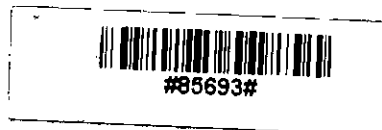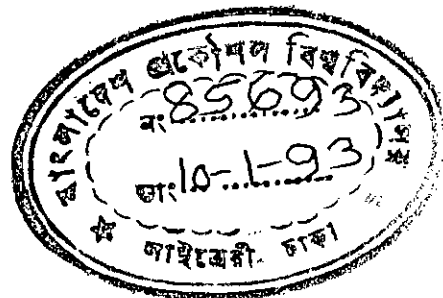# ENRICHMENT OF ATMOSPHERIC MOISTURE BY ELECTRIC FIELD FOR POSSIBLE EXTRACTION OF LATENT HEAT.

by

Md. Arif-Uz-Zaman

A Thesis submitted to the Department of Electrical and Electronic Engineering, BUET, in partial fulfilment of the requirements for the degree of Master of Science in Engineering

Department of Electrical and Electronic Engineering
Bangladesh University of Engineering and Technology
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The thesis Enrichment of atmospheric moisture by electric field for possible extraction of latent heat submitted by **Md. Arif-Uz-Zaman** , Roll No. **901301F**, Session '88-89 to the Department of Electrical and Electronic Engineering of B.U.E.T. has been accepted as satisfactory for partial fulfilment of the requirements for the degree of **Master** of **Science** in **Engineering** (Electrical and Electronic).

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CHAPTER 5: CONCLUDING REMARKS

ACKNOWLEDGEMENTS

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A B S T R A C T

A new concept of extracting renewable energy from the latent heat of atmospheric moisture is presented here. A simple calculation would reveal that significant amount of heat energy is stored in humid air in the form of latent heat. At 30^OC and 1 atmospheric pressure, 100 % humid air contains approximately 12 Kcal of latent heat per cubic meter of air. If the moisture from the atmosphere is extracted and used to enrich a closed cotainer, then the container would become saturated with moisture. If more molecules are pumped inside the container, the air inside the container can hold moisture no more and codensation of water molecules would take place releasing latent heat of condensation. Unlike other constituents of air, water molecules have permanent dipole moments due to the polar nature of its bond structure. This property of water molecule can be used to seperate it from other gas molecules by the application of electric field. A theoretical analysis is presented to calculate the percentage of moisture extraction and a simple experiment has been performed to verify the theory. Good agreement has been observed between the theory and the experiment.

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NOMENCLATURE

a   Distance of seperation.

d   Density of gas.

E   Applied electric field.

h^3 Infinitesimal volume of each cell.

K   Boltzmann constant, 1.38×10^{-23} Joules/molecular-degree.

l   Mean free path.

m   Molecular mass.

N   Total number of gas molecules per unit volume, (Avogadro Constant).

P   Polarization per unit volume.

q   Electric charge.

r   Diffusion rate.

R   Molar gas constant.

T   Absolute temperature.

U   Total energy of gas molecules.

V_x X-component of velocity before acceleration.

V_{x_0} X-component of velocity after acceleration.

α_i Ionic polarizability.

α_e Electronic polarizability.

α_o Orientational polarizability.

$\beta = 1/(KT)$.

$\upsilon = \sqrt{(2 \alpha E^2)/m}$.

μ Dipole moment per molecule.

τ Collision diameter.

θ Dipolar molecule making an angle with X-axis.
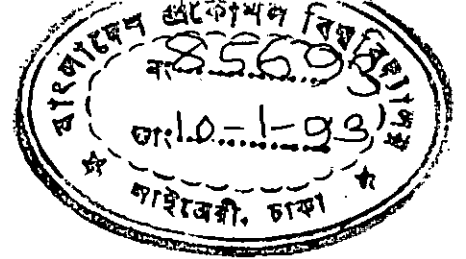
CHAPTER 1

INTRODUCTION

1.1 Importance of Alternative Energy Source

The development of the modern society depends upon the production and the use of large amount of energy. World energy consumption has grown rapidly during the period of 1950 to the present at a rate of approximately 5 % growth per year [11]. The development of a nation is characterised by the energy consumption of that nation. The energy consumption is directly related to the substitution use of machine power by human effort. Most machine power has been derived from electricity. At present the main sources of energy are Fossil fuels, Solar energy, Hydropower, Nuclear fuels etc. The expenditure of the world energy increases because of its industrial and scientific expansion. The civilization is now facing a great problem to satisfy energy demand by using the traditional energy sources. Time has come to realize that the world's fossil fuel supply is finite, its hydropower is restricted by the geographical areas and its nuclear power is also limited due to the lack of safe disposal facilities of the radioactive wastes. Another problem of using traditional fuel is the atmospheric pollution. Fossil fuel releases CO_2 after burning. This CO_2 increases the atmospheric

temperature and causes the "Green house" effect. In this respect, alternative energy source which is pollution free, may play an important role to prevent the earth from the environmental catastrophe.

Today more than 94% of the world's present energy needs are supplied from fossil fuels [1]. With the consumption rate increasing tremendously, the conventional fossil fuels are believed to be sufficient for another 500 years. Due to the population growth and the increasing industrialization , the demand of energy will be such that it would reduce that estimate by at least a factor of five [1]. Utilization of the alternative energy is still an insignificant percentage of the total energy consumption.

Pollution free energy sources like solar energy, wind energy, tide and wave energy etc. are getting more and more importance as enviornmental pollution is considered to be potentially dangerous for the earth. Some major alternative energy sources are discussed bellow

Solar energy

The energy obtained from the sun light is the Solar Energy. The sun releases a billion quads(1 quad = 10^{15} Btu) of energy per three seconds in which only 3.2 million quads [1] reaches the earth surface every year. Using solar cells, Solar energy can be

converted directly into electrical energy. The simplest conversion process for the solar energy is the conversion of sun light to heat. Using the sun to heat a working fluid to drive a turbine has also been established as a technically feasible idea. The utilization of solar energy is increasing day by day.

The major disadvantage of this source is that it is only effected during the day time. If a continuous output is needed, some large reservoir of energy such as energy storage battery or heat accumulation tank must be drawn upon at night. The output of the solar cell is also effected by the climatic condition.

Hydropower

The energy contained in a flowing stream of water is a form of mechanical energy. It may exist as the potential energy of water at some elevation with respect to a lower datum level or as Kinetic energy of a moving stream. This type of energy source can be used to drive hydraulic power plant to produce electricity. About 1 % of the energy output of the world is the hydropower. The total world hydroelectric power potential is estimated to be about ten times the present installed capacity [1]. Even if this was fully exploited, the percentage contribution to the world's utilization of energy will never be great. It will always be important in those geographical areas where it is available.

Wind Energy

Wind energy has served human beings as a power for many years. It is feasible to make wind mill to generate electricity in those countries where the wind velocity is appreciable. Especially in the coastal areas, it is suitable. Using the wind mill to drive an electric generator to produce electricity has been established as a technically feasible idea.

Ocean Energy

There is an enormous amount of energy in waves and tides. Waves are caused by the wind and the rotation of the earth, produced ocean current and moderate temperature gradient which is caused due to the continuous heating by the sun. This temperature gradient can be utilized in a heat engine to generate power. This energy is pollution free because it extract energy from waves, leaves the water in a relatively placid state.

1.2 Atmospheric Moisture as a possible source of Energy

Region on the same latitude on the earth's surface receive similar amount of solar radiation. The actual amount of solar energy reaching on the earth's surface depends on the climatic condition such as the cloudiness of any particular region. But the atmosphere receives similar amount of solar energy which is absorbed by the cloud or the earth's surface. Extremely hot

climatic condition prevails in the tropical and equatorial deserts, whereas countries under the monsoon rainfall experience extremely high level of humidity with relatively lower atmospheric temperature. This phenomenon can be explained easily, if the actual amount of energy stored in the moisture in the form of latent heat is calculated. One meter cube of 100 % humid air at a temperature of $30^{\circ}C$ contain enough moisture to have more than 12 Kcal of latent heat[10]. During the water evaporation process cooling down of the atmosphere takes place keeping the temperature within a moderate range. This large amount of heat is gradually accumulated as the wind blows over the oceans for hundreds of kilometers. Hence the amount of energy stored in the form of latent heat in atmospheric moisture is highly enriched.

Humid countries like Bangladesh have an average humidity of more than 70 % over a period of eight months (April to November) every year (see table 1.1). In Bangladesh, the reception of solar energy is not satisfactory due to the lack of the availablity of sun light throughout the year. It is also not feasible to establish windmill in this latitude due to the irregular directional flow of wind. In this respect, atmospheric moisture can be a very attractive source of energy even if a small fraction can be extracted.

The scheme presented here uses the dipolar property of

TABLE 1.1

Monthly average relative humidity for Dhaka [13].

Year / Month	1978				1979				1980			
	Dry bulb temp. °F	Wet bulb temp. °F	% relative humidity	Grains of moisture per lb of dry air	Dry bulb temp. °F	Wet bulb temp. °F	% relative humidity	Grains of moisture per lb of dry air	Dry bulb temp. °F	Wet bulb temp. °F	% relative humidity	Grains of moisture per lb of dry air
January	65.84	59.0	66	64	64.04	57.2	66	59.9	63.86	57.38	67	60.0
February	71.6	62.6	67	71.0	70.16	62.78	66	73.8	69.98	61.34	61	69.6
March	80.24	70.88	64	99.0	80.78	72.86	68	109.0	78.08	66.20	53	78.0
April	82.22	74.48	66	119.0	78.98	74.66	81	119.2	80.96	74.12	53	116.6
May	81.5	76.82	80	133.0	80.24	76.28	83	131.0	80.96	77.18	73	132.8
June	81.86	78.98	87	146.5	81.50	78.62	88	145.0	82.40	79.52	84	149.0
July	82.4	79.34	87	154.4	82.76	79.88	87	151.0	82.76	79.70	88	149.0
August	81.86	78.80	87	145.0	83.66	79.88	84	149.0	82.04	80.06	86	149.8
Septem	82.94	78.98	83	145.0	83.12	79.52	85	147.8	82.58	79.16	83	145.8
October	80.24	75.20	79	124.0	80.24	75.2	79	124.0	81.68	77.00	83	133.8
November	76.1	69.98	74	100.0	75.92	71.06	78	106.0	75.2	68.72	72	100.0
December	65.3	59.36	71	67.0	67.28	61.7	73	74.0	66.71	60.08	68	67.0

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water molecules. High electric field is applied to attract the water molecules in an extraction chamber. When the percentage of humidity reaches 100 % condesation starts in the moisture extraction chamber and latent heat of evaporation is released.

1.3 Thesis Organization

The remaining part of this thesis is divided into four chapters. Chapter 2 contains the general properties of air and its constituents and also explained the dipolar properties, drift and diffusion phenomena of gaseous molecules. The characteristics of gaseous molecules under electric field and the theoretical analysis of the possibilities on moisture enrichment is given in chapter 3. Chapter 4 contains a detailed description of constructional features of porous electric plates, moisture extraction chamber and high voltage generation. The experimental set up and results are found at the end of this chapter. The discussion of the whole thesis is included in the last chapter and also carefully evaluated the limitations of the system. Some impotant hints have been given to channelize the future work.

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C H A P T E R 2

THERMODYNAMIC BEHAVIOR OF GASES

2.1 Introduction

In this chapter thermodynamic and dipolar properties of gas molecules are discussed. Costituents of air include nitrogen, oxygen, carbon dioxide and water vapour which are in dynamic equilibrium. Dynamic behavior of the gases are described in section 2.3. As the gas molecules are Maxwellian particles, they follow Maxwell-Boltzmann distribution law which is discussed in article 2.3, along with Kinetic theory of gases. This dynamic behavior of the gas molecules result in diffusion phenomena. Bond structure and dipolar properties of different gas molecules are presented in section 2.5.

2.2 Air and its Constituents

The invisible gaseous mixture which covers throughout the earth surface is called the atmosphere. The principal contituents of air are Nitrogen and Oxygen. Besides these, there are small quantities of Carbon dioxide, water vapour, Helium, Neon, Argon, Krypton, Methane [2] available in air. In industrial areas, Hydrogen Sulphide, Sulpher dioxide, Carbon dioxide and Ammonia

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may also be available in air. Amount of Water vapour present in air depends on the climatic condition of a country. At $30^{o}C$ temperature 1 Kg of 100 % humid air contains approximately 27 gm of water [3].

Principal Constituents of Air

Nitrogen

A large quantity of free nitrogen (N_2) is available in the air. It is approximately 80 % of the total air volume. Its atomic weight is 14 and its electron distribution is $1S^2$ $2S^2$ $2P^3$. It is a colourless, tasteless and flavourless gas. It dissolves very slightly in water and it is lighter in weight than air. The molecule of Nitrogen is di-atomic. Trivalent two atoms of a nitrogen molecule are attached by covalent bond . Due to this triple bond the stability of nitrogen molecule is very high. So, Nitrogen is almost an inert gas and it does not reacts with any elements easily.

Oxygen

Almost 20 % of atmospheric air is oxygen. It is the most important element of air that all living beings takes oxygen in breathing. It is a colourless , tasteless , Flavourless gas with an atomic weight of 16. Oxygen is highly electronegative,

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for this reason it is extremely reactive. Its maximum reaction occurs at very high temperature. The molecule of oxygen is diatomic. Two atoms of oxygen molecules are attracted by a covalent bond.

