RESEARCH ARTICLE OPEN

Enhancement of performance of Air Conditioning system using Fined HPHX with staggered array

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ABSTRACT
The air conditioners generally use less than 35% of their capacity in dehumidification and the rest in cooling. If more dehumidification is required, the air must be overcooled to remove moisture and then must be reheated. This has the disadvantages as energy is required for overcooling and reheating, Equipment must be oversized to overcool, maintenance costs and Power demand are increased. The use of heat pipes can reduce or eliminate overcooling and reheating. This offers tremendous cost savings in decreased energy consumption, lower equipment investment, and reduced maintenance and demand charges.
So in this Project concentration is on developing a new central air conditioning system to study the effect of heat pipe on air conditioner of 1.0 ton for heating the conditioned air for hot and humid condition. In this system waste heat from condenser is recovered and transferred to evaporating end of heat pipe. Now heat pipe use the same heat to reheat the supply air. Since heat pipe works on temperature difference and it does not require any electrical energy, upto 42% of electrical energy is saved of the total energy consumption of system compared with system with electrical heater.
***Keywords*:** Air-Conditioners, Heat Pipes, Electrical Energy, Temperature Difference.

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I. INTRODUCTION

The effect of air-conditioning demand makes the energy consumption has been increasing quickly. The investigation reported in shows that of the total energy consumption in buildings in Mumbai, India, the amount of energy used by air-conditioning system is; 46.1% in restaurant building, 40.5% in commercial building, 49.7% in office building, and 30.3% in hospital building. The ever increasing energy requirement puts a great burden on the further economic development as our country is poor in energy resources.

As an efficient heat exchanger, heat pipe heat exchangers (HPHXs) are playing a considerable role in different fields like energy conservation, energy recovery and renewable energy based systems including air conditioning systems. A heat pipe heat exchanger is a heat transfer device, in which the latent heat of vaporization is utilized to transfer heat over a long distance with a corresponding small temperature difference. In order to reduce the energy consumption by central air conditioning system in tropical climate lot of literature is available by using the heat pipe heat exchangers. The study indicates that the relative humidity has more impact than that of indoor temperature on energy consumption and effectiveness of HPHX. A lot of literature is available on heat pipe using Methanol, Ethanol & Acetone as working fluid and three types of wick for the operating temperature range of 15 to 550C. After conducting series of experiments, it shows that lower effectiveness of HPHX was due to lack of fins, high pitch to diameter ratio and high air face velocity. Present work aims to investigate the performance of two phase heat pipe heat exchanger as heat recovery facility for air conditioning system.[1]

II. OBJECTIVES, SELECTION & METHODOLOGY

1.1 Objective

1. The objective of this project is to establish a system for energy saving of air conditioning test rig by utilising the Fined tube Heat Pipe Heat Exchanger (HPHX).

2. Our main objective is to show the energy saving by the use of heat pipe and along with the effectiveness of heat pipe.
3. To find energy balance ratio (EBR) and effectiveness of heat pipe heat exchanger.
4. To compare the energy saving calculation by using the HPHX arrangement (staggered arrangement) and Fined tube Heat Pipe Heat Exchanger and to find payback period of system.[2]

1.2 Working Fluid Selection

The design of heat pipe starts with the selection of working fluid. The selection of working fluid considers a number of factors. The working temperature range is the first criteria to be fulfilled by the working fluid.

- Compatibility with the wick and the container
- Good thermal stability
- Wet ability of wick and wall materials
- Vapour pressure not too high or low over operating temperature
- High latent heat
- High thermal conductivity
- Low liquid and vapour viscosities
- Higher surface tension

We are selecting fluid R134a (tetra fleuron-ethane) for its following properties[2]

1.3 Overview

R134A is a new refrigerant which is hydrogen fluoride hydrocarbons (referred to as HFC). Its boiling point is -26.5°C. Its thermal properties close to the R12 (CFC12), ozone-depleting potential ODP is 0, but the global warming potential WGP is 1300 (the air will not damage the ozone layer, in recent years, but it may cause the greenhouse effect). The R134a is now being used in refrigerators, freezers and automotive air conditioning system to replace Freon 12.[2]

2. Heat pipe

Heat pipe is a passive device. It does not require any external power supply. The heat pipe is a device of very high thermal conductance. The heat pipe is similar in some respects to the thermo syphon. One of the amazing features of the heat pipe is that have no moving parts and hence requires minimum maintenance.[6]

