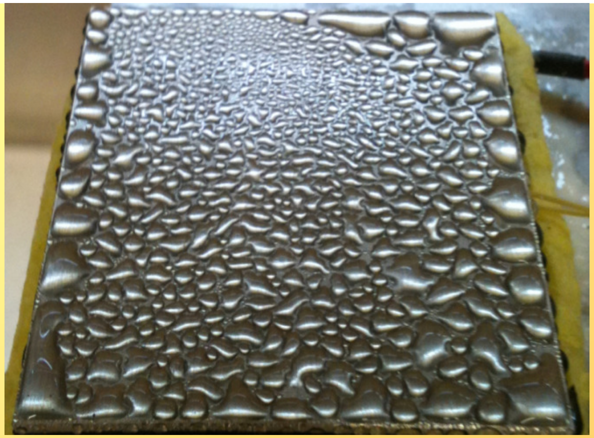

A Technique of Water Vapor Recovery Through the Characterization of Condensation Phenomena

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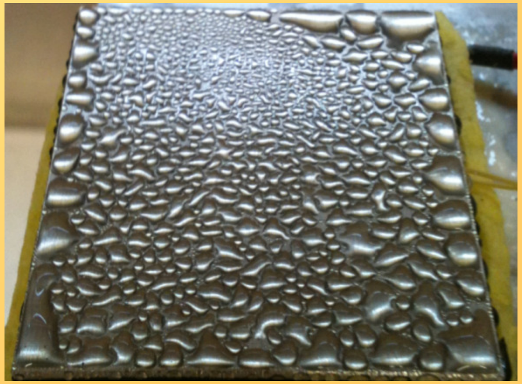
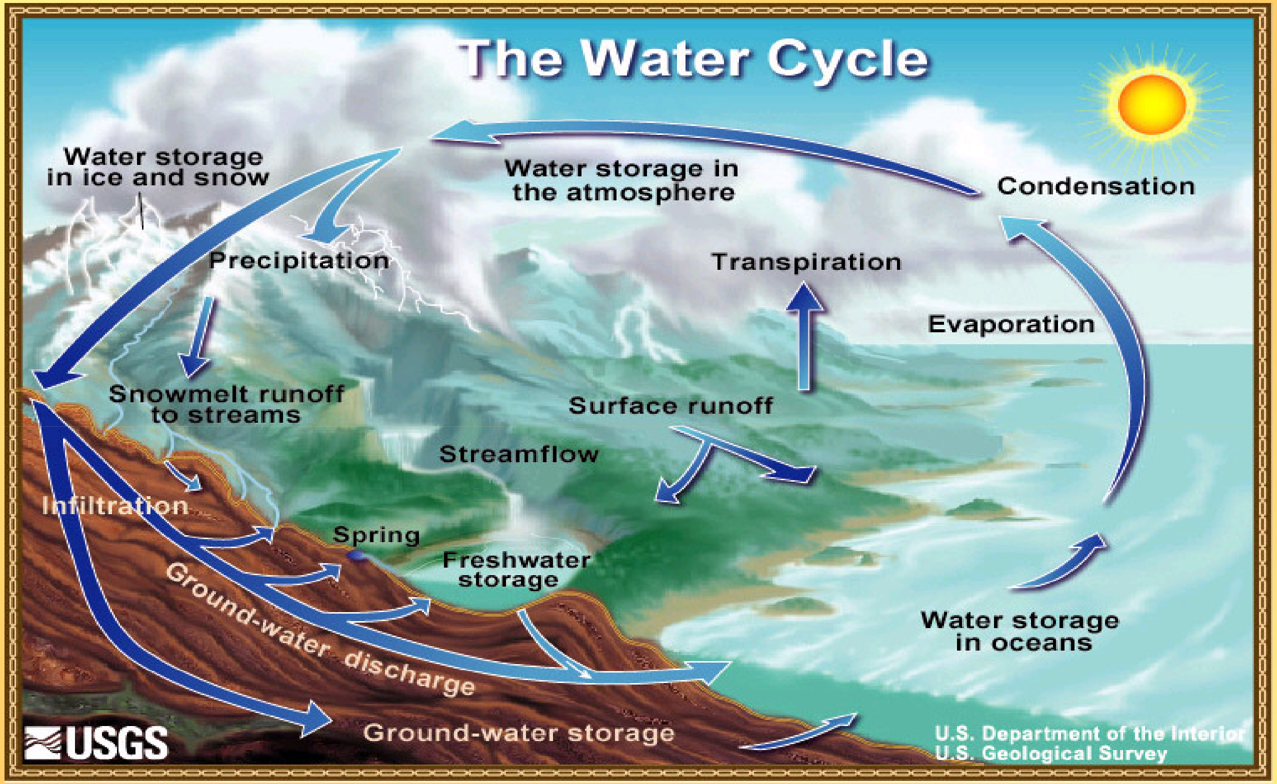
Generation of Potable water by condensation of water vapour from Atmosphere



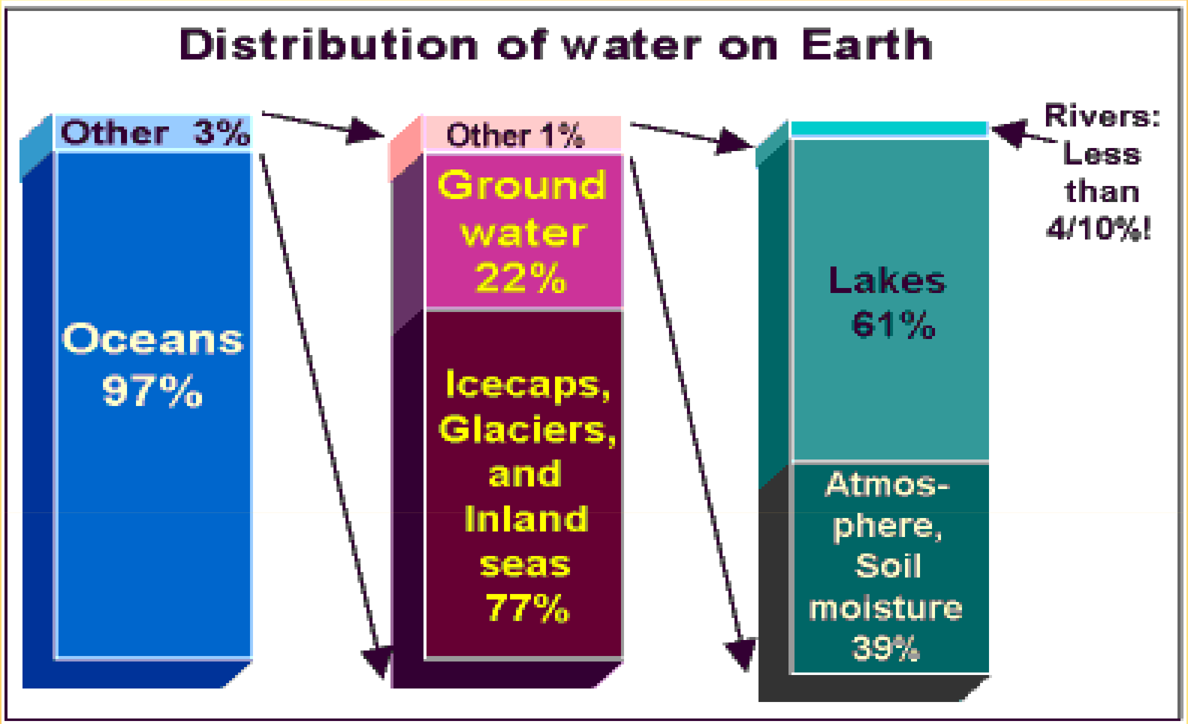
- Our Objectives here, is to study the possibility of using TEC devices to retrieve water condensate from atmospheric air in a closed/open environment.
- And to use this device, where relative humidity is high or temperature variation (Min.-Max.) is high.
- In this study for experimental viavility. we have chosen the specific regions of certain Indian states to study the data and verify the concept, such as Gujarat and Rajasthan, where availability of potable water is a challenge and above parameter is viable.

