 65% of the production capacity of the desalination industry. This market share is dominated by the multistage flashing (MSF) with more than 90% of capacity for all thermal desalination processes. The remaining 10% of thermal desalination production capacity is shared among the single and multiple effect evaporation (MEE) with/without vapor compression. The authors believe very strongly that these processes will dominate desalination in the near future. On the other hand, the reverse osmosis process (RO) has a market share close to 35% of the desalination industry (Ettouney et al., 1999a).

Expansion in the desalination industry is associated with reduction in the specific power consumption from high values of 100–250 kW/1000 gal in 1955 to 15–40 kW/1000 gal. Also, recent quotes for the unit product cost show \$0.8/m^3 for 6 mgd MSF, \$0.72/m^3 to \$0.93/m^3 for RO (depending on pretreatment cost), and \$0.45/m^3 for low-temperature MEE (Bednarski and Minamide, 1997). Irrespective of these developments, the capital cost of various configurations remains high, especially for developing countries. A desalination unit with a capacity of 6 mgd would have a capital cost that may vary between 70–100 million dollars (Leitner, 1998). Such a unit is suitable for a small community of 120,000 inhabitants by assuming a daily consumption average of 50 gal per capita.

Further expansion in the desalination industry is subject to achievement of landmark developments that result in reduction of the unit production cost. Recent research indicates various attempts that address current drawbacks of existing technologies. New and novel ideas in thermal desalination include the following studies: (1) MSF with vapor compression (El-Dessouky et al., 1999b); (2) use of plastic evaporators and condensers (El-Dessouky and Ettouney, 1999a); (3) operation of MSF with brine mixing (El-Dessouky et al., 1999c); (4) use of two steam jet ejectors for high temperature MEE (El-Dessouky and Ettouney, 1997); and (5) use of compact evaporators and condensers (Ettouney et al., 1999a). In addition, comprehensive programs for education, training and technology transfer are developed to address the needs of major manufacturers, especially in the Gulf and the Middle East countries (El-Dessouky et al., 1999d; Alatiqi et al., 1999).

Efficient and accurate computer package routines for simulation and design of thermal desalination processes form an essential element for education and training of desalination manpower. The package provides a simple-to-use tool for system design, rating simulation, and development. Various types of mathematical models for simulation of the thermal desalination processes can be found in the literature; however, the literature does not provide a comprehensive and integrated simulation and design package. This motivated execution of the current research to develop a comprehensive computer package that constitutes a number of mathematical models, which have been previously developed and tested by the authors. The authors have used the models and the package in several training courses as well as graduate and undergraduate desalination courses. The models include the following:

- The conventional brine circulation MSF (El-Dessouky and Bingulac, 1996; El-Dessouky et al., 1995)
- MSF with brine mixing (El-Dessouky et al., 1999c)
- Once-through MSF (El-Dessouky et al., 1998a)
- MSF with vapor compression (El-Dessouky et al., 1999b)
- Single-effect thermal vapor compression (Darwish and El-Dessouky, 1996; El-Dessouky, 1997; El-Dessouky and Ettouney, 1999b)
- Single-effect mechanical vapor compression (Ettouney et al., 1999b; El-Dessouky and Ettouney, 1999a)
- SEE units with mechanical, thermal, absorption, and adsorption vapor compression (Al-Juwayhel et al., 1997)
- Parallel feed MEE with/without vapor compression (El-Dessouky and Ettouney, 1998c; El-Dessouky and Ettouney, 1999d)
- Forward feed MEE (El-Dessouky et al., 1998b).
- Forward feed MEE with vapor thermal, mechanical, absorption, and adsorption vapor compression (El-Dessouky and Ettouney, 1997).

Features of the developed models include the following:

- Adopt the practice case of constant heat transfer areas in the evaporators and feed preheaters in all evaporating effects and flashing stages. This is necessary to improve the economics and the construction procedures of the plant.
- Consider the effect of vapor leak through the venting system.
- Model variations in the thermodynamic losses (boiling point elevation, non-equilibrium allowance inside the evaporators and the flashing boxes, temperature depression corresponding to the pressure drop in the demister, vapor transmission lines, and during the condensation process) from one effect to another.
- Study the effect of boiling temperature, the velocity of brine flowing through the tubes of feed heaters, the tube material of construction, and the tube bundle geometry on the required specific heat transfer area.
- Consider the effects of water temperature and salinity on the water physical properties such as density, latent heat of evaporation, viscosity, Prandtl number, and specific heat at constant pressure.
- Weight the effect of the presence of non-condensable gases on the heat transfer coefficients in the evaporators and the feed heaters.

The following sections include a description of various elements forming the computer package as well as a set of case studies for SEE and MEE. The case studies include the design and flow chart calculations.

2. Elements of the computer package

Fig. 1 shows elements of the computer package, and it includes help files, process selection, selection of calculation type, and data output. The help files include process description, process schematics, performance analysis, glossary of terms, and a description of various calculation procedures. The process selection includes SEE and MEE with/without vapor compression and MSF. The single-effect systems include the stand-alone evaporation or flashing units, mechanical vapor compression (MVC), thermal vapor compression (TVC),

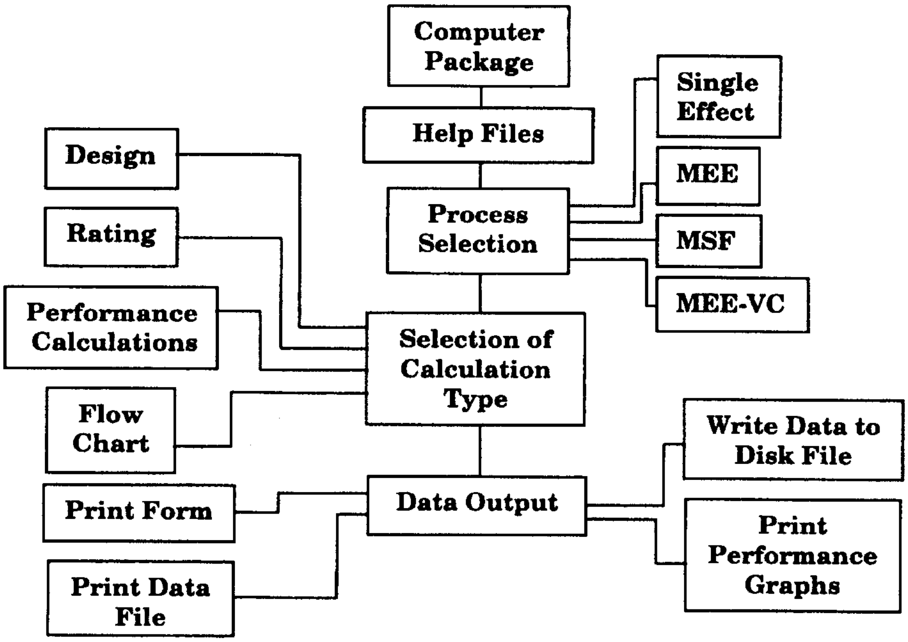


Fig. 1. Elements of the computer package.

absorption vapor compression (ABVC), and adsorption vapor compression (ADVC). The multiple effect systems include the forward and parallel feed configurations, while the multiple effect systems with vapor compression include the forward and multiple feed configurations combined with various vapor compression heat pumps including thermal, mechanical, absorption, and adsorption. The MSF systems include the conventional brine recycle arrangement (MSF), the once-through system (MSF–OT), brine mixing (MSF–M), and the vapor compression configuration (MSF–VC). Various types of calculations are included in the package; these are design, rating, performance evaluation, and flow chart. The design and rating calculations are suitable for detailed evaluation of the system characteristics, since it allows for variations in the system capacity, stream temperatures, tube geometry and thermal conductivity, fouling resistance, demister properties, and stream velocities. On the other hand, the flow chart calculations are more suitable for classroom education and training purposes since it is limited to variations in the system capacity and stream temperatures. The performance calculations allow for generation of performance charts over a range of design parameters, which may include stream temperatures and flow rates. The data output options allow for printing various forms, printing data files, writing of data files to the hard disk, and printing of performance graphs.

To optimize the computer package, it was necessary to make use of similar model components and package displays for various processes. The model components are shown in Fig. 2, which includes functions for calculations of the physical properties of seawater, vapor and condensate, thermodynamic losses, and heat transfer coefficients. Other common elements include functions for modeling the steam jet ejector, the mechanical compressor, the down

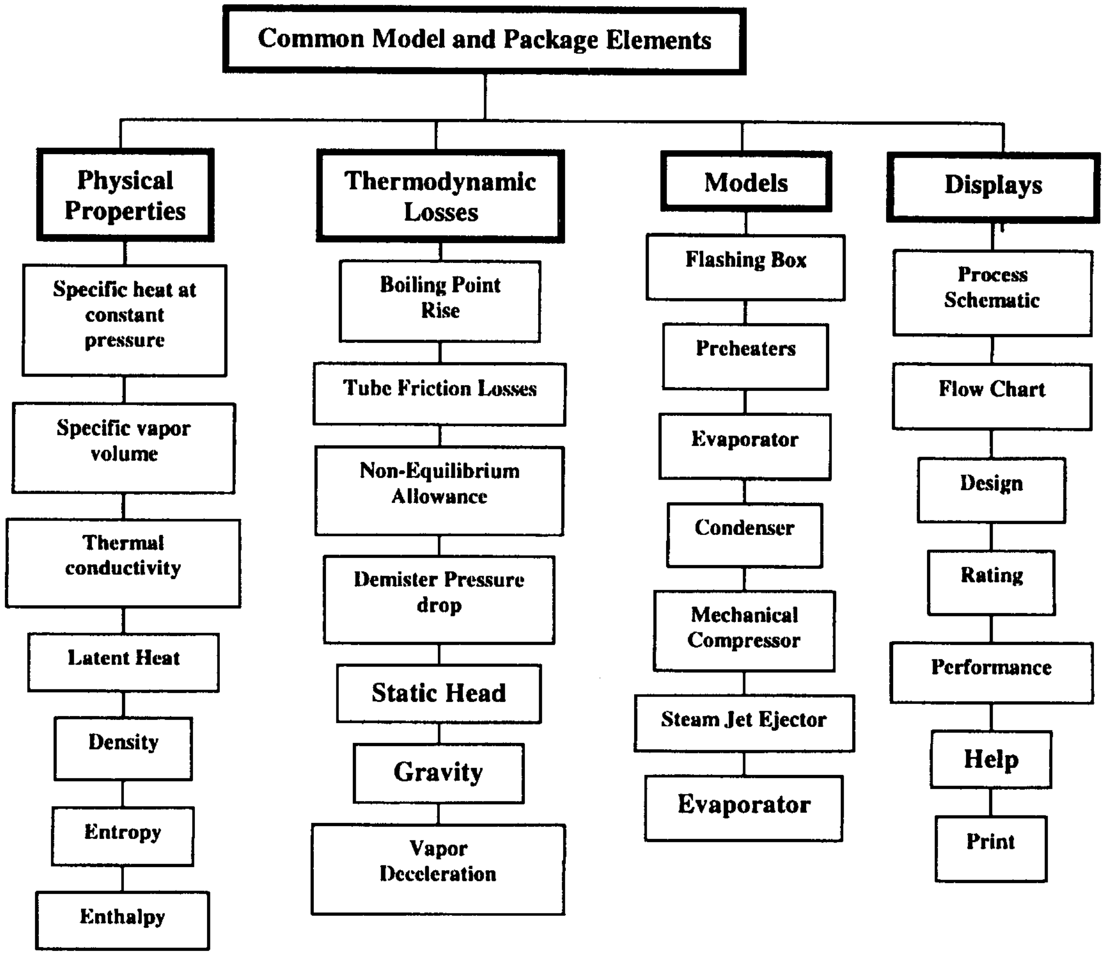


Fig. 2. Common elements of the computer package.

condenser, the evaporator, the flashing boxes, and the brine heater. On the other hand, the common package elements include displays for process schematic, flow chart, design, rating, and performance for the each of the single effect, the multiple effect, and the MSF processes.

