CHAPTER 6

EXPERIMENTAL CONSIDERATION IN DEVELOPING THE SOLAR REFRIGERATOR

The developmental work of the solar refrigerator involved various activities like precisely defining the problem and basic specifications of the product, selection of adsorbent - refrigerant pair, establishment of the stability and suitability of the adsorbent for refrigeration application, establishment of the properties of the adsorbent-refrigerant pair and the design of the various subsystems that go into the refrigerator.

6.1 DEFINITION OF THE PROBLEM

In India about 75% of the population live in rural areas of which only 1% own refrigerators[1]. Most of the people do not have reliable supply of electric power and hence conventional vapour compression systems are not well suited. But refrigeration is an important requirement to preserve food materials like fruits, vegetables, meat, fish, milk and milk products and other essential items like vaccines and medicines.

In this situation a small refrigerator, independent of any conventional fuel and without major maintenance requirements will fit perfectly into the existing and well known need for refrigeration for vaccine storage in the rural areas of the Country. Hence the investigation was directed towards developing a solar refrigerator that do not require any conventional fuel and be capable of storing essential vaccines in rural health centres.

Currently the National Immunization Scheme for vaccine preventable diseases is being organized through a process called Cold Chain. In the cold chain process, at the rural health centres vaccines are stored in vaccine carriers or cold boxes which are basically insulated boxes kept cool using ice. The typical vaccine carriers are of the order 1 to 2 litres capacity where as the cold boxes are of 15 to 40 litres[2]. The vaccines are loaded in the carriers along with sufficient ice in plastic bottles in the urban centres and transported to the rural areas. In such method, it is essential to bring the unused vaccines to the urban centres for safe keeping within about 10 hours.

The specific objective of this work has been to develop an alternative device to store the vaccines in the rural areas. With this view an attempt has been made to develop a solar refrigerator capable of producing 1 kg of ice during the night. This ice was expected to maintain the refrigerator temperature between 3 to 8 degree C throughout the day.

6.2 MOLECULAR SIEVE 13X

Molecular Sieve 13X is an indigenously manufactured synthetic zeolite which structurally resembles the natural zeolite Faujasite. As the name suggest it is a Type X molecular sieve whose structure is shown in Fig. 6.1. When the cation is Sodium (Na) it is know as 13X (NaX) and when

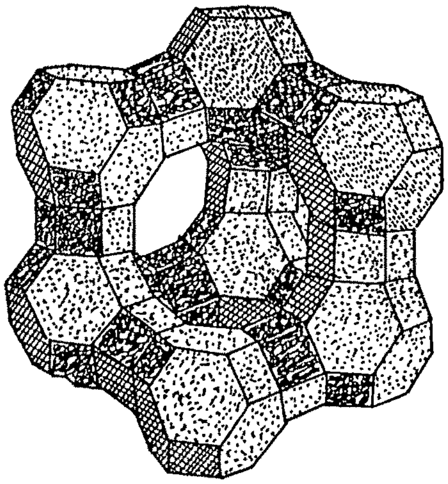


Fig. 6·1 . Structure of zeolite -X

the cation is Calcium (Ca) it is called 10X. The 13X is represented by the following chemical formula.

$Na_{86}\ [(Al\ O_2)_{86}\ (Si\ O_2)_{106}]272\ H_2O$

The channel system is 3 - dimensional 12 ring and has a uniform pore size of 10 A.

The typical specifications of 13X used in the work is given below [3,4,5].

Form	3 mm diameter cylindrical pellets
Bulk density	530 gms/litre
Crush strength	7 kgs
Molecules adsorbed	Almost all molecules with an effective diameter less than 10 A
Molecules excluded	Molecules with an effective diameter greater than 10 A Example Tri ethyl amine

Equilibrium adsorption Capacity for H2O at 30 degree C and 75% RH : 26% by weight

at 15% RH : 21% by weight

Heat of Adsorption : 1000 kcal/kg H2O

Molecular sieve 13X has one of the largest uniform pores which provides it with very high adsorption capacity. For complete thermal regeneration the adsorbent should be heated to about 250-300 degree C. However repeated exposures to temperatures above 450 degree C or hot gases having high partial pressures should be avoided.

The adsorption capacity of Molecular Sieves is due to electrostatic forces between the adsorbent and adsorbate. It is these forces which make molecular sieves unique in maintaining a high adsorption capacity at high temperatures and low partial pressures unlike other adsorbents.

The Molecular Sieve 13X used in this work was manufactured by the Indian Petrochemical Corporation Ltd. (IPCL) at their catalistic plant in Thane, Near Bombay. The plant was earlier owned by Associated Cement Company (ACC). Fig. 6.2 is a photograph of the zeolite pellets used in the study.

The adsorption and desorption are completely reversible with the respective isothermal curves coinciding completely resulting in consistent performance.

Fig. 6.2 : Molecular Sieve 13X pellets

6.3 THERMOLUMINESCENCE PROPERTIES OF 13X

Thermoluminescence properties have been used in this investigation to establish the suitability of using 13X for the refrigeration application. The work was directed to obtain the TL glow curves of samples annealed at progressively higher temperatures to determine the conditions that effect irreversible damage to the adsorbent.

Pure sample of 13X powder was obtained from the zeolite manufacturer for the TL study. A Glow curve reader, Muffle furnace and Beta source were used in this study. Experiments were conducted for samples annealed at a wide range of temperatures.

6.3.1 TL Glow Curve Reader :

The Glow curve reader used in the current investigation consisted of a Photo Multiplier Tube (PMT) Thorn EMI 9804 B, a high voltage DC supply for the PMT, a DC amplifier, temperature programmer and X-Y recorder [6,7]. A block diagram of the complete unit is shown in Fig. 6.3.

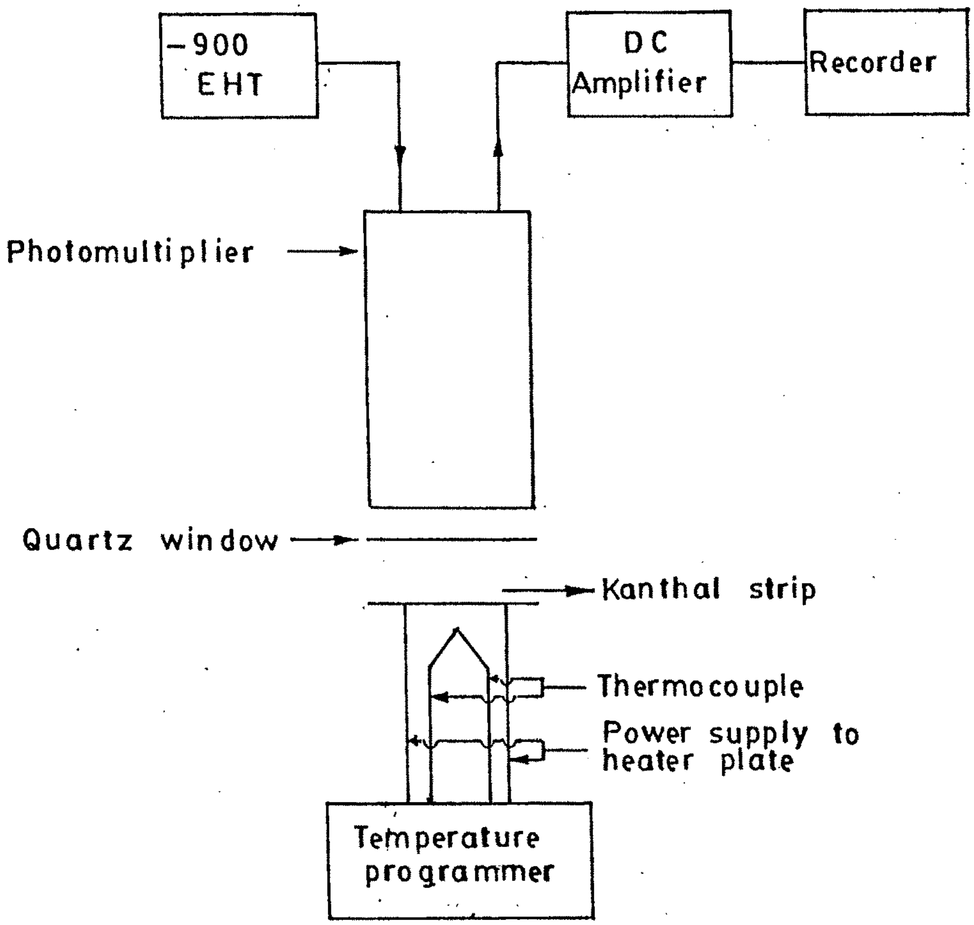


Fig. 6·3 Block diagram of TL set-up

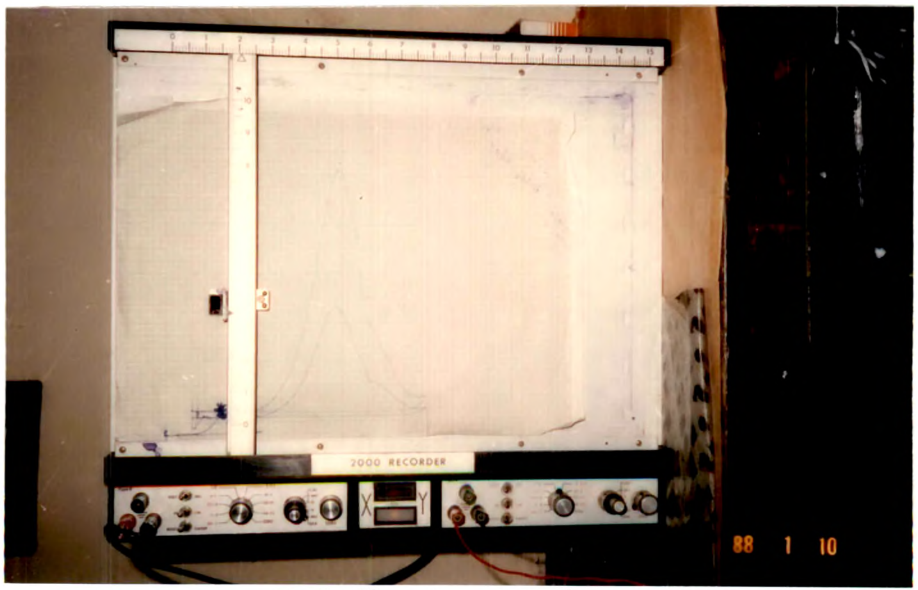
The sample was heated on a Kanthal strip heater (an alloy of Fe-72%, Cr-23%, Al-3% and Co-2%). A Chromel Alumellel thermocouple spot welded at the centre on the lower side of the Kanthal strip was used to measure the temperature. The heater and its electrodes were mounted in a drawer to facilitate easy change of samples. The photomultiplier tube was housed in a light tight brass cylinder and was mounted on the sample heating chamber such that the window of the PMT directly faced the sample being heated. This arrangement provided near total sensing of the TL-emission. To reduce the thermal background of the heater, an aluminium cover with a central hole of 20 mm diameter was used over the sample so that only the sample was vissible to the PMT. To avoid heat radiation from reaching the PM tube, a quartz window was introduced between the heater and the photomultiplier.

A negative potential of 900 volts was applied to the PMT. An Indotherm-487 temperature programmer was used to heat the sample at any rate from 5 degree C/min to 1000 degree C/min. The light emitted by the sample was detected by the PMT and later amplified and recorded using a X-Y recorder. Fig. 6.4 shows photographs of the complete TL glow curve reading arrangement.