Only H_2O molecules have a permanent dipole moment rather than any other elements in air. This is due to the fact that nitrogen, oxygen and carbondioxide molecules are bound by covalent bonds. On the other hand, two hydrogen atoms make an angle of 104° with the oxygen atom in a water molecule making it polar in nature.

$$N \equiv N \qquad O=O \qquad O-C-O$$

Nitrogen   Oxygen   Carbon dioxide

$$H \underset{O}{\overset{104^\cdot}{\diagdown \diagup}} H$$

Water
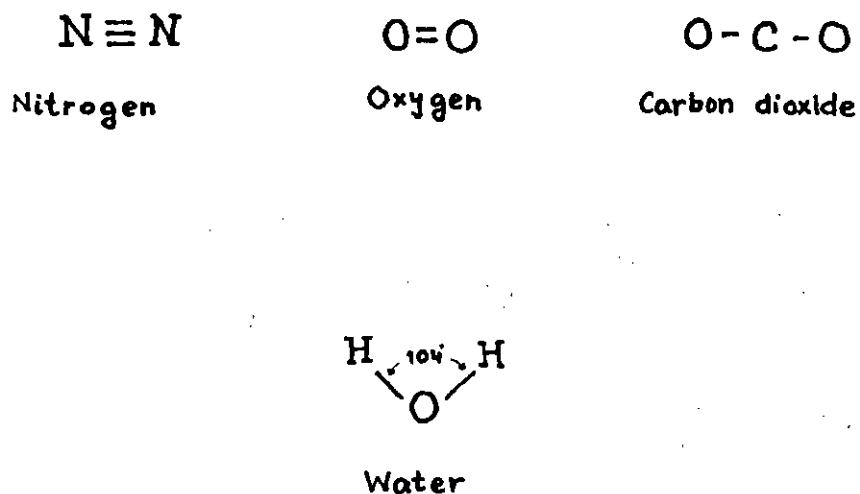
Fig 2.1 Molecular structure of the principal constituents of air.

TABLE 2.1

Average Composition of Air between Sea level and 90 km Altitude [2]

Element	Formula	% by Volume	% by Mass	Molecular Weight
Nitrogen	N_2	78.084	75.55	28.0134
Oxygen	O_2	20.984	23.15	31.9988
Argon	Ar	0.934	1.325	39.948
Carbon dioxide	CO_2	0.0314	0.0477	44.00995
Neon	Ne	0.00182	0.00127	20.183
Helium	He	0.00052	0.000072	4.0026
Krypton	Kr	0.000114	0.000409	83.80
Methane	CH_4	0.0002	0.000111	16.043

2.3 Kinetic Theory of Gases & Maxwell Boltzman ditribution

Kinetic theory states that the gas molecules move in a ceaseless random motion. When the gas molecules collide with other molecules or with the walls of the containing vessel then the molecules rebound without changing its velocity. The pressure of a gas is due to the continuous bombardment on the wall of the containing vessel.

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At a particular temperature for a mole of any gas contains a kinetic energy of 3/2 RT. Where R is 8.314 joules or 1.987 Cal [4] . So the average kinetic energy of a gas molecule a particular temperature T is 3/2 KT, where K is the Boltzmann constant. The relation between R and K is KN = R where N = 6.023 x 10^{23} molecules /mole [14]. For a particular gaseous system a fixed amount of energy is distributed among the various molecules of the gas. The energy distribution is different due to the spinning effect of the gas molecules.

Let N be the total number of gas molecules in a particular amount of a gas in a containing vessel whose energies are limited to the values u_1, u_2, u_3,....u_k arranged in increasing energy order. Let U be the total energy of the gas molecules and n_i be the number of molecules having energy u_i, then, [5]

$$n_i = g_i e^{-\alpha} e^{-\beta u_i} \qquad \ldots\ldots\ldots\ldots\ldots\ldots(2.1)$$

This is known as the Maxwell-Boltzmann distribution law.

Where g_i is the priori probability.

α and β are independent quantites of the n_i's.

The continuous distribution of the molecules will be [5]

$$n(u)du = g(u) \ e^{-\alpha} \ e^{-\beta u} \ du$$

$$\text{where} \quad e^{-\alpha} = N \ h^3/V \ (\ \beta/2\pi m \ )^{3/2}$$

In equation (2.2) n(u)du is interpreted as the number of

molecules whose energies lie between u and u+du. In terms of molecular momentum, [5]

since $u = p^2/(2m)$

$$n(u) = g(p) \ e^{-\alpha} \ e^{-\beta p^2/2m} \ dp$$

The a priori probability $g(p)$ that molecules have a momentum between p and p+dp is equal to the number of cells in phase space within which such a molecule may exist. If each cell has the infinitesimal volume h^3.

$$g(p) \ dp = \frac{\displaystyle\int\int\int\int\int\int dx \ dy \ dz \ dp_x \ dp_y \ dp_z}{h^3}$$

where the numerator is the phase-space volume occupied by paricles with the specified momenta. Here

$$\int\int\int dx \ dy \ dz = V$$

Where V is the volume occupied by the gas in ordinary position space, and

$$\int\int\int dp_x \ dp_y \ dp_z = 4\pi p^2 \ dp$$

Where $4\pi p^2 \ dp$ is the volume of the spherical shell of radius p and thickness dp in momentum space. Hence [5]

$$g(p) = (4\pi V p^2 \ dp)/h^3 \qquad \dots\dots\dots\dots(2.3)$$

and $$n(p) = (4\pi V p^2 \ e^{-\alpha} e^{-\beta p^2/2m})/h^3 \ dp \qquad \dots\dots\dots(2.4)$$

Since $\displaystyle\int_{0}^{\infty} n(p)\, dp = N$ ....(2.5)

Putting the value of n(p)dp from (2.4) to (2.5)

$$N = (4\pi e^{-\alpha}\, V)/h^3 \int_{0}^{\infty} p^2\, e^{-\beta p^2/2m}\, dp$$

$$= (e^{-\alpha}\, V)/h^3\, [2\pi m/\beta]^{3/2}$$

$$e^{-\alpha} = (Nh^3/V)[\beta/(2\pi m)]^{3/2} \qquad ....(2.6)$$

Putting (2.6) into the equation (2.4)

$$n(p)\, dp = 4\pi N\, [\beta/(2\pi m)]^{3/2}\, p^2\, e^{-\beta p^2/2m}\, dp \qquad ......(2.7)$$

Since $p^2 = 2mu$

$$dp = [m/\surd(mu)]\, du$$

Then equation (2.7) can be written as, [5]

$$n(u)\, du = \frac{2\, N\, \beta^{3/2}\, \surd u\, e^{-\beta u}}{\surd\pi} \qquad ....(2.8)$$

And the total energy of the gas molecules will be [5]

$$U = (3/2)\, (N/\beta) \qquad ....(2.9)$$

According to kinetic theory of gasess, the total energy of N molecules at the absolute temperature T is

$$U = (3/2)\, N\, K\, T$$

Where $K = 1.38 \times 10^{-23}$ Joules/molecular-degree.

$$\beta = 1/KT$$

$\sqrt{\overline{v^2}}$ = root-mean-square speed = $\sqrt{3kT/m}$

$\overline{v}$ = average speed = $\sqrt{8kT/\pi m}$

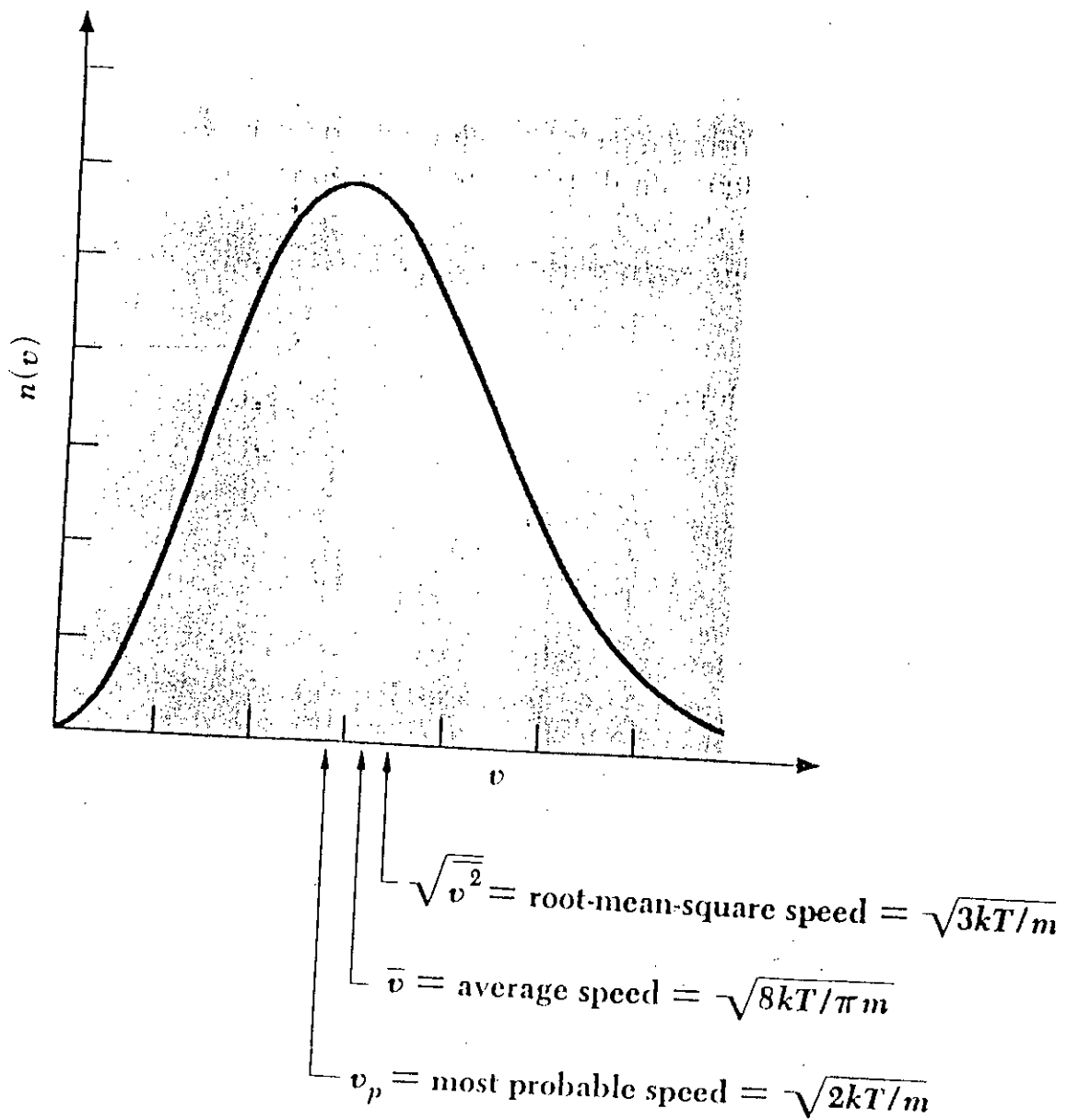v_p = most probable speed = $\sqrt{2kT/m}$

Fig 2.2 Maxwell-Boltzmann velocity distribution (taken from [10])

Then the Maxwell-Boltzmann distribution of energy is [5]

$$n(u) = \frac{2 \pi N}{(\pi K T)^{3/2}} \sqrt{u} \, e^{-u/(KT)} \, du \quad \ldots\ldots\ldots(2.10)$$

and Maxwell-Boltzmann velocity distribution is [5]

$$n(v) \, dv = \frac{\sqrt{2} \pi N \, m^{3/2}}{(\pi K T)^{3/2}} \, v^2 \, e^{-mv^2/2KT} \, dv \quad \ldots\ldots(2.11)$$

2.4 Drift and Diffusion Phenomena

The motion of gas moleecules are continuous in any vessel. The molecules collide with each other and with the walls of the containing vessel. After collisions, they change the direction. The average distance traversed by molecules between two successive collitions is called the mean free path. The mean free path l is given by [4][14] ,

$$l = 1/(\sqrt{2}\pi\tau^2 n)$$

Where   n is the number of molecules in a unit volume

τ is known as the collision diameter

Since the motion is random, hence the average flow of gas molecules is zero.

When two vessels containing gases of different concentration are connected by an interconnector, the motion of gas molecules will result in the flow of gas molecules from one vessel to the

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other. Such motion is called diffusion and occurs without any external excitation.

It may be infered that diffusion depends on charge inhomogeneity or due to the presence of a space gradient of gas density. But drift is a function of both electric field and gas density. Generally, diffusion leads to redistribution of gas molecules which is due to the non uniform mixture of gas molecules. The electric field produces a drift current which is in opposite direction to diffusion current. Finally equilibrium is achieved when the drift rate is equal to the diffusion rate, thus resulting in zero net flow of drift current [16].

2.5 Dipolar properties of Different Gas Molecules in Air

Study of different properties of different materials reveal that polarization of the molecules takes place when the material is subjected to an electric field. Molecules having ionic or polar nature of inter-atomic bonding possess permanent dipole moment which orient in the direction of the applied field. Total dipolar contribution of a material can be divided into three main components [7],

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i)   electronic polarization caused by the relative displacement
     of the nucleus and the electron cloud;

ii) ionic polarization caused by the displacement of the atoms
     in a polar or ionic molecules ;

iii) orientational polarization caused by the orientation of the
     permanent dipoles under the influence of an electric field.

If P is the polarization per unit volume of a material due to an
applied electric field E, then [7]

$$P = \epsilon_o (\epsilon_r - 1) E = N(\alpha_e + \alpha_i + \alpha_o) E$$
$$= N\alpha E = N \mu \qquad \dots\dots\dots\dots\dots\dots(2.12)$$

Where ϵ_o is the permittivity of free space

        ϵ_r is the dielectric constant of the material

        N is the total number of molecules per unit volume

        $\mu = \alpha E =$ is the dipole moment per molecule

α_e, α_i, α_o are the electronic, ionic and   orientational
polarizabilities respectively. Out of these three types of
polarizations, electronic polarization is the weakest but exists
in   all   types   of   materials.   Orientational   polarization
predominates in liquids and gases where permanent dipole moment
exists. Considering the main constituents of air, only water
molecules have permanent dipole moment. This is due to the fact
that nitrogen, oxygen and carbondioxide molecules are bound by
symmetric covalent bonds. On the other hand, two hydrogen atoms

make an angle of 104° with each other in a water molecule making it polar in nature. The permanent dipole moment in an isolated water molecule is 6×10^{-30} coul-m which is quite high [7]. Hence the effect of an electric field is much stronger on the water molecules when compared with the other gas molecules in the air.

CHAPTER 3

DEVELOPMENT OF MOISTURE ENRICHMENT FORMULATION

3.1 Introduction

A rigorous theoretical analysis is presented in this chapter to show that moisture extraction from air is possible using nonuniform electric field. The net force on the dipoles under electric field is derived in section 3.2. If atmospheric moisture is extracted and accumulated in an extraction chamber, humidity will gradually increase. When the humidity reaches 100%, any further attempt for moisture enrichment in the moisture extraction chamber will result in the condensation of the water molecules releasing the latent heat of condensation. This can be a very attractive source for pollution free energy. A formulation is developed to calculate the percentage of moisture extraction considering all the thermodynamic limitations like diffusion and thermal agitation of the gas molecules in section 3.3.

