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Examining the insulating capacity of recyclable materials

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Abstract—The earth's resources are depleting at a faster rate than they are being generated. At the same time the population is growing at a very fast pace. Examining the present situation, it will in the next 40- 50 years when we will be out of fossil fuels. Fossil fuels are most important part of our life, as they are utilized in many different fields.... such as the automobiles, industries, heating system in Europe, to generate electricity. In addition, the global warming of the planet is leading to extreme temperatures at majority of the places on Earth. To fight the heat, there are ways but to survive the cold.... there are none.....protecting us with jackets, sweaters, socks will only be effective to a certain extent, after that it is insulation that will help us survive. In order to come up with the perfect insulator, this experiment gives us the opportunity to scrutinize the properties of recycled materials that make up a good insulator. Therefore, this will protect our future generation as well as allow the present generation to preserve the depleting resources. Visiting a few rural areas nearby the city where I lived, I found out one of the major problems for such underdeveloped areas are communication, which has inhibited such regions growth. Because improving the communication is not under my approach, I decided to find out ways to survive conditions with the usage of few resources and maximum productivity. In addition to this, I want to find out a material with a very high insulating capacity that will be able to cook food without the constant use of coal or other fossil fuels. To apply a dual solution, I decided to test the insulating capacity of recycled materials which will be both environment friendly for environment, as well as ensure efficient use of resources. Hence I arrived at the research question How does the insulating capacity vary with the density of the material (with same thickness)? Its effectiveness will allow one to understand how effective each of the material will be in cooking food in the rural areas. Therefore, I am comparing the density of the material with its rate of cooling in order to come to a conclusion which would indicate what kind of recycled materials will be most efficient in insulation.

Index Terms— Physics research paper, insulating capacity of recyclable materials, bubble wrap,

1 Background Information (Physics concepts used in the experiment)

Heat can be transferred in three ways,

1. