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Development of a dynamic simulator (INFMED) for the MED/VC plant

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ABSTRACT

This paper describes INFMED (Indo-French MED simulator) Software Version 1 that is being developed, under the Indo-French collaboration, to simulate the steady state and the dynamics of a Multi-Effect Distillation Mechanical Vapour Compression (MED-VC) Desalination system. The main objectives of the simulator are to permit a thorough understanding of the steady state design, to study the behaviour of the plant under various transients, to provide training of potential operators, engineers and students, and to allow the further development of new strategies for control as well as for process optimisation. INFMED is basically designed for parallel feed configurations of MED plant coupled to MVC (mechanical vapour compression) but thermal vapour compression models currently under development would also be incorporated later on. The software will be validated with the help of operating data obtained from the Indian installation (50 m^3/day MED-VC, currently under construction at BARC, Trombay). INFMED is built in Visual Basic and can be installed on computers running on the Windows 9x/2000/XP operating systems. It offers a very user-friendly graphical user interface for simulating steady and dynamic states and also for viewing the results in both tabulated as well as in a graphical forms. The dynamic state model of an effect was taken from the CEA MED simulator, which is derived from basic mass, energy and momentum conservation equations and supplementary correlation for heat transfer and physical properties. Results of a test case, derived from an operating BARC MED-VC installation, show that the behaviour of multiple variables in the steady state and in the case of postulated transients is indeed very well represented. A complete validation of the simulator results against data from the operating BARC MED-VC installation will be reported later.

Keywords: Desalination simulator; multi-effect distillation modelling

1. Introduction

Changing climatic conditions, increasing population, rising standards of living and the development of a number of industries have all led to ever increasing water demands. While these factors are increasing the quantity of water required, factors like pollution of available water resources, over-pumping of non renewable water sources and lack or recharge of natural basins are reducing the quantity of available water resources for drinking purposes.

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Water problems are very complex and diversified. Better water conservation, water management, pollution control and water reclamation are all part of the integrated solutions to projected water shortages. Between such solutions is included desalination of seawater, which is an alternative source of water production.

Desalination technologies are well established since the mid 20th century and are now widely deployed all over the world. Desalination technologies have shown continued progress over the past decades. Nearly 50% of all worlds' desalination plants are of the thermal type (Multi-stage Flash, MSF, or Multi-Effect Distillation, MED).

Because of its relatively lower energy consumption (relative to MSF) and considerable technical improvements, MED is occupying higher and higher desalination market share today.

In November 2004, the French Atomic Energy Commission, CEA and the Bhabha Atomic Research Centre, BARC, decided to develop a bilateral cooperation for the peaceful uses of atomic energy. A specific agreement in the field of nuclear desalination was then signed by BARC and CEA on the 10th of November 2005.

During the kick-off meeting, held in March 2006, the two parties decided, among other actions, to extend the MED simulator developed by CEA [1], to include vapour compression models so that the ensemble could be tested and validated around the 50 m^3/day MED-VC installation at BARC.

This paper presents the preliminary results of this development.

While a MED plant takes low pressure steam from a heat source, the MED-VC uses a Mechanical Compressor to compress the steam generated from the last effect to a higher temperature and pressure and used as heating medium in the first effect. Thus like RO this plant requires only electricity and is capable of producing distilled quality water from sea water.

The amount and quality of steam, required to produce the desired amount of pure water, depends on the feed seawater temperature, the maximum brine temperature and the type, design and performance of the distillation plant. Usually, the efficiency of distillation plant is expressed in kg of pure water produced per kg of steam used in the first effect: this ratio is called the gain output ratio (GOR). GOR is roughly proportional to the number of MED effects.

2. Process description

In the MED evaporative process, the feed seawater is heated in the product and brine blow down preheaters. It is then fed in parallel to the evaporator stages where it is sprayed on the tube bundle.

The steam condensing inside the first effect tube bundle gives up its latent heat and generates an almost equal amount of vapour from the feed. The concentrated brine is sent to the next effect maintained at a slightly lower pressure. The vapour produced in the first effect condenses on the inside of the heat transfer tubes in the second effect, giving up its latent heat and generating an almost equal amount of vapour from the feed brine.

For multi-effect distillation, the same process is carried out successively at lower pressures for the remaining stages. The condensate and blow-down brine from each stage is cascaded till the last stage and is collected as product water and brine blowdown respectively. The vapour generated in the last effect is taken to a Vapour Compressor (VC) where it is compressed to a higher temperature and used as heating steam in the first stage. Here thin film evaporation of brine occurs on the outside of horizontal tubes and condensation of vapour occurs on the inside of the horizontal tubes in the evaporator resulting in high heat transfer coefficients. In the vapour compression process (Fig. 1) the compressor provides the driving force for this heat transfer and provides the energy required in separating the solution and overcoming the dynamic pressure losses and other irreversibilities. A schematic diagram of two effect MED-VC desalination plant is shown in Fig. 1.

2.1. Software package description

Desalination Software includes models for the MED-VC process (Fig. 1). This software runs under the Windows 9x/Me/2000/XP operating system.