3.2 Dipoles under electric field

If an electric dipole having a dipole moment μ is placed in a uniform electric field, equal and opposite forces will act on the positive and negative charges of the dipole to keep the
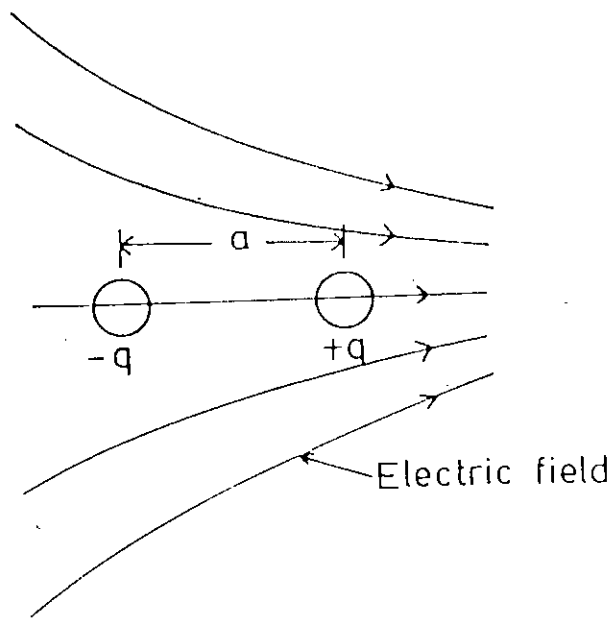
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Fig 3.1 Dipole in an electric field.

resultant zero. Hence nonuniform electric field , as shown in Fig 3.1, is required for the movement of the dipoles. Let $E(x)$ be the applied electric field in the +x direction and the dipole is made out of charges +q and -q seperated by a distance of "a" . If the dipole is aligned towards the electric field and forces on the +q and -q charges are F_+ and F_- respectively, then

$$F_- = - q E(x) \qquad \dots\dots\dots\dots\dots\dots\dots\dots(3.1)$$

$$F_+ = q E(x + a) = q [E(x) + (dE/dx) a] \qquad \dots\dots\dots(3.2)$$

Hence, net force on the dipole is

$$F = F_+ + F_- = q a (dE/dx) = \mu \ dE/dx \qquad \dots\dots\dots\dots\dots(3.3)$$

Where dipole moment $\mu = q a$

3.3 Theoretical anlysis on moisture enrichment under electrics field

The process of enrichment of the water molecules is a complex one as the molecules will collide as they drift under the influence of the applied electric field. These collisions drastically reduce the actual drift velocity making the enrichment process a weak one . The other natural force acting against the enrichment is the diffusion which starts alongwith the enrichment process. This is an inherent thermodynamic process which can neither be eliminated nor be reduced. The moisture enrichment process will continue till the diffusion establishes an equal and opposite flow of water molecules. Considering the

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electrical force on the water molecules the overall transfer mechanism can be expressed as [8]

$$-dN/dx + N \ F/KT = 0 \qquad \ldots\ldots\ldots\ldots\ldots(3.4)$$

assuming that 100 % humidity is not achieved.

Putting the expression for F from eqn(3.3) and $\mu = aE$, The equation (3.4) becomes as

$$dN/dx = N \ F/(KT)$$

$$\text{or,} \qquad dN/dx = [N/(KT)] \, a \ E \ dE/dx \qquad \ldots\ldots(3.5)$$

$$\text{where} \qquad F = \mu \ dE/dx = a \ E \ dE/dx$$

Rearranging eqn.(3.5) and integrating between positions x_1 and x_2,

$$\int_{N_1}^{N_2} dN/N = a/(KT) \int_{x_1}^{x_2} E \ (\delta E/\delta x) \ dx$$

$$\text{or,} \quad \ln(N_2/N_1) = a/(KT) \int_{E_1}^{E_2} E \ dE$$

$$\text{or,} \quad N_2/N_1 = \exp[\, a(E_2^2 - E_1^2)/2KT]$$

$$N_2 \approx N_1 \, [1 + a(E_2^2 - E_1^2)/2KT] \qquad \ldots\ldots\ldots(3.6)$$

$$\triangle N = N_2 - N_1 = N_1 \, a \, (E_2^2 - E_1^2)/2KT \qquad \ldots(3.7)$$

Here N_i and E_i are the number of water molecules and the electric field respectively at position $x_i (i=1,2,3,\ldots)$.

This means that enrichment of moisture between two points depends on the difference of the electric field squared indicating that no moisture enrichment is possible if the applied electric field is uniform. If E_1 is taken to be 0 and E_2 is taken to be 3×10^6 v/m, $\Delta N/N_1$ turns out to be 3.2×10^{-5} using $\epsilon_r = 87$ for normal water at room temperature [7]. This is an extremely low value of $\Delta N/N_1$ to have any practical application. However, the situation can be improved significantly if the applied electric field can be increased further. If E_2 can be increased to 10^7 v/m then the situation will improve by about 10 times. But there is a practical limitation on the maximum value of the applied electric field. A high field phenomena called corona can cause flash over if the electric field is increased beyond 3×10^6 v/m in air at 1 atm. pressure [9]. Hence, it appears that there is an upper limit of $\Delta N/N_1$ which is approximately 3.2×10^{-5} for a pair of electrodes.

Force on the water molecules can be increased by increasing dE/dx keeping the maximum value of E within the maximum limit (eqn. 3.3). However, it may appear that any change in dE/dx does not have any effect on the enrichment value as dE/dx term is absent in eqn.(3.7). Let us consider an electric field which has a step distribution as shown in fig. (3.2). Such a distribution is possible when porous parallel plate electrode is used. Although an exact step function can not be achieved, dE/dx can be
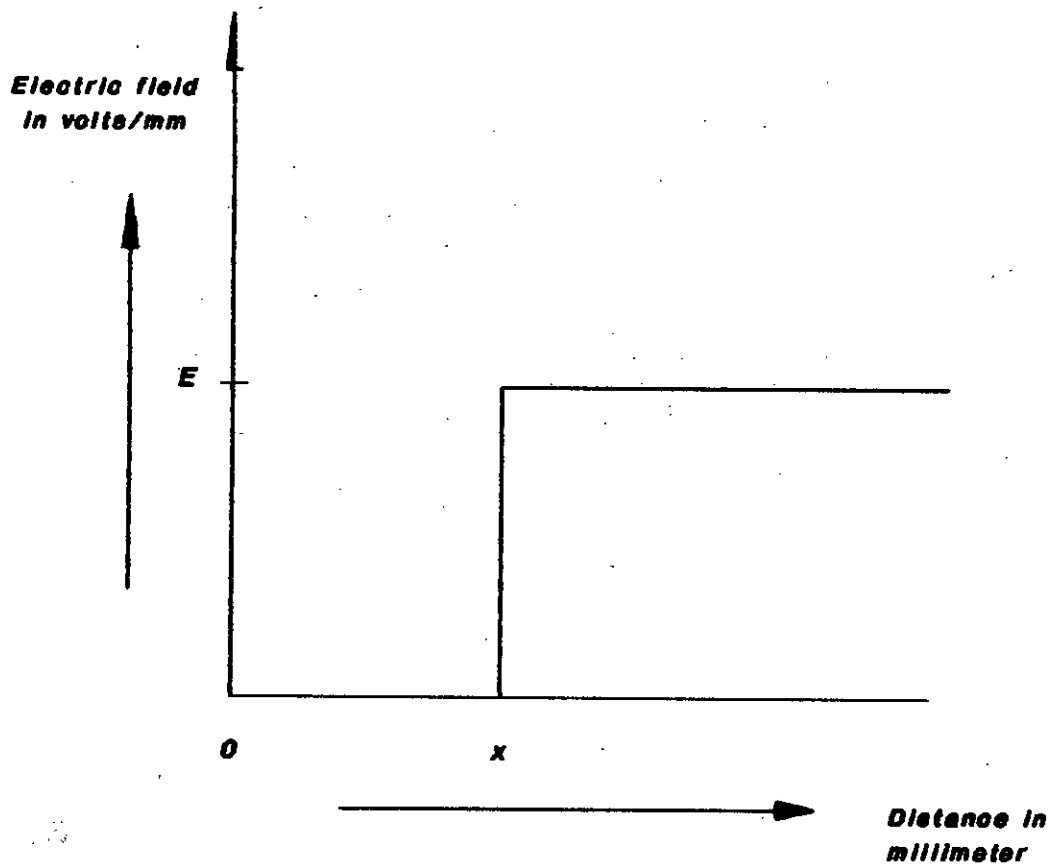
Fig 3.2 A step electric field. Here, E is the amplitude of the electric field and x is the distance after which the electric field is initiated.

made very high. Such a field distribution will apply extremely large force over a very small distance. As the distance over which the force applies is small, very few or no collision of molecules take place resulting in higher drift velocities. Let a dipole moment of μ have point charges of magnitude q separated by a distance "a", then the force will act on the dipole for a distance "a". Hence

$$dV_x/dt \quad = \quad qE/m$$

$$dV_x \quad = \quad (qE/m)\ dt$$

$$= \quad (qE/m).(dt/dx).dx$$

$$= \quad (qE/m).(1/V_x).dx$$

$$V_x\ dV_x \quad = \quad (qE/m).dx \qquad \ldots\ldots\ldots\ldots(3.8)$$

Where V_x is the x-component of velocity and m is the moleculer mass. Integrating equation (3.8)

$$\int_{V_{x_o}}^{V_x} V_x\ dx \quad = \quad \int_{o}^{a} (q\ E)/m\ dx$$

or, $\quad \tfrac{1}{2}\ (V_x^2 \ - \ V_{x_o}^2) \quad = \quad (q\ a\ E)/m$

$$= \quad (\mu\ E)/m$$

$$= \quad (\alpha\ E^2)/m$$

Where $\quad \mu \ = \ qa \ = \ \alpha E$

$\quad \alpha$ is the polarizability.

$$V_x^2 \ - \ V_{x_o}^2 \quad = \quad (2\ \alpha\ E^2)/m \qquad \ldots\ldots\ldots\ldots\ldots(3.9)$$

$$V_X = \sqrt{[\ V_{X_o}^2 + (2\ \alpha\ E^2)/m\ ]} \qquad \dots\dots\dots\dots\dots(3.10)$$

$$\delta V_1 = V_X - V_{X_o}$$

$$= \sqrt{[\ V_{X_o}^2 + (2\ \alpha\ E^2)/m\ ]} - V_{X_o}$$

$$= \sqrt{[\ V_{X_o}^2 + \sigma^2\ ]} - V_{X_o}$$

Where V_X and V_{X_o} are the velocities after and before acceleration and let $\sigma^2 = (2\alpha E^2)/m$. Dipolar molecules having same velocity V can be incident at $X = 0$ from different directions making an angle θ and $(\theta+d\theta)$ with the X-axis. By putting $V_X = V \cos \theta$, it is possible to find out the average value of δV_1 for the water molecules incident with a velocity of V.
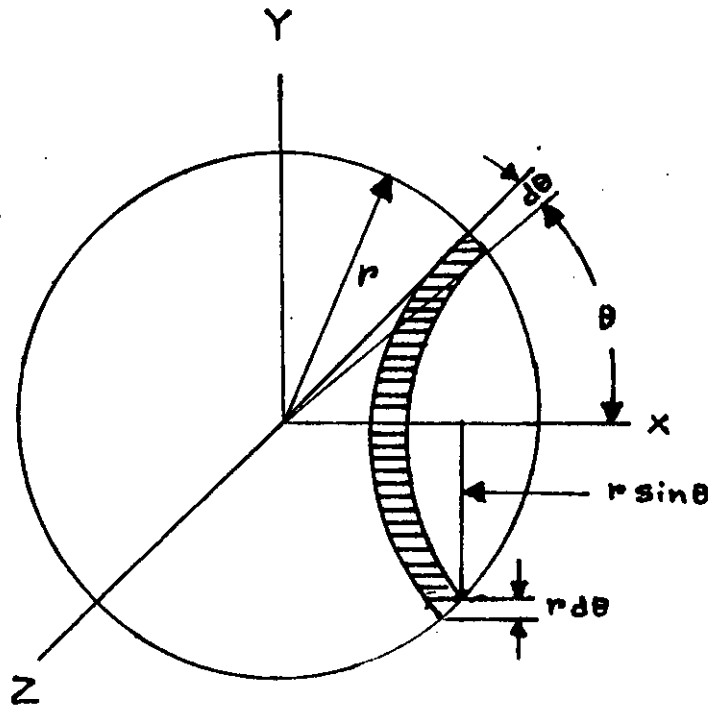

Fig 3.3 Obtaining average change in velocity by taking elemental change in velocity over angle dθ and by integrating along θ and Φ direction.

Here the porous plate is considered to be X-Y plane.