During the experiments a Beta-source Sr-90 with a strength of 50 mci was used to irradiate the samples. Its irradiation rate was 200 and 2400 rads per minute at irradiation distances of 14 mm and 3 mm respectively.

Photomultiplier tube

Amplifier and temperature programmer



X-Y Chart recorder

Fig. 6.4 : Photographs of the TL glow curve reading arrangement

6.3.2 Preparation of Sample :

Pure 13X sample without any binding material was used in the TL study. All zeolites can be dehydrated to some degree without any alteration to their structure. Those can be subsequently rehydrated by introducing water vapour. The TL studies were conducted using fresh samples and samples annealed for one hour at various temperatures starting from 100 degree C to 1000 degree C. In each TL experiment, about 5 mg of sample was heated to 400 degree C at the rate of 400 degree C/min on the Kanthal strip of the TL glow curve reader setup. Samples were irradiated using Sr-90 beta source.

6.3.3 TL Glow Curves :

The virgin sample not exposed to any annealing was tested for TL after irradiating using a beta source for different test doses. As this sample did not indicate any TL peak, the 13X samples were annealed at different temperatures. The samples annealed upto 800 degree C for one hour intervel did not produce any TL peaks. The typical glow curve obtained for virgin samples and those annealed upto 800 degree C is shown in Fig. 6.5. The samples annealed and quenched from 100, 200, 400, 600 and 800 degree C and given a beta dose upto 1,00,000 rads did not give any considerable TL output.

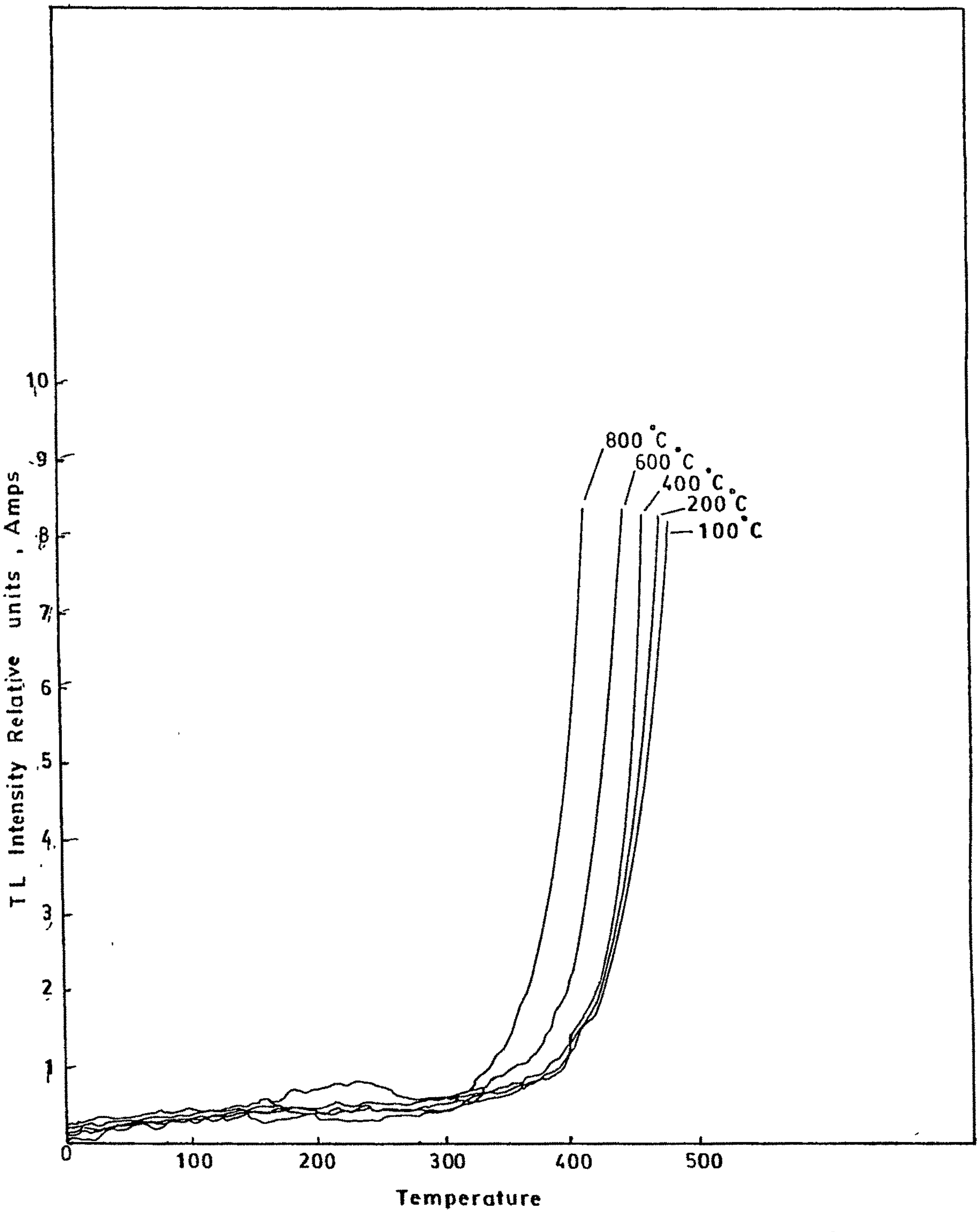


Fig. 6.5 TL Glow curve for samples annealed up to 800 °C and exposed to various β - doses

Samples annealed at 850 degree C for one hour showed a clear peak at about 110 degree C. Samples annealed at 900 and 1000 degree C also showed the same peak. Figures 6.6, 6.7 and 6.8 show the TL glow curves for samples annealed at 850 degree C, 900 degree C and 1000 degree C respectively [8].

As a pure crystal does not show any TL glow curve due to the absence of any defects in the structure, the absence of TL glow in samples annealed upto 800 degree C indicate that the crystal structure is intact till such temperature. In other words, even if the zeolite 13X is heated upto 800 degree C in the course of operation as the adsrobent in a solar refrigerator, the adsorbent will remain active and the adsorption desorption cycles will occur.

Heating to temperatures above 850 degree C has resulted in the TL glow curve indicating permanent damage to the structure. As irreversible damage occur at temperatures above 850 degree C, the 13X should not be ever exposed to that temperature or higher.

In normal operation of the solar refrigerator the zeolite will not be exposed to temperatures higher than 200 degree C. But any welding if done with the zeolite inside the collector will damage the zeolite and hence should be avoided.