Evaporation, Condensation and Precipitation: The main processes of the water cycle



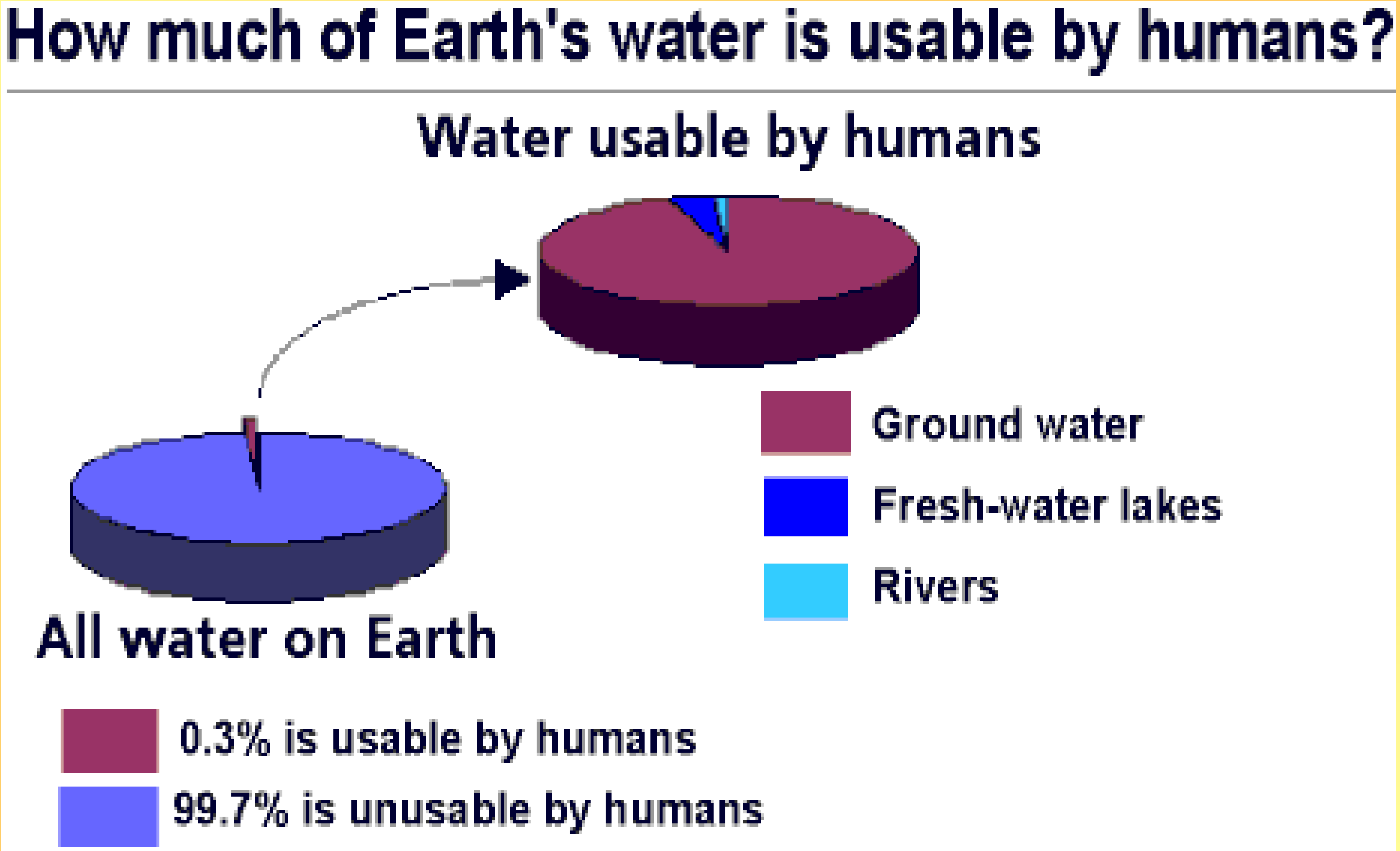
- The atmosphere contains more than **12.9 x 10^{12} m^3** of renewable water.