Average change in velocity of the water molecules incident with a velocity V,

$$\delta V = 1/(2\pi r^2) \int_0^{2\pi} \int_0^{\pi/2} (r \sin \theta) [\delta V_1] \, r \, d\theta \, d\Phi$$

$$\delta V = 1/(2\pi r^2) \int_0^{\pi/2} 2\pi r^2 (\sin \theta) [\delta V_1] \, d\theta$$

$$\delta V = 1/(2\pi) \int_0^{\pi/2} 2\pi \sin \theta [\sqrt{(V_{x_0}^2 + \sigma^2)} - V \cos \theta] \, d\theta$$

$$= \int_0^{\pi/2} \sin \theta [\sqrt{(V^2 \cos^2\theta + \sigma^2)} - V \cos \theta] \, d\theta$$

$$= -\int_0^{\pi/2} V \sin \theta . \cos . \theta \, d\theta + \int_0^{\pi/2} [V^2 \cos^2 \theta + \sigma^2]^{\frac{1}{2}} \sin \theta \, d\theta$$

Let $I = \int_0^{\pi/2} [V^2 \cos^2\theta + \sigma^2]^{\frac{1}{2}} \sin \theta \, d\theta$

Putting $V \cos \theta = Z$

$$- V \sin \theta \, d\theta = dZ$$

$$\sin \theta \, d\theta = - 1/V . dZ$$

at $\theta = 0$, $Z = V$

at $\theta = \pi/2$, $Z = 0$

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$$I = - 1/V . \int_V^o \not f \; [Z^2 + \sigma^2] \; dZ$$

$$= - \sigma/V . \int_V^o \not f \; [1 + Z^2/\sigma^2] \; dZ$$

after integrating it will become,

$$I = - (\sigma/V).[\; \tfrac{1}{2} \{ \; Z \not f(1+Z^2/\sigma^2) + \sigma \; \ln(\; Z/\sigma + \not f(1+Z^2/\sigma^2))\}]_V^o$$

$$= \sigma/(2V).[V\not f(1 + V^2/\sigma^2) + \sigma \; \ln\{ \; V/\sigma + \not f(1 + V^2/\sigma^2)\}]$$

$$= \tfrac{1}{2} \not f[\; V^2 + \sigma^2 \;] \; + \; \sigma^2/(2V) \; \ln[\; V/\sigma + \not f(\; 1 + V^2/\sigma^2 \;)]$$

$$\delta V = \tfrac{1}{2} [\not f \; (V^2 + \sigma^2) - V] \; + \; \sigma^2/(2V) \; \ln[\; V/\sigma + \not f(\; 1 + V^2/\sigma^2 \;)]$$

$$\approx \tfrac{1}{2} [\; \sigma^2/(2V)] + \sigma^2/(2V) \; \ln(2V/\sigma)$$

$$= \tfrac{1}{2} \; \sigma^2/(2V) + \sigma^2/(2V) \; \ln \; 2 + \sigma^2/(4V) \; \ln(\; V^2/\sigma^2 \;)$$

$$= \sigma^2/V \; [\; \tfrac{1}{4} + \tfrac{1}{2} \; \ln \; 2 \;] + \sigma^2/(4V) \; [\; V^2/\sigma^2 \;]$$

The average change in velocity δV is due to the water molecules having a velocity of V.

Now using Maxwell-Boltzmann distribution considering all the velocities,

Mean drift velocity $\langle \delta V \rangle$ will become,

taking $V^2 \; = \; Y$

$\quad 2V \; dV \quad = \quad dY$

$$\langle\delta V\rangle = 1/N \int_{0}^{\infty} (\sqrt{2\pi Nm^{3/2}})/(\pi KT)^{3/2} \{[\tfrac{1}{4} + \tfrac{1}{2} \ln 2] \sigma^2 + \tfrac{1}{4} \sigma^2 \ln V^2/\sigma^2$$

$$x \exp.[(-mV^2)/(2KT)] \ V \ dV$$

$$= \int_{0}^{\infty} (\sqrt{2\pi m^{3/2}})/(\pi KT)^{3/2} \cdot \{(\tfrac{1}{4} + \tfrac{1}{2} \ln 2 \ ) \sigma^2 \}.\tfrac{1}{2} \exp[(-mY)/(2KT)].dY$$

$$+ \int_{0}^{\infty} (\sqrt{2\pi m^{3/2}})/(\pi KT)^{3/2} \cdot \sigma^2/8 \cdot \ln(Y/\sigma^2) \cdot \exp[(-mK)/(2KT)].dY$$

$$= \int_{0}^{\infty} (\sqrt{2\pi m^{3/2}})/(\pi KT)^{3/2} \cdot \{(\tfrac{1}{4} + \tfrac{1}{2} \ln 2)\sigma^2 - \sigma^2/8 \ \ln \ \sigma^2 \}.\exp[-mY/2KT].dY$$

$$+ \int_{0}^{\infty} (\sqrt{2\pi m^{3/2}})/(\pi KT)^{3/2} .\sigma^2/8.(\ln \ Y).\exp[-mY/2KT].dY$$

$$= (\sqrt{2\pi m^{3/2}})/(\pi KT)^{3/2} .\{\tfrac{1}{4} + \tfrac{1}{2} \ln 2)\sigma^2 \ - \ \sigma^2/8 \ \ln \ \sigma^2 \} \ [1].(2KT/m)$$

$$+ (\sqrt{2\pi m^{3/2}})/(\pi KT)^{3/2} . \sigma^2/8.[(2KT/m).\{0.5772 + \ln \ (m/2KT)]$$

$$= 2 \ x \ (2m/\pi KT)^{1/2} \ \{(\tfrac{1}{4} + \tfrac{1}{2} \ln 2)\sigma^2 - \sigma^2/8.\ln \ \sigma^2 \ \}$$

$$+ (\ 2m/\pi KT)^{\frac{1}{2}} .2.\sigma^2/8.[-0.5772 - \ln(m/2KT)]$$

For H_2O at $T = 300^\circ K$.

$$(2m/\pi KT)^{1/2} \quad = \quad [(2x18x1.660x10^{-27})/(\pi x1.380x10^{-27})]^{1/2}$$

$$= \quad 2.1 \ x \ 10^{-3}$$

and $\ln \ (m/2KT) = \ - \ 12.56$

$\langle\delta V\rangle = 2 \ x \ 2.1 \ x \ 10^{-3} \ \{\sigma^2(0.596 - o.125 \ \ln \ \sigma^2)\}$

$$+ \ 2.1 \ x \ 10^{-3} \ x \ 2 \ x(\sigma^2/8) \ [11.29]$$

$$= 4.2 \times 10^{-3} \, \sigma^2 \, (0.596 - .25 \ln \sigma) + 6.2 \times 10^{-3} \, \sigma^2 \quad ..(3.11)$$

Dielectric constant of water at room temperature is 87 and number of water molecules/m^3 is 3.47 x 10^{28}. Putting these values in eqn(2.12), the average value of α is calculated to be 2.2 x 10^{-38}. This gives

$$\sigma^2 = 10.49 \times 10^{-13} \, E^2 \qquad ....(3.12)$$

For the water molecules incident from x<0 and x>0 regions, their average velocity changes by $<\delta V>$ and $-<\delta V>$ respectively. Let N and N + $\triangle$N be the density of molecules for x>0 and x<0 regions respectively. At equilibrium, drift due to the electric field is compensated by diffusion in the opposite direction.

$$N/2 \, (<V_x> + <\delta V>) = (N + \triangle N)/2 \, (<V_x> - <\delta V>)$$

$$\triangle N/N = 2(<\delta V>)/<V_x> \qquad ....(3.13)$$

Percentage moisture enrichment per 100 electric plates is calculated using equation (3.13) as a function of electric field. This results show that percentage enrichment has increased considerably making the scheme practically viable.

A rough calculation shows that one pound of moisture condensate at 80°F releases 1048 BTU of latent heat[10]. One cubic feet of 100 % humid air at 80°F contains 156 grains (7000 grains = 1 lb) of moisture [see psychrometric chart in

appendex A]. If 10 % of this moisture content i.e. 1.56 grains
are condensed, then the heat released from 1.56 grains of
moisture is equivalent to 0.2336 Btu of heat per ft^3 of air and
it is equivalent to 2.08 KCal per meter cube of air.

C H A P T E R   4

EXPERIMENTAL SET UP AND RESULTS

4.1 Introduction

A simple experiment was performed to verify the theory developed in chapter 3. Specially designed electrodes were made and placed in an array with an average spacing one millimeter (2 mm for the plastic plates) in between two plaes. The arrangement of the plates were made in a manner such that moisture would flow from one end of the array to the others. Detailed description of the electrodes and their costruction procedure are section 4.2. Two identical chambers were constructed, as described in section 4.3, and placed at the ends of the array of the electrodes. High voltage was generated using six small sized transformers in series and then adding a doubler circuit in cascade as given in section 4.4, was capable of producing a maximum of 3696 volts. The overall set up are described in section 4.5. Operating principle of the system is briefly explained in section 4.6. Results were presented in section 4.7.

4.2 Electric Plates

Two types of electric plates were designed for the experimental set up. One of which is the Porous plate and the

other is the Non-Porous plate.

Porous plate

The first type of electric plate , shown is fig 4.1, is
the porous plate. The 5"x5" plates were made from hard paper of
approximately 1 mm (2 mm for the plastic plates) thick. A 2"x2"
window was cut at the middle of the plate. A very fine porous
conducting media was made of commercially available kitchen foil
which was cut to shape to cover the window. Extreme care had been
taken during the manual pricking of the foil so that pores did
not become large. This was necessary to make the electric field
distribution like a step function. This was done by inserting a
large number of pins in a solid sheet of rubber with the sharp
ends of the pins projecting out from the other side. The rubber
sheet was then pressed delicately on the kitchen foil a number of
times to attain the fine pores. The fine pored foil paper was
then glued on the 2"x2" window. A conducting wire was connected
with the foil paper to apply voltage on the porous plate. Thus a
porous plate had been manufactured. The photograph of a porous
plate was shown in fig 4.2. A special hand made tool was used
for making perforation of the kitchen foil paper as shown in
fig 4.5.

Conducting Wire

(2" x 2") punched aluminium foil paper

1.5" 2" 1.5"
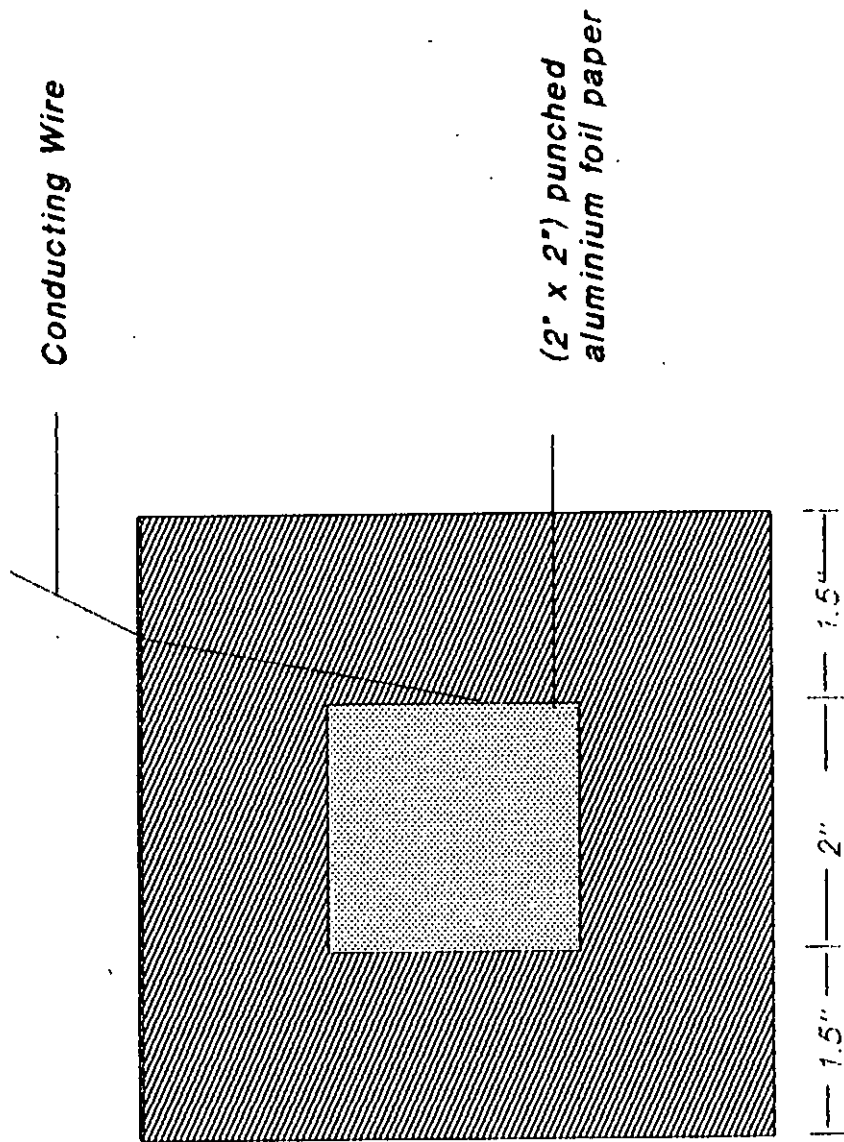
Fig 4.1 A porous plate.
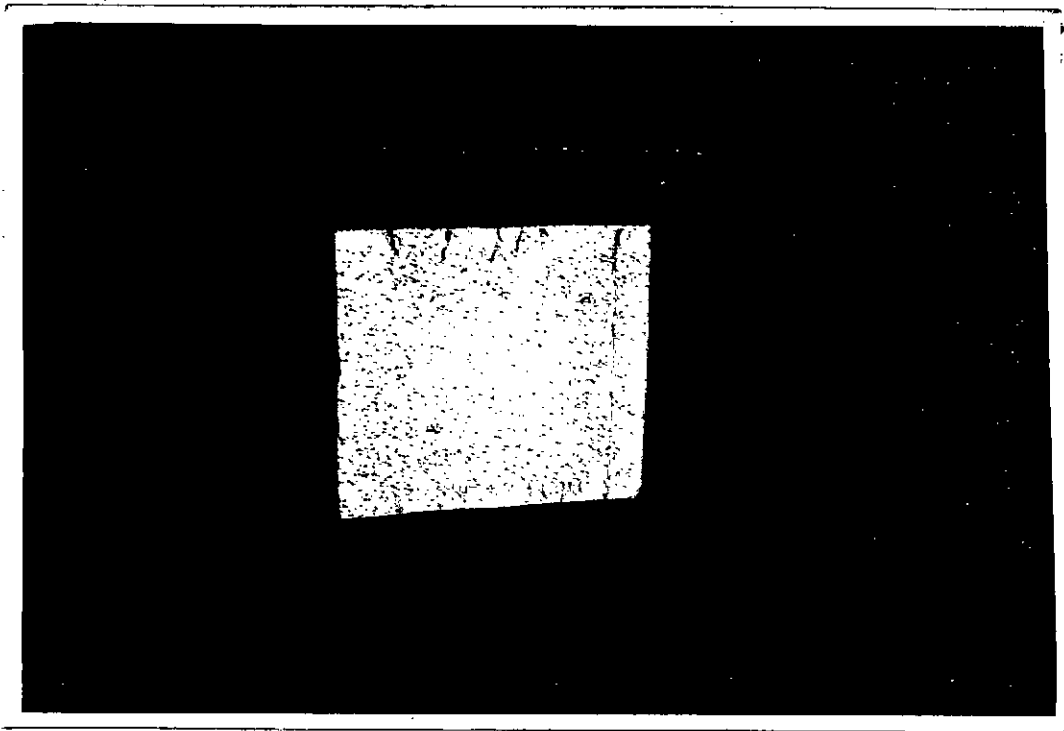
Fig 4.2   Photograph of a porous plate.

