Waste Heat Recovery from Domestic Gas Geyser for Space Heating Application

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A thesis submitted in partial fulfillment of the requirements for the degree of Bachelors of Engineering in Mechanical Engineering

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FINAL YEAR PROJECT REPORT

We hereby recommend that the dissertation prepared under our supervision by: {Insert names of group members followed by NUST Regn No} Titled: {Complete FY

P Topic} be accepted in partial fulfillment of the requirements for the award of Bachelors of Engineering in Mechanical Engineering degree with (grade)

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Copyright Statement

Dedicated to my parents

Acknowledgments

First of all I would thank ALLAH Almighty, who gave me knowledge and dedication to be able to complete this report.

Abstract

Most of the people in Pakistan use Gas Geysers in their homes to heat water for domestic usage. Flue gases at 250 Degree centigrade are being wasted from the top vent of Geyser whenever we turn it on. These gases are being wasted in the environment and are of no use. In winter season, people in Pakistan rely on Gas and Electric Heaters for Space Heating applications which are quite uneconomical sources. Our project is related to recovering this waste heat for space heating purposes. We have designed a heat exchanger which has Aluminum cylinders containing Phase Change Material. Phase Change Materials are an excellent source of storing and radiating heat, the PCM we have selected for this purpose is **MgCl2.6H2o**, this hydrated salt melts at 117 Degree centigrade. The operation takes two steps, first we charge our heat exchanger by placing it on the top of the geyser vent, Flue gases at 250 degrees Celsius enter our heat exchanger and escape the outlet vent of our heat exchanger at around 60 degrees Celsius thereby losing most of its energy to the Aluminum cylinders which ultimately melts the PCM in 35 Minutes. Once the heat exchanger is charged, it can be placed inside a room and a DC Fan can be attached to it's outlet, the Fan convects hot air of temperature around 75 to 80 degrees Celsius for around one hour which increases the temperature of the room substantially.

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Symbols

AL2024 T3	Aluminium Alloy 2024 heat treated
F	Load
t, t_1, t_2	Adherend thicknesses
t_a	Adhesive thickness
$\varepsilon, \varepsilon_{x1}, \varepsilon_{x2}$	Longitudinal strains
T	Shear stress
G	Modulus of rigidity of adhesive
E_1, E_2	Modulus of elasticity for plates
E_a	Modulus of elasticity for adhesive
l	Length of overlap
B	Width of overlap
A, B	Constants of solution of differential equation
τ_m	Mean tangential stress
$\tau_{n,}$	Destructive stress
M	Bending moment
E_{Total}	Total strain energy
σ	Tensile stress
$\sigma_{p(max)}$	Max peel stress
$d\Omega$	Structural domain

Chapter 1 Introduction

1.1 Background

Pakistan is facing deficiency in energy production and yet our people waste lot of heat and electric energy. One of the example is the heat of the flue gases of our domestic Gas Geysers that is being wasted in the environment. Keeping in mind the deficiency of our state, we aim to recover or reuse that waste heat. We are doing this by proposing a very simple, economical and efficient solution for this problem. We have designed a heat exchanger which is very simply in design, easy to use and manufacture, portable and economical. This Heat Exchanger uses Phase Change Material (PCM) to store that waste heat in it and then heats the required space by forced convection method.

1.2 Aim and Objectives

The aim of this project is to propose an easy and efficient solution to recover waste heat from whatever source it is being wasted. We have done our research on Gas Geysers specifically but we aim to propose a general solution for all types of waste heats. The following objectives were identified in order to achieve the overall aim of this project.

- To design and fabricate Waste Heat Recovery Unit for the application of Space Heating.
- The Design should be simple, portable and easy to manufacture.
- Working prototype that is marketable.

1.3 Thesis Structure

The brief description of the contents of the remaining chapters in thesis is described below.

Error! Reference source not found. Error! Reference source not found. and Calculations: Chapter provides a summary of the literature that has been reviewed and identified to be relevant to this research.

Error! Reference source not found. Design and Specifications: This chapter includes details and specifications of design of our Heat Exchanger, CAD models of our design , choice of materials and selection criteria for PCM and Initial and Alternate design

Error! Reference source not found. Error! Reference source not found.: This chapter includes all the results and findings of our research and experimentation in the form of tabulated data and graphs.

Error! Reference source not found. Error! Reference source not found.: This chapter presents the conclusion of the conducted research along with the proposed future work some new ideas that can be integrated with our project to use it in industrial applications as well.

Chapter 2 Literature Review and Calculations

2.1 Introduction

Flue gases at 250 Degree centigrade are being wasted from the top vent of Geyser whenever we turn it on. Our project is related to recovering this waste heat for space heating purposes. We have designed a heat exchanger which has Aluminum cylinders containing Phase Change Material. Phase Change Materials are an excellent source of storing and radiating heat, the PCM we have selected for this purpose is MgCl2.H2o, this hydrated salt melts at 117 Degree centigrade. The operation takes two steps, first we charge our heat exchanger by placing it on the top of the geyser vent, Flue gases at 250 Degrees Celsius enter our heat exchanger and escape the outlet vent of our heat exchanger at around 60 degree Celsius thereby losing most of its energy to the aluminum cylinders which ultimately melts the PCM in 35 Minutes. Once the heat exchanger is charged, it can be placed inside a room and a DC Fan can be attached to its outlet, the fan convects hot air of temperature around 75 to 80 Degree Celsius for around one hour which increases the temperature of the room substantially.

2.2 Thermal Energy Storage:

Thermal energy storage can be stored as a change in internal energy of a material as sensible heat, latent heat and thermochemical or combination of these.

2.2.1 <u>Sensible heat storage</u>:

In sensible heat storage (SHS), thermal energy is stored by raising the temperature of a solid or liquid. SHS system utilizes the heat capacity and the change in temperature of the material during the process of charging and discharging. The amount of heat stored depends on the specific heat of the medium, the temperature change and the amount of storage material.