Distribution of Water on Earth

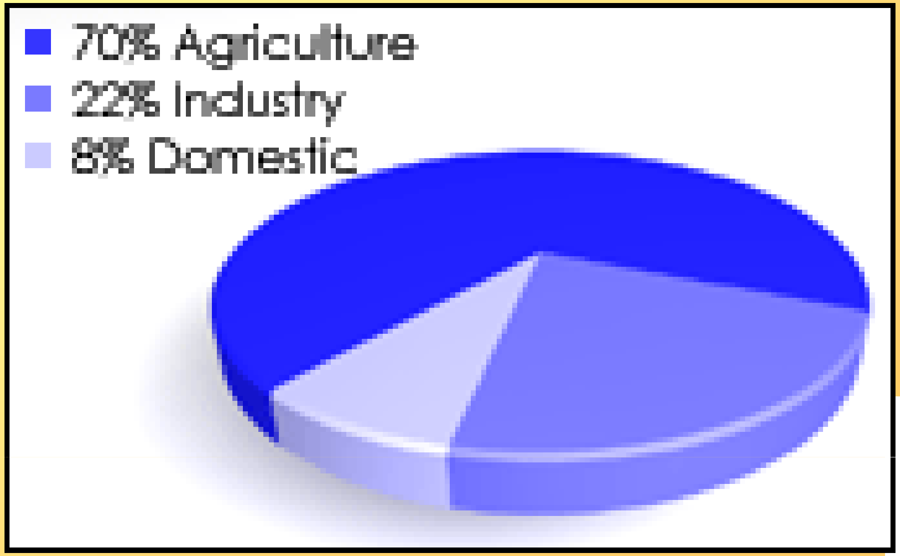


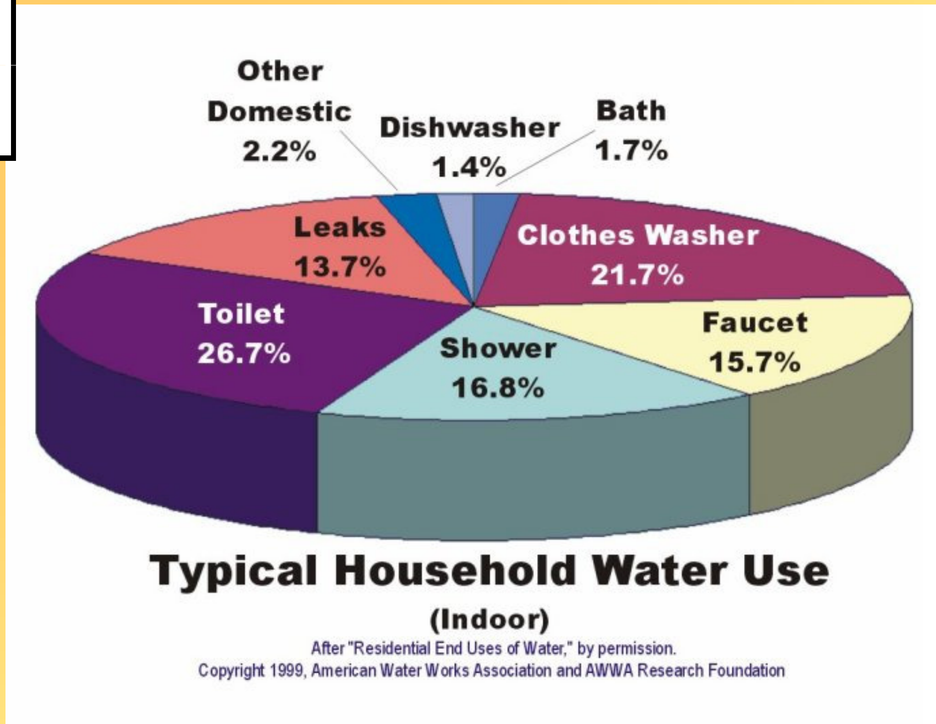
- Most of the Earth’s water is in oceans.
- Oceans contain salt water and covers most of the earth’s surface.
- Of the final 1%, only 0.4% of water comes from rivers, a major source of the water we use.

Where is the water we use?



Where is Fresh water used for?





Concept of Study: Basics of condensation

Condensation

Filemwise | **Dropwise**

Heat Transfer Coefficient $h_{film} << h_{drop}$

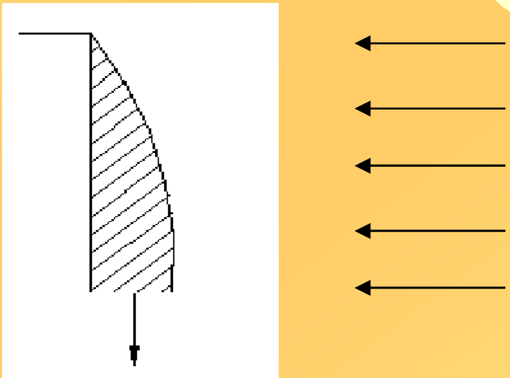
Filemwise:

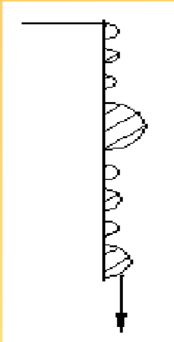
- Liquid wets the surface.
- Continuous film over the surface, that flows down the surface under the action of gravity.
- The layer of liquid condensate acts as a barrier to heat flow, and hence low heat transfer rate.

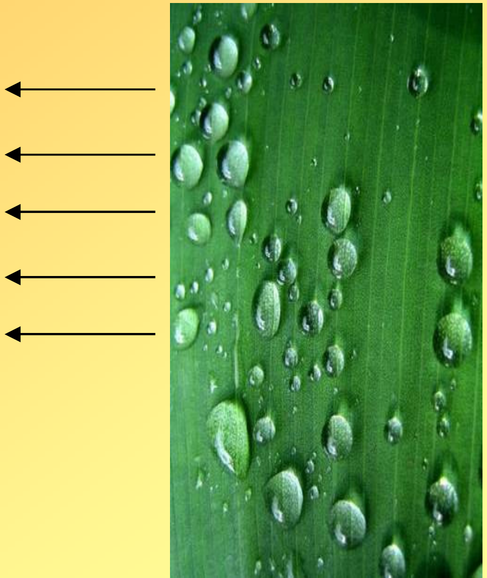
Dropwise:

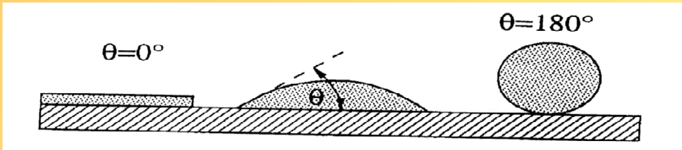
- Liquid does not wet the solid surface.
- Forms separate drops at nucleation sites.
- Drops coalesce to form large drops and sweeping clean a portion of the surface, where again new droplets are generated.

Notion

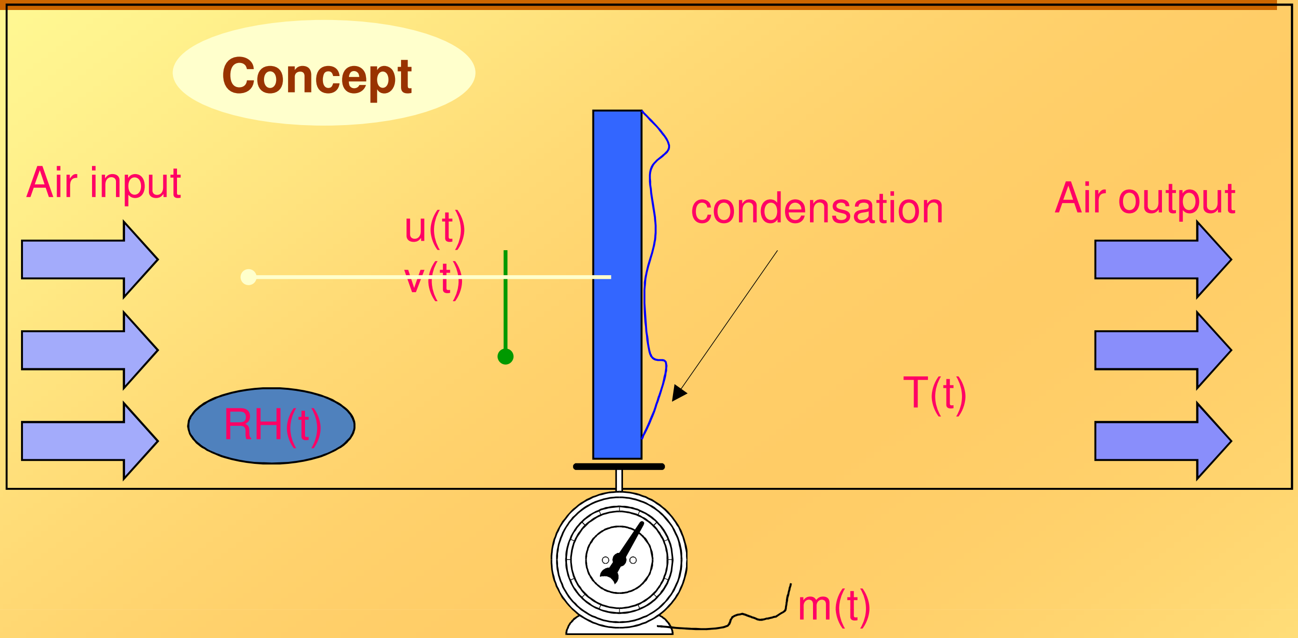








Concept of the study: Experimental



Mean entrance velocity (0.0 - 5.0 m/s), Temperature (18-35) ℃, Controlled RH 25-90 %