Non-Porous Plate

The non-porous plate is also made from the hard card paper. The size of the plate is 5″x5″. Four windows of size 2½″ x ¼″ were cut ¼″ away from the edges of the plate as shown in fig 4.3. Alluminium foil paper of size 2″x2″ was pasted at the centre of the plate. A conducting wire was also connected with the foil paper to supply voltage to the non-porous plate. A photograph of a non porous plate is shown in fig 4.4.

Again a few experiments were also carried out using Porous and Non Porous plastic plates. The sizes of the plates were same except they were of 2 mm thick.

4.3 Moisture Extraction Chambers

Two extraction chambers having dimension 12″x12″x9″ were constructed as depicted in fig 4.6 . A 5″x 5″ opening was cut on one of the sides . A hole of 1″ diameter was punched at the centre of the top surface so that a thermometer can be inserted easily. The extraction chambers were made from 24 SWG G.I. Sheet. The chambers were then made thermally insulated by covering them with a layer of cotton. This ensures a resonable adiabatic condition inside the chambers and making them insensitive to any change in ambient temperature. A wooden tray
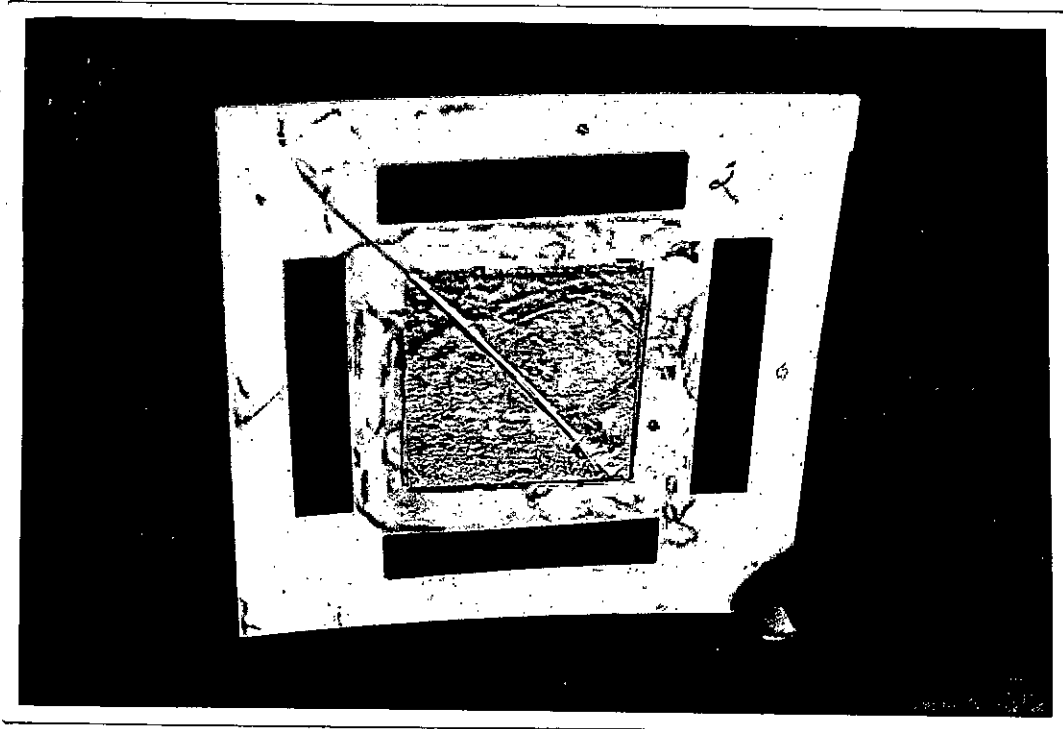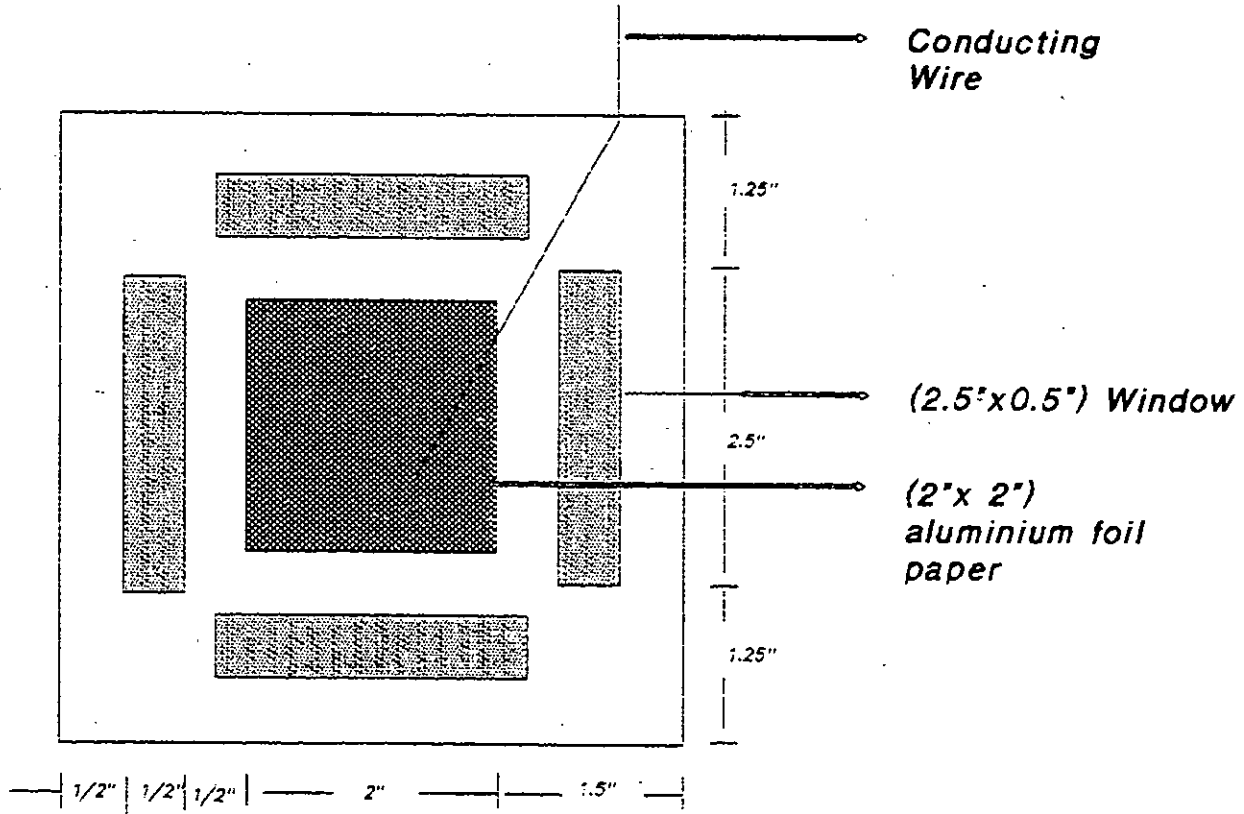
Fig 4.3   Photograph of a non porous plate.

Fig 4.4 A non porous plate.
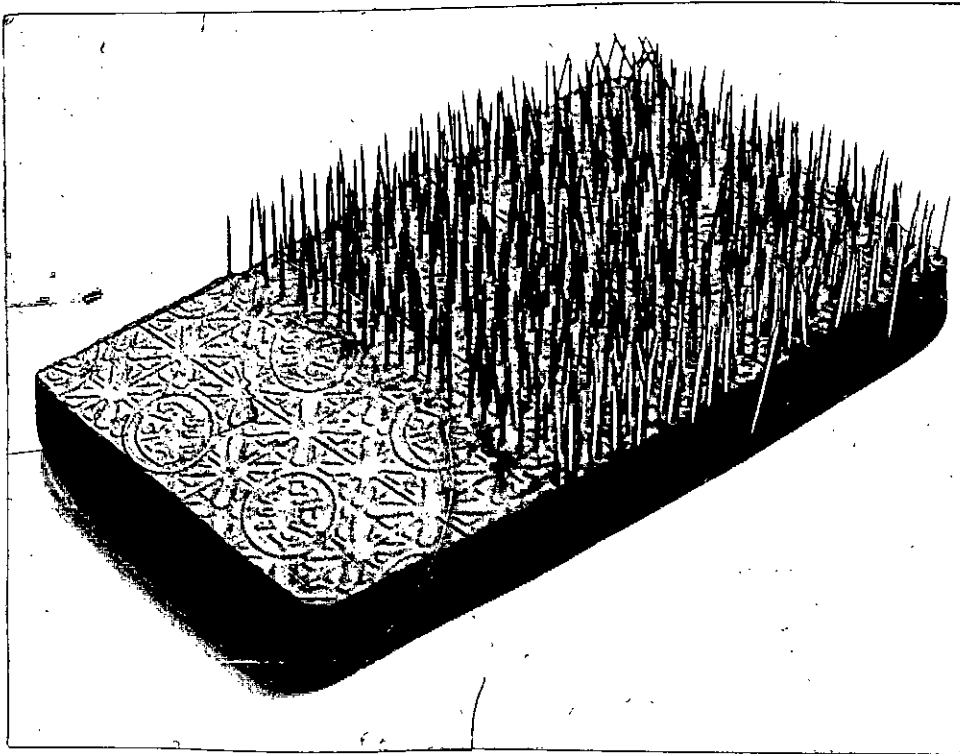
Fig 4.5   Photograph of the tool for making perforation.

6.5"

5"x 5" air
gap

5'

1/2'

9'   1"

Front View

6.5"

5"x 5" air
gap

5'

1/2'

2'   5'   2'

Side View

9"

2"

5"

2"

Top View

1" diameter hole
at the center

Fig 4.6 Moisture extraction chamber.

5"   **0.5"**   **0.5"**

36"

Front View

0.5"   **5"**   **0.5"**

36"

Top View

5"   **0.5"**

6"
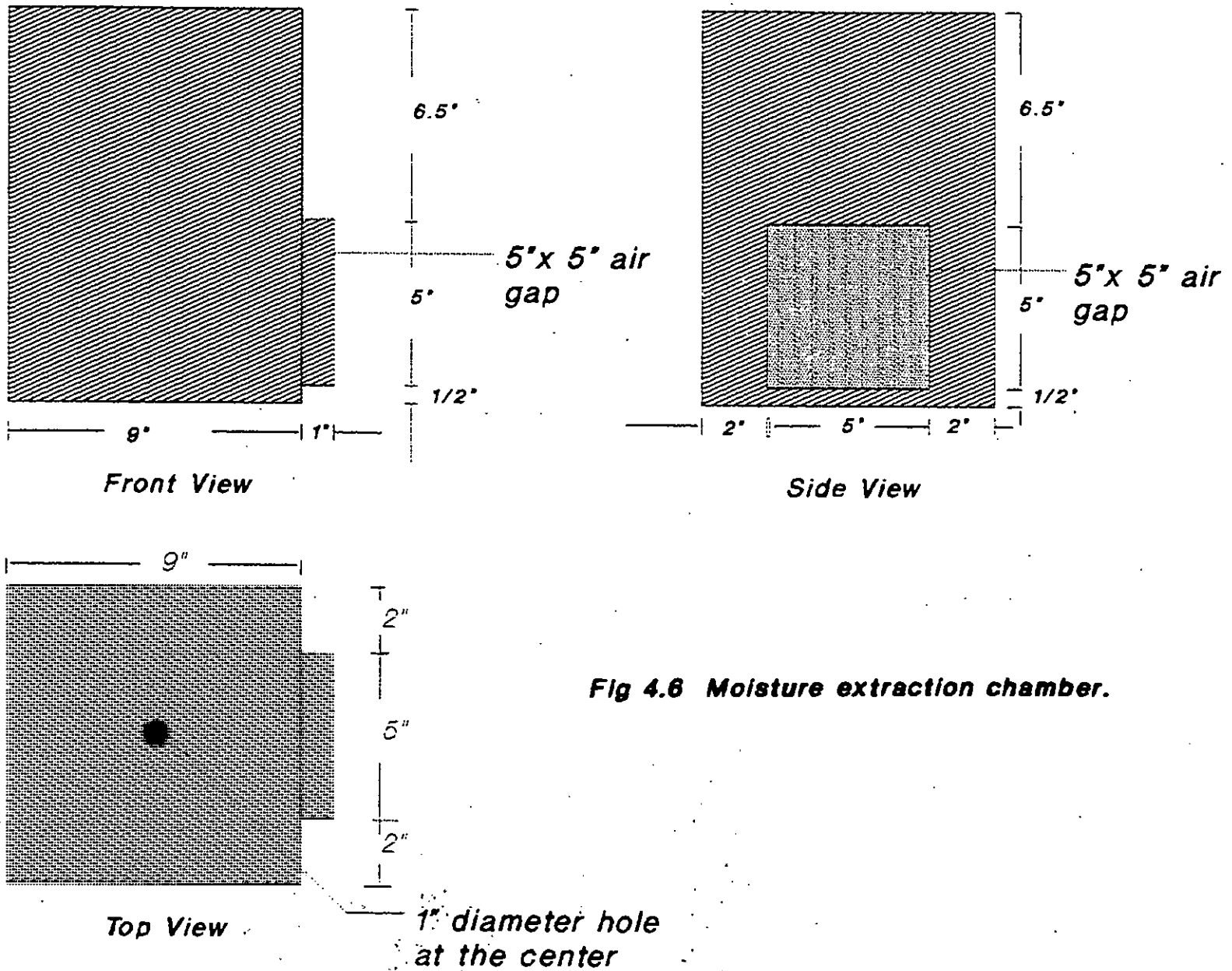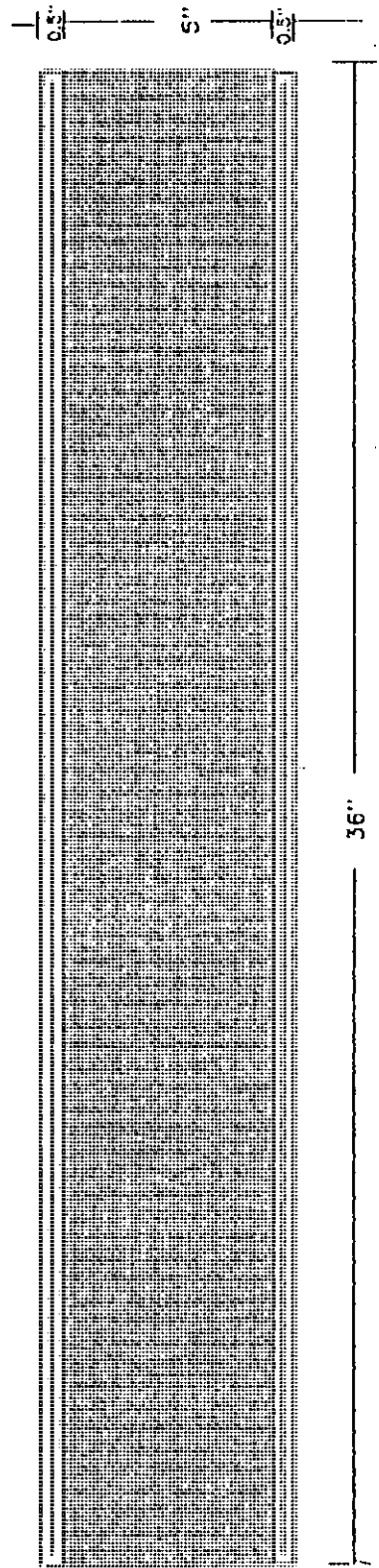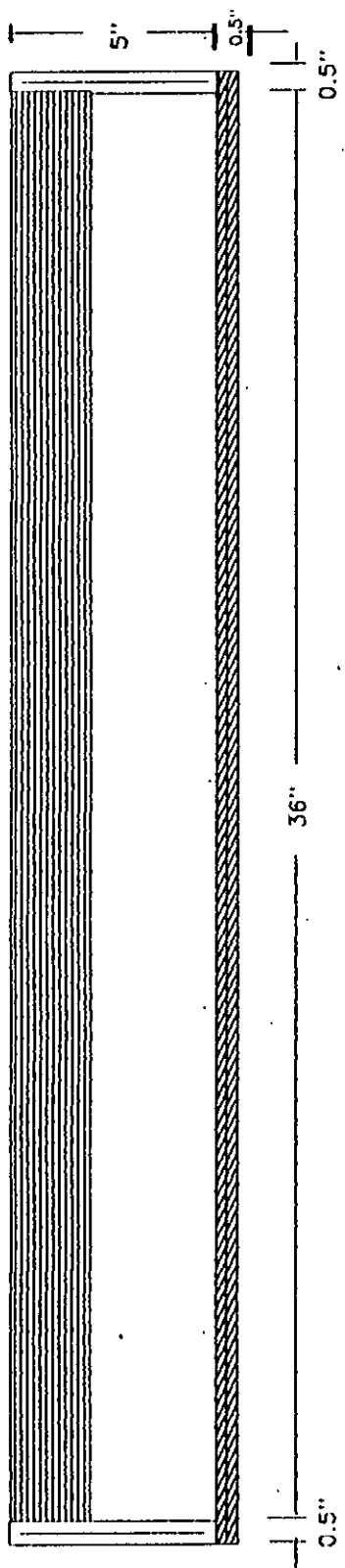
Side view