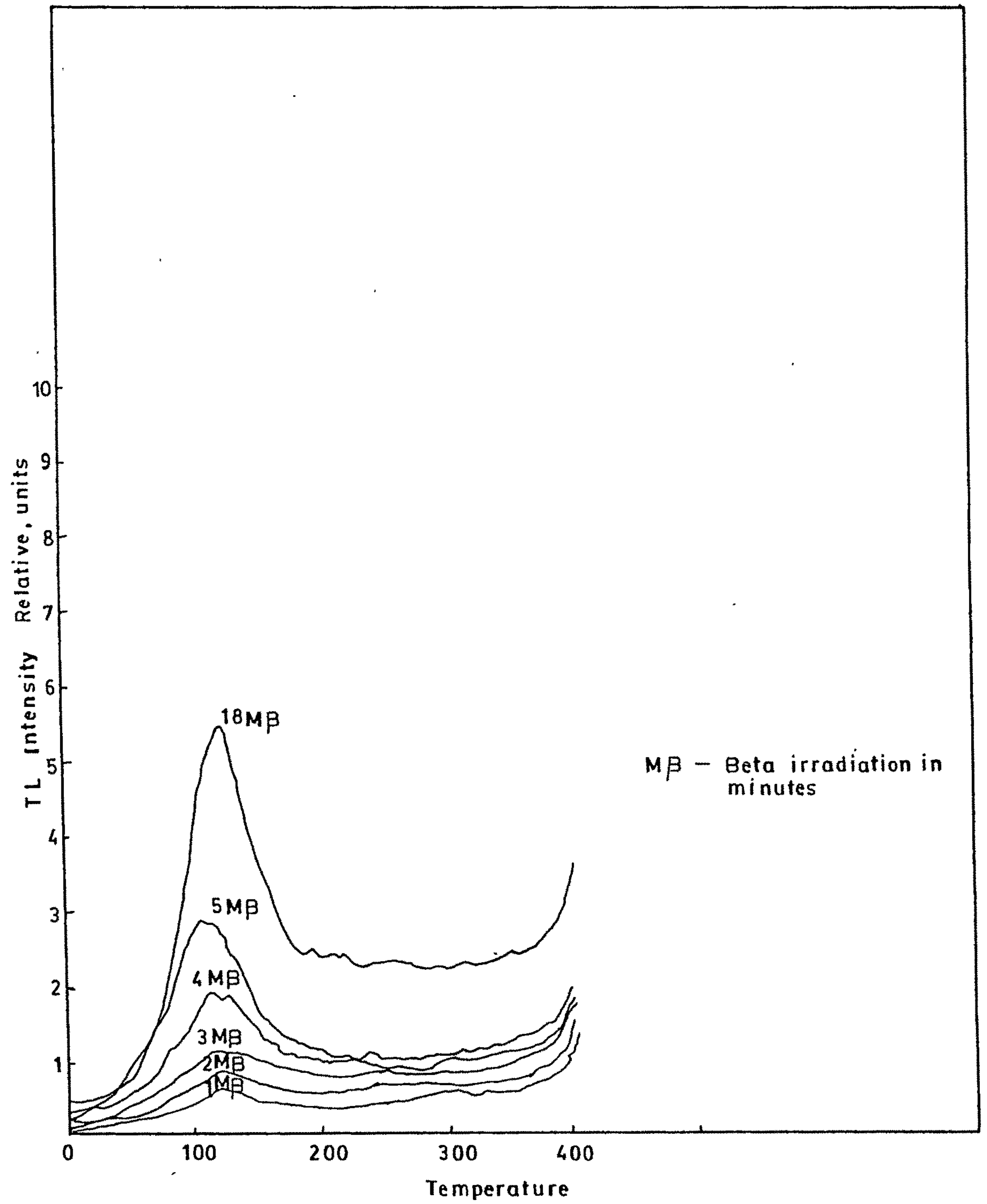


Fig. 6·6 T L Glow curve for 13X samples annealed and quenched from 850 °C

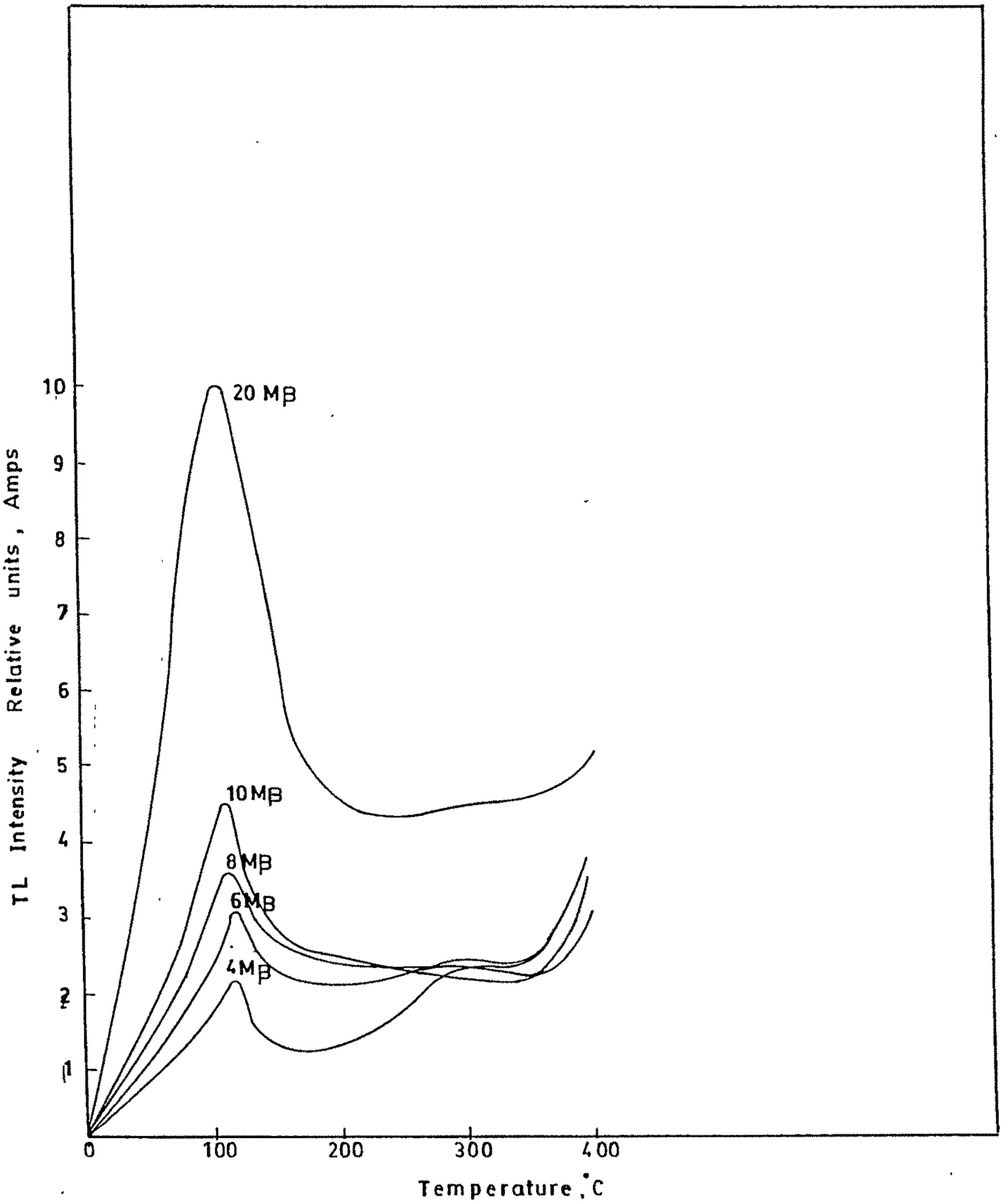


Fig. 6.7 TL glow peaks for 13X annealed and quenched from 900 °C

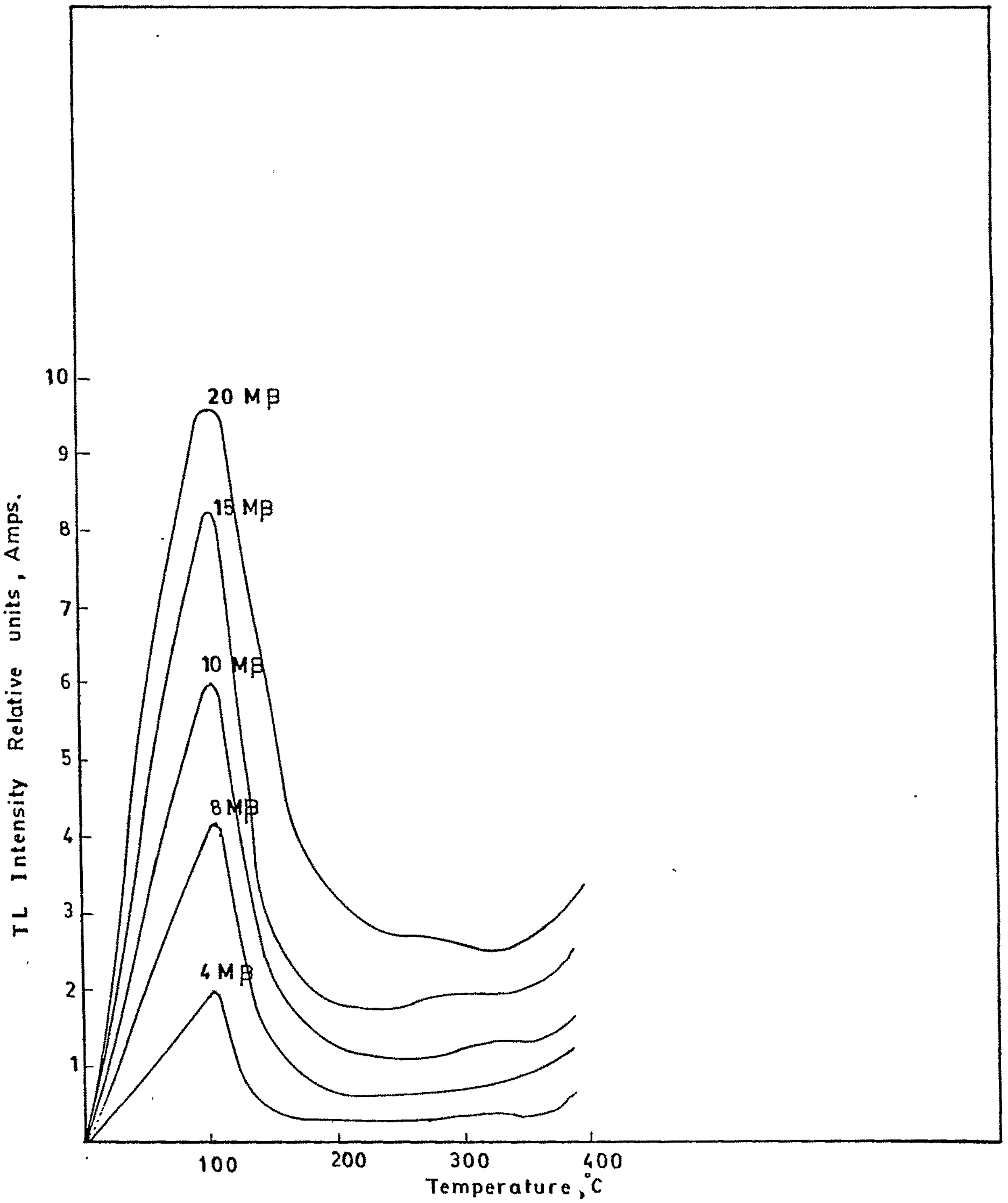


Fig. 6.8 TL glow peaks for 13X annealed and quenched from 1000°C

6.4 INFRARED SPECTROSCOPY

The infrared spectra was obtained for wave length range of 4000 to 200 cm^{-1} (2.5 to 50 µm). It was obtained by placing the sample in one beam of a double beam infrared spectrophotometer and measuring the relative intensity of transmitted light energy versus wavelength.

Fresh sample, and samples annealed at 900 degree C and 1000 degree C for 1 hour were used to determine the IR spectrum. About 1 mg of each sample was ground finely with Potassium Bromide. The mixture was dried to remove moisture and pressed at high temperature and pressure to form wafers. These wafers were used to determine the spectrum. Fig. 6.9 shows the IR spectrum of fresh sample. As can be seen, the vibrations are strongest in the far infrared region of 1200 to 200 cm^{-1}. The vibration at 950-1200 cm and 420-500 cm^{-1} are the strongest and these are due to internal tetrahedron vibrations. The vibration at 950 cm^{-1} is normally assigned to T-O stretch and the 420-500 cm^{-1} region is assigned to T-O bending mode[9].

Streatching modes mainly due to the tetrahedral atoms are seen in the region 650-820 cm^{-1}. The band in the 500-650 region is due to the presence of the double rings in the frame work structures. Another main frequency which is assigned to external linkages is in the 300-420 cm^{-1} portion of the spectrum and is related to pore openings.

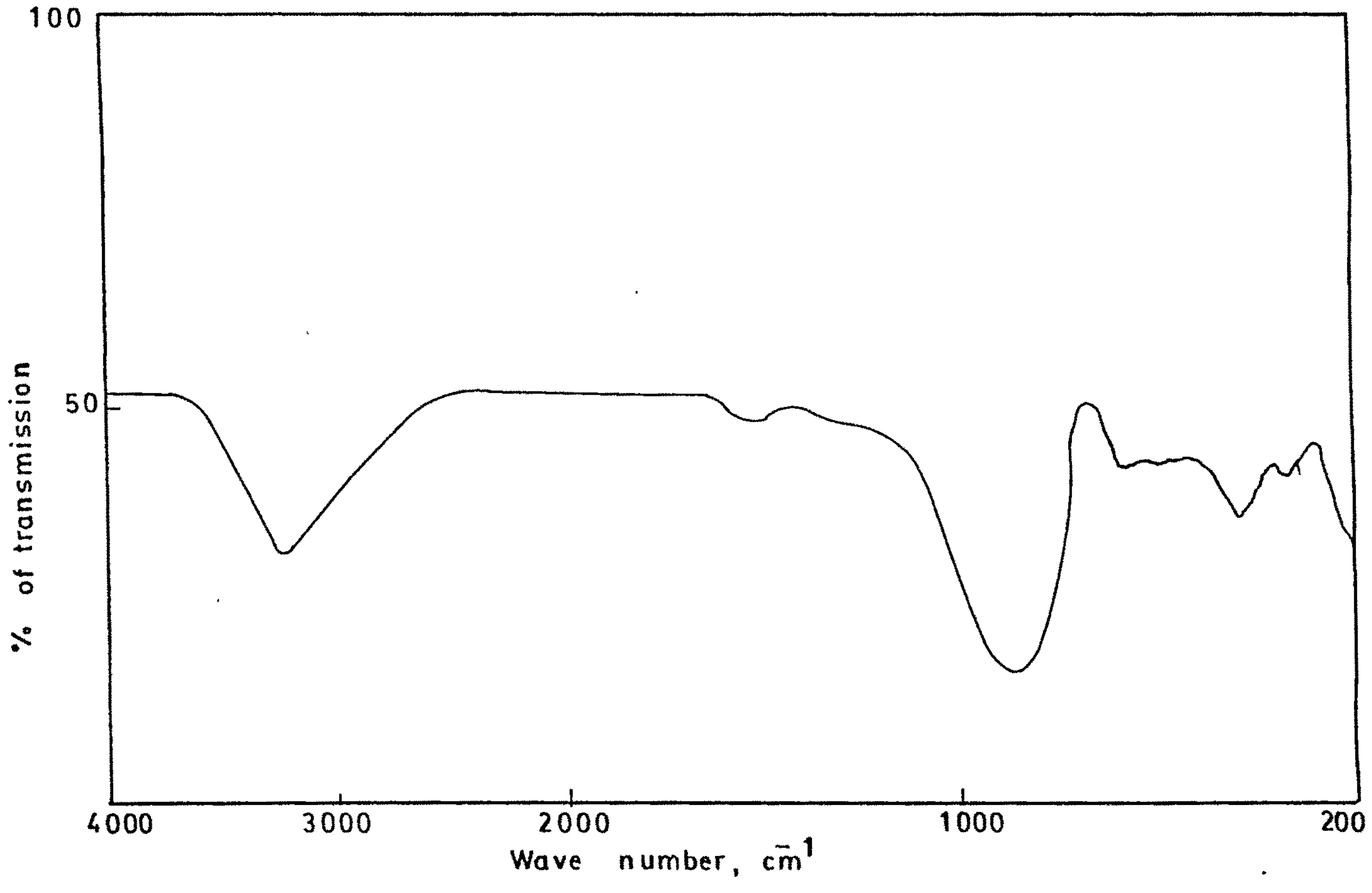


Fig. 6.9 IR Spectra of Zeolite 13 X fresh specimen

The spectrum of samples annealed at 900 degree C and 1000 degree C are shown in Fig. 6.10 and 6.11. As can be seen, the well documented vibrations of 13X are missing in these samples indicating a complete collapse of the crystal structure.

