INVESTIGATION OF PLATE TYPE HEAT EXCHANGER PERFORMANCE FOR LIQUID DESICCANT BASED AIR CONDITIONING CYCLE

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ABSTRACT *Demand for air conditioning is rising rapidly with growth of economy, population and craving for comfortable life. The demand of electricity to run ACs put pressure on existing electric grid and power plants. These power plants, which mainly use fossil fuels, are responsible for large amount of pollution and greenhouse gas emission.This work is about investigating performance of various plate type heat exchangers that can be placed in a LDAC cycle to transfer heat between hot desiccant, coming out of regenerator and cold desiccant, coming out of dehumidifier.For plate type heat exchanger, maximum heat transfer rate achieved was 0.841 kW at flow rate 75 kg/h and maximum rise in temperature was 20.8oC at floe rate 40 kg/h.*

Keywords*: plate type heat exchanger, liquid desiccant, heat transfer rate, temperature differance*

1.1 Liquid Desiccant based Air Conditioning System

Liquid desiccant systems provide an innovative alternative that can overcome these and other concerns with conventional air conditioning. A key advantage of liquid desiccant systems is that they provide independent control of temperature and humidity, enabling sensible cooling (temperature reduction) and latent cooling (humidity reduction) to match the needs of the application and avoid the energy wasted in overcooling. And also it needs low grade heat energy that can be from renewable sources. Desiccant is a material which has property of attracting and holding water vapour due to vapourpressure difference. It may be solid (Silica gel, Zeolites, Alumina Gel, etc.) or liquid (aqueous solutions of Potassium format, LiBr, Triethelene glycol, CaCl2 etc.). Fig. 1.1 shows actual diagram for LDAD process. Here we are using liquid desiccant which absorbs humidity from air (in the dehumidifier unit) & finally it rejects that humidity in the atmosphere when it passes through regenerator as shown in fig. Outside humid air or return air is supplied to the dehumidifier where it loses its moisture to the cool concentrated desiccant solution and it becomes hot & dry, which is supplied to the conditioned space, after evaporative cooling (not shown in fig.). Then this diluted or weak desiccant is heated up with heater (low grade heat/waste heat can be used) & sprayed in the regenerator, where its concentration increases (it becomes strong solution) after giving its water to the air. And this air is then exhausted to the atmosphere.

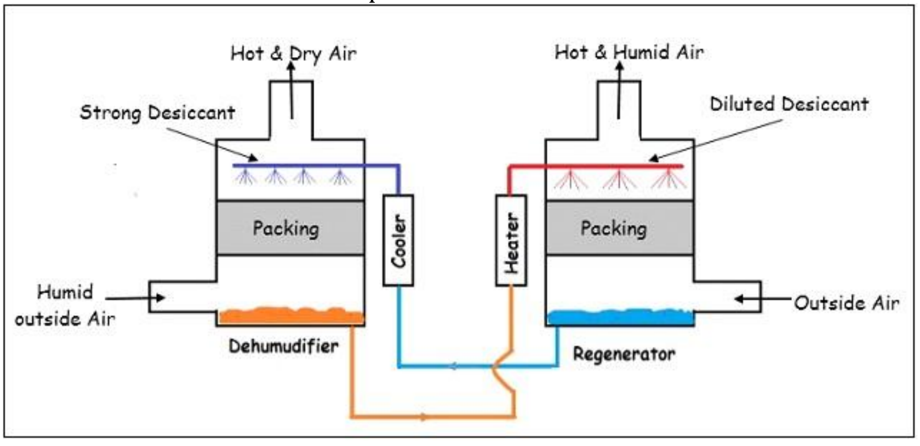


Figure 1.1: Liquid Desiccant Dehumidification

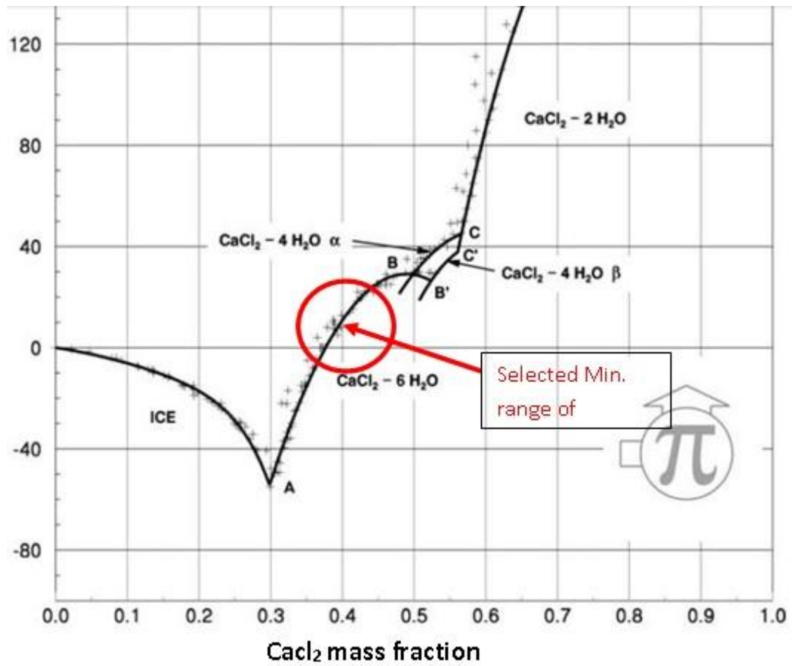
1.1.1 Significance of heat exchanger

Now, we know that the desiccant coming out from regenerator is hot and needs to be cooled down before entering dehumidifier, and the desiccant coming out from dehumidifier is hot and needs to be cooled down before entering regenerator. So, there can be placed a liquid to liquid heat exchanger, that can transfer heat from hot desiccant (coming out from regenerator) to cold desiccant (coming out from dehumidifier). It can save energy and improves the C.O.P. of system.

Experiments with Plate Type Heat Exchanger

2.1 Determination of Flow Rate

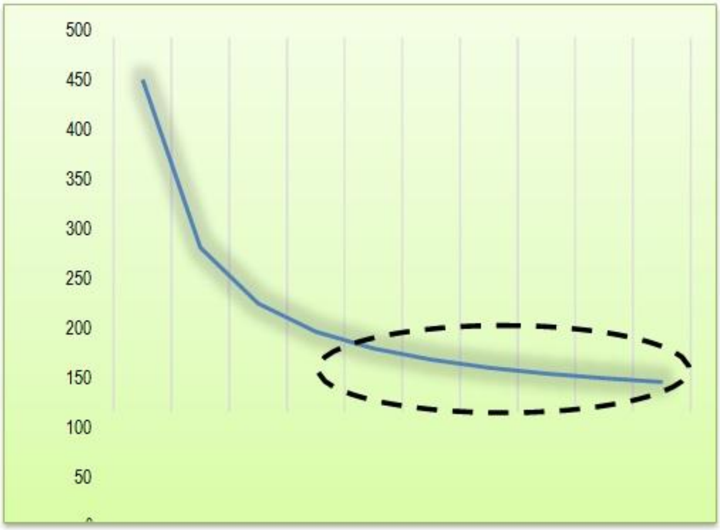
We are going to analyses the heat exchanger suitable for LDAC system catering tonne TR latent load Now, 1 TR=3.5 kW or 3.5 kJ/s And, latent heat of evaporation for water is 2257 kJ/kg. So, we should remove 3.5 2257 =.0015kg of water from air in 1 second. In other words, 5.4 kg of water is removed in one hour in dehumidifier of the system. Following exercise is done to calculate the flow rate of LD through the LD-LD heat exchanger employed in this system. Now, if we choose some value of LD concentration at inlet of dehumidifier, we can have different values of LD concentration at outlet of dehumidifier, for different values of M.F.R. of LD through dehumidifier as shown in table 2.1. The value for LD concentration at inlet of dehumidifier was chosen based on Solubility boundary of LD the solubility boundary defined as the conditions at which salt hydrates or anhydrous salt crystalize from the solution or the conditions at which ice crystals start to form. Solubility boundary depends on minimum temperature to deal with as shown in fig.



The value chosen for minimum temperature to deal with was 20oC. So, we have LD concentration at inlet of dehumidifier was 40%.In order to keep LD flow rate low for lower pumping power consumption, the flow rate may be kept in the range of 40 to 70 kg/h (row 6 to 10 in table 2-1).