Fig 4.7 Wooden tray.
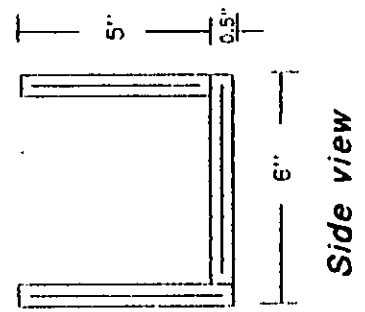
having dimension of 36"x6"x5½"   was made to place the array of electric plates as shown in fig 4.7 .

4.4 Electronic Circuit to Generate High Voltage

Six transformers of rating 24-220 volts were connected in series to generate a high voltage of 1320 volts at the output. Primary sides of the transformer were connected in series and the secondary sides of the transformers were also connected in series so that the output voltages were in phase. The required input primary voltages of the transformer is   24x6   volt to develop   1320 volts at the transformer output. The   input   24x6 volts was obtained by using an auto-transformer. The voltage doubler circuit doubles the output voltage to   3696 volts d.c. [15] [17]. The circuit diagram is shown in fig 4.8 .

4.5 Experimental Set Up

The complete set up for the experiment is shown in fig 4.12. The electric plates, as described in section 4.2, were placed in an array of a wooden tray. The plates were placed very close to each other and about one milimeter (two millimeters for plastic plates) was maintained to ensure the flow of water molecules. In this experiment two types of connections for the porous and non porous plates were provided. Mode of electrical

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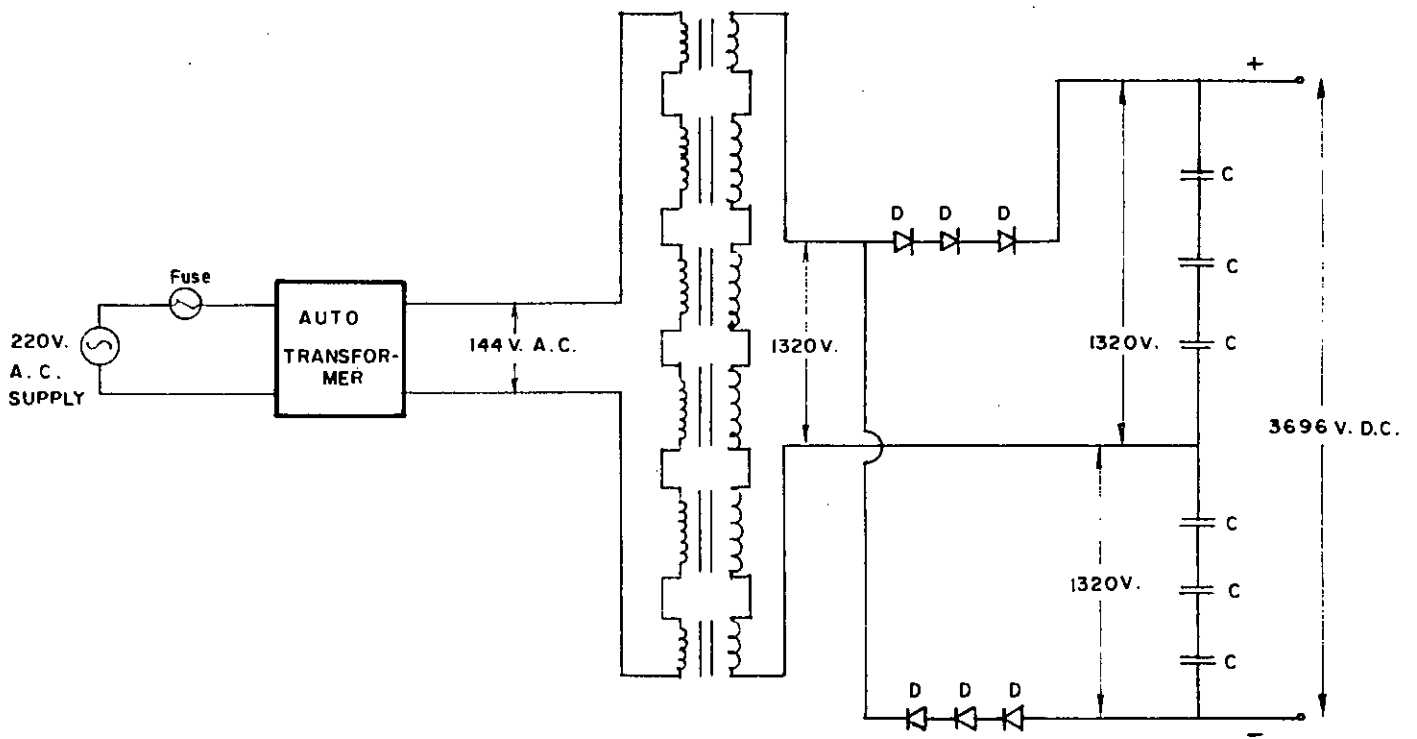
THE DIODES USED WERE 4007 HAVING A RATING OF 1000V, 1A.
ALL THE CAPACITORS USED IN THE DOUBLER CIRCUIT WERE RATED
AT 2·5 MF 400V A.C.

Fig 4.8 Electronic circuit to generate high voltage.

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Porous Plate
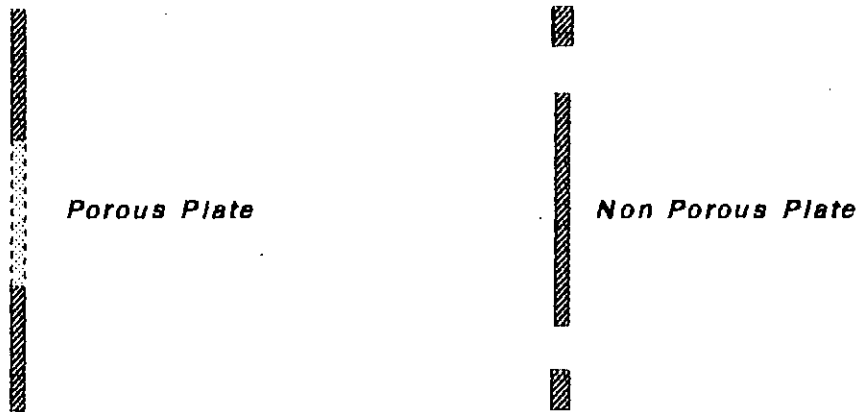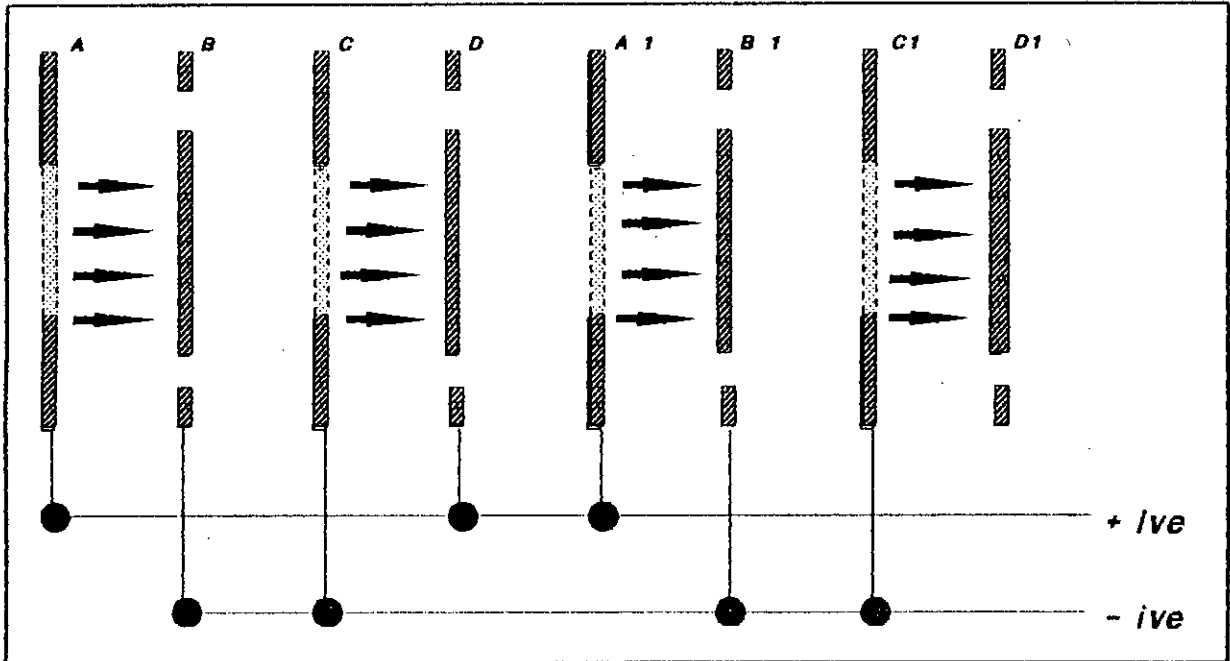
Non Porous Plate

Fig 4.9 Type-1 : Electric connections for electrodes.

Porous Plate

Non Porous Plate

Fig 4.10   Type-2 : Electric connections for electrodes.

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connections are shown in fig 4.9 and fig 4.10. In type-1 connection first porous plate, nearest to the extraction chamber, was supplied from the positive terminal of the source. Then adjacent to this plate,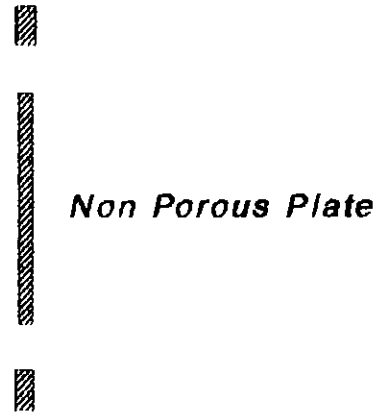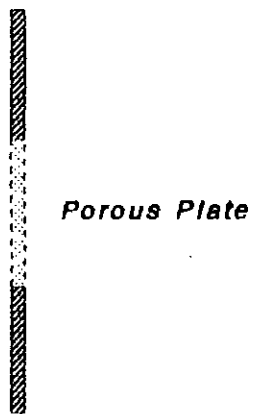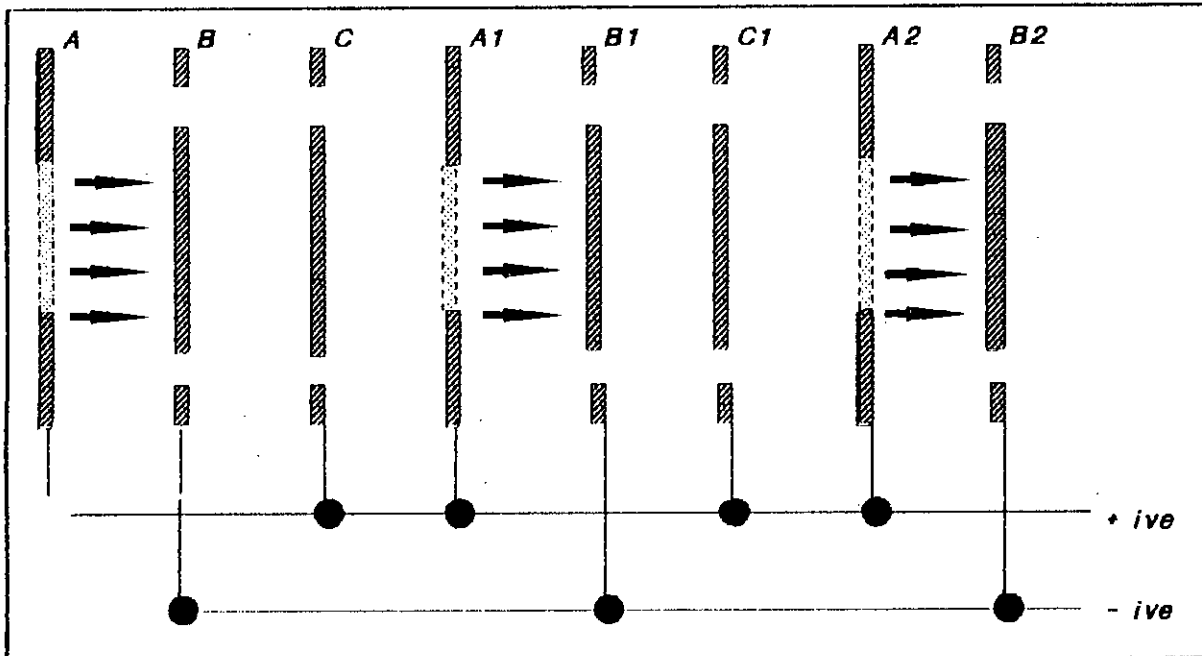 non porous plate connected with the negative polarity of the source was placed. Then again porous plate connected to the negative polarity of the source was placed. Finally a non porous plate , connected to the positive polarity of the source, was set close to them and this process of connection was repeated in this type of cofiguration as shown in fig 4.9 . In this configuration the polarity of porous plate may be either positive or negative. All porous plates were maintained positive in the second type of connection as shown in fig 4.10 .

