CHAPTER 6

EXPERIMENTAL INVESTIGATION ON LOW TEMPERATURE FLASH VAPORIZATION

6.1 INTRODUCTION

This chapter describes about the two experimental facilities (low and high flow) used in the research work. The flow rate of feed water in the low flow experimental facility is limited to 1000 kg/hr, whereas for the high flow facility it is limited to 10800 kg/hr. Also this chapter describes the salient features, description of the two experimental facilities, details of test procedure and the reason for selecting the parameters for experiments is also discussed.

6.2 DESCRIPTION OF LOW FLOW EXPERIMENTAL FACILITY

The salient features of low flow experimental facility are:

Flow rate of feed water : 1000 kg/hr (max)
Temperature of feed water : 25 – 35°C
Pressure in the vaporizer : 5 – 30 mm of Hg (abs)
Temperature of cooling water : 5 – 20°C
Flow rate of cooling water : 6000 kg/hr (max)
The schematic of the low flow experimental facility is shown in Figure 6.1. It has a vertical vaporizer having provision for injecting the feed water at different heights and varying the resident time of feed water in the vaporizer. Swirl type injectors (nozzles) were used for injecting the feed water as droplets in the vaporizer. The fine water droplet formed by the swirl nozzles give larger surface area for vaporization and help to enhance vaporization rate. The bottom of the vaporizer column is connected to a residue tank of 2 m$^3$ capacity to collect the unevaporated water (residual water) from the vaporizer.

![Figure 6.1 Schematic of low flow experimental facility](image)

The top of the vaporizer is connected to a condenser. A chilling plant is established to supply the cooling water at temperature between 5 and 15°C and at a maximum flow rate of about 6000 kg/hr to the condenser. The condensate from condenser is collected in a fresh water collection tank.
Figure 6.2A Various components of low flow experimental facility

Figure 6.2B Vaporizer condenser assembly of low flow experimental facility
A vacuum pump is connected to a vacuum chamber and this is connected to the condenser, vaporizer and residue collection tank to maintain the desired vacuum. The non-condensed vapour coming out from the condenser is trapped by the vacuum chamber before reaching the vacuum pump. Various components of low flow experimental facility like vaporizer, residue collection tank, feed water storage tank and chilled water storage tank is shown in Figure 6.2A, and the vaporizer condenser assembly of low flow experimental facility is shown in Figure 6.2B.

6.2.1 System for feed water and residual water

The feed water is stored in a tank of 1.5 m$^3$ capacity where the feed water is maintained at the required temperature between 25°C to 35°C. Heaters are used for raising the temperature of the feed water. Water from chilling plant is also used for lowering the feed water temperature. A vertical stirrer kept at the top of the tank, helps to maintain the required water temperature in the tank. A centrifugal pump is used to transport water from the feed water storage tank to the vaporizer. The bottom of the vaporizer column is connected to a residue tank of 2 m$^3$ capacity to collect the unevaporated water (residual water) from the vaporizer.

6.2.2 Vaporizer with Injector system

The vaporizer is of circular cross-section with a diameter of 300 mm and has a length of 3 m made up of 5 modules as shown in Figures 6.1 and 6.2B. It is made of 5 mm thick Perspex glass, so as to enable visual observation of flow inside the vaporizer. It is maintained at low pressures between 5 mm of Hg and 30 mm of Hg. The modular construction provides the flexibility to increase or decrease the vaporizer column length as and where required. Each Perspex glass module is held between two flanges,
which have a groove in which the glass tube is seated. Four tie rods connect the flanges and carry the loads.

A torrid of thickness 12 mm is placed in between the vaporizer modules, which have 3 holes of 6 mm each, two holes are used for inserting pressure and temperature (RTD) measuring probes and the third hole is connected with the injector (nozzle) through which water feed in to the vaporizer. The primary purpose of atomization is to increase the surface area of the water and thereby enhancing the rate of evaporation of the water droplet. The swirl nozzles (injectors) used for garden sprays, operates at small values of injection pressure drops between 0.5 and 2.0 bar is seen to be adequate to produce the necessary spray pattern. Two types of swirl injectors N1 and N2 with spray pattern at different injection pressures is given in Figures 6.3 A and 6.3 B. The orifice diameter is 1.86 mm for Nozzle N1 and for Nozzle N2; there are three outlets holes (orifices) each of diameter is 0.96 mm. Spray characteristics of the nozzles N1 and N2 are given in Table 6.1.

Table 6.1 Spray characteristics of the nozzles N1 and N2

<table>
<thead>
<tr>
<th>Nozzle code</th>
<th>[(P)\text{_inj}] (bar) [gauge]</th>
<th>Flow rate (kg/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N1</td>
<td>0.5</td>
<td>43.5</td>
</tr>
<tr>
<td></td>
<td>1.0</td>
<td>58.2</td>
</tr>
<tr>
<td></td>
<td>1.5</td>
<td>68.4</td>
</tr>
<tr>
<td></td>
<td>2.0</td>
<td>78.0</td>
</tr>
<tr>
<td>N2</td>
<td>0.5</td>
<td>40.2</td>
</tr>
<tr>
<td></td>
<td>1.0</td>
<td>54.0</td>
</tr>
<tr>
<td></td>
<td>1.5</td>
<td>66.0</td>
</tr>
<tr>
<td></td>
<td>2.0</td>
<td>73.8</td>
</tr>
</tbody>
</table>
Figure 6.3A  Spray nozzle N1 with spray pattern

Figure 6.3B  Spray nozzle N2 with spray pattern
A nozzle with RTD and U-tube manometer are connected to a torrid 300 mm in diameter as shown in the Figure 6.4. Based on the initial study made by the researcher (Muthunayagam and Nicholas 2003), it is decided to carry out experiments using single injector mounted at the centre of the vaporizer with upward and downward nozzle orientation to provide large resident time for the injected water droplets.

This injector system can be located at different levels in the vaporizer column and therefore give varying resident time of the droplet in the vaporizer. The physical processes, which take place in the vaporizer, are:

i) Atomization of feed water by spray nozzles into fine droplets.

ii) Vaporization from the droplet surfaces.

iii) Fall of the unevaporated droplet inside the vaporizer by gravity.

In order that the mass transfer takes place efficiently, the droplets have to be small so that they would have a high specific surface area. However, very small diameter droplets could be entrained in the vapour and carried over to the condenser, which affects the purity of freshwater. Packing material composition of non reacting plastic is provided in the topmost section in order to prevent carry over of unevaporated droplets to the condenser, later this is replaced by perforated baffle plates 270 mm in diameter (approximately 700 holes at an average diameter 3 mm each), which seats in the torrid and the plate is shown in Figure 6.5.
Figure 6.4  Injector torrid with RTD and U-tube manometer in the vaporizer

Figure 6.5  Packing material and Baffle plate in the vaporizer
6.2.3 System for fresh water

The top of the vaporizer is connected to a condenser. A chilling plant with capacity 20 TR is established to supply the cooling water at temperature between 5°C and 15°C and at a maximum flow rate of about 6000 kg/hr to the condenser. The condensate (fresh water) from condenser is collected in a fresh water collection tank capacity 0.035m³. The condenser used in the experimental facility is a shell and tube type heat exchanger and is shown in Figure 5.2, which is connected to the top of the vaporizer column to condense the low-pressure vapor from the vaporizer. Here the condensation occurs in the shell, outside the tubes and chilled water is passed through the tubes. The condenser will also be maintained at the same vacuum as at vaporizer.

Specifications of condenser are:

<table>
<thead>
<tr>
<th>Type</th>
<th>Shell and tube</th>
</tr>
</thead>
<tbody>
<tr>
<td>Configuration</td>
<td>3 tube pass mode</td>
</tr>
<tr>
<td>Tube fluid</td>
<td>Cold Water</td>
</tr>
<tr>
<td>Shell fluid</td>
<td>Water vapour</td>
</tr>
<tr>
<td>Shell material</td>
<td>SS 316L</td>
</tr>
<tr>
<td>Tube material</td>
<td>Copper</td>
</tr>
<tr>
<td>Heat transfer area</td>
<td>5 m²</td>
</tr>
</tbody>
</table>

6.2.4 Vacuum Pumping System

The vacuum pumping system is required to maintain the desired vacuum in the vaporizer, condenser and residue collection tank. This vacuum pumping system which consists of a vacuum pump and a vacuum chamber. The vacuum pump which is connected to the vacuum chamber and this is connected with the condenser. Since the vaporizer is connected with the condenser, same
level of vacuum is maintained in vaporizer. The residual tank which is connected with the vaporizer is also maintained at same level of vacuum.

During the evaporation process, non-condensable gases, which include \( \text{O}_2, \text{N}_2, \) and \( \text{CO}_2 \), are released from the seawater. Also practical systems are not fully leak free; there will be air leakage through the joints in the vaporizer and other accessories. These gases flow with the formed vapor into the condenser; upon condensation, the non-condensable gases would accumulate in the overhead space in the condenser. Therefore, it is necessary to provide a vacuum pump to remove the non-condensable gases continually. This is to prevent their accumulation, which would increase in the heat transfer resistance and reduce the overall heat transfer coefficient. Also, an increase in the amount of the non-condensable gases reduces the partial pressure of the condensed vapor. This reduction is associated with decrease in the vapor temperature, which reduces the driving force for heat transfer. Proper design and operation of the condenser and vacuum chamber eliminates the need for using a deaerator for the non-condensed vapour.

6.3 TEST PROCEDURE FOR LOW FLOW EXPERIMENTAL FACILITY

The system is checked and the leak tightness is ensured. The chilling plant is started to achieve the desired temperature of the cooling water. The cooling water is circulated through the condenser, then the vacuum pump is started to attain the steady state of vacuum (low pressure) in the condenser, vaporizer and residue collection tank. After the desired vacuum is achieved, then the feed water pump is started and the feed water is taken through the pipe along the side of the vaporizer and injected into the vaporizer through the control valves as desired in one or more locations. The flow rate of injected water is changed by operating under different feed pressures. Different injector configurations are also experimented to produce different droplet size distribution. Thus several experiments are conducted with varying
temperatures of feed water, flow rates of feed water, vacuum in the vaporizer and the injector location to determine the influence of these parameters on fresh water produced as a percentage of the feed water. It is observed from the initial experiments, that the time required for creating vacuum in the residual tank is high, so it is decided to keep the bottom two module of vaporizer for residual collection, by closing the valve, $V_5$ (Figure 6.1).

Seawater was not used in the experiments. Instead, common salt was used to prepare the saline water. The weight of the salt in water was maintained at 35 grams per liter, because the major content in seawater is NaCl. The variation in the vapour pressure due to the salt content in the water was seen to be negligible (Lange 1969), and the results were not influenced by the salinity of the feed water.

6.3.1 Measurements

All measurements are taken under steady state only. Total duration of the experiments was 30 minutes; the measurements in the system are noted for every 10 minutes and the average value was taken for the calculations.

The volumetric flow rate is directly measured by flow level indicator fitted in the feed water tank. The accuracy of the level indicator was ±1 mm, which translates to an accuracy in mass of ±1.3 kg. Volume of fresh water produced is measured by collecting the freshwater in a measuring jar (after the experimental run). The accuracy of the measuring jar is ±5 ml and the capacity of the measuring jar is 500 ml, giving an accuracy of ±1 % in the flow measurement of the fresh water. For measuring the pressure drop across the injector a Bourdon type pressure gauge is used with an accuracy of ±0.04 bar.
The temperature of feed water and temperature of vapour at different locations of vaporizer (Figure 6.1) was measured with an accuracy of $\pm 0.3^\circ$C using RTDs. The temperatures were read from the direct temperature display in the control panel, shown in Figure 6.6A. The pressure measurements are made using an array of ‘U’ tube monometers with an accuracy of $\pm 1$ mm of Hg is shown in Figure 6.6B. A Vacuum gauge is also used for comparison, with an accuracy of $\pm 7.6$ mm of Hg.

The pH value of the condensate is measured using pH meter and some of the samples are tested with litmus paper, which gives the pH value range only. The measurement accuracy is $\pm 0.01$ for pH meter. The conductivity of the condensate is measured using conductivity meter in $\mu$s/cm (micro siemens per centimeters), and is shown in Figure 6.6C. The measurement accuracy is $\pm 2\mu$s/cm for conductivity meter.
Figure 6.6B  Array of ‘U’ tube monometers for vacuum measurements

Figure 6.6C  pH meter and conductivity meter to check the quality of fresh water
6.4 SELECTION OF PARAMETERS FOR LOW FLOW EXPERIMENTS

A series of experiments is carried out with different combination of parameters so that the data would be useful for scaling up the desalination process. The temperature of the feed water, the pressure in the vaporizer, the resident time of the injected water inside the vaporizer and size of the droplet are identified as parameters influencing vaporization at low pressures.