Table 2-1: Outlet concentration of LD in Dehumidifier vs. Mass Flow Rate

Sr. No.	LD concentration at Dehumidifier Outlet (kg of $CaCl_2$/kg of solution)	Mass Flow Rate of LD (kg/h)
1	0.395	438.7
2	0.390	216.60
3	0.385	142.55
4	0.380	105.52
5	0.375	83.31
6	0.370	68.50
7	0.365	57.92
8	0.360	49.98
9	0.355	43.81
10	0.350	38.87



2.2 Development of Test Set Up

As we are not testing the heat exchanger on actual LDAC system, we would like to simulate the conditions for heat exchanger, where the regenerated LD would enter at around 70oC. Considering losses in tubings, we would like to maintain LD in the source tank at around 75oC. The flow rate of cold as well as hot LD should be in the range of 40 to 70 kg/h.

2.2.1 Arrangement to control temperature in hot LD tank

We need an arrangement that can maintain constant temperature in a tank filled with LD and from which LD is flowing continuously. The solution is to use a temperature controller as shown in Fig. 2.3. Here, the RTD sensor continuously measures the temperature in tank and give feedback to temperature controller. The heater in the tank is connected to the temperature controller. The heater can be automatically switched ON/OFF by temperature controller according to the temperature in the storage tank (measured by RTD). So, there will be always constant temperature in tank if the flow rate from tank is under the capacity of heater.

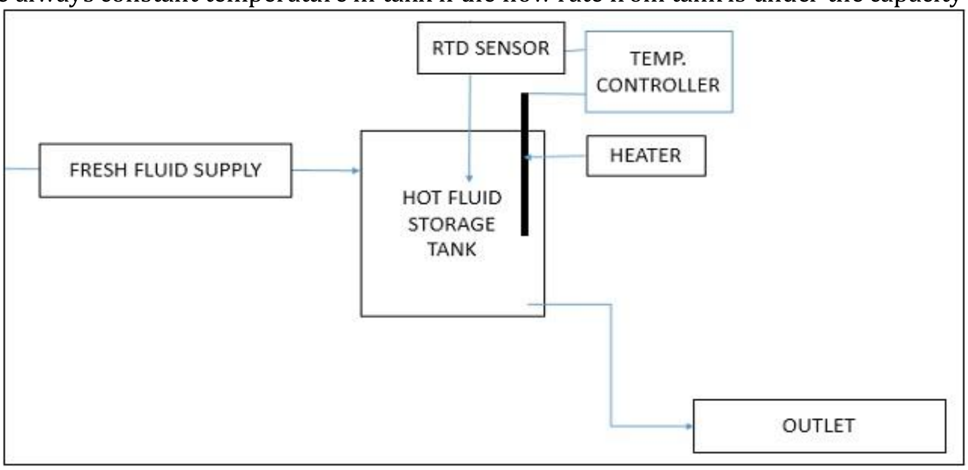


Figure 2.2: Hot fluid storage tank with temperature controller

2.2.2 Arrangement to get desired flow rate

2.2.2.1 Cold LD

Now, we want MFR of LD in the range of 40 to 70 kg/hour. A usual centrifugal pump with its minimum capacity is too higher for that purpose and its difficult to get desired MFR in such small range, because the resolution of assembly of centrifugal pump and valve will be too higher for our purpose that it is very difficult to control flow rate of LD at particular value that we want in range of 40-70 kg/hour. So, the pump selected was diaphragm type D.C. pump made of aluminum body. It consist of rubber diaphragm fitted over aluminum plate. This pump has very small flow rates of liquid involved and low power consumption. Diaphragm pumps can transfer liquids with low, medium or high viscosities and also liquids with large solids content. They can also handle many aggressive chemicals such as acids. The specification of the pump are listed in Table 2.2

Type	Diaphragm type
Nominal flow rate	1.8 LPM
Max. pump output	110 PSI, 7.5 bar
Max. inlet pressure	60 PSI
Voltage	48DC

2.2.2.2 For hot LD

The diaphragm pump we used for cold LD can't be used for hot LD because it has diaphragm made of rubber whose performance will be poor at higher temperature. Also, it has some plastic parts so hot LD can't be handled by it.

The method we used was to get desired flow rate by gravity i.e. put the tank of hot LD at higher level and it will flow due to difference between head. For the flow rate to be constant, the level of liquid in the tank at higher level also needs to be constant.

There was a level control valve with floating ball mechanism fitted near top of tank as shown in fig. It controls the flow of LD from source tank to storage tank according to the level of LD in the storage tank. So, the level of LD will always be constant in storage tank and so does the mass flow rate of LD which depends upon the level if LD in the storage tank.