Desalination Software has a modular architecture (Fig. 2). It consists of a graphical user interface (developed under Microsoft Visual Basic) for simulating and viewing the results of both steady and unsteady states of MED-VC desalination system

2.2. Mathematical models

The aim of modelling MED dynamics is to determine how the process responds during transient conditions, such as plant start-up and shutdowns, gradual changes in important parameters and unusual disturbances.

Process models can be analytical, semi-empirical or empirical [2–4].

The models considered in the CEA simulator are analytical; they derive from basic mass, momentum

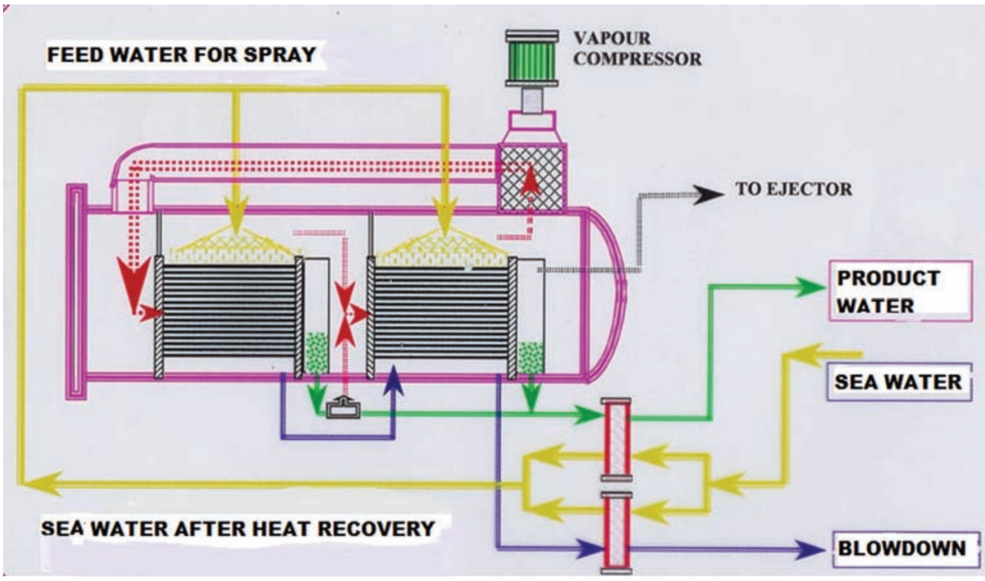

Fig. 1. Schematic diagram of an MED-VC system.

and energy principles applied to process subsystems. They also include correlations for heat transfer coefficients and thermo-physical properties of pure and saline water.

Opting for analytical models rather then empiric or semi-empiric ones offers two important advantages: 1. they provide physical insight into process behaviour and, 2. they are applicable over wide ranges of conditions. They are, however, generally expensive and time consuming to develop. Some assumptions and simplifications should thus be introduced to ensure that the model equations can be solved.

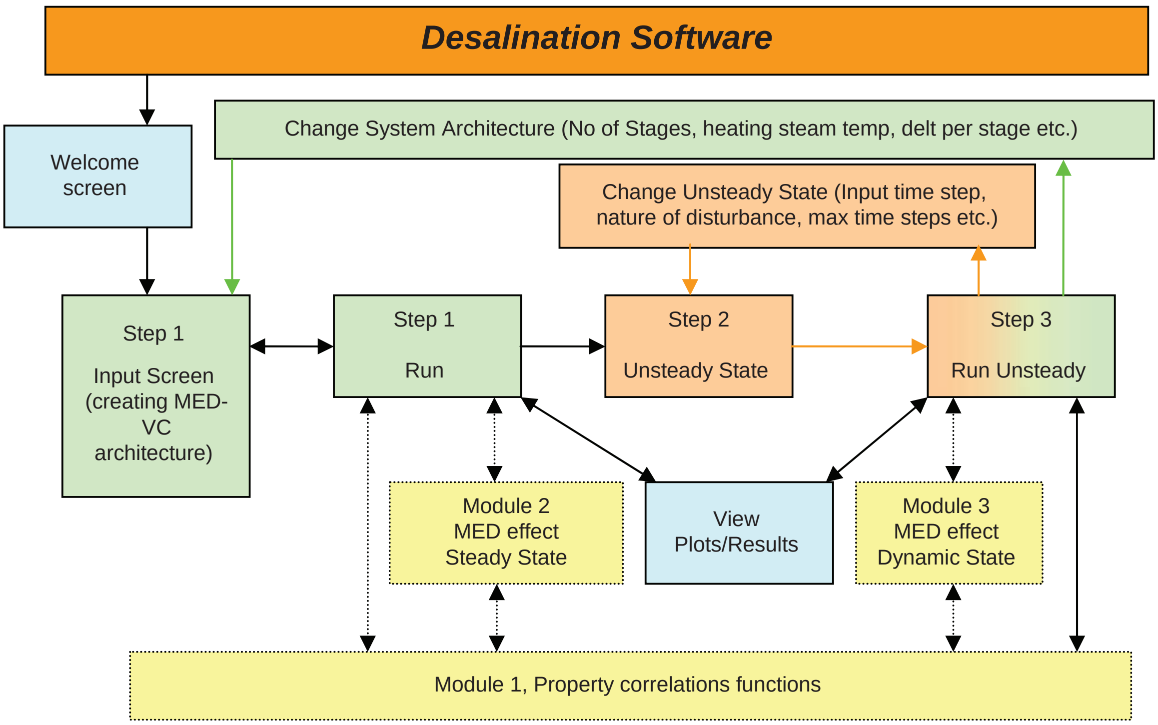

Fig. 2. General System Architecture.