3. Case studies

The following case studies include analysis of the SEE with/without vapor compression. Also, a case study is presented for the stand-alone forward feed MEE The case studies include process description as well as design and flow chart calculations.

3.1. Single-effect evaporation (SEE)

Process description and details of the mathematical model for the SEE system can be found in the textbook on fundamentals of desalination by El-Dessouky and Ettouney (1999c). The package displays for the SEE system are shown in Figs. 3–6. The process schematic is shown in Fig. 3, which contains an evaporator and a condenser. The evaporator is driven by a saturated heating steam. The intake seawater enters the down condenser where its temperature is increased by absorbing the latent heat of the formed distillate vapor. This process is necessary to improve the process efficiency and to remove the heat added to the system by the heating steam. Part of the intake seawater, which is known as the cooling water, is rejected back to the sea. The remaining portion of the intake seawater forms the feed stream to the evaporator, which is sprayed over of the horizontal tubes in the evaporator. The seawater spray forms a falling film over the evaporator tube and it absorbs the latent heat of the condensing steam inside. Part of this heat increases the seawater temperature to saturation where evaporation commences. The formed vapor flows through the demister to remove entrained brine droplets and then is condensed in the down condenser.

The design display is shown in Fig. 4, and it includes two sets of input data. The solution parameters include the system capacity, the boiling temperature, the intake seawater temperature and salinity, the temperature difference of heating steam and boiling brine, and the temperature difference of the feed seawater and boiling brine. The design parameters include tube diameter, thickness, and thermal conductivity. It also includes the fouling resistance, stream velocity, and thickness of the falling film and demister and demister density. Variations in the solution and design parameters affect the product unit cost, which is affected by the calculated flow rate of the heating steam, the heat transfer area, and the flow rate of the intake seawater.

Results for the above design data are shown in Fig. 5, which includes the solution parameters, the heat transfer areas, flow rates, temperatures, and pressures. As is shown, the performance ratio for the single-effect evaporator is 0.97, less than one, which is consistent with the performance of single-effect units. The heat transfer areas are also within practical values where the evaporator area is 224.24 $m^2/(kg/s)$ and the condenser area is 95.9 $m^2/(kg/s)$. The overall heat transfer coefficient for the evaporator and condenser are 2.07 $kW/m^2\,°C$ and 1.95 $kW/m^2\,°C$, respectively.

The flow chart displays have several modes including the start-up flow chart, design, and results for individual units. Fig. 6 shows the design display, which is used to vary the input data before solution of the problem and calculation of the results. Use of the flow chart display is suitable for classroom education and training purposes. On the other hand, detailed calculations that require variations in the design parameters are made in the design display shown in Figs. 4 and 5. Results of the flow chart calculations are displayed upon pressing the system blocks. For example, pressing the evaporator/condenser block gives a display for the unit heat transfer area, overall heat transfer coefficient, mean temperature difference, and thermal load.

3.2. Single-effect mechanical vapor compression (MVC)

Modeling and analysis of the MVC system can by found in several studies by the authors including Al-Juwayhel et al. (1997), El-Dessouky and Ettouney (1999a) and Ettouney et al. (1999b). A limited number of displays is shown for the MVC system, which includes the process schematic (Fig. 7) and the flow chart results display (Fig. 8). Other displays for the MVC process are not shown here because of their similarity with the SEE process. The MVC process display is shown in Fig. 7. The process contains a mechanical compressor, evaporator, and feed preheaters. The intake seawater is heated in the feed preheaters by absorbing the sensible heat of the rejected brine and the distillate product. The feed preheaters are plate

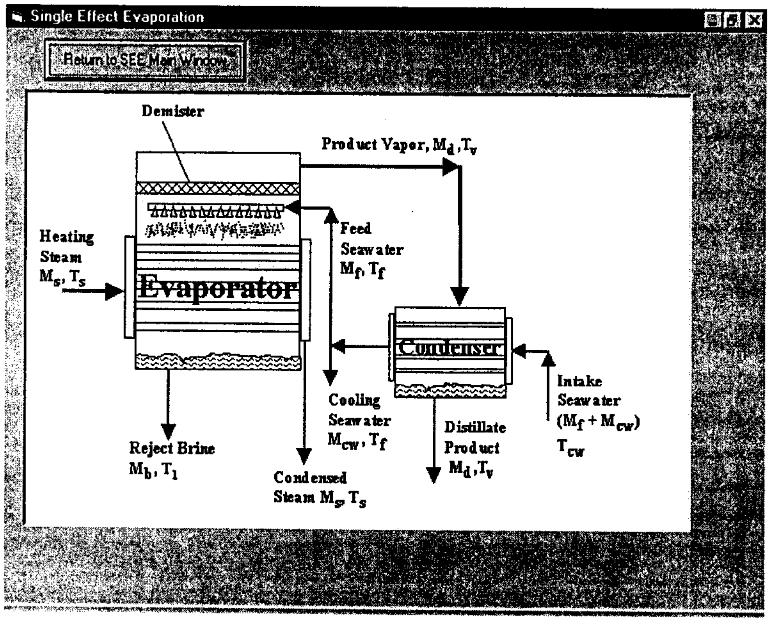
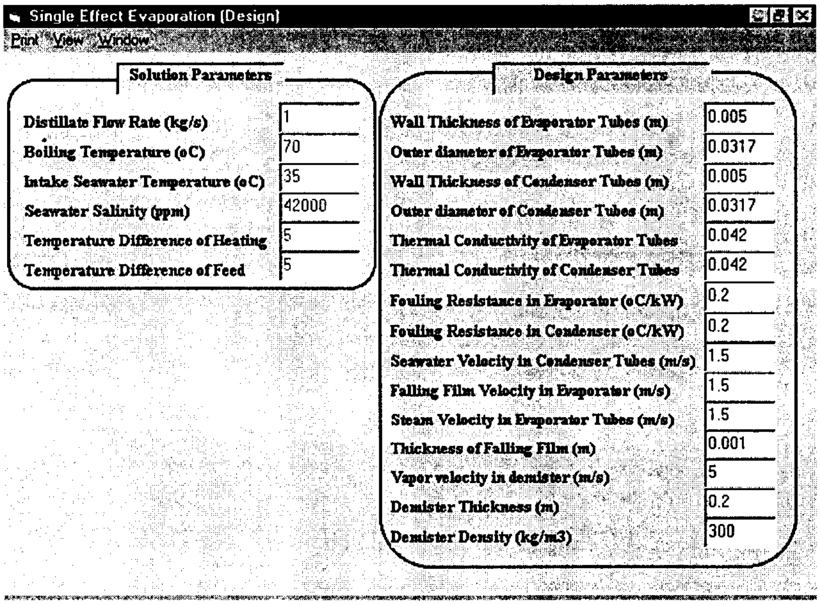