The IR spectra obtained for fresh 13X is idential to the spectras reported in literature[9,10]. The permanent damage of the crystal structure when exposed to temperatures above 800 degree C has been clearly indicated in the IR studies also. But as that temperature is much higher than anything that is possible using a solar flat plate collector, the 13X can be safely used for the refrigerator work.

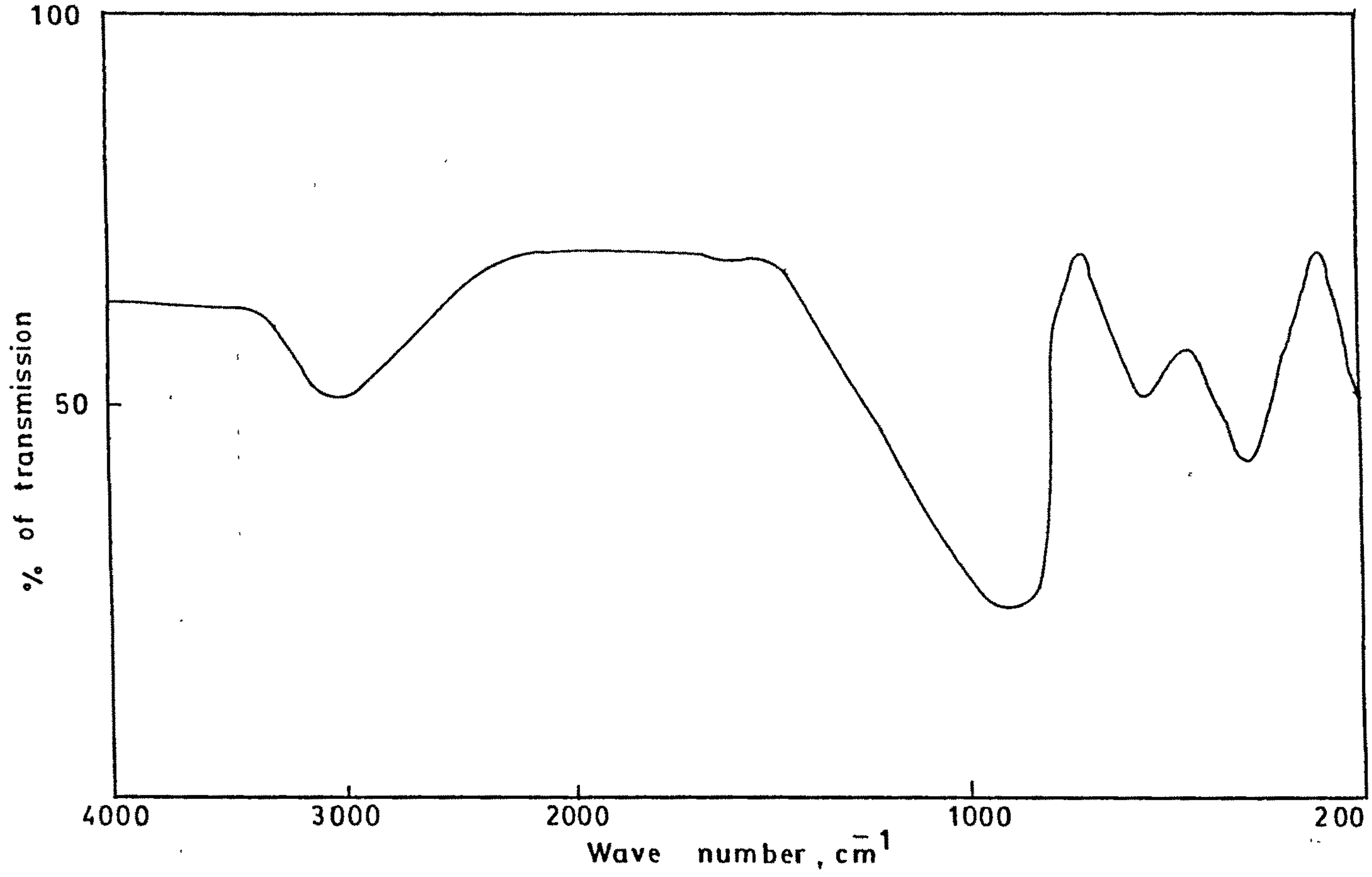


Fig. 6.10 IR Spectra of Zeolite 13 X annealed and quenched from 900 °C

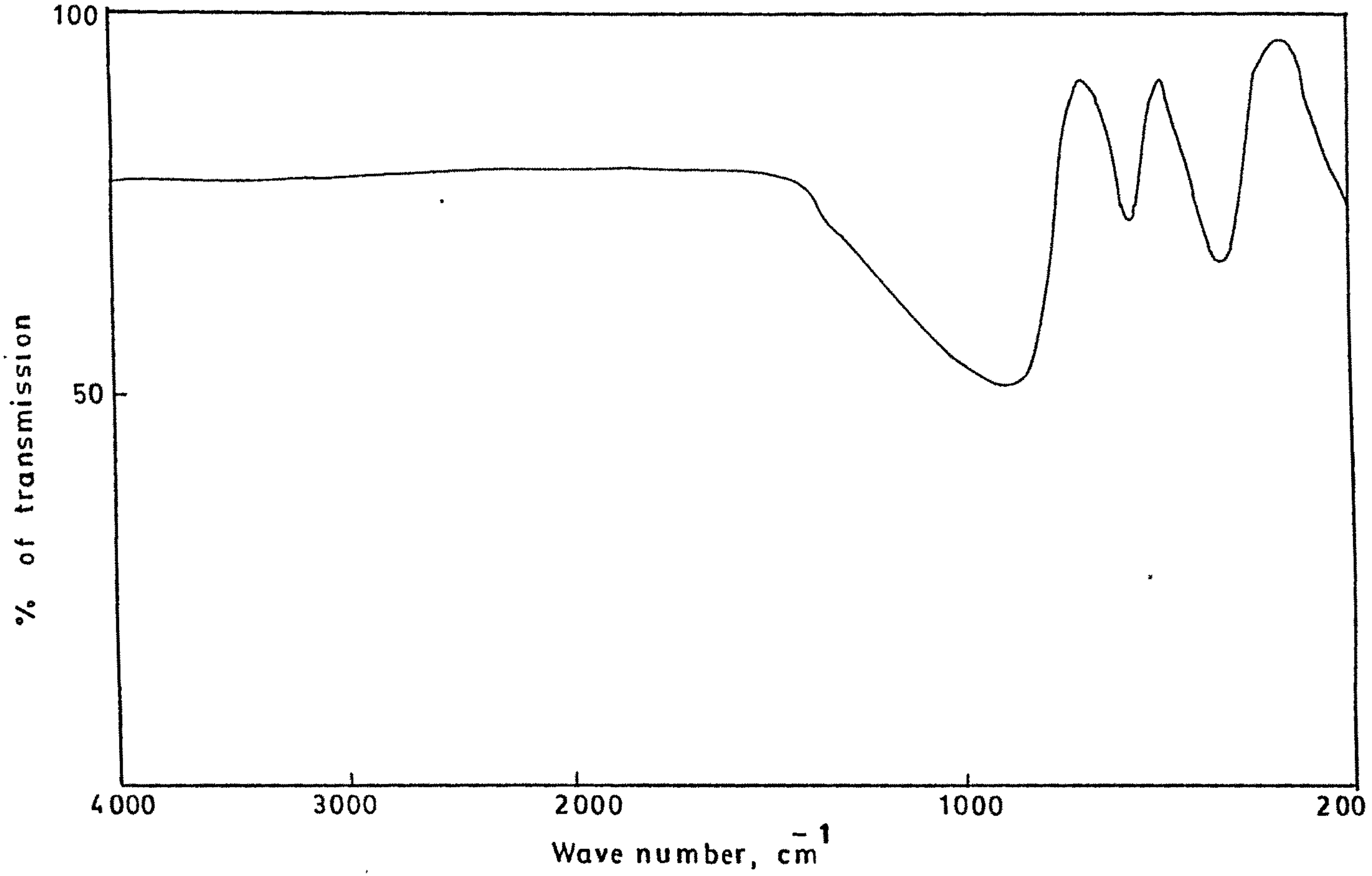


Fig. 6.11 IR Spectra of Zeolite 13 X annealed and quenched from 1000 °C

6.5 ESTABLISHMENT OF BASIC PARAMETERS FOR REFRIGERATION

Though some basic information was available in product information brochures[3,4,5] and other published literature on Molecular Sieve 13X, it was essential to experimentally evaluate some of the parameters because of the unique application to which locally available 13X was being used. Also it was found essential to establish the working of the zeolite refrigerator in the laboratory scale before undertaking the expensive prototype development work.

6.5.1 Experimental set up :

The laboratory level experimental set-up developed for conducting the simulated experiments is shown in Fig.6.12 [11,12]. A 30 cm long 54 mm diameter and 3 mm thick copper tube was used as the container for housing the zeolite. A 12 mm diameter and 1 mm thick tube with 2 mm perforations on the wall was fixed inside the larger tube as shown in Fig. 6.13. After filling the space between the two tubes with Molecular sieves 13X, both the edges were sealed to prevent any leaks. The 12 mm diameter tube had 30 cm extra length to connect it to the rest of the set-up.

A 250 ml round bottom glass flask was used in the system to function both as the evaporator and condenser. The flask was provided with temporary insulation when it functioned as the evaporator. To connect the flask to the zeolite container, a tube network was prepared as in Fig. 6.12.

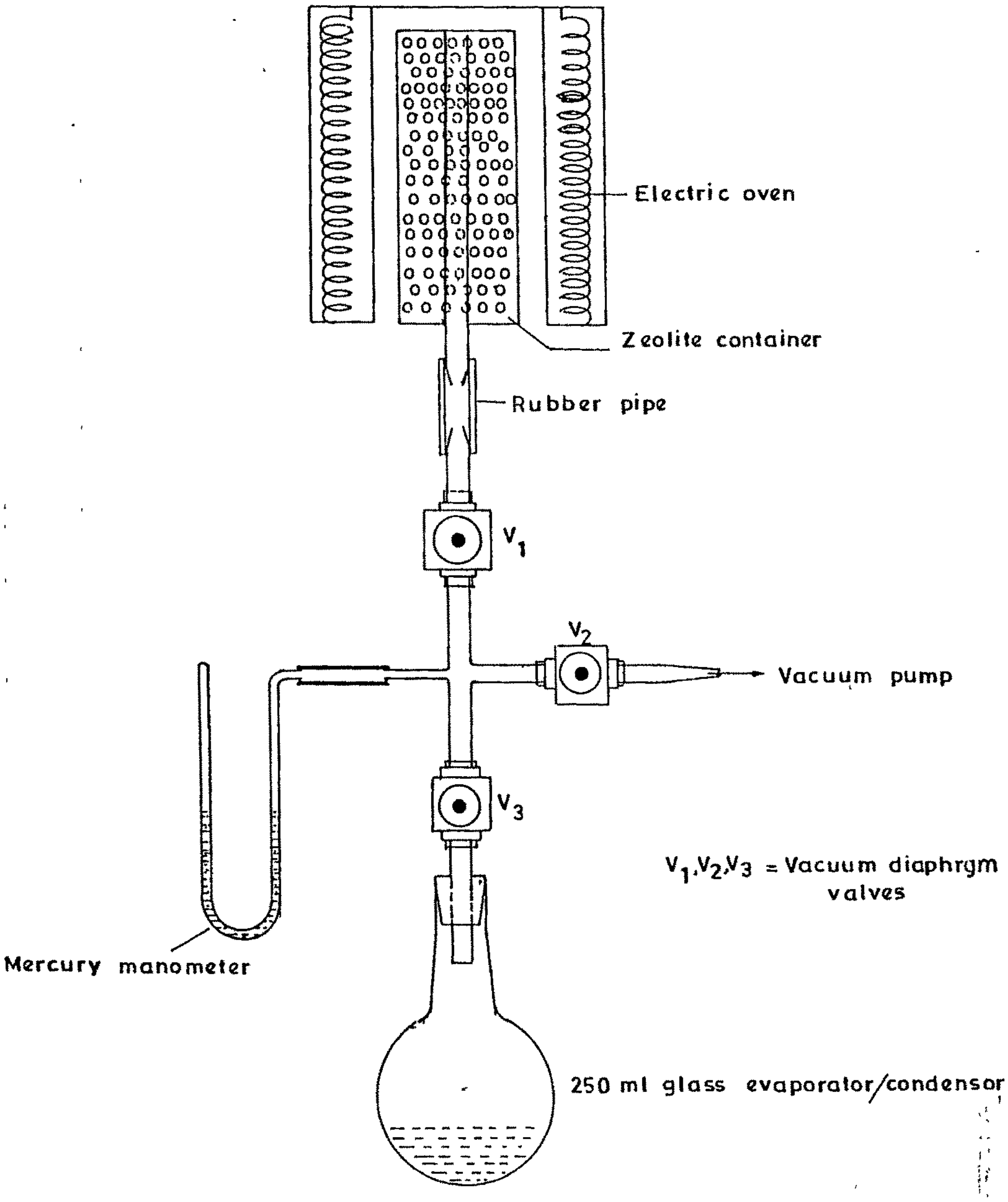


Fig: 6·12 Layout of the laboratory experimental setup

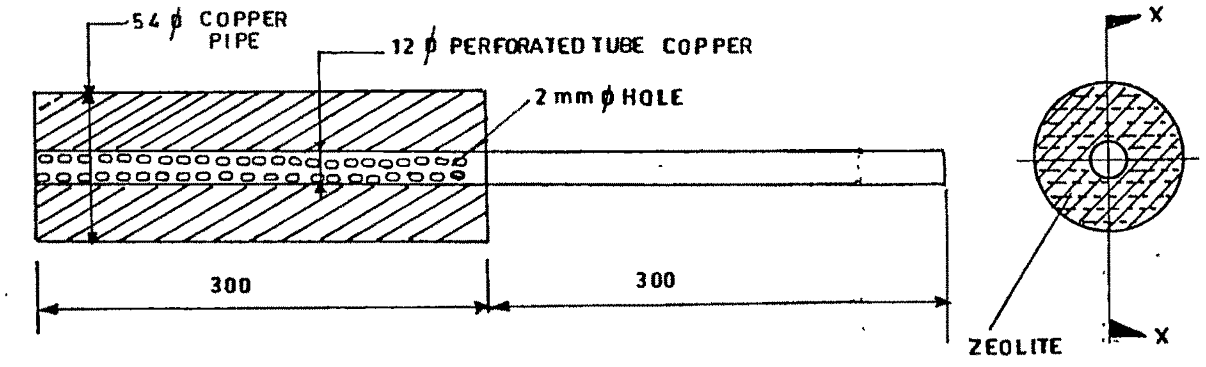


Fig. 6.13 Copper container for Zeolite used in laboratary tests.

DIMENSION IN MM

Three diaphragm valves of 12 mm size were connected to three arms of the pipe network. The valves had neoprene rubber diaphragm.

A one side closed U-tube mercury manometer was connected to the set-up to measure the vacuum levels inside the set-up. To connect the pipe network to the various components like zeolite container, glass flask and manometer, vacuum rubber pipes were used.

To raise the temperature of the zeolite to various higher levels, an electric oven was fabricated. The oven was cylindrical in shape with a central opening so that it could be placed on top of the zeolite container with the help of a stand. The 500 W oven was capable of heating the zeolite container upto 350 degree C. To control the level of heating a variac was utilized.

A double stage rotary vacuum pump was connected to the set-up through one of the diaphram valves. The pump was used initially for leak testing the set-up and later for evacuating and degassing. The complete laboratory experimental set-up is shown in Fig. 6.14.

Fig. 6.14 : Laboratory set up of zeolite water refrigerator

6.5.2 Instrumentation :

For temperature measurement at the surface of the zeolite container and the glass flask, Copper-Constaintain Thermocouples (T type) along with a data logger made by Campbell, USA was used. The datalogger had an inbuilt cold junction temperature compensation arrangement. The instrument had an accuracy of ± 0.1 degree C. The basic data logger had eight temperature measuring channels out of which two channels were expanded to measure 64 more channels using two multiplexers. The logger was capable of being programmed to measure upto 16 channels per second.

During the experimentation to study adsorption and desorption, the vacuum levels expected in the set up was 5 to 50 mm of Hg. To measure this level of vacuum a one side closed U tube Hg manometer was used. The range of the manometer was upto 200 mm of Hg.

6.5.3 Observations :

Before charging the set up with water, the complete system was tested for leaks by evacuating upto 0.1 mm of Hg. After ensuring the system to be leak proof, the zeolite was heated upto 300 degree C to desorb water vapour present within using a vacuum pump. After completely drying the zeolite, the valve V1 (Fig. 6.12) was closed to isolate the zeolite.

The evaporator was then removed and 100 ml of distilled water was filled in. The evaporator was again fitted with the system and the water was degassed by freezing and then boiling the water. When this was completed the system was isolated from the vacuum pump by closing the valve V2. Valves V1 and V3 were then opened so that the water in the flask could evaporate and get adsorbed in the zeolite. On measurement, 34 ml of water was found to have been adsorbed which was 11% of the weight of zeolite taken in the container.

With the set up thus ready for experimentation, a series of adsorption-desorption tests were conducted at zeolite temperatures varying from ambient to 250 degree C. Very little increase in vapour pressure was observed at zeolite temperatures below 60 degree C. Above 60 degree C, increase in vapour pressure was observed indicating desorption of water vapour from the zeolite, but upto 100 degree C condensation did not start. At temperatures around 120 degree C about 10 ml of water condensed in desorption cycles which lasted about 4 hrs. This was about 3% of the weight of zeolite. When the temperature was raised upto 250 degree C about 25 ml of desorption was obtained. In this temperature range, one could see drops forming in the edge of the pipe line and falling into the flask.

Every desorption experiment was followed by adsorption cycle. Every time the entire water that was desorbed in the previous cycle was adsorbed by the zeolite. Cooling of the flask due to evaporation was observed during the adsorption cycle. Sub zero temperatures were observed when the flask was insulated. In the adsorption cycle temperature on the outer surface of the flask dropped upto -2 degree C and production of about 100 gms of ice was obtained. Fig. 6.15 is a photograph of ice formed inside the evaporator during one of the experiments. Fig. 6.16 is a graph showing the

Fig. 6.15 : Ice formed inside the flask during laboratory experiment

container top, middle and bottom and ambient temperatures during one of the desorption cycles. Fig. 6.17 is a graph showing the flask (evaporator), container middle and ambient temperature during adsorption cycle. These graphs are for two consecutive cycles and cover a whole day operation.

The fluctuations in zeolite container temperature during the desorption experiment is due to the manual controls used in maintaining the temperature. The difference in the container top, middle and bottom temperatures were due to the vertical positioning of the container.

The slight increase in the container temperature during the initial part of the adsorption cycle was due to the heat of adsorption. For the adsorption cycle to function effectively, the heat of adsorption should be dissipated to the atmosphere and not allowed to raise the temperature of