2.3. Evaporator model

2.3.1. Steady state model and equations used

The main components used in the model are the evaporator, pre-heater and compressor sub-models.

Some of the assumptions made are as follows:

- The driving force for heat transfer in the evaporator is assumed constant and equal to the temperature difference of the condensing steam and boiling brine.
- Heat losses to the surroundings from the evaporator, pre-heater, compressor and piping systems are small and negligible.
- The steam entering the evaporator is saturated and product is salt free.
- The parallel feed configuration of MED is considered for the calculations.

Table 1 describes the variables that are used in the formulation of the steady state model.

The general equations governing the steady state behaviour are given below:

Equations (1) to (8) are the same as those used in [1]. The added equations (9) to (11) correspond to the compressor and pre-heater.

Overall mass balance

$$F(0) = BD(n) + CAP. \tag{1}$$

Overall salt balance

$$F(0) \times XF = BD(n) \times XBD(n). \tag{2}$$

Overall energy balance

$$F(0) \times hF = BD(n) \times hBD + CAP \times hD. \tag{3}$$

Mass balance for the *i*th effect

$$F(i) + BD(i-1) = BD(i) + D(i). \tag{4}$$

Salt balance for the *i*th effect

$$F(i) \times XF(i) + BD(i-1) \times XBD(i-1) = BD(i) \times XBD(i). \tag{5}$$

Energy balance for the *i*th effect

$$F(i) \times hF + BD(i-1) \times hBD + Q(i) = BD(i) \times hBD + D(i) \times hD. \tag{6}$$

where

$$Q(i) = D(i-1) \times Lambda(i-1). \tag{7}$$

Table 1
Description of variable used in the steady state calculations

n	Number of stages
i	Current stage number (counter used in code)
$F(0)$	Total feed to the plant
$BD(n)$	Blow down brine from the last stage
CAP	Plant capacity in ton/day
$XF(0)$	Feed salinity initial
$XBD(n)$	Final blow down salinity from the last stage
hF	Specific Enthalpy of feed stream
hBD	Specific Enthalpy of blow down brine stream
hD	Specific Enthalpy of distillate stream
lambda	Latent heat of steam
CR	Concentration ratio
$P2$	Final/discharge pressure of compressor
$P1$	Initial/suction pressure of compressor
$T2$	Saturation temperature corresponding to discharge pressure
$T1$	Saturation temperature corresponding to suction pressure
$Wcomp$	Compressor work
η_{comp}	Efficiency of compressor
R	Ideal Gas constant
$T2'$	Superheated temperature after compression
Mc	Mass flow rate of cold stream in pre-heater
Cpc	Specific heat capacity of cold stream
$TcHot$	Outlet temperature of cold stream
$TcCold$	Inlet temperature of cold stream
Mh	Mass flow rate of hot stream in pre-heater
Cph	Specific heat capacity of hot stream
$ThHot$	Inlet temperature of hot stream
$ThCold$	Outlet temperature of hot stream

Overall concentration ratio

$$CR = \frac{XBD(n)}{XF(0)}. \tag{8}$$

Compressor equations

Work done by the compressor in compressing the steam from a pressure P1 to pressure P2 is calculated as:

$$Wcomp = \frac{\gamma}{\gamma - 1} \frac{1}{\eta_{comp}} RT_1 \left[\left(\frac{P_2}{P_1} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right], \tag{9}$$