Fig. 3. Schematic display of the single-effect evaporator.



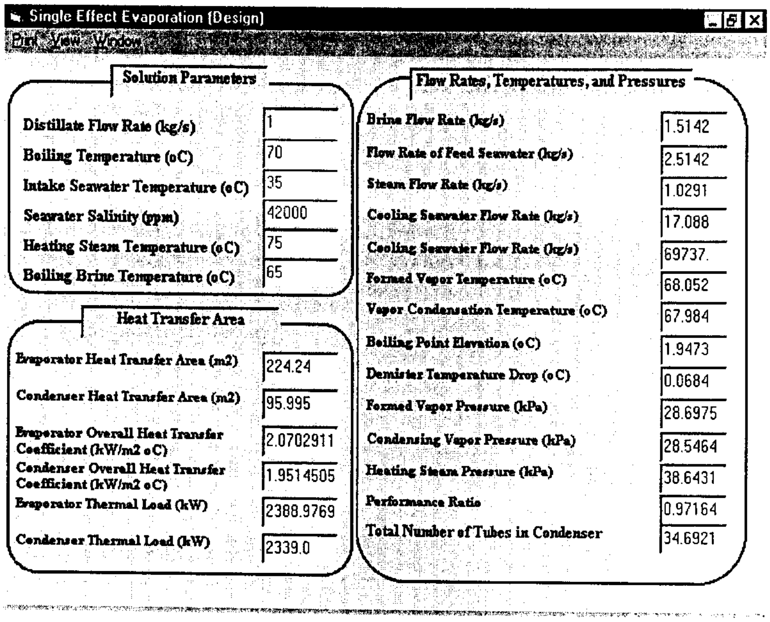
Solution Parameters

Distillate Flow Rate (kg/s)	1
Boiling Temperature (oC)	70
Intake Seawater Temperature (oC)	35
Seawater Salinity (ppm)	42000
Temperature Difference of Heating	5
Temperature Difference of Feed	5

Design Parameters

Wall Thickness of Evaporator Tubes (m)	0.005
Outer diameter of Evaporator Tubes (m)	0.0317
Wall Thickness of Condenser Tubes (m)	0.005
Outer diameter of Condenser Tubes (m)	0.0317
Thermal Conductivity of Evaporator Tubes	0.042
Thermal Conductivity of Condenser Tubes	0.042
Fouling Resistance in Evaporator (oC/kW)	0.2
Fouling Resistance in Condenser (oC/kW)	0.2
Seawater Velocity in Condenser Tubes (m/s)	1.5
Falling Film Velocity in Evaporator (m/s)	1.5
Steam Velocity in Evaporator Tubes (m/s)	1.5
Thickness of Falling Film (m)	0.001
Vapor velocity in demister (m/s)	5
Demister Thickness (m)	0.2
Demister Density (kg/m3)	300

Fig. 4. Display of solution and design parameters for single-effect evaporation.



Solution Parameters

Distillate Flow Rate (kg/s)	1
Boiling Temperature (oC)	70
Intake Seawater Temperature (oC)	35
Seawater Salinity (ppm)	42000
Heating Steam Temperature (oC)	75
Boiling Brine Temperature (oC)	65

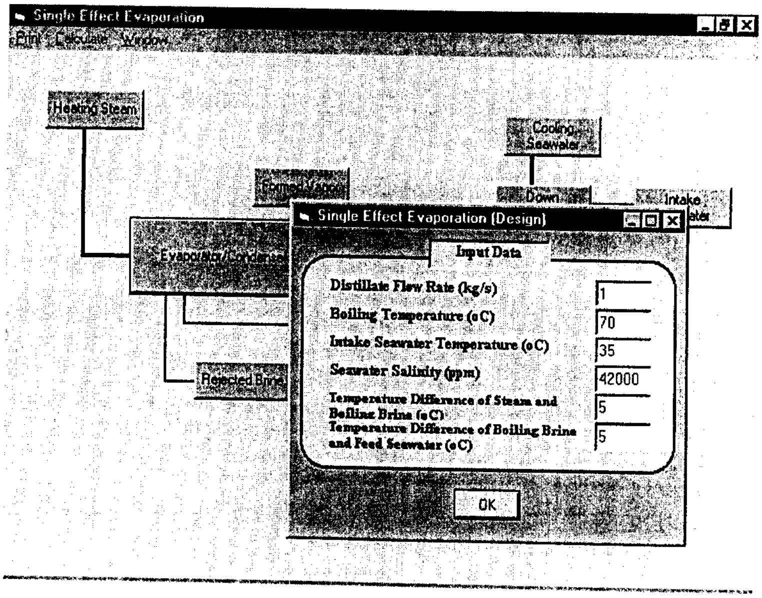
Heat Transfer Area

Evaporator Heat Transfer Area (m2)	224.24
Condenser Heat Transfer Area (m2)	95.995
Evaporator Overall Heat Transfer Coefficient (kW/m2 oC)	2.0702911
Condenser Overall Heat Transfer Coefficient (kW/m2 oC)	1.9514505
Evaporator Thermal Load (kW)	2388.9769
Condenser Thermal Load (kW)	2339.0