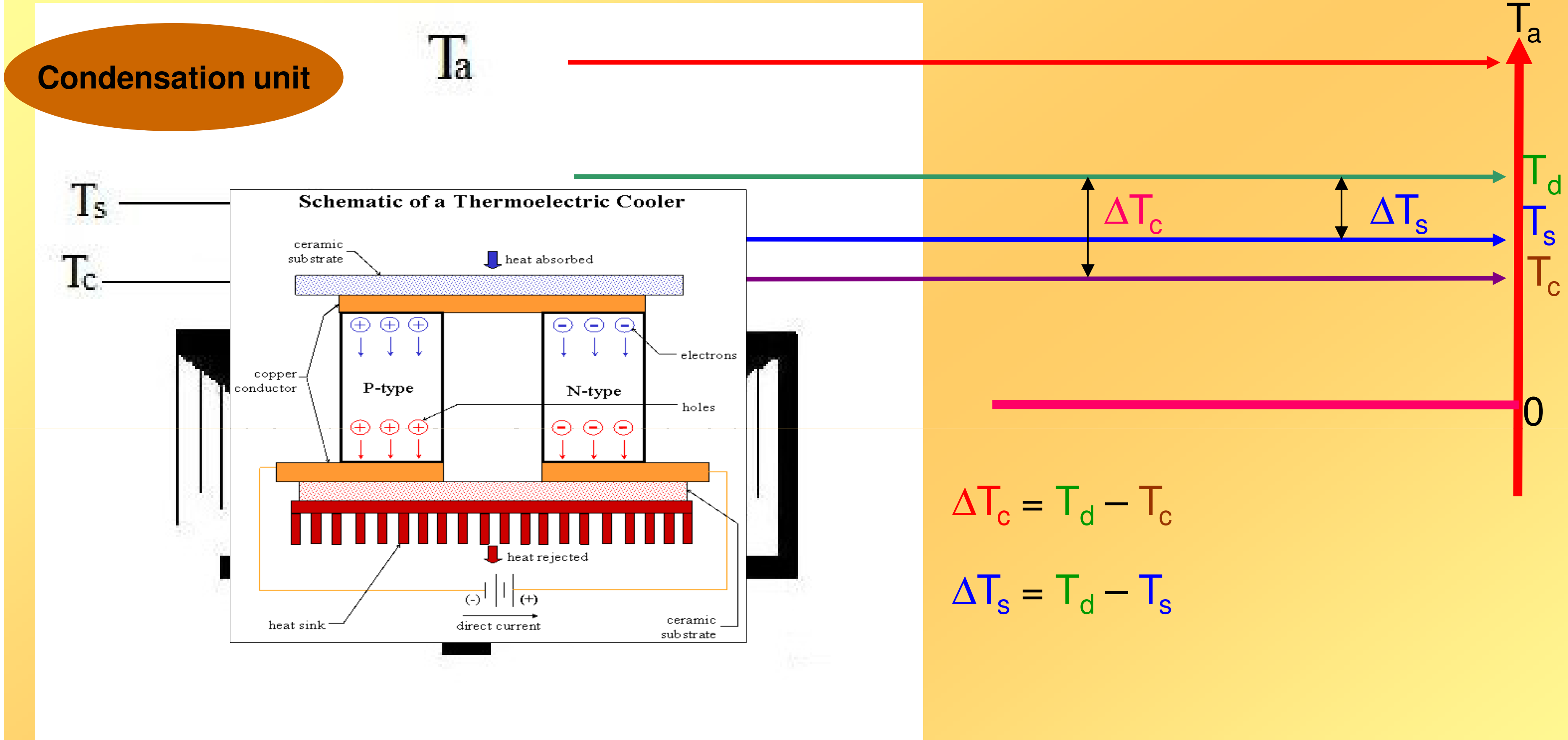
Dry phase

- Validation of concept : Characterization of wind flow and temperature profile
- Choice of simple geometries & surface material

Humid phase

- Condensation of water vapour from humid air in an open environment (In a Room)
- Validation in a controlled conditions (Inside the wind tunnel)
- Modeling of results

Condensation unit and Temperature profiles



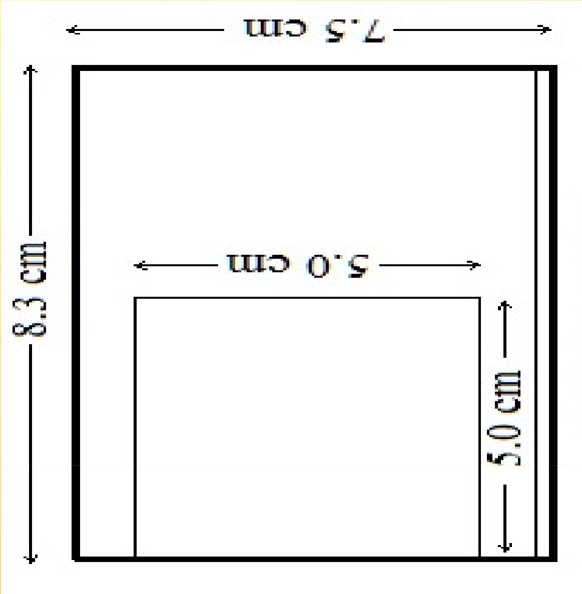
$\Delta T_c = T_d - T_c$

$\Delta T_s = T_d - T_s$

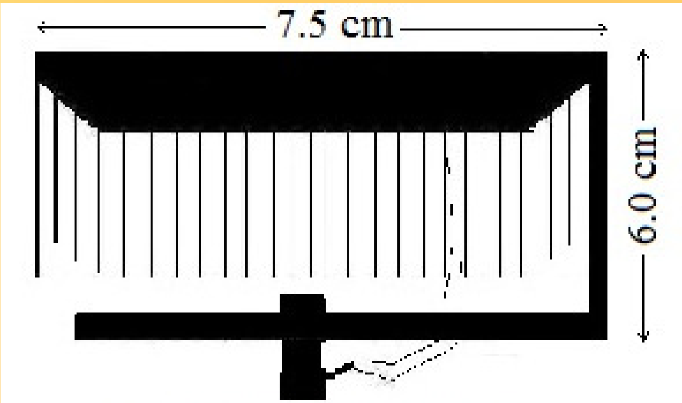
Basic questions one has to deal with :-

1. Choice of Material, its thickness, size and proper heat sink for removal of heat from hot side
2. Measurement of different temperatures
3. Characterization of flow profile on its active surface