6.4.1 Pressure in the vaporizer

The desalination plant could be barge mounted with appropriate piping system for intake of ocean water from upper strata for flash evaporation in the vaporizer and cold ocean water from lower strata of the ocean as cooling water for condensing the vapour in the condenser. The barge shall be moored, single point or multi point, at the required depth to get the cooling water at 6°C, in the deep sea around 1000m depth (Muthunayagam 2003d). The desalination plant could also be shore-based for which the cold sea water at 12°C and 15°C could be available from depth around 350 m and 200 m at distance less than 1000 m from the shore. The above bathymetry data is for Cheyur coast near Puducheray, India. The distance from shore to the cold water available situate depends on the bathymetry of the coast and varies from place to place.

Onshore desalination plants could also be established along the coast where favorable bathymetry exists with deep waters available at short distance from shore. The feed water and the cooling water are taken by pipelines from the sea. At Kavaratti, Lakshwadeep Island, the cooling water is typically from a depth of about 350 m at a distance of about 650 m from shore where the water temperature is around 12°C. The bathymetry determines the mooring location of the barge. The cold water drawn from the deep sea for
condensing the vapour and with feed water drawn from the upper strata of the sea around 30°C, so that a temperature difference of about 15°C is possible. For effective condensation a temperature difference of 5°C is planned between the cooling water inlet temperature and the saturation temperature corresponding to the vaporizer pressure (i.e., the temperature of vapour). Therefore 10, 14 and 18 mm of Hg (abs) vaporizer pressures are chosen for which the saturation temperature are 11.25°C, 16.42°C and 20.43°C respectively, which are approximately 5°C higher than the cooling water temperature for the above three cases. The vacuum pressure in the vaporizer was varied in steps of 4 mm of Hg between 10 and 18 mm of Hg.

6.4.2 Temperature of feed water

Desalination plant could also be established with warm water drawn from the upper strata of the sea. The temperature of the upper strata of sea around India varies over the year between 26°C and 32°C. The feed water temperature derived from the sea would therefore be between 26°C and 32°C. Experiments are planned for four temperature levels for the feed water; viz 26, 28, 30 and 32°C.

6.4.3 Feed water injection pressure

To study the influence of size of water droplet on vaporization, it is decided to vary the water injection pressure, which is directly proportional to size of droplet. The water injection pressures in the experiments are varied in steps of 0.5 bar from 0.5 bar to 2 bar for a given injector. This also increases the flow rates of feed water.
6.4.4 Different locations for feed water Injection

Water is injected in to the vaporizer either vertically upwards or downward, as shown in Figure 6.1, at different heights to provide residence times greater than the vaporization time (i.e., droplet lifetime). The resident time for vaporization is varied by injecting the feed water at three different heights (different injection plane) from the top of the vaporizer; viz 650 mm, 1300 mm and 1950 mm, these heights are named in the experiments as IP-1, IP-2 and IP-3 respectively (Figure 6.1).

The range and parameters studied are:

- Feed water temperature ($T_{\text{feed}}$) : 26, 28, 30 and 32°C.
- Vaporizer pressure ($P_{\text{vac}}$) : 10, 14, and 18 mm of Hg (abs)
- Feed water injection pressure ($[\Delta P]_{\text{inj}}$) : 0.5, 1.0, 1.5 and 2 bar
- Different location for water injection : 650, 1300 and 1950 mm from the top of the vaporizer (i.e., IP-1, IP-2 and IP-3 respectively)
- Type of nozzle : N1 and N2

6.5 Description of High Flow Experimental Facility

The salient features of the experimental facility are:

- Flow rate of feed water : 10800 kg/hr (max)
- Temperature of feed water : 25–35°C
- Pressure in the vaporizer : 05 – 30 mm of Hg (abs)
- Temperature of cooling water : 05 – 20°C
- Flow rate of cooling water : 30000 kg/hr (max)
The schematic of the experimental facility is given in Figure 6.7. The experimental plant consists of an air-tight barometric vaporizer, positioned so that the altitude of the free surface of the liquid water it contains is at least 10.3 m above seawater level in a tank as shown in Figure 6.7.