2.2.2 <u>Latent heat storage:</u>

Latent heat storage (LHS) is based on the heat absorption or release when a storage material undergoes a phase change from solid to liquid or liquid to gas or vice versa. Amongst above thermal heat storage techniques, latent heat thermal energy storage is particularly attractive due to its ability to provide high-energy storage density and its characteristics to store heat at constant temperature corresponding to the phase transition temperature of phase change material (PCM). Phase change can be in the following form: solid– solid, solid–liquid, solid–gas and liquid–gas and vice versa. In solid–solid transitions, heat is stored as the material is transformed from one crystalline to another. These transitions generally have small latent heat and small volume changes than solid–liquid transitions. Solid–solid PCMs offer the advantages of less stringent container requirements and greater design flexibility.

2.2.3 <u>Thermochemical energy storage:</u>

Thermochemical systems rely on the energy absorbed and released in breaking and reforming molecular bonds in a completely reversible chemical reaction. In this case, the heat stored depends on the amount of storage material, the endothermic heat of reaction, and the extent of conversion.

2.3 Latent Heat Storage System:

A latent heat storage device utilizes phase change materials; these PCMs change their phase and store or dissipate thermal energy. PCMs themselves cannot be used as heat transfer medium. A separate heat transfer medium must me employed with heat exchanger in between to transfer energy from the source to the PCM and from PCM to the load. PCMs' volume changes as their phase changes, design considerations should cater for that. Also there are different categories of PCMs, some may react with the housing of PCM, and so material compatibility should be studied in detail.

Any latent heat energy storage system therefore, possess at least following three components:

(i) A suitable PCM with its melting point in the desired temperature range,

(ii) A suitable heat exchange surface, and

(iii) A suitable container compatible with the PCM.

2.4 Heat Transfer Mechanisms:

Heat transfer is the exchange of thermal energy between physical systems. The rate of heat transfer is dependent on the temperatures of the systems and the properties of the intervening medium through which the heat is transferred. The three fundamental modes of heat transfer are conduction, convection and radiation.

Conduction

On a microscopic scale, heat conduction occurs as hot, rapidly moving or vibrating atoms and molecules interact with neighboring atoms and molecules, transferring some of their energy (heat) to these neighboring particles. In other words, heat is transferred by conduction when adjacent atoms vibrate against one another, or as electrons move from one atom to another. Conduction is the most significant means of heat transfer within a solid or between solid objects in thermal contact. Fluids especially gases are less conductive. Thermal contact conductance is the study of heat conduction between solid bodies in contact. Abbott, J.M. Smith, H.C. Van Ness, M.M. (2005).

Convection

Convective heat transfer, or convection, is the transfer of heat from one place to another by the movement of fluids, a process that is essentially the transfer of heat via mass transfer. Bulk motion of fluid enhances heat transfer in many physical situations, such as (for example) between a solid surface and the fluid. *Çengel, Yunus (2003).*

Radiation

Thermal radiation occurs through a vacuum or any transparent medium (solid or fluid). It is the transfer of energy by means of photons in electromagnetic waves governed by the same laws. Geankoplis, Christie John (2003).

Thermal radiation is energy emitted by matter as electromagnetic waves, due to the pool of thermal energy in all matter with a temperature above absolute zero. Thermal radiation propagates without the presence of matter through the vacuum of space.(Thermal-FluidsPedia Radiation").

2.5 The Resistance Method for Calculation of Heat Transfer:

There is an electrical analogy with conduction heat transfer that can be exploited in problem solving. The analog of Q is current, and the analog of the temperature difference, T2-T1 is voltage difference. From this perspective the slab is a pure resistance to heat transfer and we can define

Q= T2-T1/R

Total resistance

By this resistance method the overall resistance can be calculated by the following formula, and from the formula onward we can calculate the heat transfer.

1/R = 1/R1 + 1/R2….

Calculations:

Dimensions of Cylinder:
Length = L = 8’’ = 0.2032m
Outer radius = 0.0095 m
Inner Radius = 0.0081m
Outer Area: 0.0121m^2
Inner Area: 0.01034m^2
Volume: 4.18x10^{-5} m3

Mass inside One Cylinder: Density x Volume
: 1450 x 4.18x10^{-5} = 0.0607 Kg

Now

$$\dot{Q} = \frac{\Delta T}{Rtotal}$$

$$Rtotal = R1 + R2 + R3$$

$$R1 = \frac{1}{hA1} = \frac{1}{(77.82)(0.0121)} = 1.06$$

$$R2 = \frac{\ln\left(\frac{r2}{r1}\right)}{2\pi KL} = 6.24x\ 10E-4$$

$$R3 = \frac{L}{KA} = 1.37$$

We have taken L = inner radius, K = 0.570 of PCM, and A= inner area.

$$Rtotal = 2.43$$

$$Q = \frac{250-25}{2.43} = 92\ Watts.$$

But With the Passage of Time Our PCM at 25 would heat up and its Temperature would raise, this will change the heat transfer rate.
The decline in Heat transfer rate is Linear with respect to rise in the temperature of PCM, so we can take the average heat transfer rate Value.

Time required to raise the Temperature of PCM from 25 to 250 Degree Celsius:
This process will take place in 3 stages:

Stage 1: from 25 to 117 Degree.
Q= m * Cp *ΔT

Q = 0.0607 * 2.25 * (117-25) = 12.56 KJ

Time required to raise this temperature:

$$t = \frac{12560}{74}$$

Where 74 watts is the average heat transfer rate from 25 to 117 Degree.
This comes out to be: 2.82 Minutes (169s)

Stage 2: time required in Melting:

$$t = \frac{10234}{54}$$

Where 10234 is the Heat of fusion of 0.0607 kg of PCM and 54 Watts is the heat transfer

Rate at this point. This comes out to be 3.15 Minutes.

Stage 3:
Time required to raise the temperature from 117 to 250 Degrees in Liquid Phase.

Q= m*Cp* ΔT

Q= 0.0607* 2.61 * (200-117)

Q= 13.14 KJ

$$t = \frac{13149}{37}$$

This comes out to be 6 Minutes.

So total Time required to raise the temperature of PCM from 25 to 200 Degree, with a constant Supply of Flue gases at 250C, is 12 Minutes.

Heat Transfer from PCM heat exchanger to Room air:

The heat transfer in this case would neither be constant not be linear, since the temperature of both PCM and room air is continuously changing. So we have assumed the heat transfer rate to be sinusoidal, so the RMS values of heat transfer rate will be a good assumption.