Flow Rates, Temperatures, and Pressures

Brine Flow Rate (kg/s)	1.5142
Flow Rate of Feed Seawater (kg/s)	2.5142
Steam Flow Rate (kg/s)	1.0291
Cooling Seawater Flow Rate (kg/s)	17.088
Cooling Seawater Flow Rate (kg/s)	69737.
Formed Vapor Temperature (oC)	68.052
Vapor Condensation Temperature (oC)	67.984
Boiling Point Elevation (oC)	1.9473
Demister Temperature Drop (oC)	0.0684
Formed Vapor Pressure (kPa)	28.6975
Condensing Vapor Pressure (kPa)	28.5464
Heating Steam Pressure (kPa)	38.6431
Performance Ratio	0.97164
Total Number of Tubes in Condenser	34.6921

Fig. 5. Results display for design of single-effect evaporation.



Input Data

Distillate Flow Rate (kg/s)	1
Boiling Temperature (oC)	70
Intake Seawater Temperature (oC)	35
Seawater Salinity (ppm)	42000
Temperature Difference of Steam and Boiling Brine (oC)	5
Temperature Difference of Boiling Brine and Feed Seawater (oC)	5

Fig. 6. Display of the input data for the flow chart calculations of the single-effect evaporator.

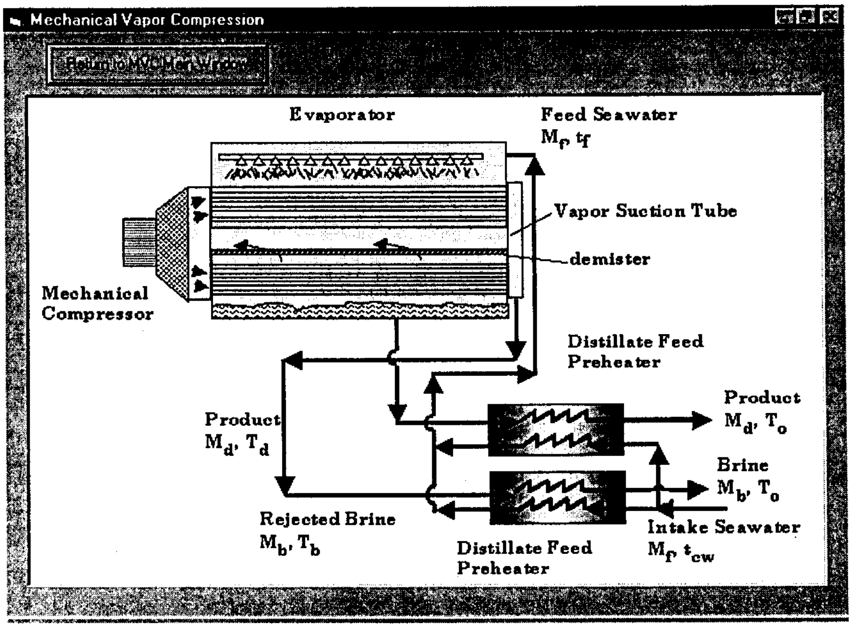
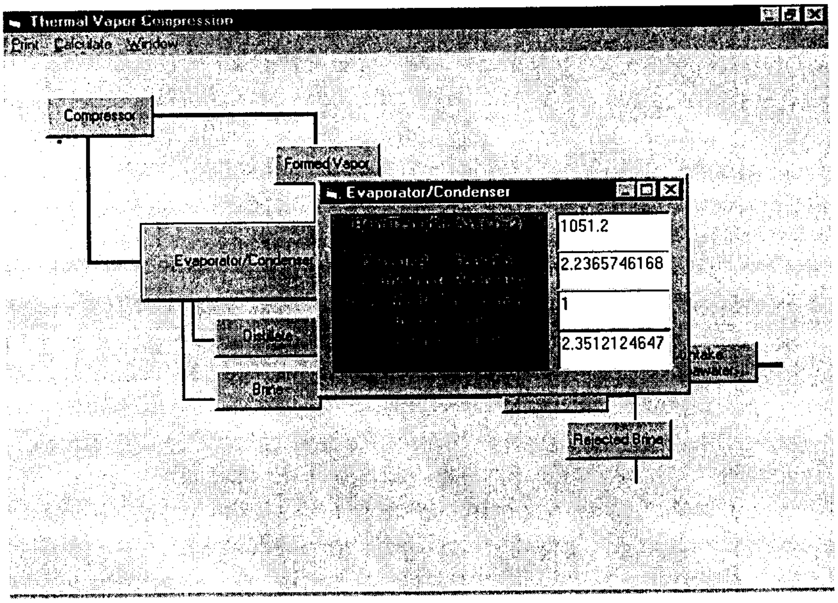


Fig. 7. Schematic display of the single-effect mechanical vapor compression desalination process.



1051.2
2.2365746168
1
2.3512124647

Fig. 8. Display of flow chart calculations for the MVC system.

type, which several advantages over common shell-tube system. The plate-type heat exchangers are compact, have a short start-up time, small liquid hold, small temperature approach, low fouling, and a small heat transfer area. The warm feed seawater is sprayed over the evaporator tubes forming a falling film over the successive tube rows. As the falling film absorbs the latent heat of the condensing compressed vapor inside the tubes, vaporization commences and the formed vapor flows through the demister pad and into the mechanical compressor. The compression process increases the temperature of entrained vapor to the desired value and the compressed vapor is routed through the evaporator tubes.