Figure 6.7 Schematic of high flow experimental facility

This height of a water column is equivalent to one standard atmospheric pressure at sea level (1.01325 bar) and therefore, provides for the minimum vacuum pressure at the water surface in the barometric chamber. Heights greater than 10.3 m are certainly acceptable; however increasing the height above this will not reduce the chamber pressure any further. Therefore the experimental plant is established in a structure with the vaporizer and condenser at an elevation of about 13 meter from the ground level where the storages for feed water, cooling water and fresh water systems is located to ensure barometric seal during operation as shown in the Figure 6.8.
Figure 6.8  Vaporizer and condenser assembly of high flow facility

It has a vaporizer having provision for injecting the feed water through a pair of impinging conical swirl injector (nozzle), the fine water droplet producing by the impingement of swirl nozzles give larger surface area for vaporization and help to enhance vaporization rate. The barometric seal, provided by the long HDPE (High density poly ethylene) pipe connecting the vaporizer with a tank (i.e., BW-1 in Figure 6.7) enables to maintain the vacuum in vaporizer and also to discharge large volume of water which is not vaporized (residual water) in the vaporizer without the aid of any pump.

The top of the vaporizer is connected to a condenser. A 20 TR capacity chilling plant is established to supply the cooling water at temperature between 5 and 15°C and at a maximum flow rate of about
30000 kg/hr to the condenser. The barometric seal, provided by the another HDPE pipe connecting the condenser a tank (BW-2 in Figure 6.7) enables to maintain the vacuum in condenser and also to discharge fresh water from the condenser without the aid of any pump. A vacuum pump is connected to a vacuum chamber and this is connected to the condenser and vaporizer to maintain the desired vacuum. The non-condensed vapour coming out from the condenser is trapped by the vacuum chamber before reaching the vacuum pump. Components like condenser and vaporizer of high flow experimental facility are given in Figure 6.8.

6.5.1 System for Feed water and Residual water

The feed water is conditioning in a tank of 1.5 m$^3$ capacity where the feed water is maintained at the required temperature between 25°C and 35°C. Heaters are used for raising the temperature of the feed water. Water from chilling plant is also used for lowering the feed water temperature. A vertical stirrer kept at the top of the tank, helps to maintain the required water temperature in the tank. A centrifugal pump is used to transport water from the feed water conditioning tank to the feed water storage tank. The capacity of the sintex storage tank is 10 m$^3$. A centrifugal pump is used to transport water from the feed water storage tank to the vaporizer through a pair of conical swirl injector.

The barometric seal, provided by the long HDPE (High density poly ethylene) pipe connecting the vaporizer with a tank (i.e., BW-1 in Figure 6.7) enables to maintain the vacuum in vaporizer and also to discharge large volume of water which is not vaporized (residual water) in the vaporizer without the aid of any pump.
6.5.2 Vaporizer with Injector system

The vaporizer is of circular cross-section with a diameter of 1200 mm and has a height of 1000 mm. It is made of 10 mm thick Stainless steel 316 L. The vaporizer was found to be mechanically stable with internal pressures as low as 133 Pa (abs). It is maintained at low pressures between 5 mm of Hg and 30 mm of Hg (abs). It is decide to keep two swirl injectors in the opposite direction for impinging of the water film (sheet of water) coming out from the injectors. This vaporizer has an arrangement to hold two injectors in the opposite directions as shown in Figure 6.9, also there is provision to vary the distance between the injectors, to produce different droplet size distribution; there by the influence of size of water droplet on vaporization was studied.

In order that the mass transfer takes place efficiently, the droplets have to be small so that they would have a high specific surface area. However, very small diameter droplets could be entrained in the vapour and carried over to the condenser, which affects the purity of freshwater. Baffle plates are used to avoid carry over of unevaporated droplets to the condenser.

A swirl-type injector is used for the present study due to its favorable spray characteristics, such as the atomization performance and the spray shape controllability (Yasuo Moriyoshi et al 2002). The swirl injector used is slope bottom type whirl jet spray (Spraying systems 1998), which is generally used in cooling towers, spray ponds and evaporation ponds. These selected injectors can produce 1mm droplets at a far away distance (approximately 1meter) from the injector outlet. In the experiments two such swirl injectors (pair of N3 and N4) are taken, the photograph of the spray nozzles used in the experiment is shown in Figures 6.10A and 6.10B.
Figure 6.9 Injector holding plates inside the vaporizer

Figure 6.10A Spray Nozzle N3
The water sheet produced by a same pair of the injectors was allowed to impinge each to produce fine droplets at a shorter distance from the injector outlet shown in Figure 6.11.