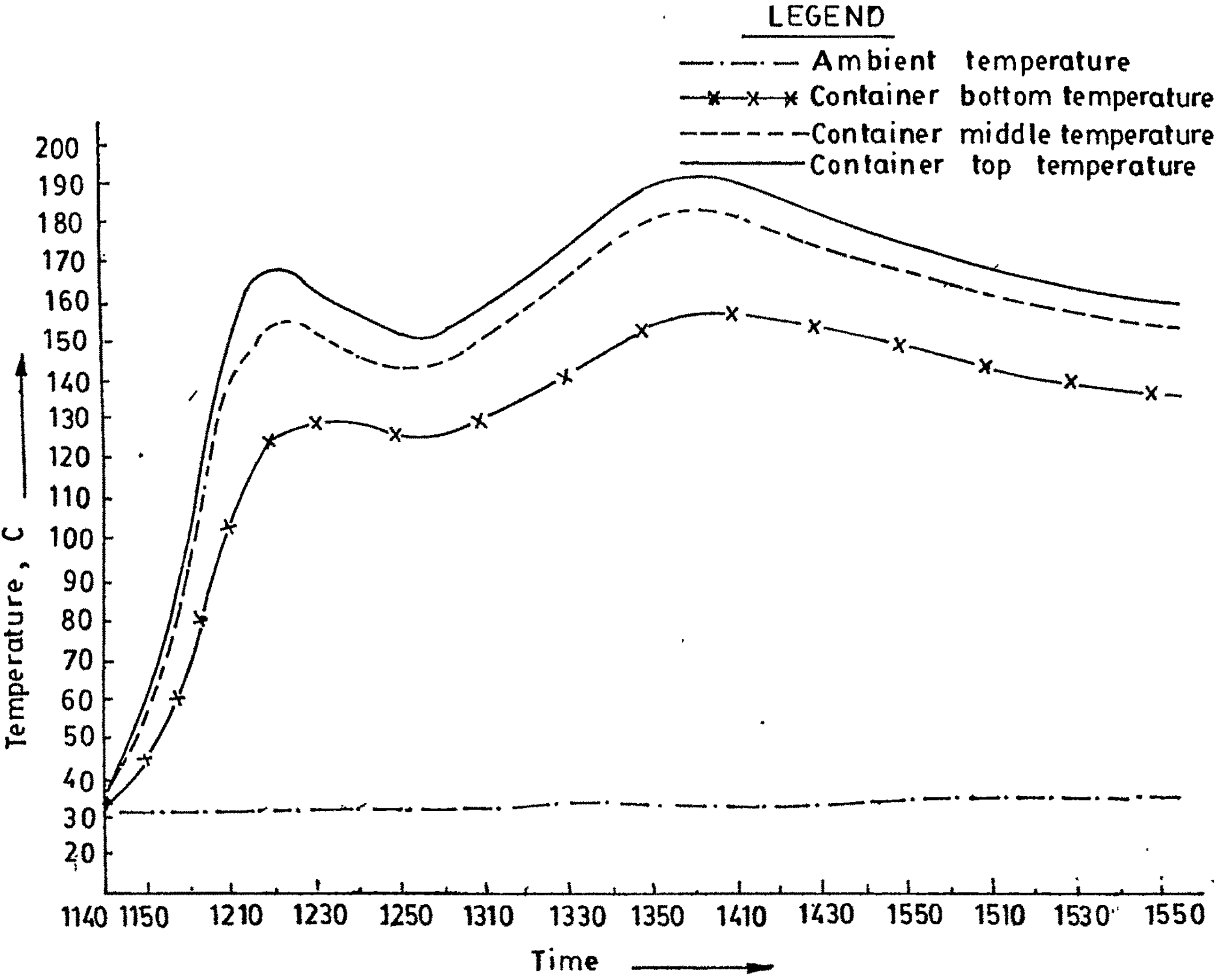


Fig. 6.16 Temperature profile during desorption experiment

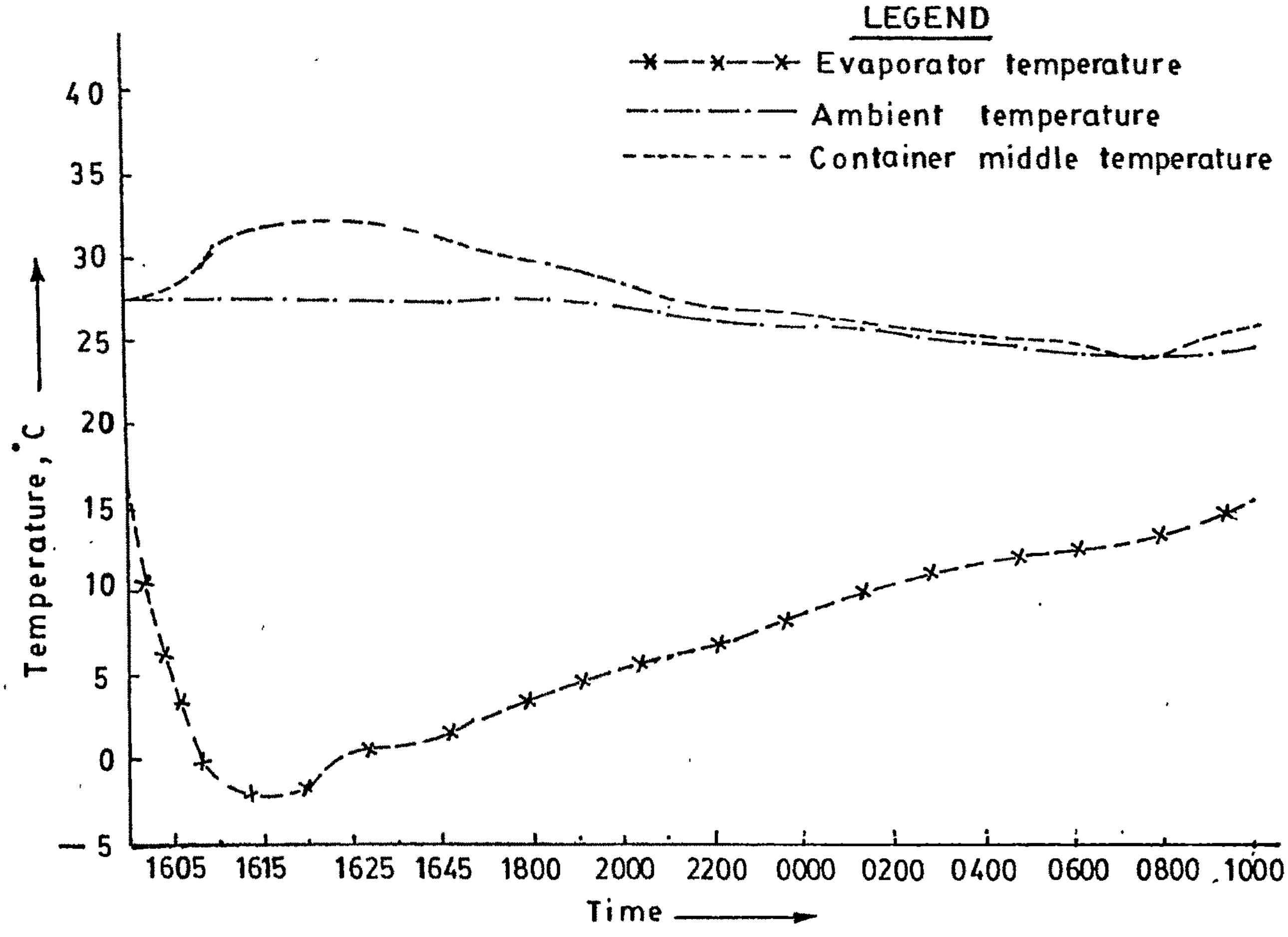


Fig. 6.17 Temperature profile during adsorption experiment

zeolite to such an extent where the adsorption could slow down.

Adsorption-desorption experiments were conducted at various container temperatures. It was estimated that for an operating temperature of 120 to 130 degree C, about 3.5% desorption was possible. This estimate was used in the design and development of the prototype. Though the operating principle of zeolite-water refrigerator system seems simple, the conditions under which the cycles function are quite rigid. In the laboratory experiments various construction materials, valves, fittings and degassing procedures were tried out before deciding the final arrangement used in the prototype. The most important requirement for the cycles to operate is the maintenance of required vacuum in the set up. During adsorption, as water has to evaporate at temperatures below 35 degree C, the pressure in the system needs to be maintained below atmospheric.

Even a minor leak which leads to an increase in the pressure will adversely affect the performance or even stop the working. Another important requirement for the working of the system is proper degassing of water used in the system. Even traces of trapped air would hinder the proper working of the system.

In the laboratory experiments, condensation of the vapour was achieved without actually using a condenser. This was possible because the vapour to be condensed was small and the pipe through which it had to flow was sufficiently long. But in the prototype a separate condenser would be required. More over, in a prototype the ice formed during one adsorption cycle was expected to keep the refrigerator cool throughout the next desorption cycle. Hence it was not desirable to allow the hot vapour or condensate into the evaporator during the desorption time.

Based on the observations made in the laboratory experiments, the complete design of the prototype was developed.

6.6 THEORITICAL DESIGN OF THE PROTOTYPE

The divariant equilibrium state of zeolite in water vapour depends on absolute temperature T, pressure P, and relative absorbed mass of water ma [13]. Fig. 6.18 shows an ideal cycle for a zeolite refrigerator on the Clapeyron diagram. Point A represents the state when zeolite is cold and connected to the evaporator {low pressure (Pe) and low temperature (T1)} when it has adsorbed the maximum water vapour. From here the collector is heated by the sun along the isoster AB until the pressure reaches the saturation pressure (Pc) of the condenser. During AB, no condensation takes place, but the pressure in the circuit keeps building up. At point B, the condensation begins and the pressure remains constant at Pc until the zeolite reaches its maximum temperature (T3) at point C (end of desorption). In the

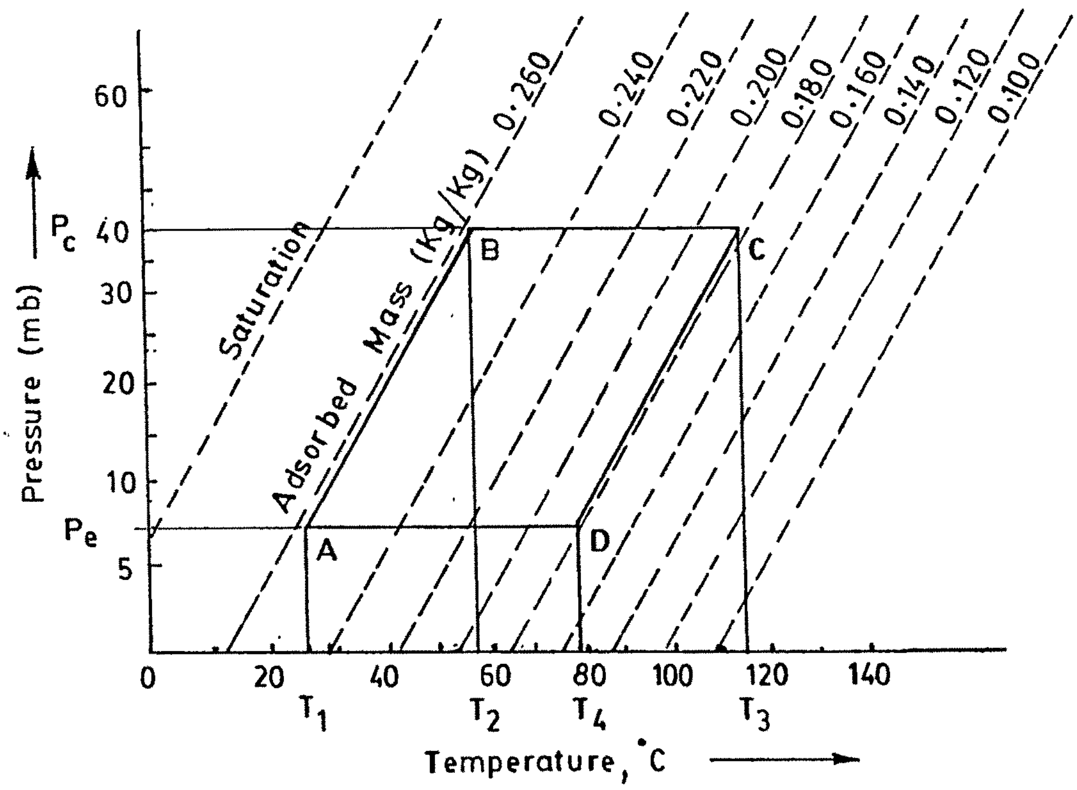


Fig. 6.18 Ideal zeolite water cycle on Clapeyron diagram

evening the collector cools following the isoster CD. At point D the zeolite is cool enough to be connected to the evaporator for the adsorption to occur which will last until the morning.

Thus essentially the system consists of matched solar collector, condenser and evaporator. Hence each of these components needs to be designed to match the others.

The starting point in the design has been the development of a system capable of producing 1 kg of ice during the adsorption cycle which was expected to keep a 25 l refrigerator between 3 to 8 degree C for storing the following essential vaccines [14,15] used in the immunization programme.

Vaccines	Required temp.	Duration for which remains potent
Polio vaccine	2 to 10 degree C	3 months
Measles	0 to 2 degree C	2 years
	4 to 8 degree C	8 months
BCG	4 to 8 degree C	1 year
Dual Antigen (DT)	4 to 10 degree C	2 years
Triple Antigen (DPT)	4 to 10 degree C	1 1/2 years
Typhoid	4 to 10 degree C	1 1/2 years
Tetanus Toxoid	4 to 8 degree C	1 1/2 years

6.6.1 Quantity of Zeolite and Design of Collector :

The starting point adopted in the design of the zeolite refrigerator was the production of 1 kg of ice inside the evaporator during an adsorption cycle. Assuming the water in the evaporator to be at 30 degree C at the start of the adsorption cycle, the heat to be removed for producing 1 kg of ice is equivalent to the sensible heat to be removed for cooling water to 0 degree C and the latent heat of freezing which is as under :

Heat to be removed = $ma \; Cp \, \Delta T + ma \; L$

Where,		
Where,	ma	is the mass of water, kg
	Cp	specific heat of water, Kcal/kg degree C
	ΔT	Sensible temperature difference, degree C
	L	Latent heat of freezing at adsorption pressure, kcal/kg

Adsorption pressure based on laboratory studies is about 5 mm of Hg.

Thus heat to be removed = 1 kg x 1 Kcal/kg degree C x 30 degree C + 1 kg x 79.71 kcal/kg

= 109.71 kcal

Considering about 35% extra cooling to offset the possible heat infiltration, the cooling capacity of the refrigerator was assumed to be 148 kcal[16].

To remove this heat, water which is the refrigerant should evaporate at about 5 mm vapour pressure. Hence the amount of water that needs to evaporate is

$$= \frac{148 \text{ kcal}}{596 \text{ kcal/kg}}$$

$$= 0.248 \text{ kg}$$

Say 250 ml

The laboratory experiments had indicated desorption of about 3.5% by weight at operating temperature of 130 degree C which is possible using a solar flat plate collector. The amount of zeolite required to adsorb 250 ml of water works out to 7.1 kgs.

Bulk density of zeolite 13X = 0.53 kg/litre

Hence volume of 7.1 kg of zeolite = 13.4 litres

Limiting the depth of the zeolite bed in the collector to be 45 mm for proper heating, the surface area of the collector works out to be 0.3 sq m. A square geometry was used for the zeolite container to make fabrication and operation easier. The sides of the container were of 0.55 m length.

To help in the free diffusion of water vapour throughout the zeolite bulk, it was essential to provide a free passage for water vapour. Hence a collector with two compartments was developed. The upper compartment of 45 mm depth housed the zeolite and the 15 mm lower one was empty to aid in diffusion. The outer body of the collector was made of 3 mm thick copper sheets and the partition between the compartments was done by fixing a 1 mm thick sheet at 15 mm above the bottom plate. This sheet had 2 mm perforations throughout its surface to aid in the diffusion of water. To prevent the collector from collapsing while evacuation, 25 vertical supports were provided at a distance of 93 mm from each other. The supports were useful in conducting the heat collected by the top surface to the entire zeolite bed. The details of the collector is shown in Fig. 6.19.

The whole collector was installed in an outer box of 0.718 m x 0.718 m x 0.2 m size with sufficient back and side insulation and double glazing. The glazing frame was hinged to the outer box on one side so that the whole cover could be lifted open to facilitate faster cooling.

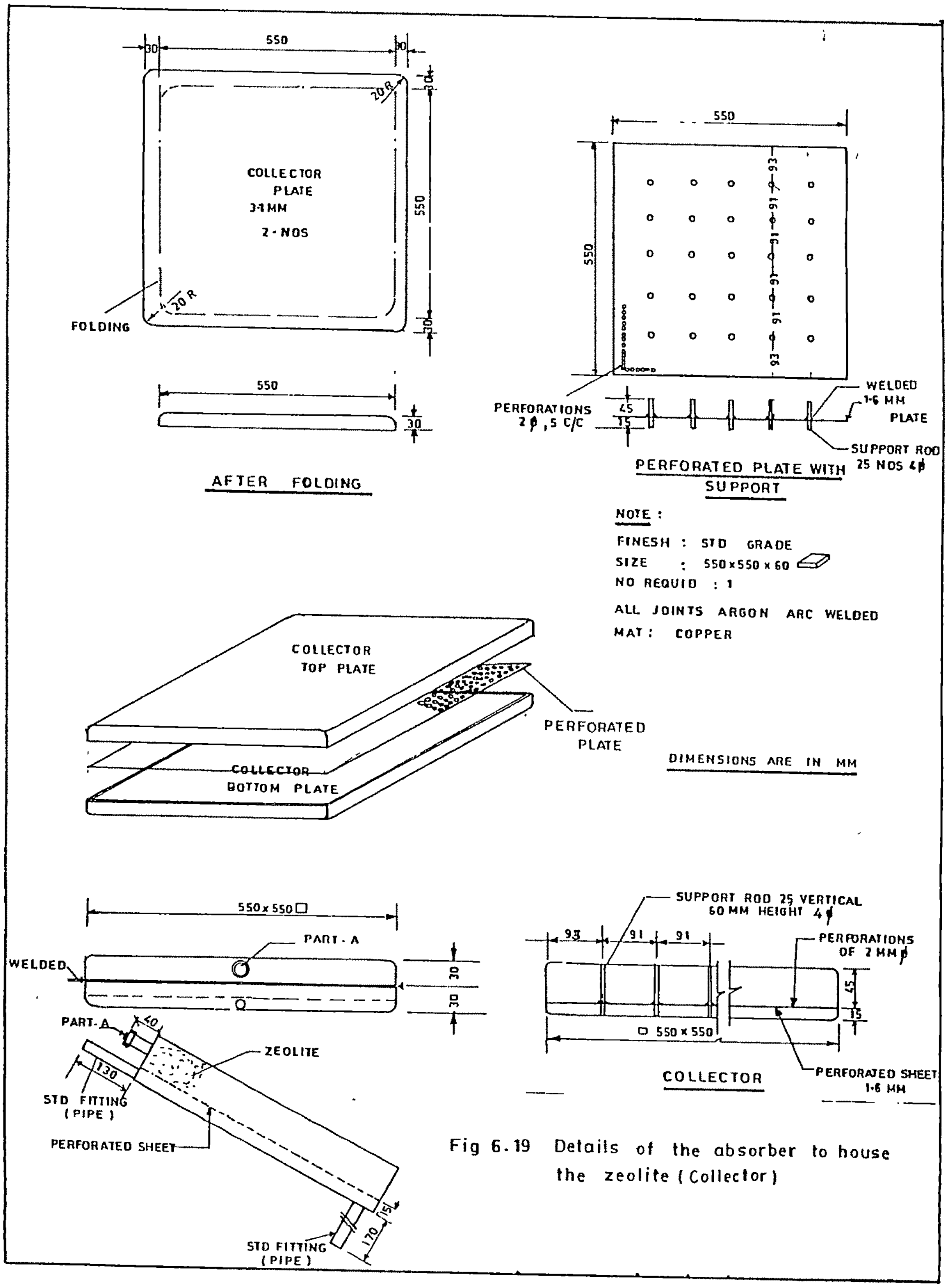


Fig 6.19 Details of the absorber to house the zeolite (Collector)

6.6.2 The Condenser :

The function of the condenser is to effectively condense all the vapour desorbed from the zeolite so that the vapour pressure inside the system is maintained at the saturation vapour pressure at condenser temperature. A well designed condenser is an essential requirement of a zeolite based refrigerator as an increase in condenser pressure will adversily affect the desorption. As the high day time ambient temperature in Gujarat during summer season may restrict the effectiveness of an air cooled condenser, a stagnant water type condenser was used in the system. The design of the condenser is explained below.

Assumptions

Temperature of incoming vapour : 80 degree C (Max)
Condensation temperature : 45 degree C (Max)
Initial temperature of water in the bath : 40 degree C (Max)
Final temperature of water in the bath : 41 degree C (Max)

Quantity of water vapour to be condensed : 250 gms
Total condensation time : 5 hrs.

Heat to be removed for cooling 0.25 kg of water vapour from

80 degree C to 45 degree C = 0.25 kg x 1 kcal/kg degree C x (80 - 45) degree C

= 8.75 kcal

Heat to be removed for condensing 0.25 kg of vapour at 55 mm of Hg vapour pressure

$$= 0.25 \text{ kg} \times 574.7 \text{ Kcal/kg}$$

$$= 143.7 \text{ Kcal}$$

$$\text{Total heat to be removed} = (8.75 + 143.7) \text{ kcal}$$

$$= 152.45 \text{ kcal}$$

$$\text{Say } 152 \text{ kcal}$$

$$\text{Heat extraction rate} = 152 \text{ kcal/5 hrs.}$$

$$= 30.4 \text{ kcal/hr}$$

$$\text{Capacity of the condenser} = \frac{30.4 \text{ kcal/hr} \times 4187 \text{ J/kcal}}{3600 \text{ sec}}$$

$$= 35.3 \text{ W}$$

$$\text{Say } 35 \text{ W}$$

The function of the condenser can be separated into two parts, the first part being sensible cooling of the vapour from 80 to 45 degree C and the second part being condensation of the vapour at 45 degree C. The two parts are shown in Fig. 6.20.

The Log Mean Temperature Difference (LMTD) [17]

$$= \frac{\Delta T1 - \Delta T2}{\ln \left[\frac{\Delta T1}{\Delta T2} \right]}$$

$$\text{For part 1, LMTD} = \frac{40 - 5}{\ln \frac{40}{5}}$$

$$= 16.8 \text{ degree C}$$

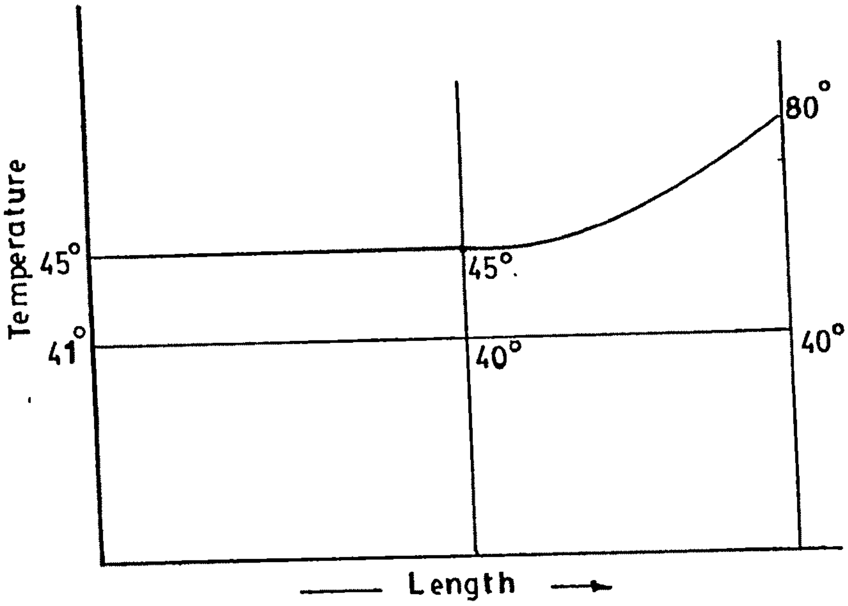


Fig. 6·20 Condenser temperature states

For part 2, LMTD

$$= \frac{5 - 4}{\ln \left[\frac{5}{4} \right]}$$

$$= 4.48 \text{ degree C}$$

Average LMTD = 10.64 degree C

Capacity of the condenser, Q = U A LMTD

Where Q	Rate of heat transfer, J/sec
U	Heat transfer coefficient, J/sq m sec degree C
Ac	Heat transfer area, sq m

The overall heat transfer coefficient for a tube in stagnant water type condenser is assumed to be a modest 50 kcal/sq m hr degree C (58.15 J/sq m sec degree C)[17].

$$\text{Area of the condenser, } A_c = \frac{Q}{U \ \text{LMTD}}$$

$$= \frac{35 \text{ W}}{58.15 \text{ J/sq m sec degree C} \times 10.64 \text{ degree C}}$$

$$= 0.056 \text{ sq m}$$

$$\text{Say} \quad 0.06 \text{ sq m}$$

If the condenser is made of 10 parallel tubes of 12 mm diameter, the length of each tube works out to be 16 cm.

Volumetric capacity of the condenser

$$= \frac{\pi}{4} \times 0.012^2 \times 0.16$$

$$= 18 \text{ ml}$$

As the volume of the condenser was insufficient to hold the 250 ml of water that is expected to be desorbed, tubes of 0.50 meter length were selected.