2.1 Principle of working

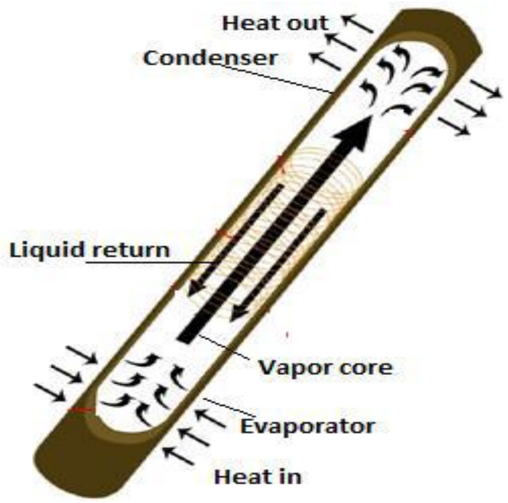


Fig 3.1 Cross section of heat pipe

There are 3 sections, evaporative section, vapour or adiabatic section, condenser section. Heat gets added in evaporator section. Due the heat the working fluid present in heat pipe boils and get converted into vapour. As vapour has low density it travels to the condenser section. In condenser the vapour rejects its latent heat and gets converted into liquid. Due to its weight the liquid moves downward and gets collected in evaporative section. And thus the cycle continues. Above Fig.1.1 shows the different sections of heat pipe. A Heat pipe is a self-contained passive energy recovery device. A heat pipe can transfer up to 1000 times more thermal energy, than copper, the best-known conductor. One of the amazing features of the heat pipe is that have no moving parts and hence requires minimum maintenance. They are completely silent and reversible in operation and require no external energy other than thermal energy they transfer.[6]

2.2 Heat pipe Types

2.2.1 Tubular

These are the simplest and most popular type of Heat-pipe and are used in most applications to transfer heat energy from one point to another. They can also be used as heat spreaders to isothermalise components where a uniform temperature is desired. Although Heat-pipes are predominantly used in cooling applications, they can also be used very effectively in heating applications; this negates having multiple electrical heating elements, and simplifies cabling, design and installation

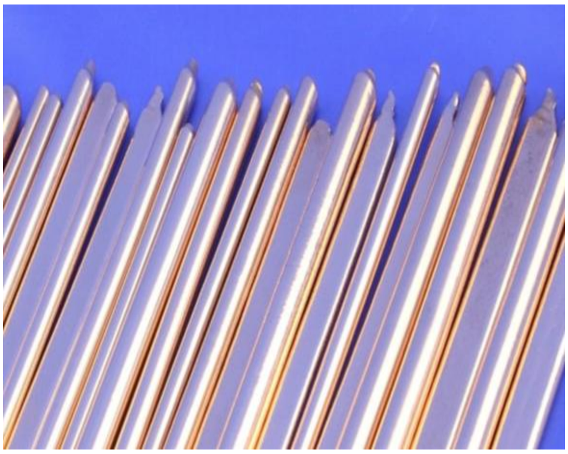


Fig 3.2.1 Tubular heat pipe

These are Heat-pipes with an axial concentric hole through the middle. These may be used in a variety of situations where high heat transfer is required together with mechanical access, examples include; as a flow channel for gas or liquid, for cabling or thermocouple access, as a push rod mechanism location sleeve.[3]

2.2.2 Baffle Heat-pipes

Baffled Heat-pipes are used in water cooled applications i.e. core cooling applications used commonly in plastic injection moulding tools. The Heat-pipes are installed into manifolds and transfer heat from the heat source to the cooling water. The baffle plates direct water along the Heat-pipe cooling length to give an increased cooling area contact. [3]

2.2.3 Bent Tubular Heat-pipes

Common application requirements require Heat-pipes to be bent to fit a route in a particular installation, possibly involving complex 3-D architecture. By using special internal wick structures, CRS Engineering is able to produce Heat-pipes which can be formed to shape by customers upon installation.