$$T2' = T1 + (T2 - T1)/\eta_{comp} \tag{10}$$

The pre-heater energy balance equation are given as

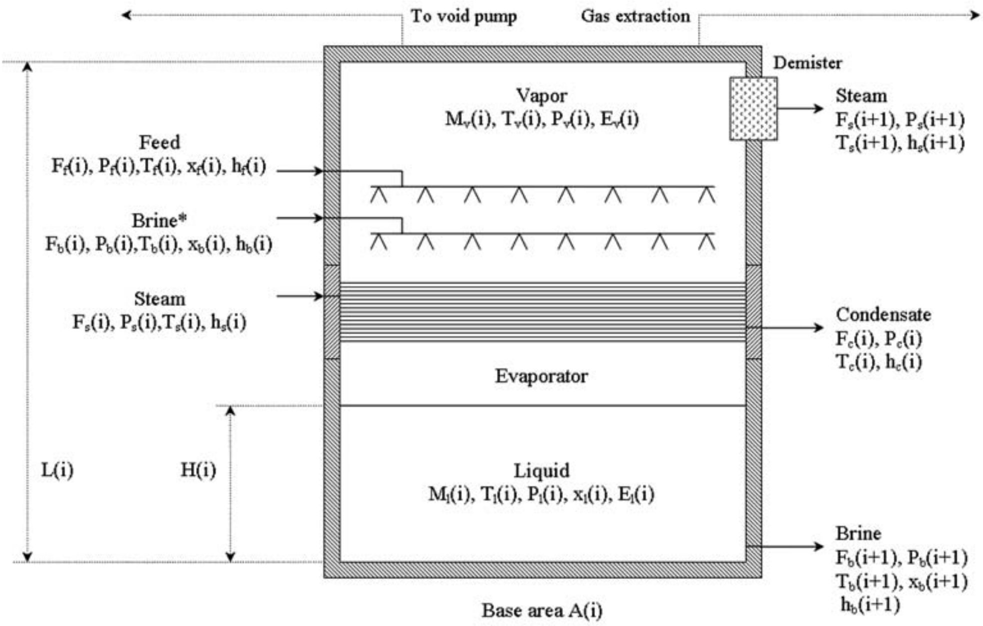

Fig. 3. INFMED evaporator scheme.

$$Mc \times Cpc \times (T_{cHot} - T_{cCold}) = Mh \times Cph \times (T_{hHo}t - T_{hCold}). \quad (11)$$

2.3.2. Calculation procedure adopted for steady state

This procedure can be summarized as follows:

1. Start
2. Read inputs
3. Initialise inputs to array variables for each stage
4. Evaluate inputs for errors
5. Assume heating steam for stage 1 (capacity of plant/no of stages)
6. Call function medeffect_ss to calculate vapour generated, blow down brine flow mass and energy balance of the stage
7. Update the vapour generated in each stage by adding the vapour generated from cascading product and brine flashing from previous stages
8. Continue calculation till the last stage as described up to step 7
9. The vapour generated in the last effect goes to the compressor where it compressed to pressure corresponding to the heating steam temperature as provided in the input. The de-superheating product is calculated and it taken from the production of the plant
10. The condensate from each stage is the product of that stage. The summation of the product from each stage is the final capacity. If summation of product is less than specified capacity of plant change the first effect heating steam quantity assumed and go to step 6
11. The summation of the product from each stage and final blow-down brine from the last stage go to their respective pre-heaters and heat the incoming feed.
12. The evaporator is designed
13. The pre-heaters are designed
14. Outputs printed/plotted
15. Stop

2.3.3. Dynamic State Model and equations used

2.3.3.1. Evaporator equations

To give an illustrative example of the modeling in the simulator, the evaporator model is schematically shown in Fig. 3 [1].

The evaporator mathematical model describes the variation with time of the evaporator temperature, liquid height and salinity.

The evaporator is supposed to be well stirred and thermally isolated. The thermal inertia of its metallic structure is neglected [6].

The temperature of the liquid phase is higher then that of the vapour phase because of the presence of salt. The temperature difference is known as the boiling point elevation δ.

$$\delta(T_v, x_l) = T_l - T_v = a(T_v) + b(T_v)c(x_l)^2, \quad (12)$$

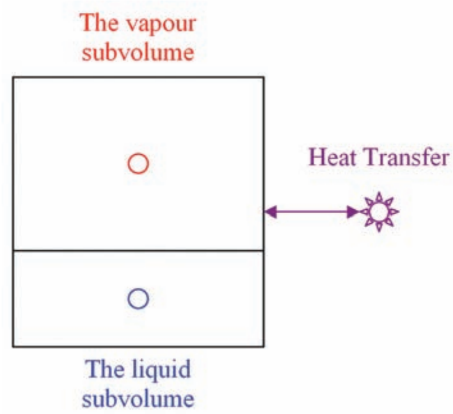

Fig. 4. The CEA Simulator Volume.

$$a(T_v) = 0,2009 + 0,2867 \cdot 10^{-2} \cdot T_v + 0,0020 \cdot 10^{-4} T_v^2, \quad (13)$$

$$b(T_v) = 0,0257 + 0,0193 \cdot 10^{-2} \cdot T_v + 0,0001 \cdot 10^{-4} T_v^2, \quad (14)$$

$$c(x_l) = \frac{x_l}{3,4416 \cdot 10^{-2}}. \quad (15)$$

The formulation of the CEA simulator model of evaporator [1] is based on the notion of a simulator volume, which is equally applicable to modelling the other HT-MED plant components (flashing chambers, evaporators, condensers).

The CEA simulator volume consists of two sub volumes (liquid and vapour phases). It may exchange heat with an external source or sink (heat losses to the surroundings are neglected).

The variables used to describe the component are given in Tables 2–4.

The physical model is based on the equations of conservation of the structure volume, total mass, salt mass and energy, applied to the CEA Simulator Volume.

Structure volume conservation equation

$$V + V_v = V_l \quad (16)$$

Total mass balance equation

Table 2
Variables describing the CEA simulator volume

V	Structure volume, m^3.
$\dot{Q}$	Rate of heat transfer with the external source or sink, kW.