The electric connections shown in fig 4.10 require less number of porous plates compared to the electric connections shown in fig 4.9. So the second type of electric connections i.e type-2 is economically feasible. That is why the second type of electric connections has been used frequently.

Two identical chambers were placed at the ends of the array of the wooden tray containing porous and non porous plates and care was taken to make the set up reasonably air tight. The chambers were externally covered by cotton wool to keep them adiabatic. The wooden tray was covered with a meter long

Fig 4.11 Photograph of the experimental set up.

Moisture extraction chamber

Moisture enrichment chamber

Wooden tray

Electric Plates

Polythene paper

1" diameter hole

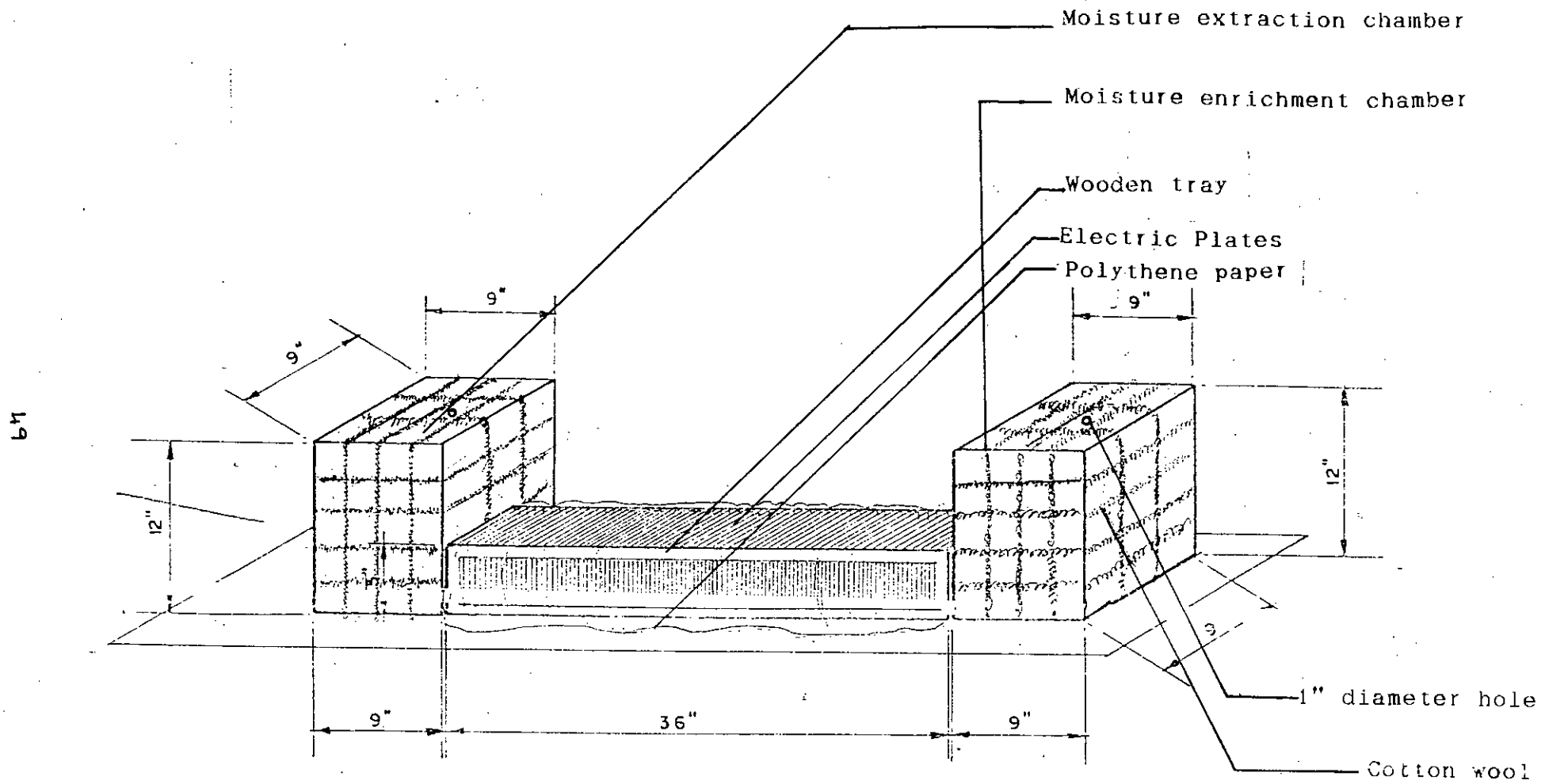Cotton wool

9"

9"

9"

9"

12"

12"

9"

36"

9"

Fig 4.12   Experimental set up of the system.

polythene paper to make it fully air tight so that no water molecule can be able to move out from the wooden tray except through the prescribed path.

The high voltage was supplied to the porous and non porous plates with an appropriate polarity from the high voltage section as described in art.4.4. Proper insulations were provided to prohibit the electric short circuit.

Two rubber corks of about one inch diameter were placed at the top surface of the moisture extraction chamber so that adiabetic atmosphere inside the chambers can easily be maintained. During experiment high sensitive thermocouple thermomer was inserted through the hole of the top surface of the extraction chamber and the rubber corks were placed into the hole to ensure the chambers fully air tight. The thermometer has an accuracy of measuring $\pm 0.1^{O}F$. Photograph of the complete set up was shown in the fig 4.11.

4.6 Block Diagram of the Set up and the Operating Principle

The block diagram of the set up is shown in the fig 4.13 to describe the operating principle of the system. Initially the moisture contents of the two extraction chambers were the same as they were in contact with the atmosphere. During the

Moisture
extraction
chamber (1)

*Water
molecules*

Wooden tray
containing
porous
and
non porous
plates

*Water
Molecules*

Moisture
extraction
chamber (2)

High electric field

A.C.
Supply

Electronic circuit
to generate high
voltage
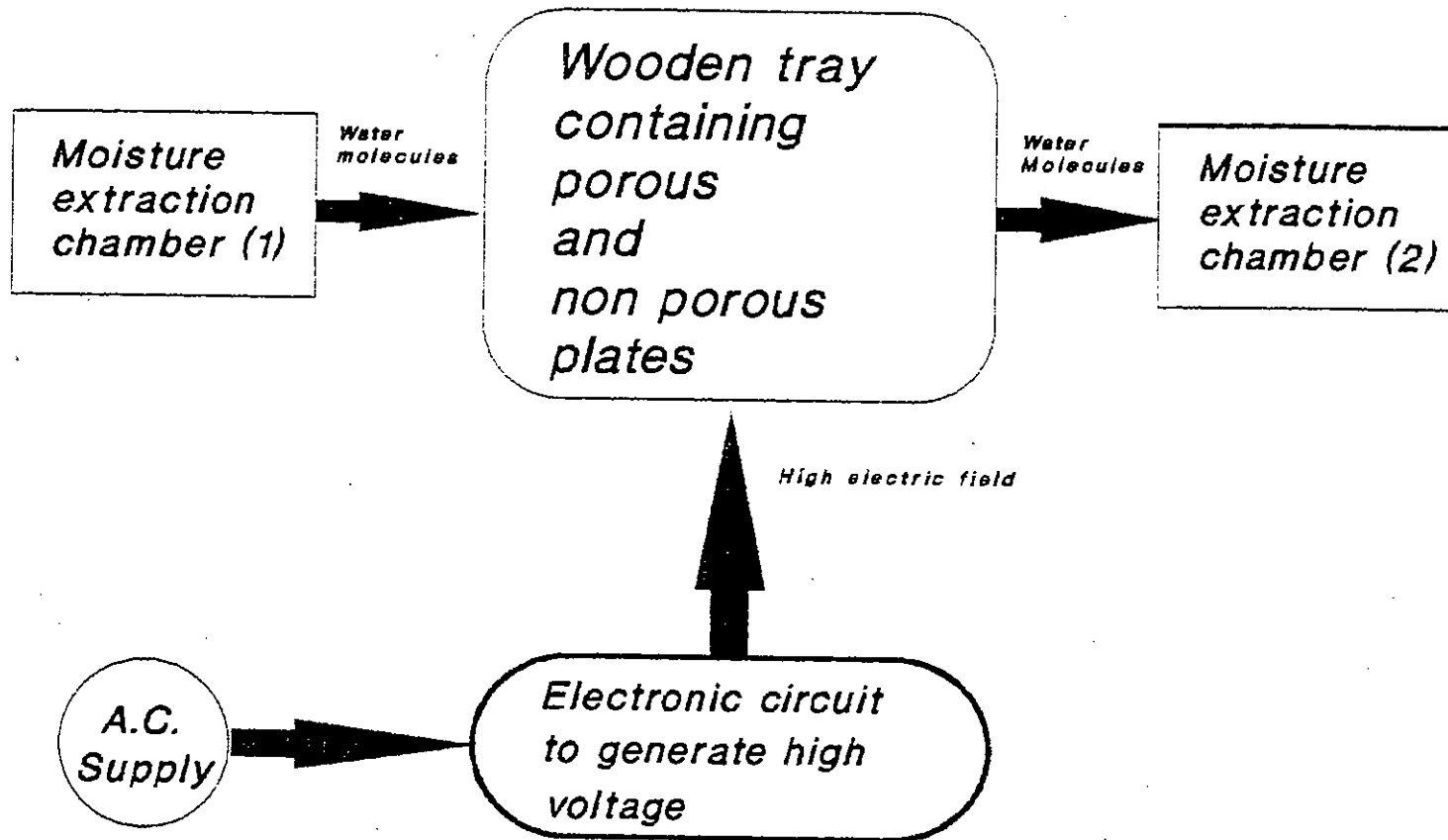
Fig 4.13 Block diagram of the set up.

experiment the wooden tray was tightly attached with the identical moisture extraction chambers so that the set up was air tight. When 2500 volts was applied in the plates, an electric field of 2.5 x 10^6 volts/m was established in between the positive and negative plates and moisture was extracted from one chamber to the other chamber. The extration procedure is different for the two types of the configuration.

In type-1 connection, porous and non porous plates were connected as shown in fig 4.9 . After applying high electric field across the porous and the non porous plates, the water molecules of the chamber (1) were attracted by the porous plate A. The negatively charged Oxygen ion of H_2O molecules were found to be attracted by the porous plate so that the H_2O molecules were passed through the tiny gap of the porous plate. The non porous plate B, which is connected to the negative terminal of the source, allures the hydrogen ion of the water molecules, so the water molecules were accumulated across the non porous plate B and enriches the water molecules in between the plates A and B. This enrichment of moisture diffuses through the windows of plate B to the equipotential surface in between the plates B and C. As the plate C is porous it attracts the water molecules. The enrichment process goes on at each porous plate of the array of the electric plates. These water molecules pass through the fine gap of the porous plate and attracted by

the negative charged of the non porous plate. The water molecules are then accumulated and enriched and passed through the window of the non porous plate D. This process is repeated and the enrichment process occurs at each porous plate.

In type-2 connection, all porous plates were supplied from the positive polarity of the source as shown in fig 4.10 . In this type of cofiguration first porous plate attracts the water molecules and enriches in between the plates A and B and pass through the window of B. The positive polarity of non porous plate allures the water molecules to move to the equipotential surface between the plates C and A_1. Since plate A_1 is porous, so it enriches the water molecules. This process is repeated for the next stages.

In this experiment both types of the configuration systems were used to evalute and compare the efficiency of moisture exrtraction. Each of the configuration was set on the wooden tray and care was take to make the setup resonably air tight. When high voltage about several killovolts were applied in the plates, an electric field was established in between the positive and negative plates and moisture was extracted from chamber (1) and push it into chamber (2). Highly sensitive thermocouple thermonometer was used to measure the temperatures. Percentage of enrichment of moisture on chamber (2) from chamber (1) was

obtained by using the Psychrometric chart with the experimental data of the dry and wet bulb temperatures.

4.7 Results and Discussion

The readings of the experiment are tabulated in table 4.1. The percentage increase in humidity both for the practical and the theoretical cases are given in table 4.2. In this experiment two qualities of plates were used; one of which were made from hard paper and the other from plastic. Temperatures were recorded at a regular time interval to learn how the dry and the wet bulb temperatures were varied. When there is no change in the temperature readings i.e. at steady state the temperatures were recorded for the calculation of the humidity.