Fig 3.2.3 Bent tubular heat pipe

Where exact bending is required, or where tight bending radii are involved, it is essential that CRS Engineering carry out this process during manufacture. [3]

2.2.4 Flexible Tubular Heat-pipes

A limited degree of flexibility is possible with most standard range Heat-pipes, as a function of their length and diameter. Often this may be sufficient to accommodate small dimensional tolerance differences encountered during assembly and installation with other components. Truly flexible Heat-pipes incorporate an intermediate convoluted bellows section providing excellent flexibility and anti-vibration characteristics. [3]

2.2.5 High Performance Heat-pipe Heat Sinks

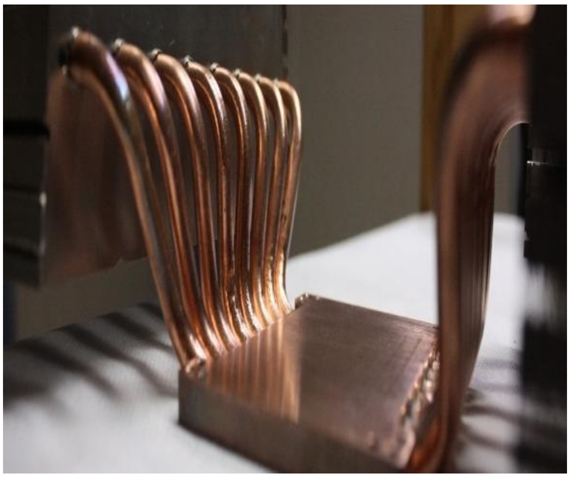


Fig3.2.5 High performance heat pipe

Integral Heat-pipe heat sinks built with cooling fin assemblies provide one of the most effective means of providing efficient cooling for power electronics components. The forced air cooled assembly shown opposite achieves an outstanding thermal performance. R_{th}=0.09°C/W. i.e with 100 W heat dissipation the input heat block temperature is only 9°C higher than the ambient cooling air temperature. [3]

III. EXPERIMENTATION

3.1Description of experimental test set up

We have performed test for overall setup having 35 Nos. of heat pipe with rectangular fins. The required nos. of heat pipe is calculated from formulae which are given in calculation part of report. We have conducted tests for two different arrangements of heat pipe and the coefficient of performance is calculated for each arrangement in order to find out the energy conserved in each stage.

Fig. 4.1 Experimental Test Set up

3.2Staggered Arrangement

The important part in the design of duct for staggered arrangement is the required pitch for heat pipe. The pitch can be calculated from the formulae as given in calculation part of report. Based on the calculated pitch, holes are drilled in duct for staggered arrangement using drill bit of diameter 19 mm. Before putting pipes in duct rectangular fins are assembled on them. Fins are assembled on evaporator and condenser section on a length of 300 mm each. These two sections are separated from each other by providing adiabatic section. Precaution is taken for slippage of fins in adiabatic section by fitting lock fin at the top of each section. For assembly of pipes with fins in duct pair of pipe is fitted with rectangular steel plate at their bottom as this provides ease for assembly. In this way all pipes are located in duct with staggered arrangement. Top and middle part of pipes is fitted with wooden plates in between pipes. This arrangement gives tight and safety fitting. Whole portion is covered by insulation (foam) to avoid further losses of air. Precaution is also needed to be taken while press fitting the heat pipe.

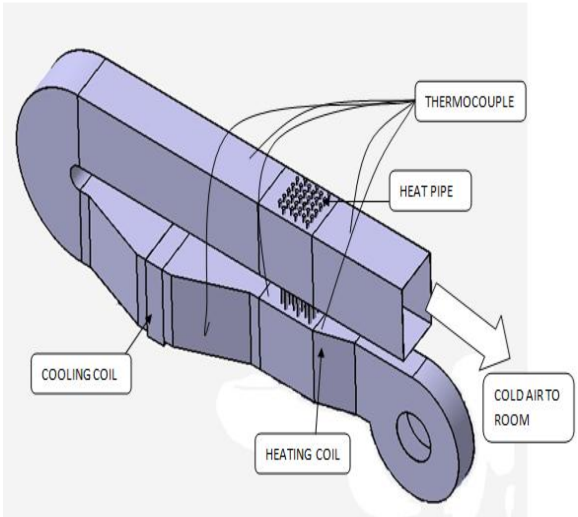


Fig.4.2 Staggered arrangement Experimental set up

The required costal condition of air is achieved with the help of two heating coils, specification of which is given in report. This hot air is then allowed to pass over the evaporator section of heat pipe. The temperature drop of 7°C (as fins provide added advantage compared to only pipe arrangement) is achieved and then air is allowed to pass over cooling coil and then over the condenser section of heat pipe. Air after passing over cooling coils returns to the condenser trough U-shape duct. Here cooled air absorbs heat from condenser section of heat pipe. Finally the air is discharged into room where the cooling is required.