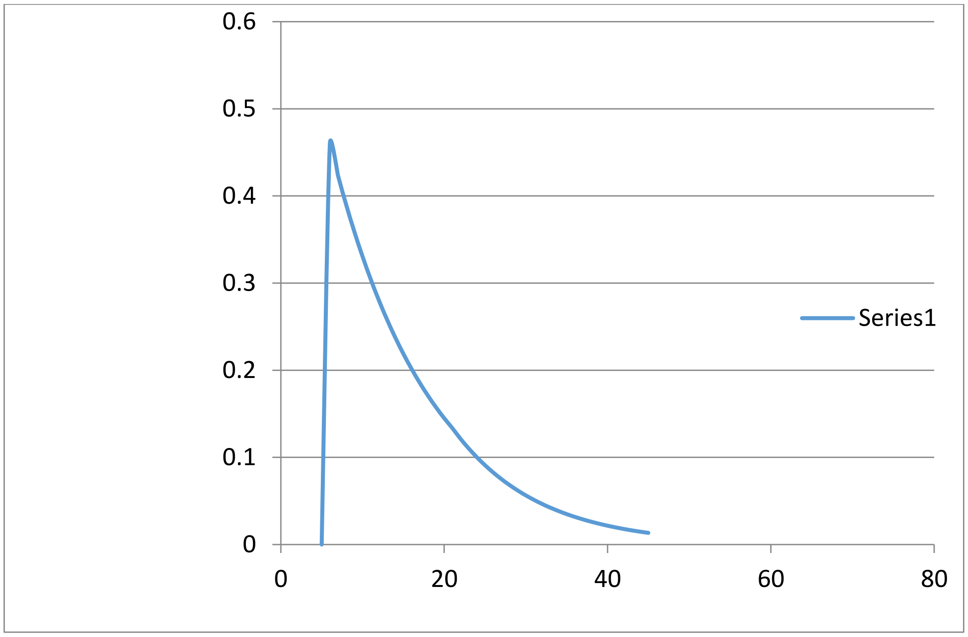


Figure 2.1

The heat lost by PCM to the surrounding air is lost in 3 stages:

Stage 1: From 200 to 117 degree

RMS heat transfer rate: 0.09096 Kilowatts.

Heat Energy Lost: m*Cp*ΔT = 13.14KJ

Time required to loose this heat energy with 0.9096 kilowatts rate: 144s = 2.4 Min.

Stage 2: during Solidification

Energy lost: 10.234KJ

Average Heat transfer rate: 0.06507KW

$$t = \frac{10.234}{0.0607}$$

This comes out to be almost 2.8 Minutes.

Stage 3: from 117 to 60 degree

Heat energy lost: 7.78KJ

Average Heat transfer rate: 0.04619KW

Time required to lose this heat energy: 7.78/0.04619 = 3 Min

So a total of **9 Min** will be required to lower the temperature from 200 to 60 degree Celsius.

During this time, the total heat lost from one cylinder: 0.09096+0.06507+0.04619 = 0.2022KW.

Total heat load of our room = 1.6KW But since Pakistani Buildings are not according to Ashrae Standards we assume it to be 2.5KW. in that case we will need 4 cylinders heat exchanger.

2.6 Heating Load Calculation:

To Calculate the Heating load of a Normal Living room of Islamabad, we are taking a Normal room which has two walls exposed to the outer environment, has one window which is Single Glazed, and one door which is infiltrating the outside air.

Load through walls:
Fundamental Equation: q = U*A* ΔT

Wall 1: Facing west

Area of the wall = Total Area – Window Area
= 13.378m^2 - 3.6 m^2= 9.78 m^2

U = 4.42 W/m2K.
ΔT= 295K-283K

Q = 4.42* 9.79* (295-283)

Q= 518.73 Watts.

Wall 2: Facing South:

Area of the wall = Total Area – Window Area

= 13.378m^2 - 0m^2= 13.378 m^2

U = 4.42 W/m2K.
ΔT= 295K-283K

Q = 4.42* 13.378* (295-283)

Q= 709.56W

Load through Window:
Fundamental Equation: q = U*A* ΔT

Where U = 4.5 W/m2K
Area: 3.6 m^2

$$\Delta T = 295 - 293 = 12$$

Q= 195W

Load through Infiltration:

$$q = 1.20 * Q * (hi - ho)$$

$$Q = \left(\frac{A}{1000}\right) * \sqrt{Cs\Delta T + CwV^2}$$

Where Cs = Stack Coefficient = 0.000435

Cw = Wind Coefficient = 0.000271

V = Average Wind Speed = 6.2 m/s

A = Leakage Area = 54 cm^2

$$\Delta T = 12$$

This gives:

Q= 192W

Total Heating Load: 518+709.56+195+192 = 1614W ≅1.6 KW

Chapter 3 Design and Specifications

3.1 Choice of Phase Change Material:

Phase Change Materials: Phase change materials (PCM) are ‘‘Latent’’ heat storage materials. The thermal energy transfer occurs when a material changes from solid to liquid, or liquid to solid. This is called a change in state, or ‘‘Phase.’’ Initially, these solid–liquid PCMs perform like conventional storage materials, their temperature rises as they absorb heat. Unlike conventional (sensible) storage materials, PCM absorbs and release heat at a nearly constant temperature. These are the materials that can absorb, store and release large amount of energy in the form of latent heat during its phase change. It has high storage density with small temperature change.

Heat Capacity of PCM's:

Phase Change Materials differ in Phase Change Temperatures and Heat Storing Capacities. They have very high energy storage density and have heat storing capacity more than other materials. Following graph shows a comparison of Heat Storing Capacity between other materials and Phase Change Materials.