2.3 Instrumentation

2.3.1 Temperature controller

The temperature controller used. It is connected to an RTD and a heater. It measures the temperature with RTD and turn ON/OFF the heater to reach or maintain desired temperature. It works on time proportion control action. It has some decided period of time after which its ON/OFF cycle repeats. And the duration of keeping the heater ON during a time period is directly proportional to difference between set temperature and measured temperature, i.e. the more is the gap between set temperature and measured temperature, the more time heater will be ON in duration of one time period.

2.3.2 RTD sensor and Multichannel Scanner

PT 100 type RTDs with 8 channel scanner is used. It measures the temperature by correlating the resistance of the RTD elements with temperature. Range of it is -100°C to 400°C. It can be used to measure 8 different temperatures at same time. The limitation with this is, it can't record data and shows only one temperature at a time.

2.3.3 Cylindrical flask

The Density/Specific gravity of desiccant was measured by using a cylindrical 1 LTR flask and a small scale electrical weighing machine.

The specifications of cylindrical flask are listed in table below.

Cylindrical Flask	
Capacity	1 LTR
Resolution	10 ml
Accuracy	±5 ml

2.3.4 Thermocouple with data logger

Later on, the thermocouple with data logger was used to measure temperature, as it can record the data.

2.3.5 Weighing machines

The mass flow rate of both hot and cold LD was measured by measuring the weight of LD coming out of HE at regular interval of time (1 min) by weighing machine with capacity of 150 kg. The other type of small scale- capacity 10 kg weighing machine used was for measuring density of LD.

The specifications of weighing machines are as in table

Big scale weighing machine		**Small scale weighing machine**	
Capacity	150 kg	Capacity	10 kg
Resolution	10 gm	Resolution	1 gm

2.4 Final test set up

The finally prepared test set up is as shown in fig. below.

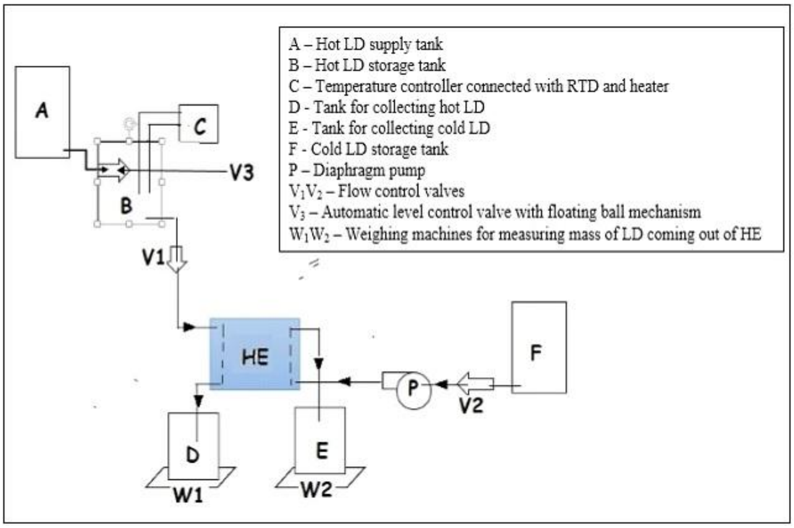


Figure: Line diagram of finally prepared test set up

Here, we can see that, for hot side LD is coming from supply tank A to storage tank B through the valve V3. The level of LD in storage tank will always be constant due to floating ball mechanism of valve V3. The storage tank has RTD and heater in it which are connected to temperature controller C. The LD coming out of storage tank B can be easily controlled by flow control valve V1. So, LD can be made to pass through HE at desired flow rate. The hot LD coming out of HE is collected in tank D and its weight is measured at regular interval (to ensure MFR) by weighing machine W1.Similarly, for cold side LD from tank F is made to flow through HE by diaphragm pump P and its MFR is controlled by valve V2. The cold LD coming out of HE is collected in tank E and its weight is by weighing machine W2.

2.5 Experimentation Procedure

¬ Prepare the LD solution carefully. Left the solution to cool down.

¬ Prepare the set up as shown in fig.2.12 and make sure that all the connections are leakproof.

¬ Measure the density of LD by measuring weight of 1 litre LD. Find its concentration by using the equations from Conde et al. paper.

¬ Fill the tanks A and F with LD

¬ Set the temperature of the inlet hot LD in the temperature controller cum indicator. It should be 75oC. Then, wait for 15 to 20 minutes to get LD at set temperature.

¬ After that open the hot LD valve V1and set it to get desired flow rate. The flow rate can be measured by measuring the weight of collected LD at outlet by weighing machine W1.