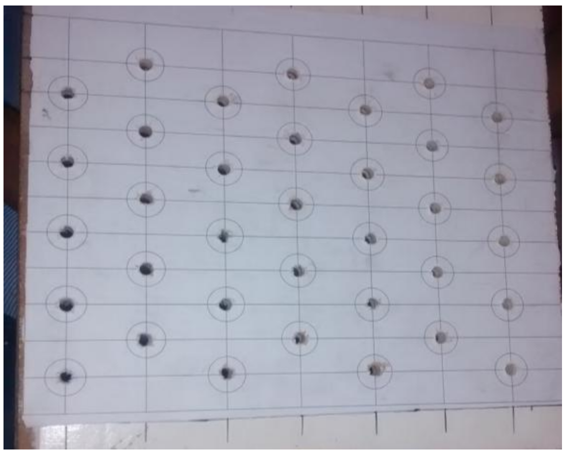


Fig 4.3 Staggered tube sheet spot marking

At a specific point air inlet velocity and various temperatures are measured using sensors of data logger. Velocities at various points are measured using anemometer. The required temperature of air is achieved by varying the voltage supplied to the heating coils. It is also possible to control the inlet velocity of air supplied from blower. The above two control functions can be effectively handled via a dimmer stat. The heating coils and the blower are connected to different dimmer stat which controls the temperature and velocity by manually varying the voltage as per the test.

Fig 4.4 Assembly of Duct

Sr	**Name of**	**Technical specifications**
1.	Air conditioner	Capacity 0.75 Ton Electricity Rating 1ϕ, 230V, 50Hz Dimensions WxHxD(mm)470x495x355
2	Heat pipe	Temperature range +5 ^{0}C to +200 ^{0}C. Working fluid tetraflouroethane(R-134a) Material Copper. Diameter 19.1 mm Length 700mm long Evaporator length 300 mm Condenser length 300 mm
3	Axial blower	Electricity Rating 50 watt, 230 V AC Speed 2350 rpm (variable). Air discharge 290 m^3/hr (Variable)
4	Electrical coil heater	Electricity Rating 1000 watt, 230 V AC, 5 A
5	Data Logger	Manufacture- Yog Electro Process Pvt. Ltd. Range- Selective Input- Universal Temperature and humidity sensor- 0 to 1 V Range- temperature > -40^{o}C to +60^{o}C
7	Vane probe anemometer	Make Lutron 4201 Property Low-friction ball-bearing vane Temperature range 0 to 60 ^{0}C Accuracy +/- 0.1 m/s
8	Ammeter	Select MA12 Supply 240V AC Accuracy +/- 20%
9	Voltmeter	Select MV15 Supply 240V AC Accuracy +/- 20% Maximum rated power – 5VA

Calculations

Average energy saving calculations

The experimentation is done after the completion of overall fabrication of experimental set up. The each reading is taken for 10 minutes of working of air conditioner. The observation table is attached as appendix I from observation table here we are calculating the heat transfer from electrical heater, heat pipe to air conditioned air after passing through cooling coil of air conditioner. Also here we have calculated the mass flow rates of air streams of both hot and cold side and condenser heat recovery along with the thermal efficiency of heat pipe or effectiveness of heat pipe. The annual money saving is also calculated which is helpful for calculating the payback period of investment.