Device Dimensions of condensing unit



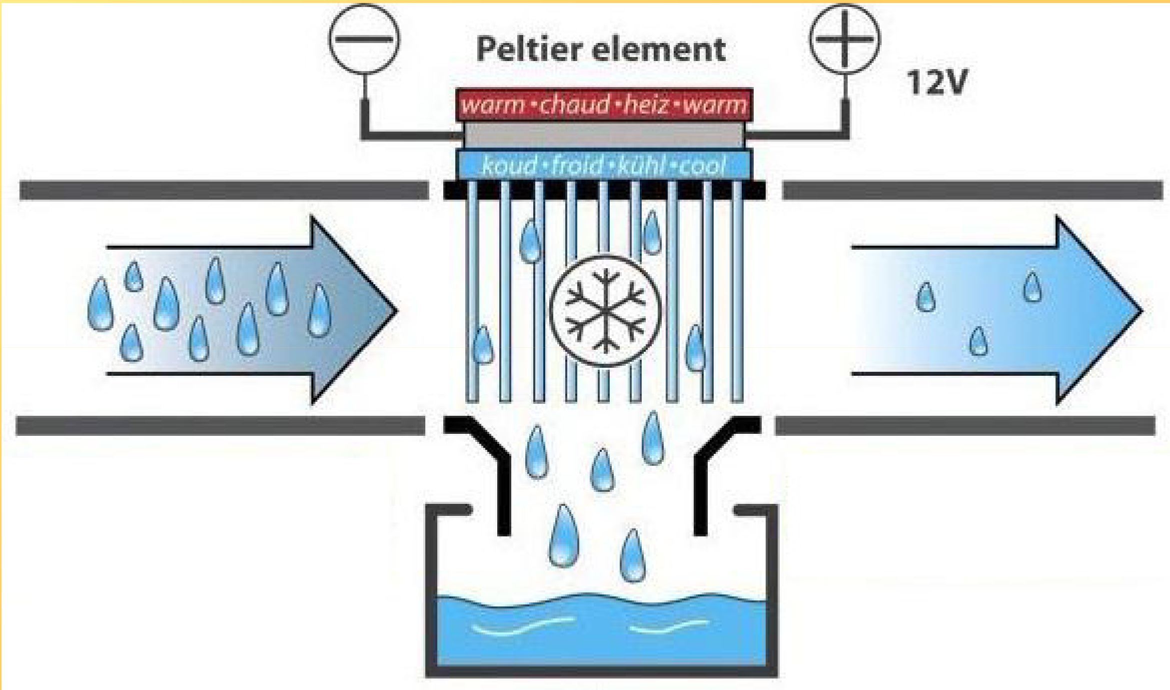
Dimension of upper side



Finned front face side

Use of Peltier Device

Tentative Schematics:



Challenges in this study:

- Development of a low cost technique to produce the drinking water from humid air.
- To create a low temperature surface which may produce water condensate.
- To enable tuning of the cold surface for regulating temperature.
- To create a technological viable solution at low price for drinking water production.
- To locate the regions, where this kind of device may be fruitful.

Estimation of water condensation

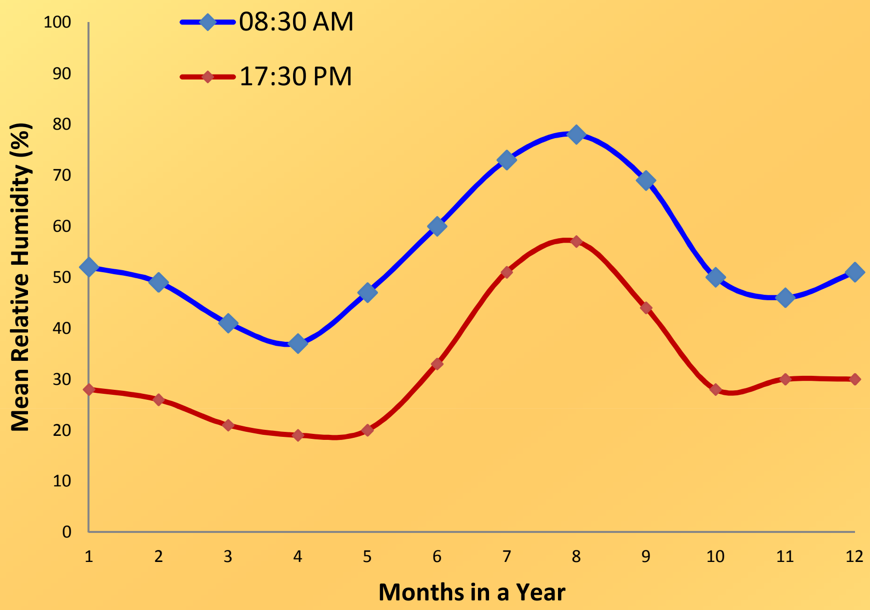
To calculate the amount of water that one can condense on a TEC device cooled at 10℃. The following equation for the generation of water from ambient air may be used*:

$$L_w = \frac{(H_x^{\phi} - H_{10}^{100\phi})}{100} \times E$$

Where L_w is the generated liquid water (g/m^3), H_x absolute humidity at any point (g/m^3), H_{10} absolute saturated humidity at 10℃ (g/m^3), E the efficiency of the TEC device (it's the ratio of the amount of the water extracted to the total moisture content of the air).