Mechanism of water sheet formation from a swirl injector is given by David P. Schmidt (Engine Research Center, University of Wisconsin). The
liquid forms a film along the inside walls of the injector and an air core in the center. The liquid film becomes a free sheet which then disintegrates into droplets, forming a hollow cone spray. In order to predict the behavior of swirl atomizer, the near-field region of hollow cone sprays must be understood. This region includes the liquid sheet as it leaves the injector and breaks up. At the injector exit, the flow through the orifice becomes a free sheet that later forms the spray. This important boundary, along with the aerodynamic interaction with the ambient gas, determines the behavior of the spray. Thus knowledge of the flow field at the injector exit is necessary for spray prediction.

The transition from internal injector flow to fully developed spray can be divided into three steps: film formation, sheet breakup, and atomization. A sketch of how this process is thought to occur is shown in Figure 5.2. The process begins inside the injector, where swirl ports direct the liquid into a swirl chamber. The swirling motion forces the liquid against the walls. When the film exits the injector and becomes a free liquid sheet, the force of the walls is no longer present. Consequently, the tangential velocity of the liquid becomes radial. As the radial distance from the centerline to the sheet increases, the rotation decreases as indicated by conservation of angular momentum. The trajectory approaches a straight line whose angle from the centerline is determined by the ratio of the tangential to axial velocity. Additionally, because of conservation of mass, the sheet thins as it progresses.

The spray characteristic of the selected spray nozzles N3 and N4 in the high flow experiments are listed in Table 6.2 (Spraying systems 1998).
**Table 6.2 Spray characteristics of the nozzles N3 and N4**

<table>
<thead>
<tr>
<th>Nozzle code</th>
<th>Nozzle type and material</th>
<th>Flow rate [kg/hr]</th>
<th>$[\Delta P_{inj}]$ (bar) [Gauge]</th>
<th>Spray angle ($\theta$) [degree]</th>
<th>Diameter of Inlet and Outlet of the nozzle [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>N3</td>
<td>1¼CX SS 16-SS.316</td>
<td>3600</td>
<td>0.5</td>
<td>74</td>
<td>21.4 and 20.2</td>
</tr>
<tr>
<td>N4</td>
<td>1¼CX 30-Brass</td>
<td>5400</td>
<td>0.7</td>
<td>76</td>
<td>21.4 and 24.2</td>
</tr>
</tbody>
</table>

A pair of nozzle N1 was used in the experiments when the flow rate was 7200 kg/hr and a pair of nozzle N2 was used when the flow rate was 10800 kg/hr. Same nozzles were not used for both the flow rates, because if we use nozzle N1 for getting a flow rate of 5400 kg/hr, $[\Delta P_{inj}]$ increases. Arthur H. Lefebvre (1989) shows that increased injection pressure decreases droplet size. It is also observed that both the nozzles produces similar flow pattern. From Figure 6.11 it is seen that the AD=AC=BD=BC, when the impinging is perfect. When AB is varied DC also varies. DC in Figure 6.11 is calculated using the equation $DC=AB \cdot \tan(\theta/2)$. The value of DC is calculated for different $\theta$ ($74^\circ$ and $76^\circ$), and are presented in Table 6.3.

**Table 6.3 Value of DC in Figure 6.11**

<table>
<thead>
<tr>
<th>Vertical distance between injection [AB] (mm)</th>
<th>DC (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\theta=74^\circ$</td>
</tr>
<tr>
<td>100</td>
<td>075.36</td>
</tr>
<tr>
<td>200</td>
<td>150.72</td>
</tr>
<tr>
<td>300</td>
<td>226.08</td>
</tr>
<tr>
<td>400</td>
<td>301.44</td>
</tr>
</tbody>
</table>
6.5.3 System for fresh water

The 20 TR chilling plant used in the low flow facility is augmented with additions of 2 numbers of 10 m$^3$ storage tanks (sintex) without modifying the chilling plant. The storage tanks are further insulated to reduce the heat transfer from the walls of the tank. The cooling water at temperature between 5°C and 15°C and at a maximum flow rate of about 30000 kg/hr from the storage tank is supplied to the condenser. The condenser used in the experimental facility is a shell and tube type heat exchanger which is connected to the top of the vaporizer column to condense the low-pressure vapour from the vaporizer. The heat transfer area of the condenser is 26.5m$^2$ with 6 tube pass. The condensate (fresh water) from condenser is collected in a fresh water collection tank (0.2 m$^3$ capacity), through an overflow pipe in the freshwater barometric well (i.e., BW-2 in Figure 6.7).