The design displays for the MVC process are similar to those shown in Figs. 4 and 5, and it contains solution and design parameters for the preheaters, evaporator, and demister. Performance of the MVC gives a specific heat transfer area that varies between over a range of 200–1000 $m^2/(kg/s)$. The smaller specific heat transfer areas are obtained at large differences between the temperature of the condensing heating steam and the boiling brine. The specific power consumption also depends on this temperature difference and the temperature of the boiling brine. In this regard, the specific power consumption is found to vary over a range of 4–16 kWh/m^3, where the smaller values are obtained at higher boiling temperatures and lower temperature differences between the condensing vapor and the boiling brine. The specific heat transfer area for the feed preheaters is smaller than the evaporator/condenser with values less than 100 $m^2/(kg/s)$. These small areas are caused in part by the small thermal loads of the preheaters and the high overall heat transfer coefficient, which is equal to 6.55 and 6.96 for the brine and distillate preheaters, respectively.

The MVC flow chart calculations are shown in Fig. 8. The flow chart includes the evaporator, compressor, the two preheaters, and the distillate, brine, vapor, and seawater streams. Start-up of the calculations shows a display for the input data which includes system capacity, boiling temperature, intake seawater temperature and salinity, and the temperature difference of the condensate and boiling brine. The flow chart results are obtained upon pressing individual process blocks. Fig. 7 shows the results for the evaporator/condenser, which includes the area, the overall heat transfer coefficient, the mean temperature difference, and the thermal load.

3.3. Single-effect thermal vapor compression (TVC)

Displays for the TVC system are shown in Figs. 9 and 10. Fig. 9 shows the process schematic which includes the steam jet ejector, the evaporator, and the condenser. As is shown, the intake seawater flows through the condenser, where its temperature is increased upon release of the latent heat of the condensing vapor. Part of the outlet seawater, known as the cooling seawater, is rejected back to the sea. The remaining part forms the feed seawater, which flows into the evaporator unit. The feed seawater is sprayed over the evaporator tubes where it forms a falling film over the succeeding rows of the evaporator tubes. Vapor formation commences as a result of heat exchange between the condensing heating steam and the brine falling film. The formed vapor forms two streams the first is routed into the condenser and the second is entrained by the steam jet ejector. The entrained vapor is compressed to a higher temperature by the motive steam. The compressed vapor is then used to drive the system where it condenses inside the evaporator tubes. The condensate streams from the evaporator and condenser forms the distillate product and the heating steam.

The displays for the solution and design parameters for the TVC system are also similar to the SEE and MVC systems. The input data

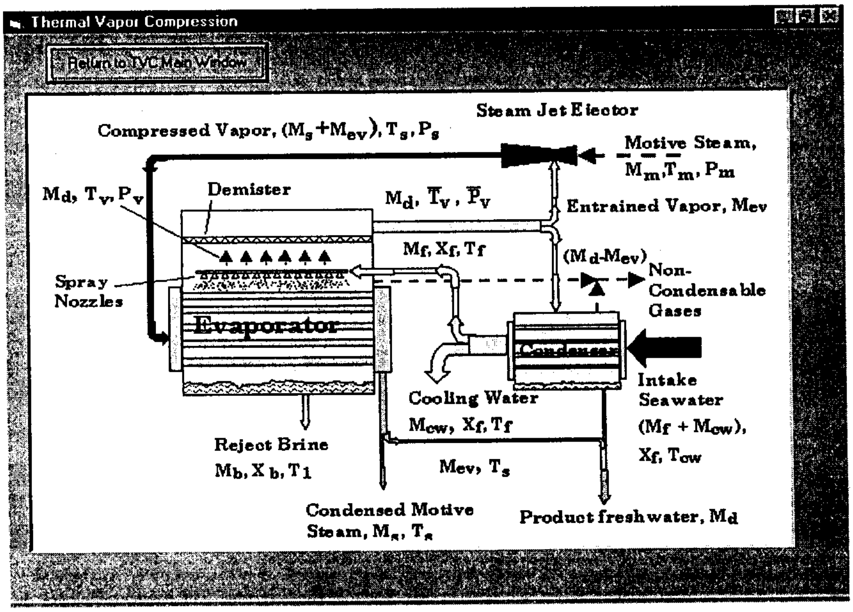
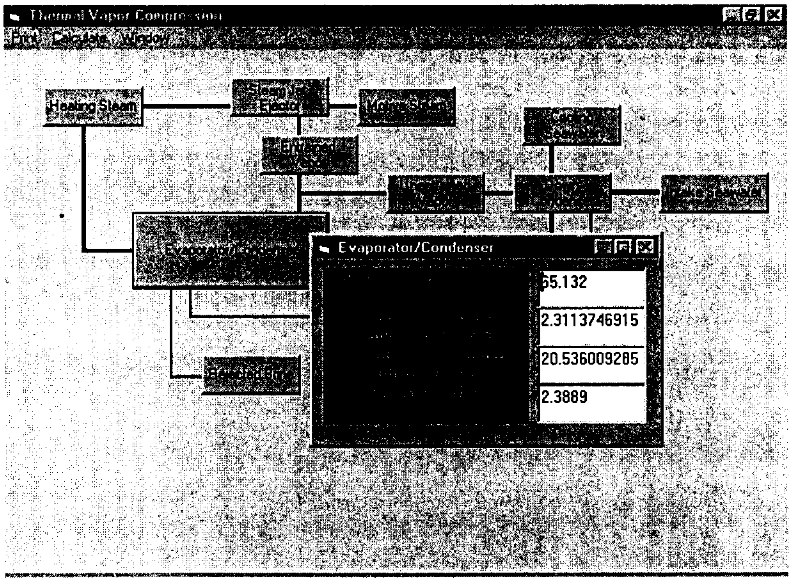


Fig. 9. Schematic display of the single-effect thermal vapor compression desalination process.