The heat transfer from electrical heater and heat pipe are calculated as follows

Let,

Refrigerant used-R22

Specific gravity-1.2

T3 (°C)=Temperature before Evaporator

T4 (°C)=Temperature after Evaporator

T_6=Temperature after Compressor

T_7=Temperature after Condenser

calculation

1 Bar=10^5N/m^2

$=10^5$ X (1/9.81) kg/m^2

1kg=2.2lb
1cm=0.39inch
1m=39inch
1m^2=1521 in^2

1 bar=10^5 X $(\frac{1}{9.81})$ X $(\frac{1}{1521})$ X 2.2

1bar=14.74psi

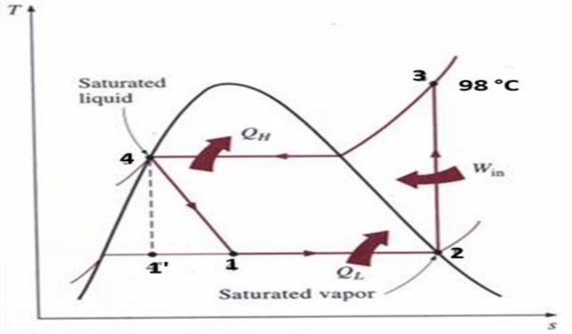


Fig 5.1. T-S diagram of R22

2.3 Energy Required
Energy Meter reading difference
E =77.75-75.04 =2.71 kw

Pd=155psi=$(\frac{155}{14.74})$

Pd=10.5756 bar
Absolute Pressure:
Ps=760-25=735 mm of hg
1mm of hg=133.35pa
Ps=0.979 bar

2.4 Experimental COP Calculations

COP=

$$\frac{(\mathrm{mCp}\Delta\mathrm{T})}{((\text{Energy meter difference reading}) \text{ X } (\text{specific gravity}))}$$

M=ρav
=0.3 X 0.225 X 1.167 X 3 = 0.2349

COP = (0.2349 X 1.005X $\frac{(40-18)}{(2.71 \text{ X } 1.2)}$)

COP=1.06

CALCULATION:
Energy Required
Energy Meter reading difference
E =98.7-97.6 = 1.1kw

Experimental COP Calculations:
COP=

$$\frac{(\mathrm{mCp}\Delta\mathrm{T})}{((\text{Energy meter difference reading}) \text{ X } (\text{specific gravity}))}$$

COP = (0.2349 X 1.005 X $\frac{(28-17)}{(1.1 \text{ X } 1.2)}$)

COP = 1.97

(COP) with Fined Heat pipe ≥ **(COP)** without Fined Heat pipe

Hence from above calculation by using Heat Pipe COP of instrument increase.

Percentage increment of Cop

$$=\frac{(COP)\text{with Heat pipe} - (COP)\text{ without Heat pipe}}{(COP)\text{ without Heat pipe}}$$

$$=\frac{\mathbf{1.97-1.06}}{\mathbf{1.06}}$$

= 85.60%

Total energy saving in KW for 1 hr trail is,
E =(Energy meter reading) without Heat pipe – (Energy meter reading) with Heat pipe
F=2.71-1.1 = 1.61 KW (Unit).
Energy saving for 1 month
Suppose AC work 16 hr in 1 day so,
G =1.61 X 16 X 30
G =772.8 Units/month.
For commercial use Unit rate is 5 Rs/Unit
H = 772.8 X 5 = 3864.0/- Rs.
Energy saving for 1 year
H = 1.61 X 16 X 5 X 365 = 47012/- Rs.

2.5 Payback period
The total electrical cost saving in 1 year is Rs 47012/-
The total cost of project is Rs 49500/-
The payback period is =

$$\frac{\text{Total cost of project}}{\text{Total electrical cost saving in 1 year}}$$

$$=\frac{\mathbf{49500}}{\mathbf{47012}}$$

=1.052 Year
i.e. Payback period is 1Year & 1 months

2.6 Effectiveness or Thermal efficiency of Heat Pipe

According to ASHRAE Standard 84-1991, Method of Testing Air-to-Air Heat Exchangers, the performance of the sensible energy transfer (dry-bulb temperature), latent energy transfer (humidity ratio), and total energy transfer of an air-to-air heat recovery device is assessed by its effectiveness. The performance of heat pipe heat exchanger is indicated by its sensible effectiveness and it ranges from 0.55 – 0.90.

$$\varepsilon = \frac{\text{Actual Heat transfer}}{\text{Maximum possible Heat transfer}}$$

OR

$$\varepsilon = \frac{\text{Heat rejected in condensation section}}{\text{Heat gain in evaporator section}}$$

Hence,

$$EBR = \frac{\text{Heat rejected (Qr (watt))}}{\text{Heat gain (Qe (watt))}}$$

$$EBR = \frac{1817.77}{1888.60}$$

EBR=0.962498

a) Pressure Drop (ΔP):-

$$\Delta P = \frac{(V1\,(m/s)^2 - V2\,(m/s)^2)}{(2 \times g)}$$

$$\Delta P = \frac{(3^2 - 2.7^2)}{(2 \times 9.81)}$$

ΔP =8.71 X 10-2 m

$\Delta P = 9.59 \times 10^{-2}$ m

ΔP =940.30010 pascal

b) Reynolds No.

$$\Delta P = \frac{4fLV^2}{(2Dh)} \; ; \; \therefore \; 8.71 \times 10^{-2} = \frac{(4 \times f \times 0.3 \times 3^2)}{(2 \times 0.019)}$$

$f = 3.064 \times 10^{-4}$

$$f = \frac{16}{Re}$$

$$Re = \frac{16}{3.064 \times 10^{-4}} = 52208.5$$

Re > 4000 flow is turbulent

c) Prandtl No.

$$Pr = \frac{\mu \times Cp}{k} = \frac{1.660 \times 10^{-4} \times 1005}{0.0757}$$

Pr = 2.20

d) Nusselt No.

$Nu = 0.023 \times Re^{0.8} \times Pr^{0.4}$

$Nu = 0.023 \times 52208.5^{0.8} \times 2.20^{0.4} = 256.965$

$$Nu = \frac{h \times L}{K} \quad \therefore 256.965 = \frac{h \times 0.3}{0.0757}$$

$h = 64.84$ w/m^{2}k

IV. RESULTS AND DISCUSSION

After the experimentation on HPHX arrangement and fined HPHX arrangement, we observed that with fined HPHX arrangement is better than the HPHX arrangement as discussed below For 35°C Temperature & 3.0 m/s Velocity:

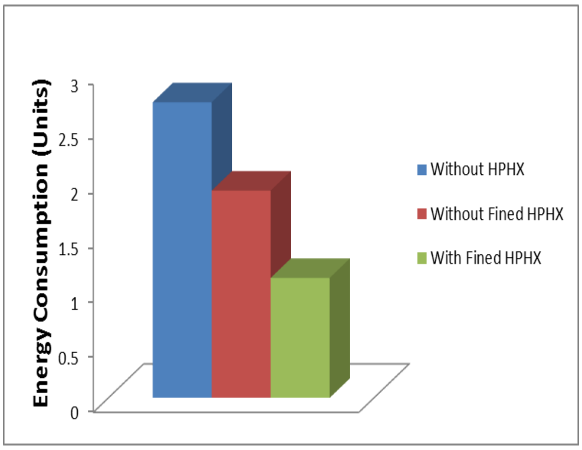
1. For fined HPHX arrangement heat transfer rate is higher than the without fined HPHX arrangement shown as below:

Temp	Without Fined HPHX	With Fined HPHX
30	358.8332	1652.52
35	535.8891	1888.60
40	566.5788	2384.35

2. There is enhancement in COP of A/C system using HPHX

COP without HPHX = 1.06
COP with HPHX = 1.76
COP with Fined HPHX = 1.97

3. Percentage saving of electrical energy 42.10% by using the HPHX
4. Bellow graph shows the energy saving by using HPHX.



IV. CONCLUSION

Heat pipes are very efficient heat transport elements. With increase in velocity and temperature effectiveness also increases. Increasing velocity results in higher heat transfer coefficients, which may be sufficient to improve performance. Periodically cleaning of system can increase heat transfer rate and effectiveness.

Heat Absorb at evaporator and heat rejected at condenser increases with increase in temperature and decreases with increase in velocity. Energy Balance Ratio (ERB) increases with increase in temperature and velocity.

Following conclusions are drawn from the trials:

1. Average Energy saved during 60 minutes is 1.61 kW (units).
2. Annual saving is Rs. 47012/- for 1.0 ton AC when it is running for 16 hrs in 1 office.
3. Percentage increment of COP 85.60 %.
4. Percentage saving of electrical energy 42.10%.
5. Average heat transfer rate of all 35 combined heat pipe is 1888.60W.
6. Payback Period is very less (1 Year & 1 Months).

VI. COST OF PROJECT

The cost of Fined Heat Pipe Heat exchanger is as follows:

Sr. No.	Part Name /Description	Cost(Rs)
1.	Heat Pipe (Copper)	30000
2.	Duct (G.I.Sheet)	9000
3.	Heating Coil	1000
4.	Packing (Air seal)	500
5.	Insulation(thermocol)	1000
6.	Transport	1000
7.	Fasteners & tools	1000
8.	Fin manufacturing	6000

Overall Cost Of Experimental Set Up: Rs. 49500 /-

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