6.5.4 Vacuum pumping system

The vacuum pumping system is required to maintain the desired vacuum in the vaporizer and condenser. This vacuum pumping system which consists of four vacuum pumps and a vacuum chamber. During the process of evaporation non condensable gases released from the sea water & the plant leakage load are constantly pumped by a vacuum system to ensure that absolute pressure in the range of 25 mbar is maintained in the vaporizer. The vacuum pump which is connected to the vacuum chamber and this is connected with the condenser. Since the vaporizer is connected with the condenser, same level of vacuum is maintained in the vaporizer. The barometric seal provided by the long HDPE pipe connecting the vaporizer with a 10 m$^3$ sintex storage tank (i.e., BW-1 in Figure 6.7) enables to maintain the required vacuum in the vaporizer and also to discharge large volume of water which is not vaporized in the vaporizer without any pump. Photograph of Karunya desalination plant is shown in Figure 6.12.
6.6 TEST PROCEDURE FOR HIGH FLOW EXPERIMENTAL FACILITY

The system is checked and the leak tightness is ensured. The chilling plant is started to achieve the desired temperature of the cooling water. The cooling water is circulated through the condenser, then the vacuum pump is started to attain the steady state of vacuum (low pressure) in the condenser and vaporizer. After the desired vacuum is achieved, then the feed water pump is started and the feed water is taken through the pipe along the side of the vaporizer and injected into the vaporizer through a pair of impinging injector and the flow rate was controlled with the help of control valve.

The temperature of the feed water and the pressure in the vaporizer was regulated according to the requirement. Two different injectors (N3, N4) are experimented to produce different droplet size distribution. The distance between the injectors was varied by altering the distance between the injector
holding plate (Figure 6.9). In experiments a pair of injector N3 was used when the flow rate was 7200 kg/hr and a pair of injector N4 was used when the flow rate was 10800 kg/hr.

Thus several experiments are conducted by varying feed water temperatures, vacuum in the vaporizer, the distance between the injectors and the vaporizer volume to determine the influence of these parameters on fresh water production.

Since the major content in seawater is NaCl, it is decided to mix only NaCl in the water to prepare artificial sea water for the experiments; therefore feed water used for experiments is mixed with common salt with 35 gms per liter (35000 ppm).

6.6.1 Measurements

All measurements are taken under steady state only. Total duration of the experiments was 30 minutes; the measurements in the system are noted for every 10 minutes and the average value was taken for the calculations. The temperature of feed water and temperature of vapour at different location in vaporizer was measured with an accuracy of ±0.3°C using RTDs. The temperatures were read from the direct temperature display in the control panel, shown in Figure 6.13A.
Figure 6.13A Control panel with temperature display in high flow facility

The rate of flow of feed water into the vaporizer was measured by a Rotameter. The accuracy of the feed water Rotameter was ± 100 liters/hr. For measuring the injection pressure a bourdon type pressure gauge is used with an accuracy of ± 0.04 bars. The pressure measurements are made using an array of U tube manometers with an accuracy of ± 1 mm of Hg. Vacuum gauge is also used for comparison, with an accuracy of ± 7.6 mm of Hg.
The rate of flow of the cold water into the condenser was measured by a Rotameter. The accuracy of the cold water Rotameter level was ± 200 liters/hr. With the help of an overflow pipe in the fresh water barometric well as shown in Figure 6.13B, the flow rate of fresh water is measured and the yield is calculated. The quantity of the condensed water was collected in a measuring jar; with an accuracy of ± 5ml. The capacity of the measuring jar is 500 ml. The pH values and the conductivity of the condensate were measured using pH meter and conductivity meter respectively.

The temperature of feed water and temperature of vapour at different locations of vaporizer (Figure 6.1) was measured with an accuracy of ± 0.3°C using RTDs. The temperatures were read from the direct temperature display in the control panel, shown in Figure 6.6A. The pressure
measurements are made using an array of ‘U’ tube monometers with an accuracy of ± 1 mm of Hg is shown in Figure 6.6B. A Vacuum gauge is also used for comparison, with an accuracy of ± 7.6 mm of Hg.