Evaporator/Condenser

5.132

2.3113746915

20.536009285

2.3889

Fig. 10. Results of the flow chart calculations of TVC.

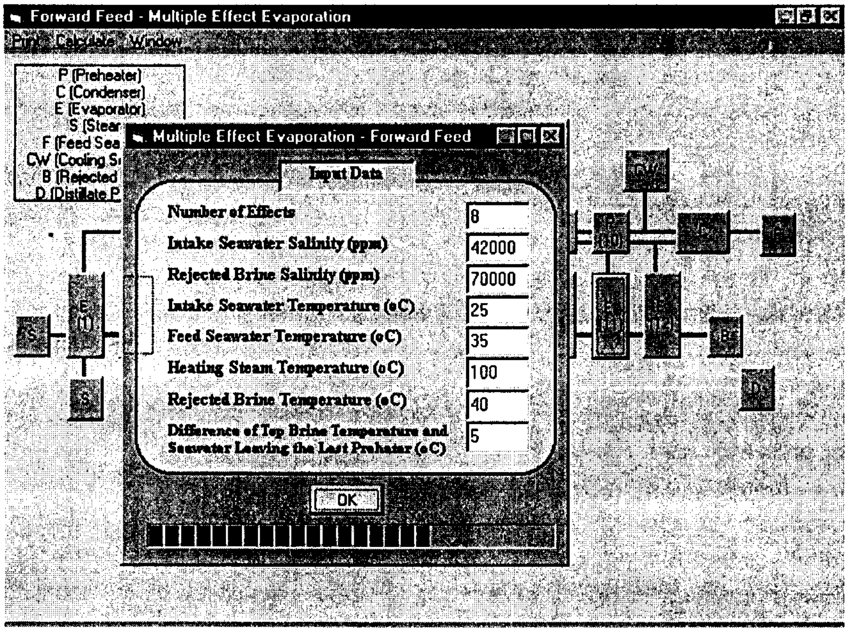
includes the system capacity, the brine boiling temperature, the temperature difference of the feed seawater and the boiling brine, the intake seawater temperature and salinity, and the steam jet ejector compression ratio and motive steam pressure. Also, tube dimensions, thermal conductivity, fouling resistance, stream velocity, and demister characteristics are included in the display. The result display includes the solution parameters as well as the heat transfer areas and stream temperatures and flow rates. Performance of the TVC system shows dependence on the pressure of the motive steam, the compression ratio, and the brine boiling temperature. High performance ratios are obtained at low boiling temperature, high motive steam pressure, and low compression ratio. Although the performance ratio for the TVC system varies over a low range of 1.5–2.5, its specific heat transfer area is much smaller than that for the MVC system. The specific heat transfer area for the TVC system varies over a range of 200–50 m^2/(kg/s). The main drawback of the TVC in comparison with the MVC system is need for cooling water with a specific value that varies over a range of 2–14. The flow chart display for the TVC system is shown in Fig. 10, and it includes the main system devices and various streams. The flow chart results are shown for the evaporator/condenser unit, and it includes the heat transfer area, the overall heat transfer coefficient, the mean temperature difference, and the thermal load.

3.4. *Forward feed multiple-effect evaporation (MEE)*

A description of the MEE process and details of the mathematical models can be found in the studies by El-Dessouky et al. (1998b) and El-Dessouky and Ettouney (1997). The display of the process schematic is shown in Fig. 11. The process include a number of evaporation effects, a down condenser, feed preheaters, and flashing boxes. The intake seawater is introduced into the down condenser where it is to condensate the vapor formed in the last effect. Part of the outlet seawater stream from the down condenser, which is known as the cooling seawater, is rejected back to the sea. The remaining part, which is the feed seawater stream, flows through a sequence of preheaters to increase its temperature to a higher value. The feed is then sprayed into the first effect where it is heated to the saturation temperature by the heating steam. This results in formation of a small amount of vapor, which is used to heat the second effect. This process is repeated in subsequent effects where the vapor formed in each effect is used to heat the brine in the next effect. The brine stream flows in the same direction as the vapor stream where it is sprayed in each effect on the outside surface of the evaporator tubes. The vapor condensate in each effect is collected in flashing boxes where a small amount of vapor is formed and is used in the feed preheaters.

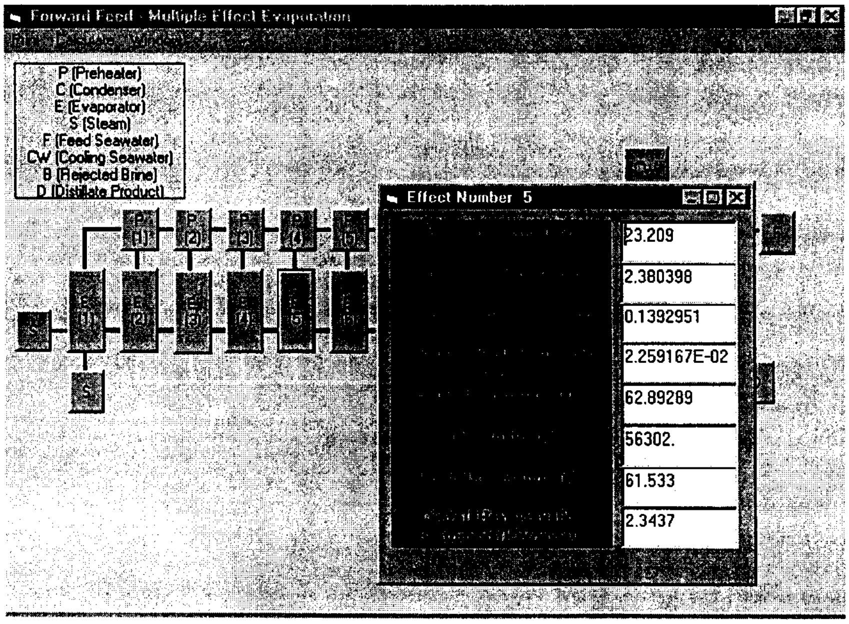
Design displays for the MEE system have a similar layout to the single-effect system where the input data include the number of effect, temperature and salinity of feed stream, and top brine temperature. The design data also include geometry, properties and dimensions of the evaporator tubes, falling film thickness, velocity, and demister properties. The results display includes the specific heat transfer area, the performance ratio, specific flow rate of cooling water, thermodynamic losses, and heat transfer coefficients. Analysis of the MEE system shows higher performance ratios at higher top brine temperatures and larger number of effects. Also, lower specific heat transfer areas for the evaporators are obtained at higher top brine temperature and smaller number of effects.