Table 3
Variables describing the Vapour Subvolume

M_v	Vapour Subvolume mass, kg.
V_v	Vapour Subvolume volume, m^3
T_v	Vapour Subvolume temperature, °C
P_v	Vapour Subvolume pressure, bar
ρ_v	Vapour Subvolume density, kg/m^3
h_v	Vapour Subvolume enthalpy, kJ/kg

$$\frac{d(\rho_v V_v + p_l V_l)}{dt} = \Delta \dot{m}_t. \quad (17)$$

The right side of the equation represents the difference in terms of total flow rate between control volume entering and leaving steams:

$$\Delta \dot{m}_t = \sum \Delta \dot{m}_{\text{in}} - \sum \Delta \dot{m}_{\text{out}}. \quad (18)$$

Salt mass balance equation

$$\frac{d(\rho_v V_l c_t)}{dt} = \Delta \dot{m}_t \quad (19)$$

The right side of the equation represents the difference in terms of salt flow rate between control volume entering and leaving steams:

$$\Delta \dot{m}_s = \sum \Delta \dot{m}_{\text{in}} - \sum \Delta \dot{m}_{\text{out}} \quad (20)$$

Energy balance equation

$$\frac{d(p_v V_v h_v + p_l V_l h_l)}{dt} = \dot{Q} + \Delta \dot{E} \quad (21)$$

The term added to $\dot{Q}$ (right side of the equation) represents the difference in terms of enthalpy between control volume entering and leaving steams:

$$\Delta \dot{E} = \sum \dot{m}\, h_{\text{in}} - \sum \dot{m}\, h_{\text{out}} \quad (22)$$

The mathematical model of the process is obtained by systemising the equations listed above

Table 4
Variables describing the Liquid Subvolume

M_1	Liquid Subvolume mass, kg
V_1	Liquid Subvolume volume, m^3
T_1	Liquid Subvolume temperature, °C
P_1	Liquid Subvolume pressure, bar
ρ_1	Liquid Subvolume density, kg/m^3
H_1	Liquid Subvolume enthalpy, kJ/kg
c_1	Liquid Subvolume salinity, ppm

2.3.3.2. Properties correlations

Under saturation conditions, the temperature of the saline solution is related to that of the vapour phase by the relation:

$$T_l = T_v + \delta(T_v, c_l) \tag{23}$$

δ is known as boiling point elevation.

Differentiating this equation, we obtain:

$$\mathrm{d}T_l = \left(1 + \frac{\partial\delta}{\partial T_v}\right)\mathrm{d}T_v + \left(1 + \frac{\partial\delta}{\partial c_l}\right)\mathrm{d}c_l \tag{24}$$

Saline water properties (e.g. density, enthalpy, etc.) depend on both T_i and c_l:

$$\mathrm{d}F_l = \frac{\partial F_l}{\partial T_l}\mathrm{d}T_l + \frac{\partial F_l}{\partial c_l}\mathrm{d}c_l \tag{25}$$

Replacing $\mathrm{d}T_i$ by its expression, we obtain:

$$\mathrm{d}F_l = f_{l,T_v}\mathrm{d}T_v + f_{l,c_l}\mathrm{d}c_l \tag{26}$$

$$f_{l,T_v} = \frac{\partial F_l}{\partial T_l}\frac{\partial\delta}{\partial c_l} + \frac{\partial F_l}{\partial c_l}, \qquad f_{l,c_l} = \frac{\partial F_l}{\partial T_l}\left(1 + \frac{\partial\delta}{\partial T_v}\right) \tag{27}$$

For the vapour phase, the properties depend only on temperature:

$$\mathrm{d}F_v = f_{v,T_v}\mathrm{d}T_v \tag{28}$$

Differentiating the structure volume conservation equation, we obtain:

$$\frac{\mathrm{d}V_v}{\mathrm{d}t} = \frac{\mathrm{d}V_l}{\mathrm{d}t} \tag{29}$$

Developing the total mass balance equation, we obtain:

$$\rho_v\frac{\mathrm{d}V_v}{\mathrm{d}t} + V_v\frac{\mathrm{d}\rho_v}{\mathrm{d}t} + \rho_l\frac{\mathrm{d}V_l}{\mathrm{d}t} + V_l\frac{\mathrm{d}\rho_l}{\mathrm{d}t} = \Delta\dot{m}_t \tag{30}$$

which may be developed further to give:

$$m_{11}\frac{\mathrm{d}V_l}{\mathrm{d}t} + m_{12}\frac{\mathrm{d}c_l}{\mathrm{d}t} + m_{13}\frac{\mathrm{d}T_v}{\mathrm{d}t} = u_1 \tag{31}$$

$$m_{11} = \rho_l - \rho_v \tag{32}$$

$$m_{12} = v_l\rho_{l,c_l} \tag{33}$$

$$m_{13} = v_v\rho_{v,T_v} + v_l\rho_{l,Tv} \tag{34}$$

$$u_1 = \Delta\dot{m}_t \tag{35}$$

2.3.3.3. Differential form of the salt mass balance equation

Developing the salt mass balance equation, we obtain:

$$\rho_l V_l\frac{\mathrm{d}c_l}{\mathrm{d}t} + \rho_l c_l\frac{\mathrm{d}V_l}{\mathrm{d}t} + V_l c_l\frac{\mathrm{d}\rho_l}{\mathrm{d}t} = \Delta\dot{m}_s \tag{36}$$

which may be developed further to give:

$$m_{21}\frac{\mathrm{d}V_l}{\mathrm{d}t} + m_{22}\frac{\mathrm{d}c_l}{\mathrm{d}t} + m_{23}\frac{\mathrm{d}T_v}{\mathrm{d}t} = u_2 \tag{37}$$

$$m_{21} = \rho_l c_l \tag{38}$$

$$m_{22} = \rho_l V_l + V_l c_l\ \rho_{l,c_l} \tag{39}$$

$$m_{23} = V_l c_l\ \rho_l,_{T_v} \tag{40}$$

$$u_2 = \Delta\dot{m}_s \tag{41}$$

Developing the energy balance equation, we obtain:

$$\rho_v V_v\frac{\mathrm{d}h_v}{\mathrm{d}t} + \rho_v h_v\frac{\mathrm{d}V_v}{\mathrm{d}t} + V_v h_v\frac{\mathrm{d}\rho_v}{\mathrm{d}t} + \rho_l V_l\frac{\mathrm{d}h_l}{\mathrm{d}t} + \rho_l h_l\frac{\mathrm{d}V_l}{\mathrm{d}t} + V_l h_l\frac{\mathrm{d}\rho_l}{\mathrm{d}t} = \dot{Q} + \Delta\dot{E} \tag{42}$$

which may be developed further to give:

$$m_{31}\frac{\mathrm{d}V_l}{\mathrm{d}t} + m_{32}\frac{\mathrm{d}c_l}{\mathrm{d}t} + m_{33}\frac{\mathrm{d}T_v}{\mathrm{d}t} = u_3 \tag{43}$$

$$m_{31} = \rho_l h_l - \rho_v h_v \tag{44}$$

$$m_{32} = V_l h_l\rho_{l,c_l} + \rho_l V_l h_{l,c_l} \tag{45}$$

$$m_{33} = V_v h_v\rho_{v,T_v} + \rho_v V_v h_{v,T_v} + V_l h_l\rho_{l,T_v} + \rho_l V_l h_{l,T_v} \tag{46}$$

$$u_3 = \dot{Q} + \Delta\dot{E} \tag{47}$$

2.3.4. The pre-heater calculations procedure

The pre-heater is designed while running the steady state. The heat transfer area is thus calculated in the steady state calculation. Now for a decrease/increase in feed flow or temperature the cold stream exit temperature and hot stream exit temperature are recalculated using the area from the steady state run as input.

A design velocity and design heat transfer coefficient is assumed appropriately in the code. If the feed flow is decreased or increased a new value of velocity is calculated and thereby a new heat transfer coefficient calculated. An initial guess is made for the cold stream exit temperature, the exit temperature of the hot stream is calculated from the energy balance equation and new heat transfer area is evaluated. The procedure is repeated till this newly calculated heat transfer area matches with the area of the one calculated in steady state for each pre-heater respectively. The bisection method is used for convergence.

2.3.5. Calculation procedure adopted for the dynamic State

1. Start
2. Reading the unsteady state inputs
3. Initialization of steady state inputs and outputs to unsteady state variables
4. Initialize counters and loops for repeated calculation till maximum number of time steps considered
5. Calculate the temperature out of the pre-heaters
6. Initialize counters to calculate for n number of stages
7. Prepare inputs for calling the CEA Simulator med-dynamic effect function
8. Call the CEA Simulator med-dynamic effect function
9. Assign new variables calculated to old variables and store them in an array
10. Repeat calculation till n number of stages
11. Make calculations of the compressor
12. Calculate summation of product and blow down brine for repeating pre-heater calculation for next time step
13. Start calculations again for the next time step
14. Print/plot results
15. Stop

3. Case study

A case study was undertaken simulating a two and three effects 50 t/day MED-VC. The main objective of this exercise was to ascertain that the addition of the VC model in the simulator has not introduced any errors or that the model itself is not erroneous.

3.1. Input section of the software

The first effect evaporator temperature is 62.5°C. Number of effects are 2. Seawater intake temperature and salinity are 30°C and 35,000 ppm. Steam temperature to the first effect is 65°C. The recovery ratio of the plant is set to 2 and the temperature difference between the stages is set uniformly to 2.5°C.

The heat transfer coefficients are calculated based on correlations as described in [5]. Outside diameter of tubes is 0.0195 m and thickness of tube is 0.0025 m. The length is calculated by the program for steam velocity of 40 m/s inside the tubes. Alternatively, the length of tubes can be provided and the program calculates the velocity of steam inside the tubes.

The default input data and other variables that can be input by the user are described in Table 5.