¬ Start the pump P and set the flow rate of cold LD same as hot LD with same method. The all four temperatures (hot LD inlet, hot LD outlet, cold LD inlet and cold LD outlet) are being measured and recorded by data logger through thermocouples.

¬ Note the weight on both weighing machines W1 and W2 at the interval of 1 minute, regularly.

¬ Wait for steady state conditions. It can be checked by observing all four temperatures in data logger.

¬ Now, run the experiment in steady state for 10 to 15 minutes.

¬ Go for result analysis.

2.6 Plate Heat Exchanger

The plate heat exchanger (PHE) used was a brazed plate heat exchanger with following configurations.

- Plate material -Stainless steel
- Brazing material -Copper
- Height of Plate B = 204mm
- Width of Plate A = 74mm
- Thickness of HE F=55mm
- Dia. of fluid entry/exit socket E=15mm
- Gap between sockets - width C=40mm
- Gap between sockets – height D=170mm
- Number to plates N =20

- Number of hot fluid chambers Nh = 10
- Number of cold fluid chambers Nc = 10
- Volume of HE V= B*A*F = 830280 mm3 = 8.3*10-4 m3
- Total heat transfer surface area S = N*B*A = 301920 mm2 = 0.302 m2
- Area density (ratio of the heat transfer surface area to its volume) B = S/V = 363 m2 /m3

The experiments were carried out in the refrigeration and air conditioning lab in The M. S. University of Baroda. The setup was developed the lab and experiments were carried out during the month of March, April, May and June. The parameters such as temperatures, mass flow rate and specific gravity are directly measured using the measuring instruments. The heat lost rate by hot LD (Qh), heat gain rate by cold LD (QC), rate of heat lost to atmosphere from heat exchanger surface (QLOST), maximum possible heat transfer rate (QMAX) effectiveness of heat exchanger (ε) and LMTD are calculated from these values.

Experiments were carried out at different values of mass flow rates (45, 60 & 75) of liquid desiccant and same values for inlet temperatures of hot (70oC) and cold LD (30oC).

The results for experiments with PHE at different mass flow rates are summarized in table

	Nomenclature	**Unit**	**1**	**2**	**3**
Mass flow rate of LD on cold side	M_C	kg/h	74.8	55.3	39.1
Mass flow rate of LD on hot side	M_H	kg/h	76.4	59.5	41.8
Temperature of hot LD at inlet	T_{HI}	^oC	67.1	67.5	70.2
Temperature of hot LD at outlet	T_{HO}	^oC	51.3	51.7	54.0
Temperature of cold LD at inlet	T_{CI}	^oC	36.2	35.3	34.9
Temperature of cold LD at outlet	T_{CO}	^oC	51.0	52.1	55.7
Heat lost rate by hot LD	**Q_H**	**kW**	**0.932**	**0.722**	**0.533**
Heat gain rate by cold LD	Q_C	kW	0.841	0.707	0.509
Heat lost rate from HE surface	Q_{LOST}	kW	0.091	0.015	0.079
Maximum possible heat transfer rate	Q_{MAX}	kW	1.759	1.354	1.048
Logarithmic mean temperature difference	LMTD	^oC	15.6	15.9	16.7
Effectiveness	ε	-	**0.53**	**0.53**	**0.49**

Table : Observation and results of experiment with PHE for different mass flow rates

2.7 Sample Calculation

Heat lost rate by hot LD (QH):

Mass flow rate of LD on hot side (MH) = 76.4 kg/h =0.020611 kg/s

Inlet temperature of LD on hot side (THI) = 67.1◦C

Outlet temperature of LD on hot side (THO) = 51.3◦C

Specific heat of LD at X=0.33 & TAVG = $THI+THO/$ 2 = 59.2◦ is CP = 2797.05 J/kg K

So, Heat lost rate by hot LD (QH) = MH * CP * (THI-THO) = 0.932 kW

Heat gain rate by cold LD (QC):

Mass flow rate of LD on cold side (MC) =74.8 kg/hour = 0.01997 kg/s

Inlet temperature of LD on cold side (TCI) = 36.2◦C

Outlet temperature of LD on cold side (TCO) = 51.0◦C

Specific heat of LD at X=0.33 & TAVG = $TCI+TCO/$ 2 = 43.6◦C is Cp = 2728.48J/kg K

So, Heat gain rate by cold LD (QC) = MC* CP * (TCI-TCO) = 0.841 kW

Rate of heat lost to atmosphere from heat exchanger surface (QLOST):

Rate of heat lost to atmosphere, QLOST = QH-QC = 0.091 kW

Maximum possible heat transfer rate (QMAX):

Heat capacity on hot side = MH * CP = 58.7 J/K s

Heat capacity on cold side = MC * CP = 57.5 J/K s

So, less is on cold side.