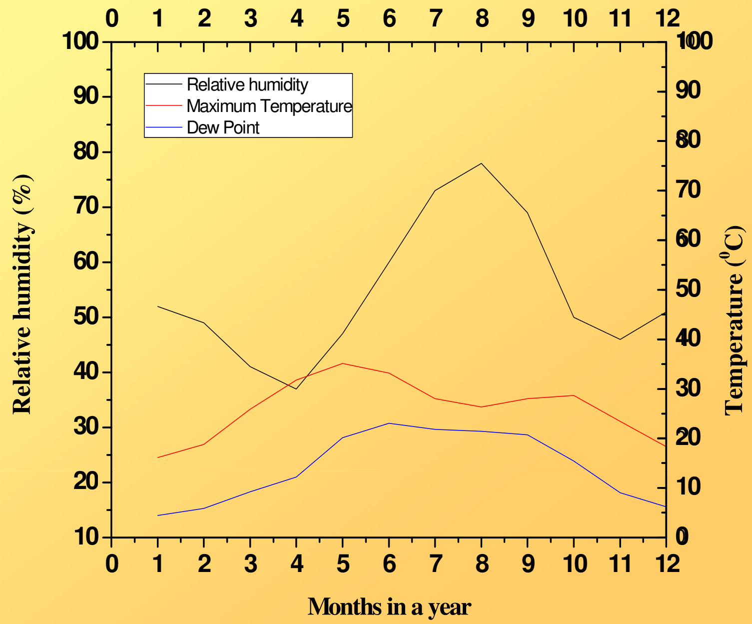
*Milani 2006

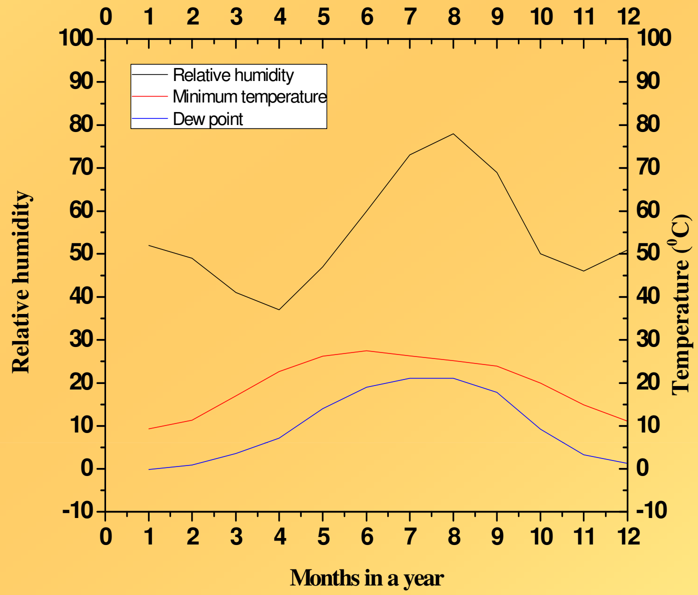
Yearly Temperature distribution at some Districts of Rajasthan



PLOT SHOWS MONTHS IN A YEAR VERSUS THE MEAN RELATIVE HUMIDITY IN TWO TIMES AT A DAY TIME IN UTC AT 3 (i.e. 08:30 IST) AND 12 (i.e. 17:30 IST)

Yearly Temperature distribution at some Districts of Rajasthan

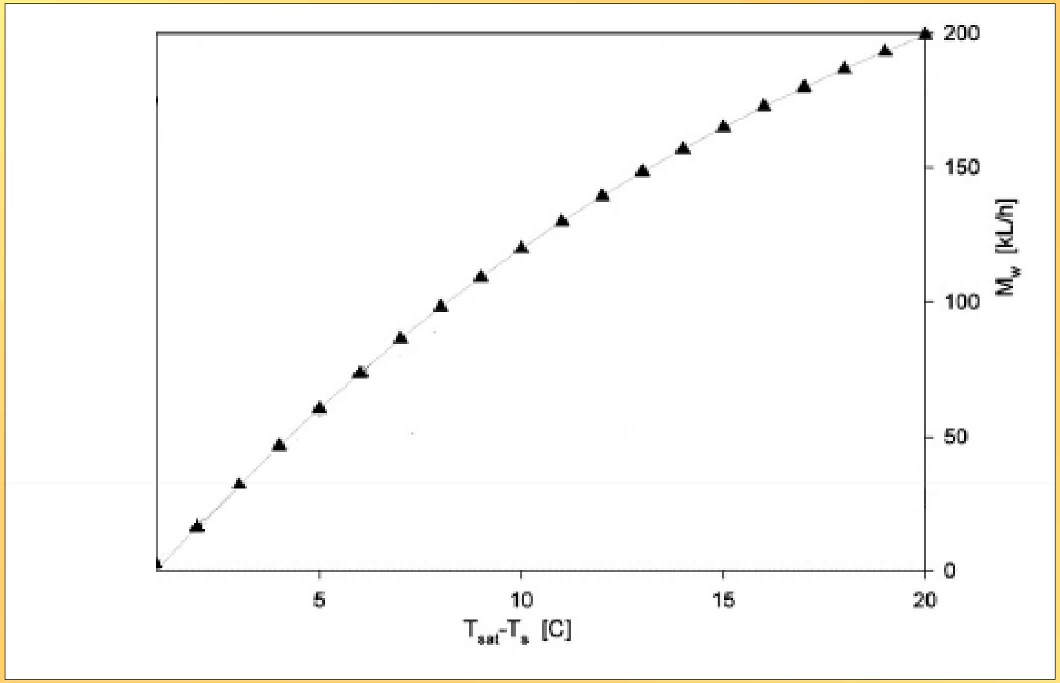




PLOT SHOWS THE MONTHS IN A YEAR VERSUS THE VALUES OF MEAN RELATIVE HUMIDITY, MAXIMUM AMBIENT AND DEW POINT TEMPERATURE.

PLOT SHOWS THE MONTHS IN A YEAR VERSUS THE VALUES OF MEAN RELATIVE HUMIDITY, MINIMUM AMBIENT TEMPERATURE AND DEW POINT TEMPERATURE.

Trend of water production as a function of temperature difference



AMOUNT OF FRESHWATER PRODUCED AS A FUNCTION OF THE TEMPERATURE DIFFERENCE BETWEEN THE DEW POINT AND THE SURFACE TEMPERATURE AT AMBIENT TEMPERATURE T = 50℃ [1].

Theoretical Estimation: Water Production

- The amount of water can be condensed with a TEC device capable to condense 50% of the water present in air (50% of efficiency), with an air flow of 1 m^3/s.

- Example:- A normal day in August in Uttar Pradesh (India), the temperature is 35℃ and the RH 80%. So the amount of water that is theoretically possible to condensate is 1927 L per day, 700kL/yr.

- On an average, An Indian household uses 135 L/day of water, 50kL/yr [*]. Thus, this system may be sufficient for 14 Indians.

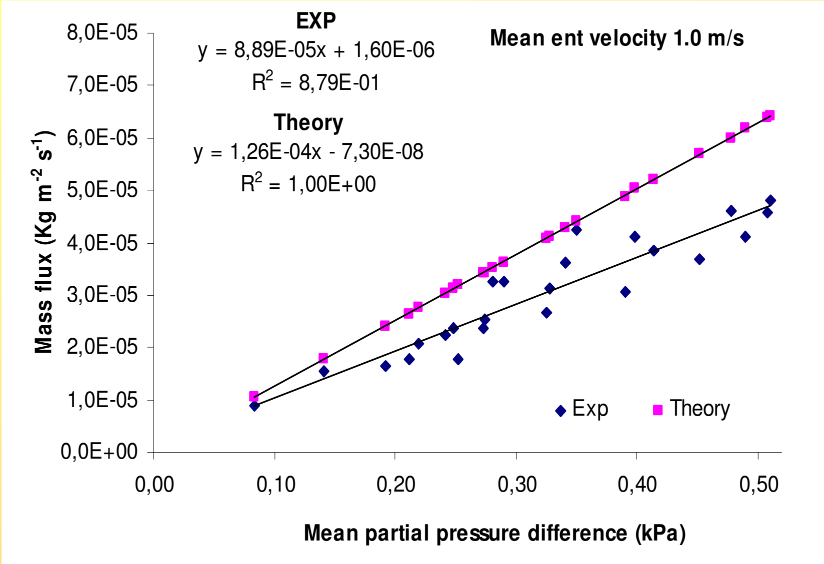
- So, the water production is significant, but too low to meet the needs of a city where it would be necessary to multiply these systems.

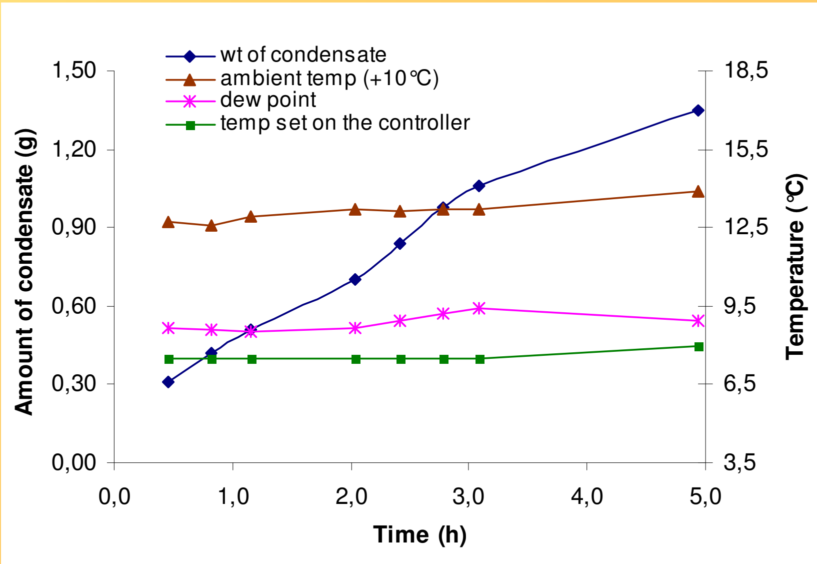
- For example it would take more than 12,00,000 devices to supply New Delhi.

- In the best case (unlikely circumstances) the price is 68.2$ for 1 m^3. The largest price in France for 1 m^3 is 5.50 €, 7.15 $. It costs almost ten times the price of potable water in France. [*]

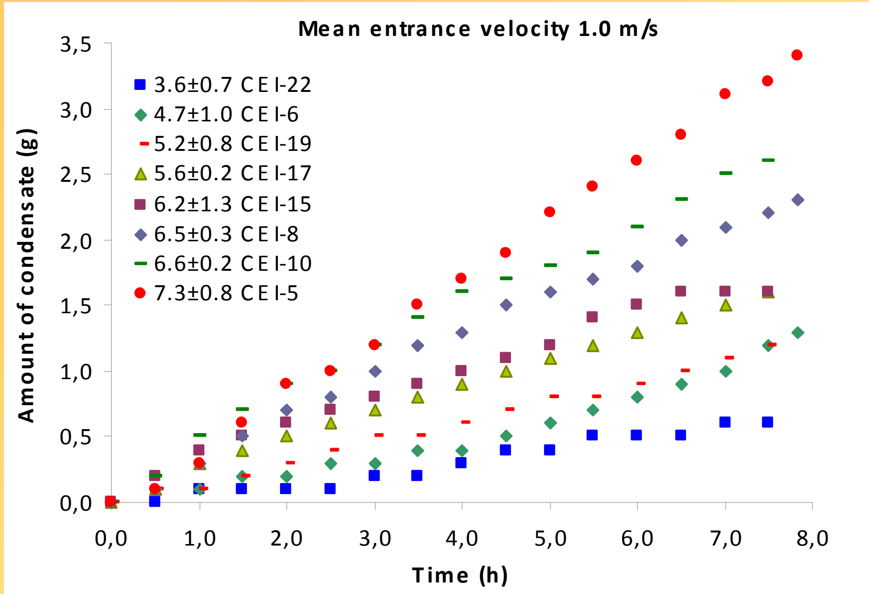
*Milani 2006

Inside closed system: Condensation mass flux





Amount of condensate versus time with different average temperature difference (ΔT_c) for 1.0 m.s^{-1}



Mass flux calculations: In a closed system

For a flat plate in a parallel flow (laminar)

1 $$\overline{Sh_L} = 0.664\,\mathrm{Re}_L^{1/2}\,Sc^{1/3} \qquad 0.6 \le Sc \le 50$$

For turbulent flow, the local Sherwood number

$$Sh_L = 0.0296\,\mathrm{Re}_L^{4/5}\,Sc^{1/3} \qquad 0.6 \le Sc \le 300$$

Where

$$\mathrm{Re} = \rho_\infty UL/\mu_\infty$$

$$Sc = \mu_\infty/\rho_s D$$

$$Sh = kL/D$$

And if it is a mixed type of flow, with a mixed boundary layer laminar/ turbulent, the leading edge has a laminar boundary and approaching the rear edge it is turbulent, then

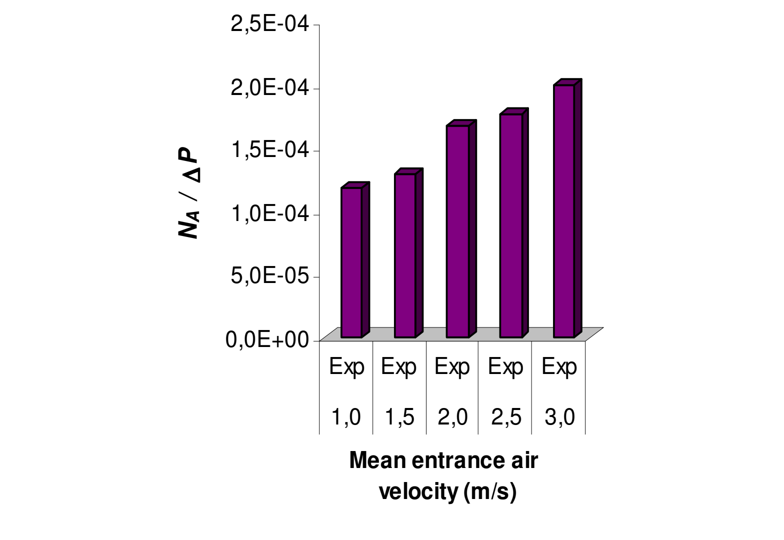
2 $$\overline{Sh_L} = 0.037\,\mathrm{Re}_L^{4/5}\,Sc^{1/3}$$

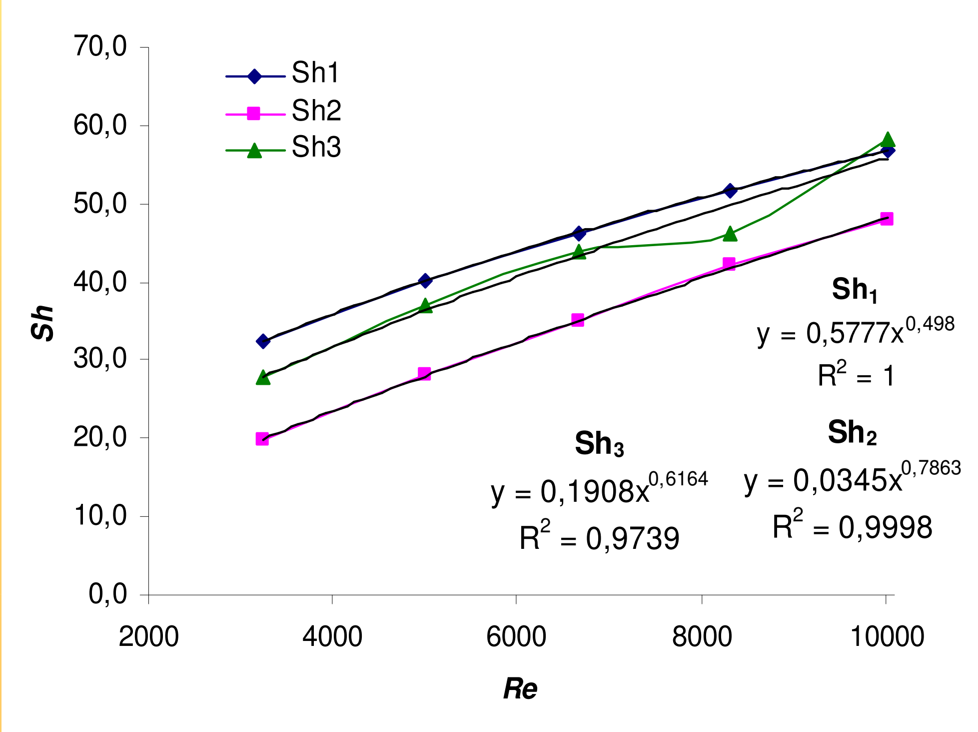
Mass flux (Asano, 2006)

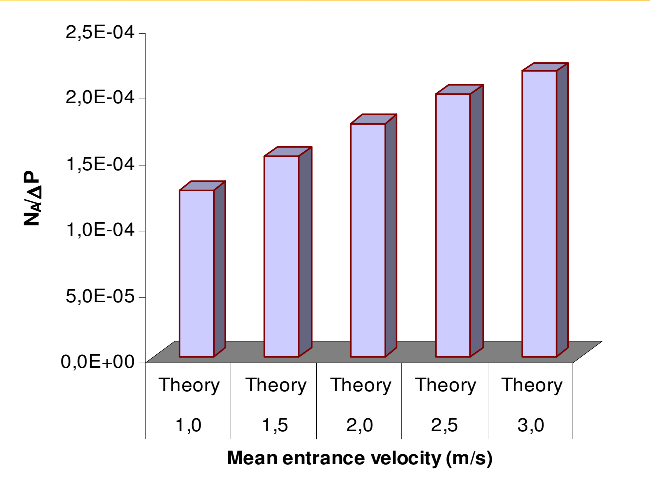
3 $$N = \frac{Sh\rho_s D(\omega_\infty - \omega_s)}{L}$$

Re = Reynolds Number
Sc = Schmidt Number
Sh = Sherwood Number
U = Mean air velocity at Free stream (m/s)
L= characteristic length (m)
ρ = density (kg /m^3)
μ = dynamic viscosity (Pa.s)
ω = mass fraction of water vapour in air
D = Diffusion Coeff (m^2/s)

Conclusions For a closed system







$Sh_1 = X_1 .\ Re^{0.498}$

$Sh_3 = X_3 .\ Re^{0.616}$

$Sh_2 = X_2 .\ Re^{0.786}$

The relation modeled for a flat plate configuration:

$$Sh = 0.225\,\mathrm{Re}^{2/3}\,Sc^{1/3}$$

Where 3000 < *Re* < 10000

Sc = 0.6

Table of water parameters compare with standard values

Parameters	Unit	Requirement (Acceptable Limit)	Desirable limit	Maximum Permissible limit	Result of Sample	Distilled water	Test Protocol
			(IS 10500:2012) Second Revision				
Colour	Hazen	15 true colour unit [1]	5.0	15	< 5.0	ND[8]	2120 B, APHA 23rd 2017
Turbidity	NTU	5 Nephelometric Turbidity unit (NTU) [1]	1.0	5.0	0.0	0.07 [8]	2130 B, APHA 23rd 2017
Chloride (Cl^-)	mg/L	5 mg/L [1]	250	1000	8.0	ND[8]	4500-Cl B, APHA 23rd 2017
Electrical conductivity	µs/cm	0.005-0.05 S/m² [2]	—	—	58.02	28 (µs/cm)[5]	2510 B, APHA 23rd 2017
Total Hardness (as $CaCo_3$)	mg/L	500mg/L as calcium carbonate [1]	200	600	0.0	0.3 mg/L [7]	2340 C, APHA 23rd 2017
Iron (Fe)	mg/L	0.4 mg/L [1]	.3	No Relaxation	*BDL	Less than 1 (mg/kg)[4]	3500Fe-B, APHA 23rd 2017
Magnesium (Mg)	mg/L	10.5 mg/L [1]	30	No Relaxation	0.0	Less than 1 (mg/kg)[4]	3500-B, APHA 23rd 2017
pH	—	6-8 [1]	6.5	8.5	7.5	6.5 – 7.5	4500-H⁺B, APHA 23rd 2017
Sulphate (So_4)	mg/L	500 mg/L [1]	200	400	8.19	Less than 2 (mg/kg)[4]	4500-So_4^{2-}, APHA 23rd 2017
Total Dissolved Solids	mg/L	1000 g/L [1]	500	2000	101	11 mg/L [4]	2540D, APHA 23rd 2017
Alkalinity (as $CaCo_3$)	mg/L	200 mg/L [3]	200	600	20.0	0.52 [8]	2320B, APHA 23rd 2017
Nitrate(NO_3)	mg/L	50 mg/L [1]	45	No Relaxation	1.12	.930 (mg/L) [5][6]	4500No_3 B, APHA 23rd 2017
Fluoride (F^-)	mg/L	1.5 mg/L [3]	1.0	1.5	0.22	0.002 [8]	4500F B, APHA 23rd 2017
Calcium (Ca)	mg/L	75 mg/L [3]	75	200	0.0	Less than 5 (mg/kg)[4]	3500B, APHA 23rd 2017

*BDL - Below Detection Limit

References:

1. Guidelines for drinking water quality standards in developing countries (Report) [illegible], 2002
2. Water conductivity solution – Lenntech, [illegible]
3. Draft Indian Standard, Drinking water – specification, Second Revision of IS 10500, Bureau of Indian Standards (BIS), ICS No. 13.060.20
4. East African Standard, Distilled water – Specification, EAS 125 (1999)
5. Chemical properties of tap and distilled water, [illegible]
6. [illegible]
7. Technical specifications, [illegible] (Distilled Water), [illegible]
8. Water Quality Report, Niagara bottling, LLC, USA(2017)

Thank you