3.2. Output of the steady state run

The net plant production is 50.07 t/day. Steam flow to the first effect is 25.5 t/day. Final blow down salinity is 70,109 ppm. The total evaporator area required by the plant is 202.73 m^2.

The performance ratio of the plant is 1.946 and compressor work is 13.635 kW h/m^3

The product water required for de-superheating the superheated vapour at the compressor outlet is 0.2546 t/day. Stage wise variables such as steam flow, steam temperature, steam pressure, feed flow rate, feed temperature, blow down brine flow, blow down temperature and salinity, vapour generated in each stage its temperature and condensate flow out of the stage, are shown on a panel. These outputs are also presented in Table 6.

An illustration of the graphic panels displayed is shown in figure 5 for a two effect MED/VC system.

3.3. Unsteady state

A perturbation in feed flow rate of 10% change in magnitude and 10 s duration is given to the system. The program is asked to calculate the response in temperature, level and salinity as a function of time (no of iterations x time step). The maximum number of iterations chosen is 100 and the time step is 1 s. A value of 0.5 for epsilon (integration limits between 0 and 1) was chosen to do the implicit Euler integration.

Variation of temperature, level and salinity in each stage for 10% step reduction in feed flow rate of a 50 t/day, 2 stage MED-VC plant are then displayed on graphic panels. The plots show changes with respect to their steady state values. The reduction of feed flow causes the temperature in each stage to increase slightly. The level in each stage falls owing to reduced blow down brine flow. The salinity therefore shows an increase. After the disturbance has been withdrawn the level and salinity both return to their new steady state values.

Table 5
Input data and outputs

Label/input	Description	Units	Value
The defaults which can be changed on running			
Plant capacity	Enter desired capacity of the plant	Tonne/day	50
1st effect boiling temperature	Enter the first effect temperature	°C	62.5
Intake sea water temperature	Ambient intake sea water temperature	°C	30
Seawater salinity (intake)	Ambient intake sea water salinity	ppm	35,000
No of effects	No of effects in MED-MVC plant	–	2
Steam temperature (first effect heating steam)	Steam temperature entering the first effect (outlet of compressor)	°C	65
Recovery ratio	ratio of blowdown brine salinity to feed salinity	–	2
Del T per stage	Temperature difference per stage. Equal temperature difference is assumed for calculation	°C	2.5
Outside diameter of tubes	Outside diameter of evaporator tube bundle	M	0.0195
Tube thickness	Thickness of tubes in evaporator tube bundle	M	0.0025
Fouling resistance of dvaporator	Fouling of evaporator tube bundle	m^2°C/kW	0.0002
Tube length	Length of tubes in evaporator tube bundle	M	0
Velocity inside tubes	Velocity of steam inside evaporator tube bundle	m/s	40

5. Conclusion

Computer simulation programs are widely used as tools for education and training purposes in the desalination industry. Most simulations are designed to expose operators/students to the actual environment where they must use their knowledge and analytical skills to make meaningful, precise decisions, especially in accidental conditions.

The dynamic model is a powerful tool for predicting the changes in the system variables under the transient operating conditions. This helps getting a better insight into the working of the process and also assists in the design of the control system for optimum operation. Complete simulator results would be verified through actual operating conditions of the MED-MVC plant, under construction.

6. Future investigations and validation

The preliminary VC model presented here is integrated into the initial CEA models of the MED plant. In this model, the input steam flow rate is governed by the values of a valve constant. In the actual BARC installation the flow rate is controlled by an extraction pump.

Table 6
Calculated variables

Variables	Description	Units
Distillate flow (T/day)	Calculated value of capacity of the plant	Tonne/day
Brine flow (T/day)	Calculated value of blow down brine	Tonne/day
Steam flow (T/day)	Steam flowing into the first effect from the compressor outlet	Tonne/day
Blow down salinity (ppm)	Final salinity of blow down brine from the last effect	Ppm
Evaporator area	Total evaporator heat transfer area of the plant	M^2
No of evaporator tubes	No of evaporator tubes in 1^{st} effect	–
Performance ratio	Ratio of cap*2330 to heat input of plant	–
Compressor work	Work input to the compressor	kW
Defaults in the code which cannot be changed		
Cp of steam	Specific heat at constant pressure of steam	kJ/kg°C
Cv of steam	Specific heat at constant volume of steam	kJ/kg°C
Efficiency of compressor	Overall efficiency	–