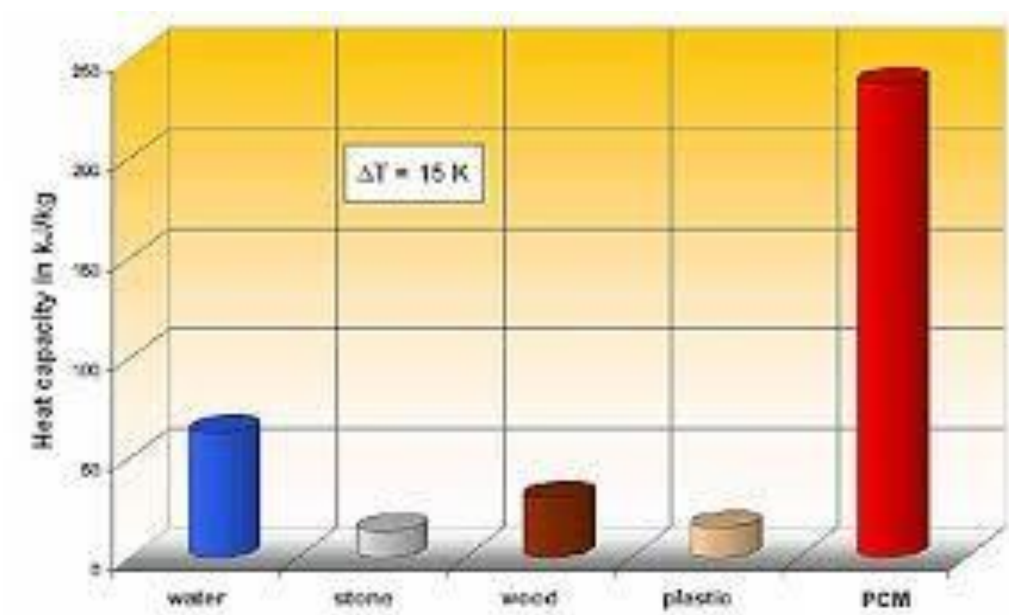


Figure 3.1

Classification of PCM's:

There are multiple classes of PCM, each having their own advantages and disadvantages and the choice of PCM depends upon the application required. The PCM's have properties that make them very attractive for storage of thermal energy.

There are more than **500 Natural and Synthetic** Phase Change Materials which differs in Phase Change Temperature range and Heat Storage Capacities. Following chart shows the classification of Phase Change Materials.

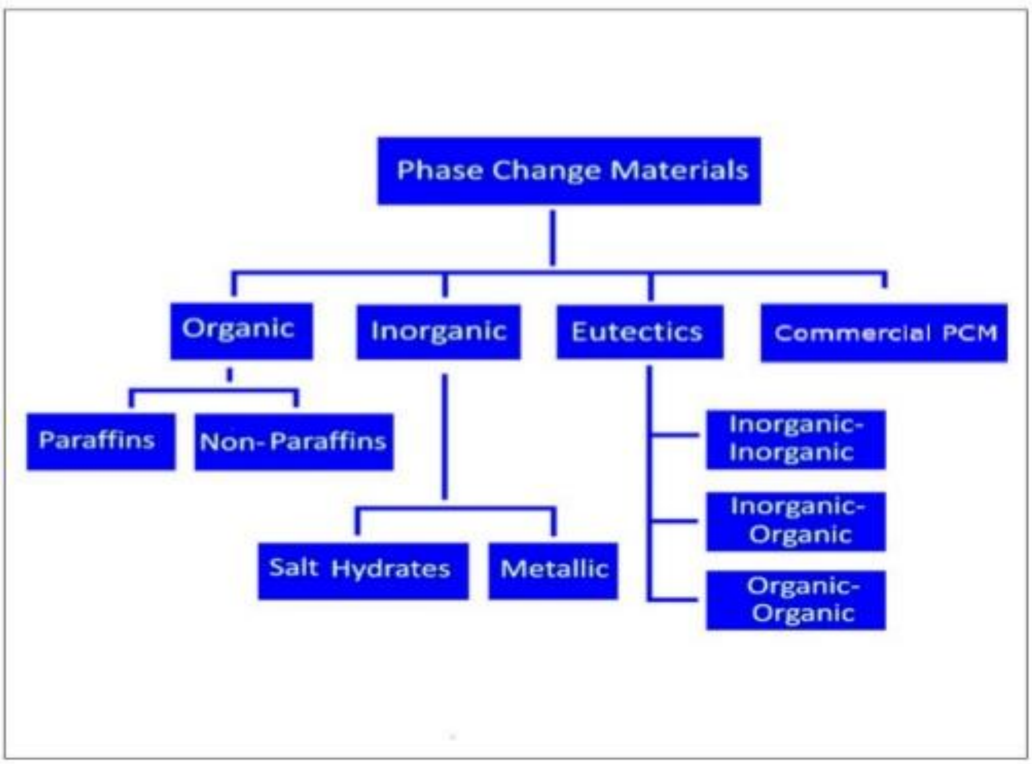


Figure 3.2

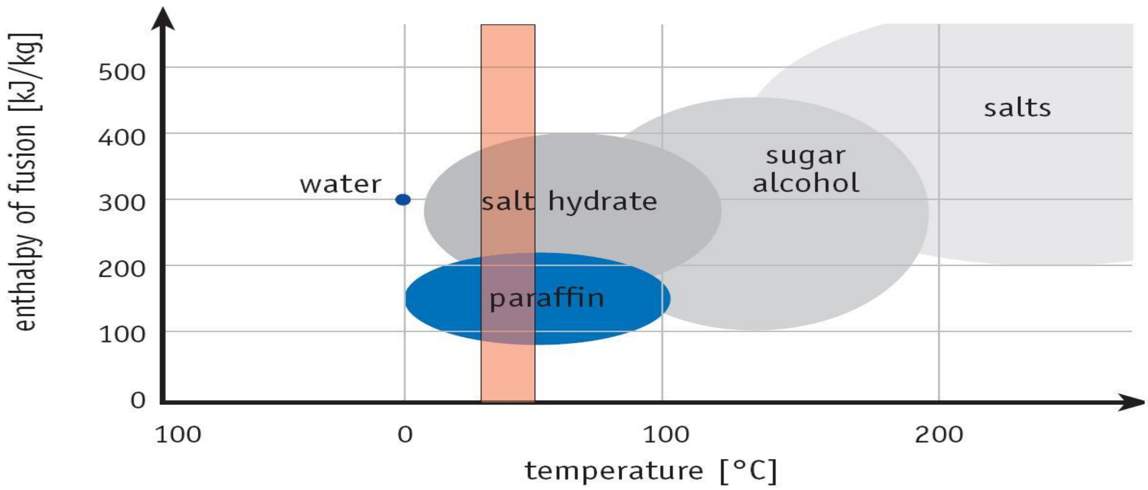
Selection Criteria of PCM:

There are a large number of organic and inorganic chemical materials, which can be identified as PCM from the point of view melting temperature and latent heat of fusion. However, except for the melting point in the operating range, majority of phase change materials does not satisfy the criteria required for an adequate storage media. So, following are different requirements and constraints that decides the choice of our PCM.