And, THI- TCI=31.0 ◦C

So, Maximum possible heat transfer rate (QMAX) = 1.759 kW

Effectiveness of heat exchanger (ε):
Effectiveness = Actual heat transferred/Maximum possible heat transfer
= 0.53 OR 53%
LMTD
Θ1 = THI-TCO = 16.1 ◦C
Θ2=THO-TCI= 15.1 ◦C
So, LMTD = Θ1-Θ2/ln(Θ1/Θ2) = 15.6◦C

2.8 Analysis
Here, we find that the change in temperature of LD (TCI-TCO) was decreasing with increase in mass flow rate. Fig. shows the same. Here, the heat transfer rate was increasing with increase in mass flow rate of LD. It is shown in fig. We can see that the effectiveness remains constant with change in mass flow rate.

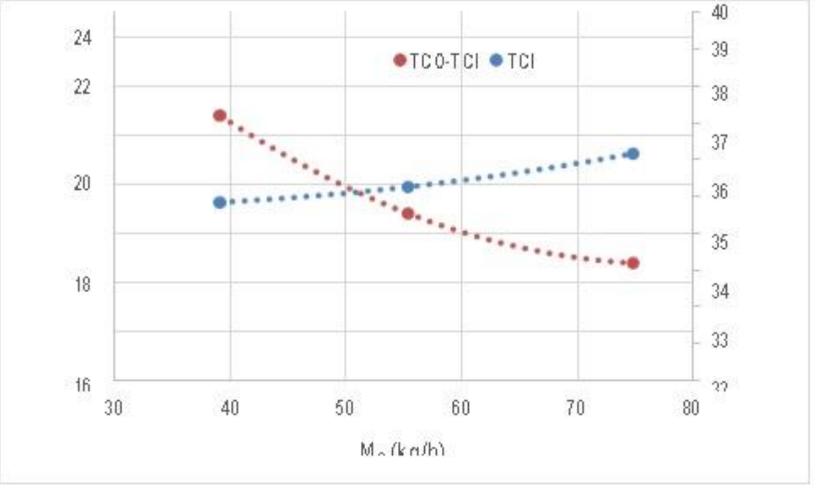


Figure: Change in temperature of cold LD & inlet temperature of cold LD with MC

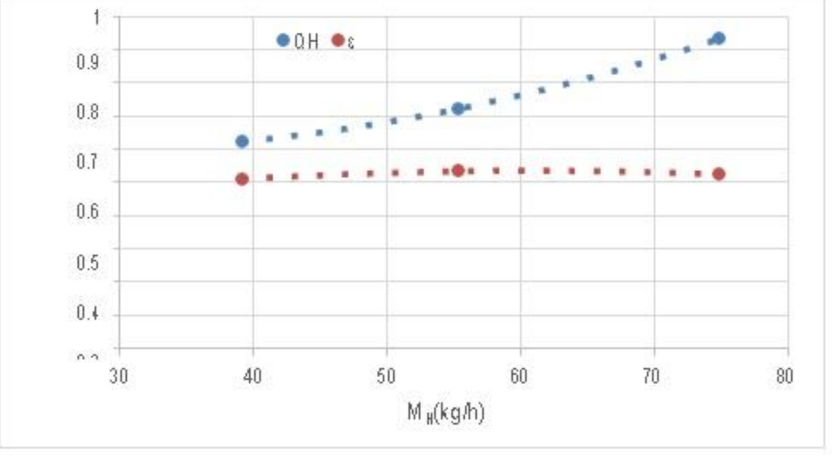


Figure: Effectiveness and heat transfer rate (on hot side) vs. MH

Conclusion and Scope for Future Work
3.1 Conclusion
For plate type heat exchanger, the experiment was run for three different mass flow rate 75, 55 and 40 kg/h (same for both hot and cold LD). The heat transfer rate (according to heat lost by hot LD) was 0.932, 0.722 and 0.533 kW for mass flow rates 75, 55 and 40 kg/h respectively. The temperature rise was 14.8, 16.8 and 20.8oC for mass flow rates 75, 55 and 40 kg/h respectively.

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