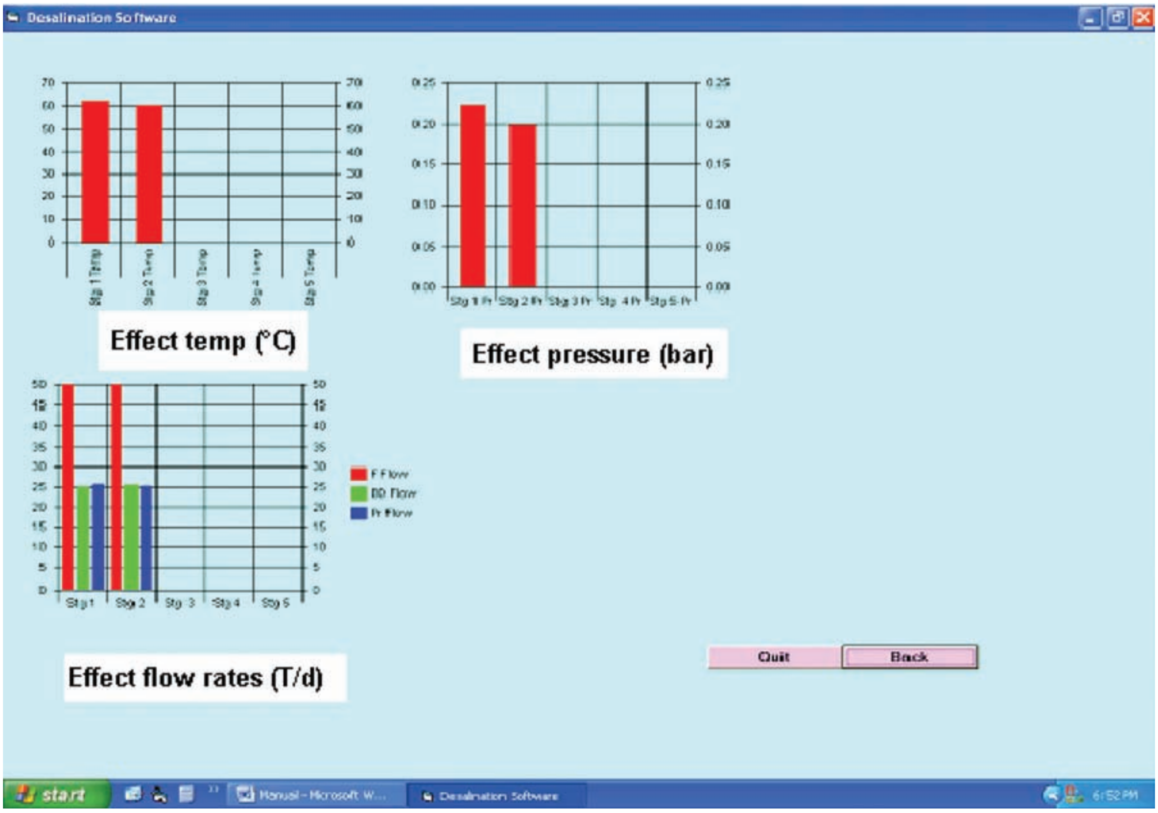

Fig. 5. Graphic steady state results for a two effect MED/VC plant.

Table 7
First steady state results from the Indian MED/VC installation; comparison with INFMED predictions

Operational Date of MED-VC (July 6th, 2007)							
MED VC PLANT PARAMETERS	LL	L	H	HH	Actual Plant Data	Calc. by INFMED	Unit
MVC SPEED			9900	9990	9674	–	rpm
TT-101 VAPOR TEMP. MVC DISCHARGE			80		59.6	59.6[1]	°C
TT-102 1ST EFFECT TEMPERATURE			65		54.8	54.8	°C
TT-103 2ND EFFECT TEMPERATURE			61		52.5	52.5	°C
TT-104 BRINE RECIRCULATION TEMP.	40	52	62.5	67	59.2	50.5[2]	°C
TT-105 VACUUM TANK TEMPERATURE			62	63	43.2	–	°C
TT107 SEA WATER TEMPERATURE		25	35		30	30	°C
TT-108 VAPOR COMPR. BEARING AS TEMP.			95	99	40	–	°C
TT-109 VAPOR COMPR. BEARING BS TEMP.			95	99	41.2	–	°C
PIT-101 VAPOR PRESSURE MVC SUCTION					186	160	mbar
PIT-102 VAPOR PRESSURE MVC DISCHARGE		80	350	400	219	200	mbar
AIT-101 DISTILLATE OUTLET CONDUCTIVITY			20		12.81	0	µs/cm
LT-101 BRINE LEVEL EXTRACTION (P-002)		120	145	149	125.1	–	cm
LT-101 BRINE LEVEL RECIRCULATION (P-001)		90	140	149	124.2	–	cm
FT-101 SEA WATER INLET FLOW RATE		100	135	149	6.43	6.1	m^3/h
FT-102 DISTILLATE FLOW RATE m3/h		0.2			3.05	3.05	m3/h
FT-103 BRINE DISCHARGE FLOW RATE m3/h					3.12	3.04	m3/h

[1] Values in grey shaded rows under Calc column are actual plant operating values that are keyed into the INMED Simulator for validation.
[2] Lower values of Calc when compared to Actual value is due to Start up heater being powered on during initial startup.

The INFMED model will therefore be modified to take into account this difference.

Furthermore, in the months to come, after the complete validation of the modified version, a thermal vapour compression model will be added and strategies will be studied to reduce the relatively high power consumption in mechanical VC. It is also envisaged to incorporate MSF and RO models in the simulator.

As an illustration of the basic validity of the models developed, we present in Table 7 a comparison of the steady state variables from the Indian installation under the final stages of completion.

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