1. Melting Temperature should be in the range of 110 to 130 degrees Celsius so that we can get the temperature gradient of 150 degrees Celsius at least.
2. Inexpensive.
3. Easily Available in Pakistan.
4. Long Term chemical stability.
5. Compatibility with encapsulated material.
6. High Thermal Conductivity
7. High Latent Heat of Transition
8. Low Volume Change during phase change.
9. Non Toxic
10. No fire hazard
11. No leakage required during phase change.

According to our need and requirement we decided to choose Inorganic Salts as our PCM which after analyzing their melting temperature range and other properties comes out to be $MgCl_2.6H_2O$ (Magnesium Chloride Hexa-hydrate).

Figure 3.3



Following table shows the properties of *$MgCl_2.6H_2O$*.

Properties	Magnesium Chloride Hexa-Hydrate
Melting Temperature (^{0}C)	117
Latent Heat (kJ/kg)	168.6
Density (kg/m^3)	1450
Energy Density (kJ/m^3)	2,44,470
Thermal Conductivity (W/mK)	0.570

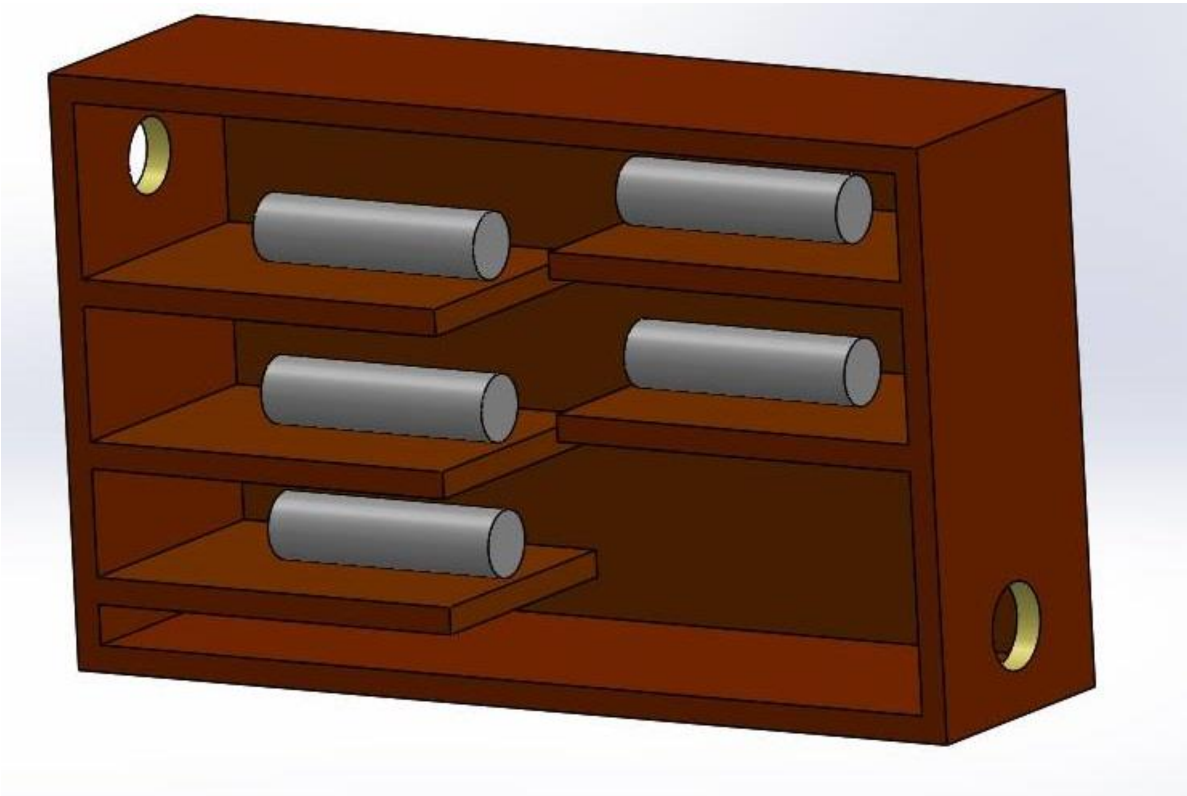
3.2 Choice of type of Heat Exchanger:

Initial Model:

We have decided to choose Shell and Tube type Heat Exchanger. CAD model of initial design is as follows. There are five cylinders in this design which encapsulates our PCM.

These cylinders rests on the wooden slabs which provide the passage for the flue gases that enter from the top and leaves the unit from the bottom hence making contact with the aluminum cylinders and transferring heat to the PCM. The cylinders are enclosed in the wooden box.

Figure 3.4



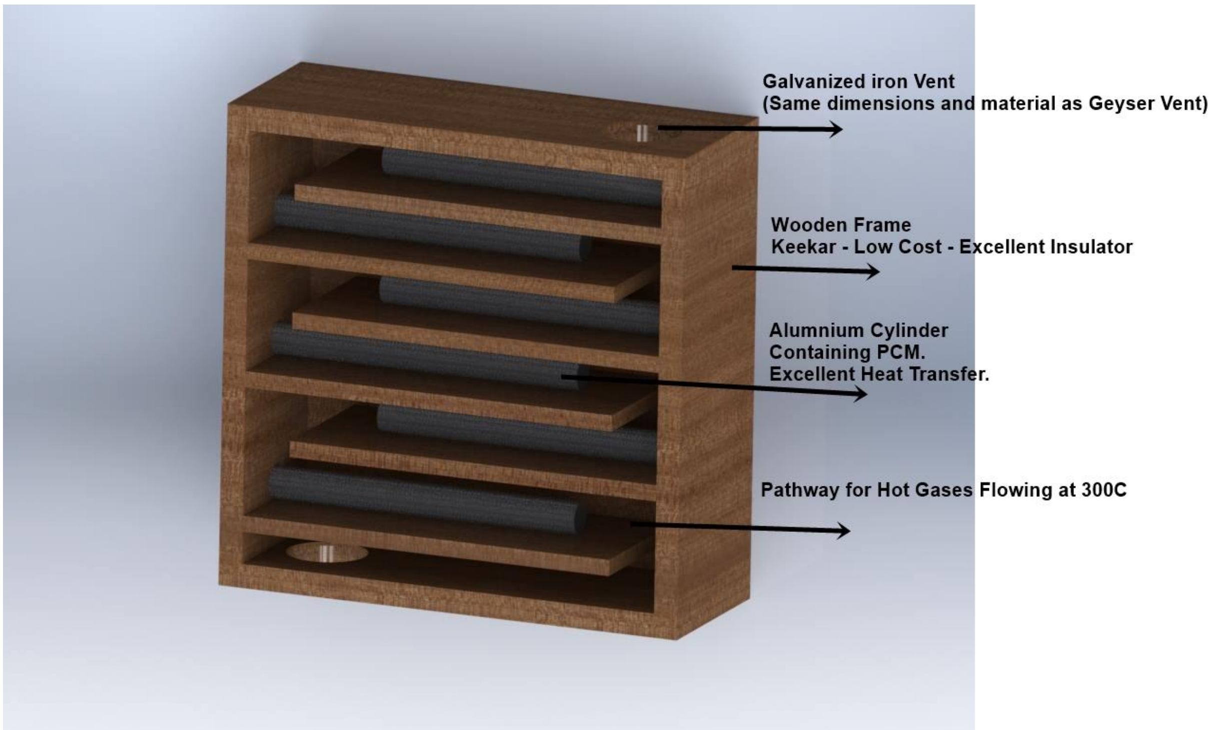
Drawbacks of Initial Design:

The reason of wooden slabs in the design was to make sure that flue gases will completely make contact with cylinders which in turn transfers heat to the PCM. But in this initial design there is extra space between the slabs on opposite sides, which will provide an easy passage for the flue gases and they will exit the box without making contact with cylinders.

Final Design:

Following is the CAD model of our final design which ensures complete passage for flue gases to make contact with the cylinders.

Figure 3.5



In this design, Flue Gases enter the unit from bottom of the box and passing through the pathway make contact with Aluminum cylinders and leave the box from top vent. This Heat Exchanger is portable and rests on the top of the geyser and stores the energy of flue gases in PCM as thermal energy. After charging this portable Heat Exchanger can be used to heat the room by forced convection.

Materials used for the fabrication of Heat Exchanger:

1. Aluminum (For Cylinders that encapsulates PCM)
2. Hard Wood (For constructing box and passage for flue gases)
3. $Mgcl_2.6H_2O$ (PCM)

Reasons for choosing Aluminum:

We need a material which must have a good thermal conductivity so that it can conduct heat completely with PCM. We are left with two options, Copper and Aluminum. Following table shows the comparison between the two materials.

Copper	Aluminum
Melting temp. = 1083 degree Celsius	Melting temp. = 660 degree Celsius
Conductivity = 400 W/m K	Conductivity= 205 W/m K
Expensive	Inexpensive
Thermal Expansion Co-efficient per degree centigrade = 17·10E-6	Thermal Expansion co-efficient per degree centigrade = 23·10E-6
Welding of copper is very expensive and unavailable	Welding of Aluminum is easily available and inexpensive

So, we chose Aluminum due to above mentioned reasons.

Reasons for choosing Wood:

For our Heat Exchanger we need a material that must not take heat of the flue gases because we wanted our flue gases to completely transfer their energy to our PCM filled cylinders only. So, using wood was a good option because its thermal conductivity is very low.

Advantages of wood:

1. Thermal Conductivity = 0.12-0.04 W/m K
2. Easily Available
3. Inexpensive
4. PCM is inert to it in case of any leakage

Why Hard Wood (Kikar)?

Advantages:

1. Hard wood
2. Can withstand larger temperature gases than any other wood.
3. Easily available in our required sizes and very cheap

3.3 Sealing Material

<u>FKP Rubber Chord</u>: which is flexible, fiber-free pipe insulation offered in pre-slit tubes with self-adhesive foam lap seals for greater seam security and increased protection against condensation, mold, and energy loss.

This product consists of 2 materials namely EPDM and Neoprene. Neoprene provides excellent resistance against oil, acid and alkalis while EPDM has good weathering, and heat resistance. FKP rubber chord can withstand temperatures up to 200 degree Celsius.

<u>Glass Wool:</u>

Glass wool is an insulating material made from fibres of glass arranged using a binder into a texture similar to wool. The process traps many small pockets of air between the glass, and these small air pockets result in high thermal insulation properties.
Glass wool is produced in rolls or in slabs, with different thermal and mechanical properties. It may also be produced as a material that can be sprayed or applied in place, on the surface to be insulated.

In our Project Glass wool was used to insulate the whole Heat exchanger prototype so that the hot flue gases can be trapped inside the heat exchanger and no heat is lost during discharging process.

Chapter No: 4 Results and Discussion

Figure 4.1

4.1 The prototype

The Final prototype was 12 x 14 x 5 in Kikar wood box insulated with FKP rubber chord from Inside and Glass wool from Outside. The wooden box had two holes of 3.5inches diameter on either side for inlet and outlet of Flue gases.

4.1.1: Inlet and outlet:

The Inlet and outlet was extended with GI Pipe, the same material as that of the geyser vent, using this pipe was extremely necessary as it could provide the necessary strength which was requited for the application. The pipe was threaded on top, to allow caps whenever required during charging or discharging application.

4.1.2: The Baffles:

The prototype was made in a way that it contained 7 small compartments, these compartments were made to allow maximum interaction between the flue gases and Aluminum cylinders, 6 out of 7 baffles had two cylinders each filled with PCM inside them, one was kept free. The reason for keeping one baffle free was to avoid direct contact of very hot flue gases with the aluminum cylinders because that might cause the cylinder to collapse due to extreme volume expansion.

4.1.3: The Cylinders:

There were a total of 12 cylinders, each 8in in length and 0.75in outer dia. Each cylinder contained a mass of 0.067 Kg PCM. All cylinders were adjusted in a way that they were at a distance from wooden walls and they had spaces in between as well.