The pH value of the condensate is measured using pH meter and some of the samples are tested with litmus paper, which gives the pH value range only. The measurement accuracy is ± 0.01 for pH meter. The conductivity of the condensate is measured using conductivity meter in µs/cm (micro siemens per centimeters), and is shown in Figure 6.6C. The measurement accuracy is ± 2 µs/cm for conductivity meter.

6.7 SELECTION OF PARAMETERS FOR EXPERIMENTS

A series of experiments is carried out with different combination of parameters so that the data would be useful for scaling up the desalination process. Selection of vaporizer pressures, feed water temperatures Selection of distance between injectors, Selection of vaporizer volume for experiments are disused.

6.7.1 Pressure in the vaporizer

The desalination plant could be barge mounted with appropriate piping system for intake of ocean water from upper strata for flash evaporation in the vaporizer and cold ocean water from lower strata of the ocean as cooling water for condensing the vapour in the condenser. The barge shall be moored, single point or multi point, at the required depth to get the cooling water at 6°C, in the deep sea around 1000m depth (Muthunayagam 2003d). The desalination plant could also be shore-based for which the cold sea water at 12°C and 15°C could be available from depth around 350 m and 200 m at distance less than 1000 m from the shore. The above bathymetry data is for Cheyur coast near Puducherry, India. The distance from shore to
the cold water available situate depends on the bathymetry of the coast and varies from place to place.

Onshore desalination plants could also be established along the coast where favorable bathymetry exists with deep waters available at short distance from shore. The feed water and the cooling water are taken by pipelines from the sea. At Kavaratti, Lakshwadeep Island, the cooling water is typically from a depth of about 350 m at a distance of about 650 m from shore where the water temperature is around 12°C. The bathymetry determines the mooring location of the barge.

The cold water drawn from the deep sea for condensing the vapour and with feed water drawn from the upper strata of the sea around 30°C, so that a temperature difference of about 15°C is possible. For effective condensation a temperature difference of 5°C is planned between the cooling water inlet temperature and the saturation temperature corresponding to the vaporizer pressure (i.e., the temperature of vapour). Therefore 10, 14 and 18 mm of Hg (abs) vaporizer pressures are chosen for which the saturation temperature are 11.25°C, 16.42°C and 20.43°C respectively, which are approximately 5°C higher than the cooling water temperature for the above three cases. The vacuum pressure in the vaporizer was varied in steps of 4 mm of Hg between 10 and 18 mm of Hg.

6.7.2 Temperature of feed water

Desalination plant could also be established with warm water drawn from the upper strata of the sea. The temperature of the upper strata of sea around India varies over the year between 26°C and 32°C. The feed water temperature derived from the sea would therefore be between 26°C and 32°C. Experiments are planned for four temperature levels for the feed water; viz 26, 28, 30 and 32°C.
6.7.3 Selection of distance between injectors

It is decide to keep two swirl injectors in the opposite direction for impinging of the water film coming out from the injectors. Different distance between the injectors (i.e., AB in Figure 6.11) is experimented to produce different droplet size distribution, there by the influence of size of water droplet on vaporization was studied. The fine water droplet formed by the swirl nozzles give larger surface area for vaporization and help to enhance vaporization rate. The distance between the injectors is varied between 100 200, 300 and 400 mm.

6.7.4 Selection of vaporizer volume for experiments

To study the influence of vaporizer volume on the rate of vaporization by varying the vaporizer volume. This was done by reducing the inner diameter of the vaporizer (Dv) by means of fixing non-reacting objects along the inner wall without affecting the impinging and vaporization process. The diameter of the vaporizer is reduced from 1200 mm (100%) to 720mm (60%) in three steps. The vaporizer volume is indirectly a function of the resident time.
The range and parameters studied are:

Feed water temperature ($T_{\text{feed}}$) : 26, 28, 30 and 32°C.

Feed water flow rate ($m_{\text{feed}}$) : 7200 and 10800 kg/hr. (For N3 and N4 respectively)

Vaporizer pressure ($P_{\text{vac}}$) : 10, 14, and 18 mm of Hg (abs).

Distance between injection planes (AB) : 100, 200, 300, and 400 mm.

Diameter of the vaporizer ($D_v$) : 100 %, 80 % and 60 % of $D_v$
(i.e., $D_v=1200, 960$ and $720$ mm)