Fig. 6.21 shows the details of the condenser pipe network that was decided.

The volumetric capacity of the actual condenser works out to be 565 ml for the ten parallel tubes and 245 ml for the bottom header pipe. In other words, till the end of the desorption cycle, the whole heat transfer area of the ten tubes would be available for condensation.

The condenser pipe network was fitted inside a 150 l capacity HDP tank. Because of the presence of the 150

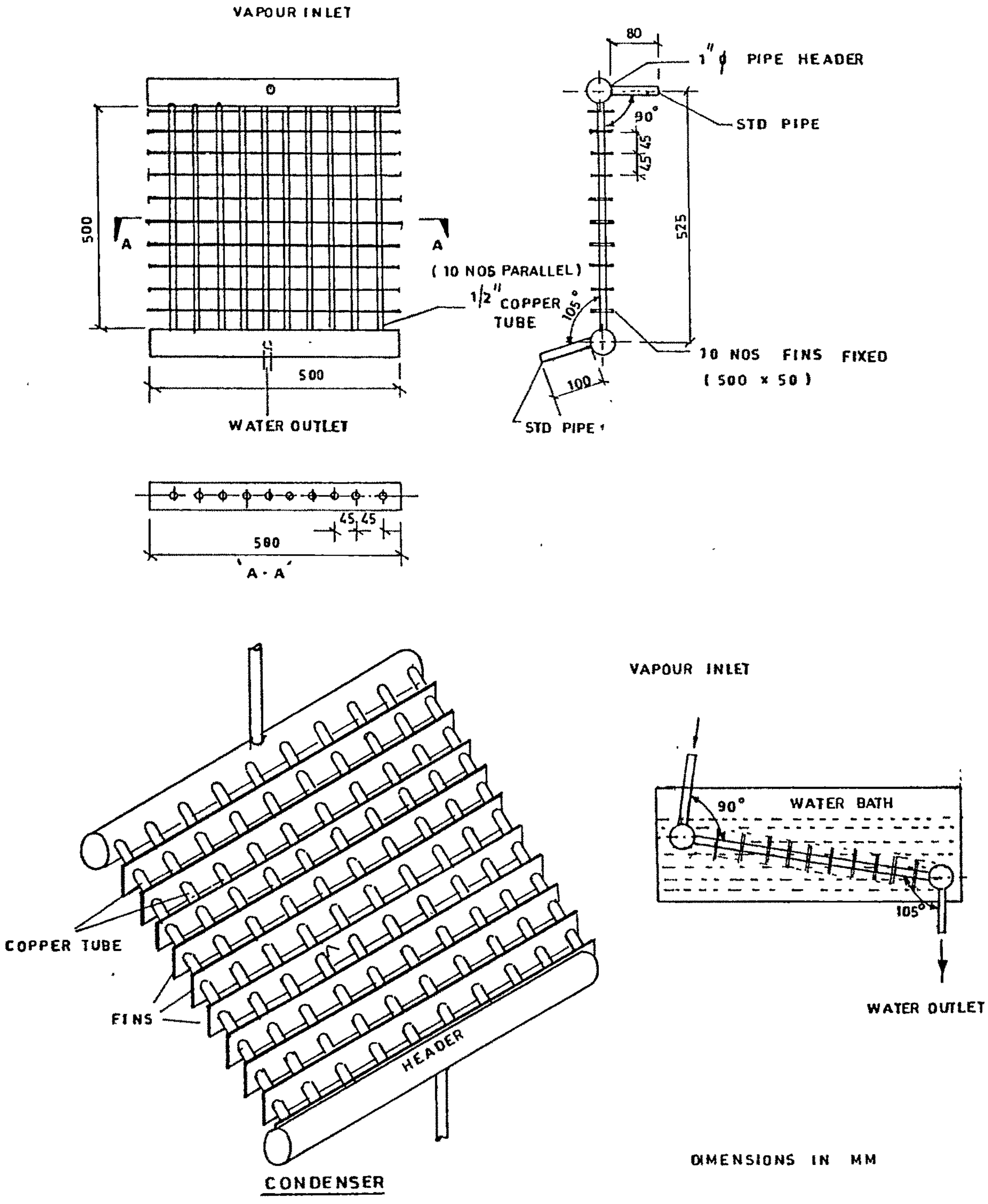


Fig. 6.21 Condenser pipe network.

litres of water, the raise in temperature of water due to heat rejection would be within the assumed 1 degree C.

6.6.3 Evaporator :

The total heat to be removed from the evaporator to freeze 1 kg of water from an initial temperature of 30 degree C is 150 kcal. (As per collector design). Assuming adsorption cycle duration to be 5 hrs., the capacity of the evaporator is 35 W.

Assuming that the temperature of the surrounding air is 35 degree C at the beginning of the adsorption cycle and this air be cooled to 3 degree C, the LMTD can be calculated as follows :

$$\text{LMTD} = \frac{(35 - 30) - (3 - 0)}{\ln \left[\frac{35 - 30}{3 - 0} \right]}$$

$$= 3.915$$

Say 4 degree C

Surface area of the evaporator, $A_c = \frac{Q}{\text{LMTD} \times U}$

Where, Q - Rate of heat transfer, W

U - heat transfer coefficient, W/sq m degree C

Boiling heat transfer coefficient, U = 2200 W/sq m degree C [17].

$$Ac = \frac{35\ W}{2200\ W/sq\ m\ degree\ C \times 4\ degree\ C}$$

$$= 3.9 \times 10^{-3}\ sq\ m$$

The evaporator has to accommodate the 1 litre water that is to be converted into ice besides the 250 ml of water that has to evaporate from the evaporator. To facilitate easy evaporation, it is essential to provide largest possible water surface area for evaporation. Hence a 2 l evaporator as shown in Fig. 6.22 was developed. It was fabricated using a 0.1 m diameter, copper tube of 0.25 m length. The two edges were closed using circular copper sheets. This design provided evaporator surface area of 0.08 sq m and water surface area of 0.025 sq m.

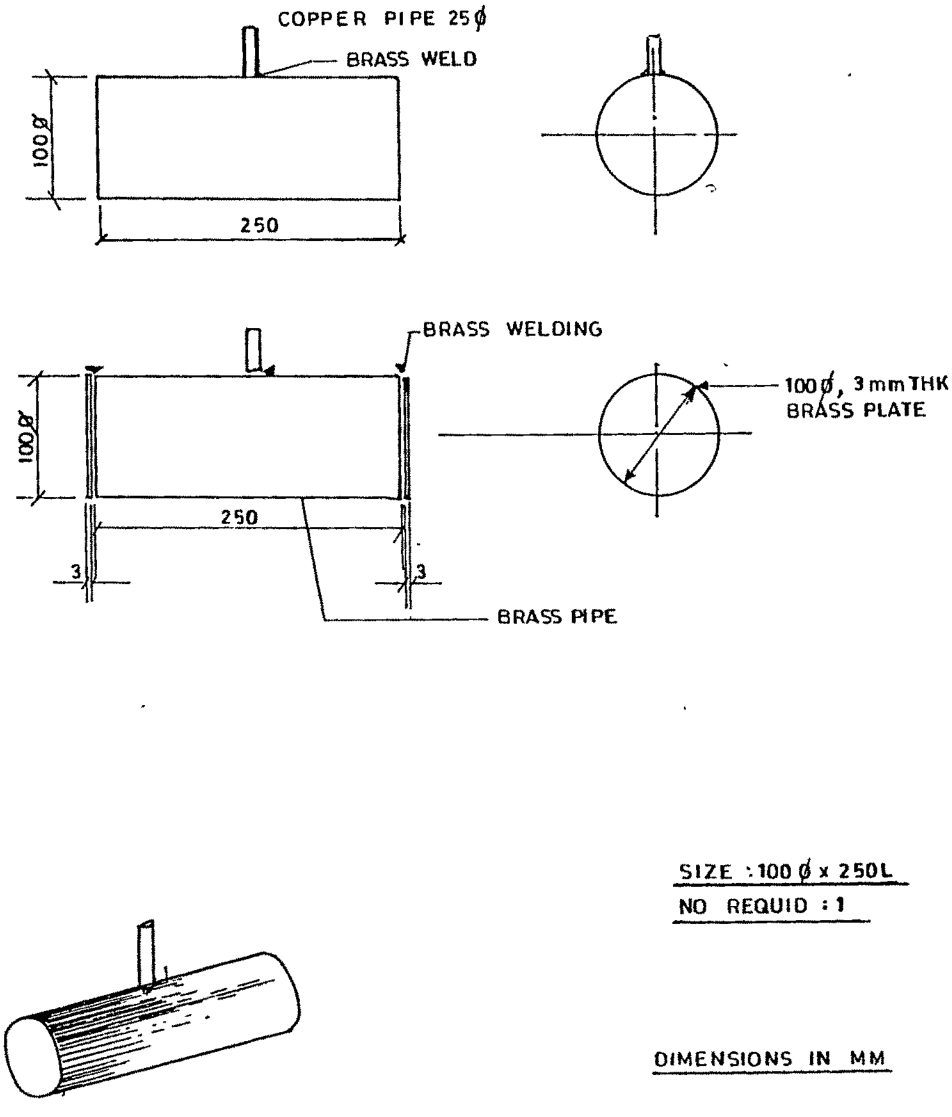


Fig: 6.22 Drawing of the 2 litre capacity evaporator

REFERENCES

1. ORG : IMRB & Enterprise, in the Mckensey Quarterly (1993), London.

2. Product Information Sheets, Expanded Programme on Immunization, (1993), WHO.

3. IPCL - CATAD Molecular Sieves, Setectosorb, Information sheet, 1992.

4. IPCL-CATAD Selectosort, Molecular Sives, Type 13X, Product information sheet, 1992.

5. UOP Molecular Sieves, brochure of UOP, USA, 1992.

6. Murthy KVR and Joshi TR, 'Thermoluminescence study of Heulandite, J. M.S. University of Baroda, Science, Technology and Medicine Number Vol. 37 - 38, No. 3, 1990-91.

7. Manmohan R., et all Thermoluminescence of Thomsonite (Zeolite), Thermoluminescence and its Applications, Tata Mc Grow Hill, 1992.

8. Prasad LHH, Philip S.K. et al, 'Thermoluminescent Characteristics of Zeolite 13X'. Luminescence Society of India, 1994.

9. Applications of Absorption Spectroscopy of Organic Compounds, John R. Dyer, Prentice Hall, 1987.

10. Zeolite Molecular Sieves, Structure, Chemistry and Use Donald W Breck, Wiley - Interscience, 1974.

11. Development of a Solar Refrigerator using Zeolite for Rural Areas, Project report, Sardar Patel Renewable Energy Research Institute, 1991.

12. Philip S.K. et all, Zeolite Based Solar Refrigerator, Proceedings of the National Solar Energy Convention, India, 1990.

13. Grenier Ph, Guillemenot, J.J., Meunier F., Pons M. 'Solar Powered Solid Adsorption Cold Store' J. of Solar Energy Engineering, 1988.

14. 'Manage the Cold Chain System' Universal Immunization Programme, Ministry of Health and Family Welfare, Govt. of India, 1987.

15. 'I need protection', It is my right', Reprint from Health Action - P. Box 2153, 157/6 Staff Road, Gunrock Enclave, Secunderabad.

16. ASHARE Handbook, Fundamentals, 1977.

17. Chemical Engineers' Handbook, Perry R.H. and Chilton C.H., McGraw-Hill, 1983.