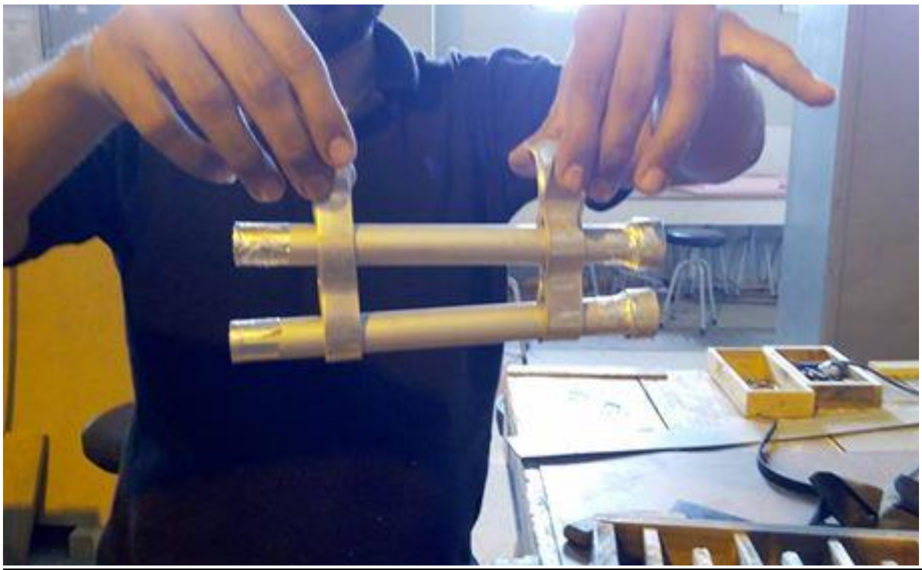


Figure 4.2

4.2 Calculation Results:

Heating Load of Normal Room : 1.6 KW.
Following were the specifications of the room selected:

1. 2 walls exposed to outside air.
2. One window – Single Glazed Glass.
3. Infiltration through One Door.

- Charging of Heat exchanger:
  One Cylinder when exposed to Flue gases at 250C melts in 12 Minutes.
  Following were the specifications of the calculation performed

  1. Calculated through $Q/\dot{Q}$
  2. Resistance Method.

- Discharging of Heat Exchanger
  Takes 9 Minutes to lower the temperature of PCM from 200 to 60.

4.3 Laboratory Experiment results:

Checking the Melting Behavior of the PCM was a big question mark faced by the team. Properties such as melting time and volume expansion could not be anticipated through calculations accurately, so experimentation was must.
for this purpose, the PCM was melt inside in a furnace and 120 Degree Constant Supply of heat was given to it, since the melting temperature of the PCM is 117 Degree Celcius, the input heat energy was sufficient to melt it. It took 35 Minutes to Melt the PCM inside the Cylinder and the beaker to Melt completely, this melting time was a little more than that of our calculated melting time because the input

temperature was not 250 as that in the case of flue gases, rather it was 120C provided by the furnace.

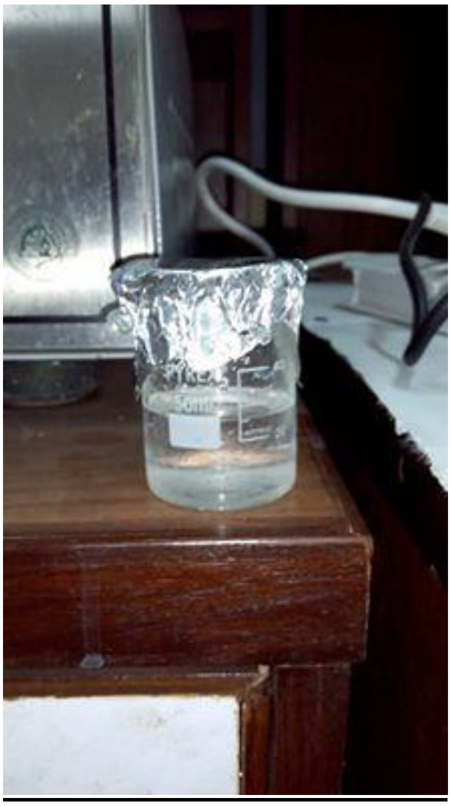


Figure 4.3

Figure 4.4

Figure 4.5

First Testing Experiment:

Once the Prototype was manufactured and sealed properly, we performed our first experiment and charged and discharged our Heat exchanger. The results are as follows. The first experiment was performed without Glass wool insulation.

4.3.1 Charging:

the Charging, the charging time was kept 35 Minutes on the basis of our laboratory experiment, the melting time was 35 Minutes. The charging was done by placing the heat exchanger on the top of the geyser for 35 Minutes, the inpur flue gases temperature reached a maximum of 260C and the output flue gases temperature reached a maximum of 58C.

Figure 4.6

Figure 4.7

The discharging:

After 35 Minutes of Charging on top of the Heat Exchanger. The Heat exchanger was now put inside a room, and a fan was installed on the output GI Pipe vent of the heat exchanger, this Fan needed a power source of DC 12V and 6A, when this Fan was turned on, the Heat exchanger initially gave an output of 56C. This temperature kept declining with the passage of time until 50 minutes passed when the output temperature of Fan and the room temperature became equal.

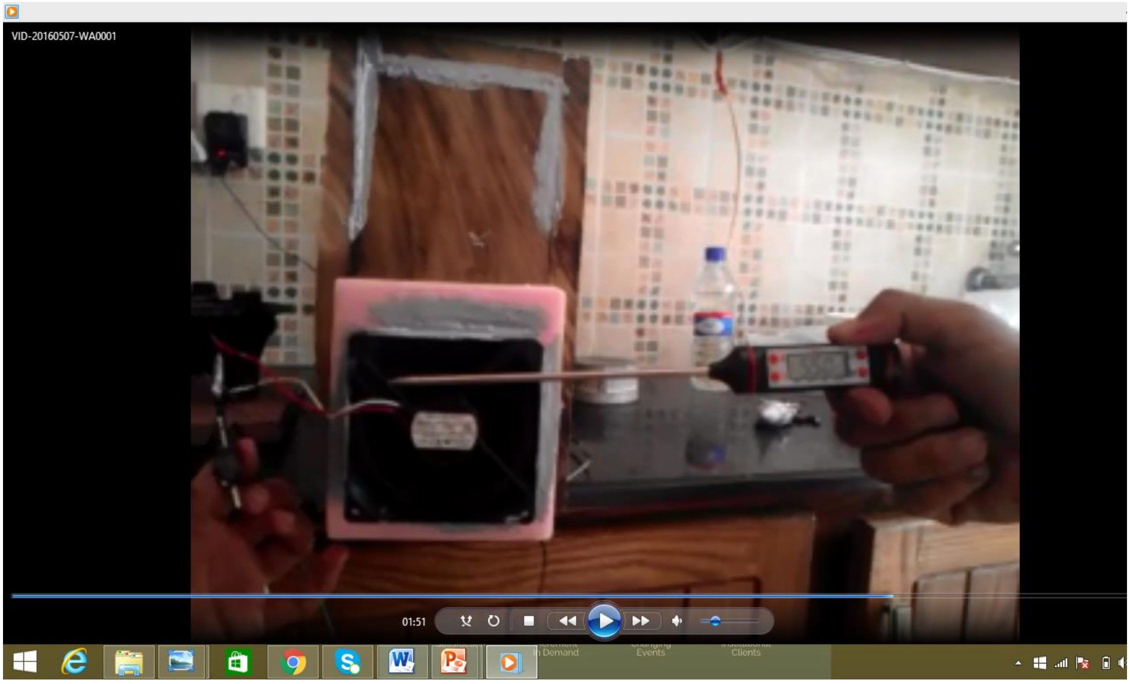


Figure 4.7

Reading No	Time (Minutes after Charging)	Output Temp (Centigrade)
1	5	56
2	10	50
3	20	44
4	30	40
5	40	36
6	50	33

Second Testing Experiment:

The second Testing experiment was done after insulating the heat exchanger with Glass wool insulation, this changed the output temperature reading, the new maximum output reading was 84C, and this output reading declined with the passage of time and after one hour the temperature of the output air was equal to the room temperature.

Reading No	Time (Minutes after Charging)	Output Temp (Centigrade)
1	0	84
2	8	80
3	13	76
4	20	71.5
5	25	70.3
6	36	48.3
7	42	45.6

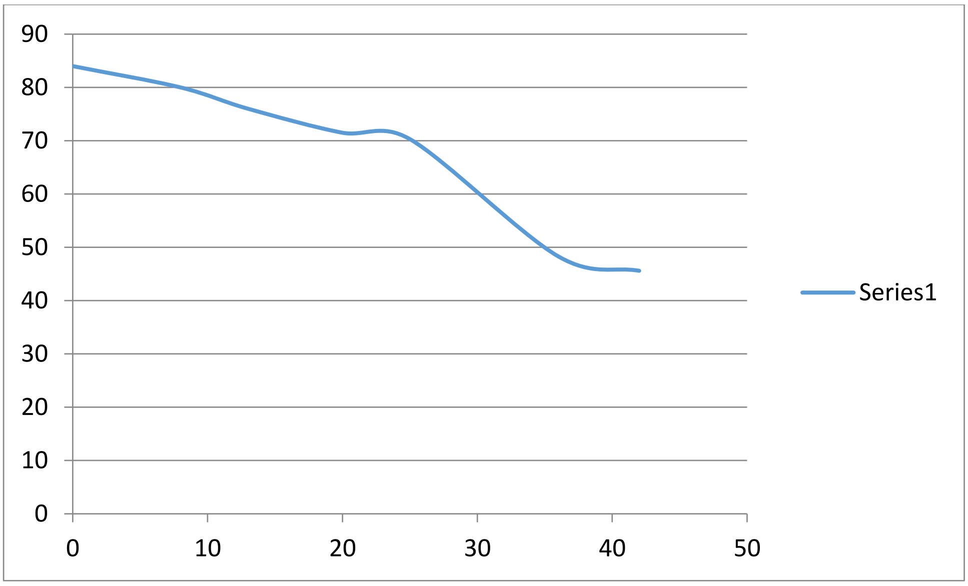


Figure 1 output graph of second experiment

4.4 Conclusion:

According to the calculation, for every one hour of usage of domestic gas geyser, 21 MJ of energy is wasted to the environment, this is not just wastage of heat energy, and the flue gases are hazardous for the environment as well. With growing energy crisis and increasing load shedding of gas, winters are becoming uneasy for domestic usage. In usual households, geysers are used for many hours during the day, and domestic gas heaters are also used, this results in an increased bill and overall greater usage of Natural gas on the country's level.

So we have made this heat exchanger that can charge on the top of gas geysers so it can utilize the waste heat that would otherwise be polluting the environment. During charging, the flue gases run through the baffles heating up the PCM Filled Aluminum Cylinders. The PCM Inside the cylinder melts at 117 Degree centigrade, so heating it with flue gases of 250C melts it within 30 Minutes depending on the flow rate and exact temperature of flue gases.

After Charging, the portable heat exchanger can be placed in a room, and a fan of 60-70 CFM can be placed on the outlet vent of heat exchanger, the room air enters the heat exchanger and runs through the baffles, gets heated up due to very hot PCM filled cylinders and emerge out of the fan outlet at around 70-80C.

This can be a marketable product which has extensive domestic application which can be used in winters for households and offices. The size of prototype we made is enough for a 1x1x1 (ft.) room. For a normal household room (12x12x12) a total of 4.5 Kg PCM filled cylinders would have to be used. This is a low cost product and can be made under 10,000 rs. This product has a very long life, and if there is no accident it can be used for ages. All the main raw material that is used has an age of a lifetime.

4.5 Future Work:

1. The present prototype is portable, which might be tedious for a user to place it repetitively on the top of the geyser and in the room. So a 3D heat exchanger can be made which is continuous in its operation. This 3D heat exchanger will have the flue gases inside the tubes, running through a bigger pipe, this bigger pipe can have a number of small pipes to accommodate the PCM, this whole assembly can be placed inside a box on one end of which a Fan can be attached for forced convection inside the room.

2. Leather Industry has a lot of drying application; this product can be used in the tanneries for drying application.
3. Alternate designs can be made to check if it can give better efficiency.
4. Such heat exchangers can be used in series to increase the overall efficiency, such that flue gases escaping one heat exchanger can charge the 2nd one and so on.

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