The display for the flow chart calculations is shown in Fig. 12, and it includes the major streams, the down condenser, the evaporation effects, and the preheaters. Also in Fig. 12 the results for effect number 5 are shown, and it includes the evaporator area, the brine flow rate,



Number of Effects: 8
Intake Seawater Salinity (ppm): 42000
Rejected Brine Salinity (ppm): 70000
Intake Seawater Temperature (oC): 25
Feed Seawater Temperature (oC): 35
Heating Steam Temperature (oC): 100
Rejected Brine Temperature (oC): 40
Difference of Top Brine Temperature and Seawater Leaving the Last Preheater (oC): 5

Fig. 11. Display of the MEE flow chart calculations.



23.209
2.380398
0.1392951
2.259167E-02
62.89289
56302.
61.533
2.3437

Fig. 12. Results of the flow chart calculations of MEE.

the amount of formed vapor, temperatures of the brine and vapor, the overall heat transfer coefficient, and the brine salinity.

4. Conclusions

A computer package was developed for design, rating, and evaluation of the performance of various thermal desalination processes. Although a number of computer packages are available for RO processes, the literature does not include a specialized package for design and simulation of thermal desalination processes. Therefore, the computer package presented here is the first of its kind to be made available to the desalination community. The features of the developed thermal desalination computer package are summarized below:

- The package includes models for MSF, MEE, and SEE.
- The MSF models include the once-through, brine mixing, brine circulation, and brine circulation with vapor compression.
- The MEE models include the forward and parallel feed with/without vapor compression.
- The SEE models include the stand-alone system as well as four vapor compression systems.
- The package includes calculations for design, rating and performance evaluation.
- The package allows for the printing of process schematics, computation forms, data files, and charts.

Features of the computer package are demonstrated for four case studies of single-effect evaporation, single-effect mechanical vapor compression, single-effect mechanical vapor compression, and forward feed multiple-effect evaporation. Results include displays for process schematics, process design, and flow chart calculations. Reported results for various systems are consistent with previous literature data and industrial practice.

References

Alatiqi, I., El-Dessouky, H.T. and Ettouney, H.M., J. Tech. Trans., in press.

Al-Juwayhel, F., El-Dessouky, H. and Ettouney, H., Desalination, 114 (1997) 253.

Bednarski, J., Minamide, M. and Morin, O.J., Proc., IDA World Congress on Desalination and Water Sciences, Madrid, 1 (1997) 227.

Darwish, M.A., and El-Dessouky, H.T., Applied Thermal Engineering, 16 (1996) 523.

El-Dessouky, H.T., Shaban, H.I. and Al-Ramadan, H., Desalination, 103 (1995) 271.

El-Dessouky, H. and Bingulac, S., Desalination, 107 (1996) 171.

El-Dessouky, H.T., Modelling and simulation of thermal vapor compression desalination process, Proc., Desalination of Seawater with Nuclear Energy, International Atomic Energy Agency, Taujon, Korea, 1997.

El-Dessouky, H.T. and Ettouney, H.M., Simulation of combined multiple effect evaporation — vapor compression desalination processes, 1st IDA Int. Desalination Conference, Cairo, 1997.

El-Dessouky, H.T., Alatiqi, I. and Ettouney, H.M., Desalination, 115 (1998a) 155.

El-Dessouky, H.T., Alatiqi, I., Bingulac, S. and Ettouney, H.M., Chem. Eng. Tech., 21 (1998b) 15.

El-Dessouky, H.T. and Ettouney, H.M., Multiple effect thermal vapor compression: Small and medium size, Int. Workshop on Desalination Technologies for Small and Medium Size Plants with Limited Environmental Impact, Rome, 1998.

El-Dessouky, H.T., Ettouney, H.M. and Al-Juwayhel, F., Desalination, 1999a, in press.

El-Dessouky, H.T., Ettouney, H.M., Al-Fulaij, H. and Al-Aryan, N., Multistage flash desalination combined with thermal vapor compression, Chem. Eng. & Proc., 1999b, submitted.

El-Dessouky, H.T., Ettouney, H.M., and Al-Roumi, Y., Chem. Eng. J., 73 (1999c) 175.

El-Dessouky, H.T., Ettouney, H.M. and Alatiqi, I., Desalination, 123 (1999d) 55.

El-Dessouky, H.T. and Ettouney, H.M., Desalination, 122 (1999) 271.

El-Dessouky, H.T. and Ettouney, H.M., Heat Transfer Eng., 20 (1999b) 52.

El-Dessouky, H.T. and Ettouney, H.M., Fundamentals of Seawater Desalination, in press, 1999c.

El-Dessouky, H.T. and Ettouney, H.M., Chemical Eng. J., 1999d, submitted.

Ettouney, H.M., El-Dessouky, H.T. and Alatiqi, I., Progress in thermal desalination process, Chem. Eng. Prog., 1999a, in press.

Ettouney, H.M., El-Dessouky, H.T. and Al-Roumi, Y., Energy, 1999b, in press.

Leitner, G.F., Int. Desalination & Water Reuse Quart., 7 (1998) 10.

Temperley, T.G., Proc., IDA World Congress on Desalination and Water Sciences, Abu-Dhabi, UAE, 1 (1995) 219.