Ten set of tests were taken to compare the percentage increase in humidity in chamber (2) between the measured value and the theoretical value. Absolute humidities in grains/lb (7000 grains = 1 lb) of air for the both chambers were obtained from the Psychrometric chart, given in Appendix-A. The increase in humidity with respect to that of chamber (1) is given in table 4.2. Theoretical percentage of increase in humidity in chamber (2) i.e. $\triangle N/N$ is calculated from the theory developed in chapter 3 by using the equations (3.11),(3.12) and (3.13) and also given in Table 4.2. A sample calculation for Test-1 is

TABLE 4.1

Dry and Wet bulb temperatures for different experimental conditions.

Test No.	Applied Voltage	Room Temperature		Chamber (1)		Chamber (2)		Temp. recorded after	Types of electric connections	No. of Porous Plates	Quality of Plates
	Kv/mm	Dry bulb temp. °F	Wet bulb temp. °F	Dry bulb temp. °F	Wet bulb temp. °F	dry bulb temp. °F	Wet bulb temp. °F	minutes			
1	2.00	83.4	80.7	83.6	81.6	84.2	83.1	30	1	92	
2	2.20	84.8	82.9	84.6	82.5	85.0	83.4	30	1	92	
3	2.30	83.1	79.5	84.0	81.1	84.0	81.6	30	2	92	
4	2.50	84.6	82.3	84.7	82.4	84.7	83.4	35	2	92	Paper Plates
5	2.50	86.5	81.3	86.3	83.1	86.7	83.8	70	2	52	
6	2.30	85.1	80.2	84.9	81.3	85.4	81.8	80	2	52	
7	2.20	84.7	80.2	84.9	81.6	85.3	82.0	30	2	52	
8	2.50	85.2	80.6	86.1	81.8	86.1	82.4	60	2	50	
9	2.90	86.1	82.4	86.1	81.8	86.1	82.2	35	2	50	Plastic Plates
10	2.65	85.5	82.5	85.8	81.8	85.8	82.4	45	2	50	

TABLE 4.2

Comparison between Measured and Theoretical percetage increase in humidity.

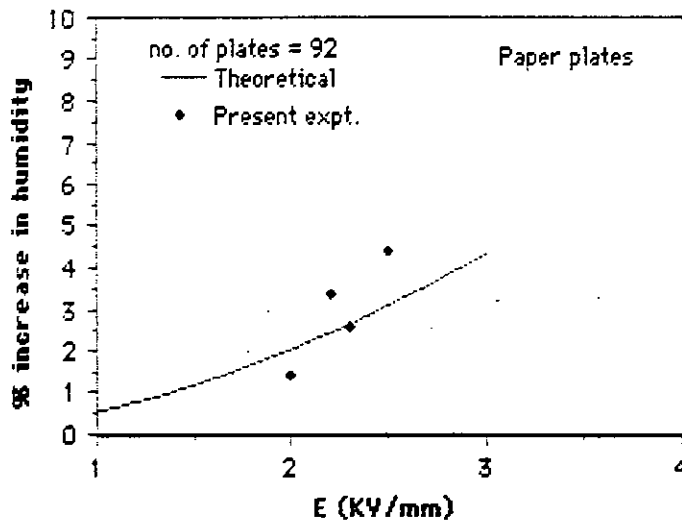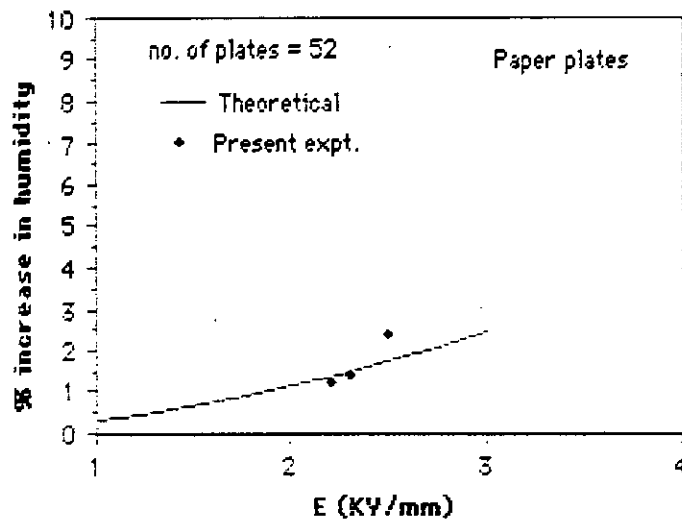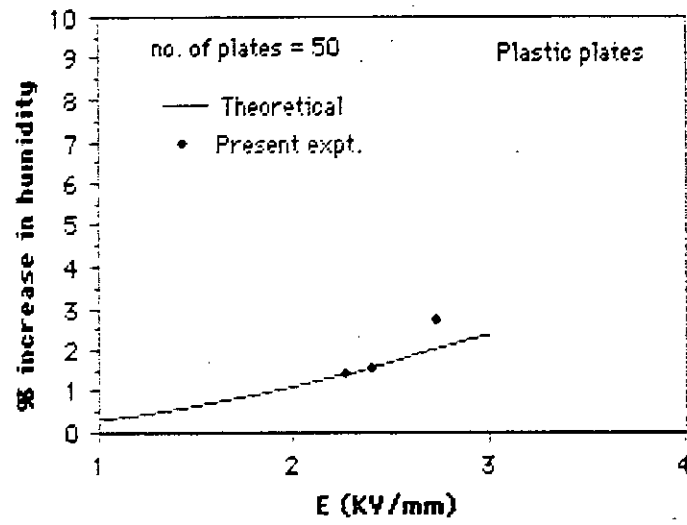| Test No.	Applied Voltage Kv/mm	Measured			Theoretical
		Chamber (1) Absolute humidity Grains/lb of air	Chamber (2) Absolute humidity Grains/lb of air	Percentage increase in humidity in chamber (2)	Δ N/N Percentage increase in humidity in chamber (2)
1	2.00	169.0	171.4	1.42	2.03
2	2.20	166.8	172.4	3.36	2.43
3	2.30	157.0	161.0	2.55	2.63
4	2.50	165.4	172.7	4.41	3.10
5	2.50	168.0	172.0	2.40	1.74
6	2.30	157.8	160.0	1.39	1.49
7	2.20	159.8	161.8	1.25	1.37
8	2.50	158.7	162.5	2.39	1.50
9	2.90	159.2	163.5	2.70	2.16
10	2.65	159.0	161.8	1.76	1.60

Fig 4.14   Percentage increase in humidity with applied
electric field.

presented in Appendix-B.

The results are also shown in fig 4.14 for different types of plates.

By comparing the theoretical and measured values of the percentage increase in humidity in chamber (2), it can be concluded that the percentage increase in humidity is fully dependent on the applied electric field and number of the porous plates. From fig 4.14 , it is seen that the measured data were close to the theoretical data for the paper type plates. In tests 2,4,5 measured values are slightly greater than the theoretical data. It is also seen from the table for the first seven tests data that the percentage of humidity increases with the higher electric field as in test-4 and also increases with the number of electrodes as compared with the test-2 and test-7.

Last three tests were done with the plastic plates. The performance of these tests were appreciable. Because the plastic plates were not hygroscopic as the paper plates and also due to the hardness which always making the plates in perfect parallel position.

C H A P T E R   5

CONCLUDING   REMARKS

5.1 Conclusions

In this work an alytical relation has been developed for the calculation of enrichment of the atmospheric moisture. The enrichment of the atmospheric moisture, ΔN is a function of applied electric field E and the number of porous plates. ΔN has a parabolic relation with E and a linear relation with the number of porous plates.

The experimental results showed good agreement with the computed values using the analytical equations, some deviations in the experimental results have been observed. This was due to the non-parallel alignment of the plates.

In the experimental set up it was possible only to extract moisture molecules due to physical limitations the experiment could not be extended to study the latent heat extraction from the condensed atmospheric moisture.

5.2 Limitations of the System

The theoretical analysis given in chapter 3 and the experimentation in chapter 4 summerized the following limitations of this project.

From the theoretical analysis and the experimental data, it has been found that moisture extraction increases with electric field E. But for practical reason voltage could not be applied beyond 3000 volts/mm because corona effect occurs above 3000 volts/mm

In this experiment, it was only possible to extract the water molecules from one chamber to the others.But latent heat could not be extracted because of the fact that it was not possible to achieve heat as 100 % humidity could not be achieved.

Hard paper plates which was used in the first phase of the experiment were found to be hygroscopic. For this reason, it was necessary to dry the plates everytime before taking readings. This disadvantage was eleminated by the use of plastic plates. The thickness of the hard paper plate used in the first experimental set up was 1 mm but in the experiment 2 mm thickness of plastic plates were used. This was done to achieved better performance of the system.

A more accurate and convenient humidity measurement system needs to be developed in order to get better result.

From the theoretical analysis and experimental data, it can be concluded that this type of system can be readily used for the extraction of moisture.

5.3 Further Research

From the experience and the the limitations of this study the following points may be noted for the further research,

This study can be extended with much bigger size so that the feasibility of its practical application can be studied.

The future experiment can be extended for its application such as air conditioning system, dehumidifier, Uranium enrichment project etc.

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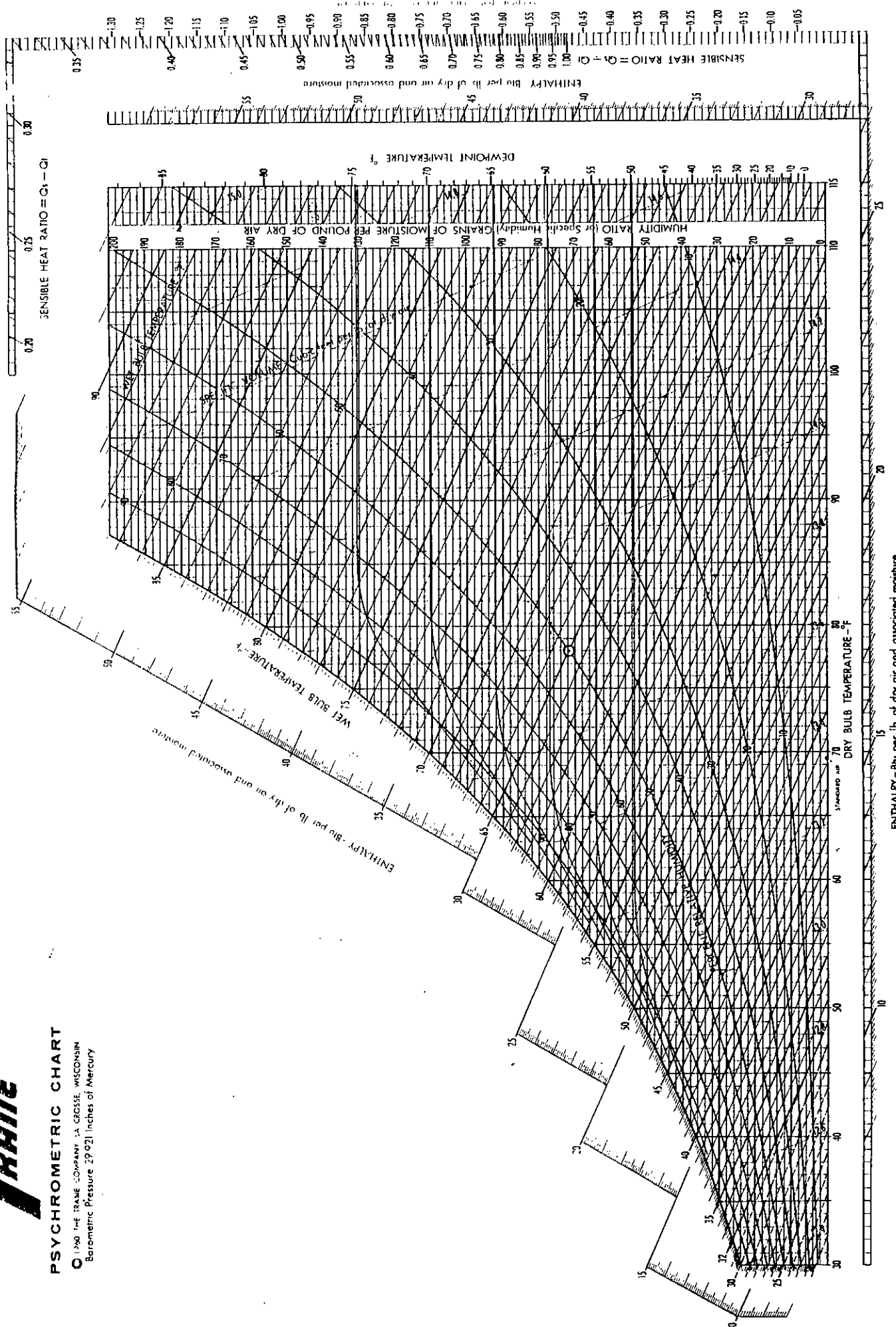
Appendix   A

Fig A.1 Psychrometric chart [taken from **TRANE** Psychrometric chart]

Appendix B

Sample Calculation

Theoretical value of percentage increase in humidity in chamber (2) was calculated as below,

From the equation no. (3.12)

$$\sigma^2 = 10.49 \times 10^{-13} E^2$$

In this experiment the variable quantites were the electric field E and the number of the porous plates.

For the first test i.e. Test-1,

electric field $E = 2$ kv/mm $= 2 \times 10^3$ kv/mm.

and number of porous plates = 92

$$\sigma^2 = 10.49 \times 10^{-13} \times (2 \times 10^3 \times 10^3)^2$$

$$= 4.196$$

$$\sigma = 2.048$$

From the equation no. (3.11),

$$\langle \delta V \rangle = 4.2 \times 10^{-3} \sigma^2 (0.596 - 0.25 \ln \sigma) + 6.2 \times 10^{-3} \sigma^2$$

$$= 4.2 \times 10^{-3} \times 4.196 \times (0.596 - 0.25 \ln 2.048) + 6.2 \times 10^{-3} \times 4.196$$

$$= 0.0334 \text{ m/s}.$$

mean drift velocity in the x direction $\langle V_x \rangle = 605/2 = 302.5$ m/s.

From the equation no. (3.13),

$$\Delta N/N = 2 \times \langle \delta V \rangle / \langle V_x \rangle = (2 \times 0.0334)/302.5 = 2.2083 \times 10^{-4}$$

Percentage of increase in humidity for one porous plate

$$= 2.2.83 \times 10^{-4} \times 100$$

$$= 0.02208 \text{ %}$$

Percentage increase in humidity for 92 porous plates

$$= 0.02208 \times 92$$

$$= 2.03 \text{ %}$$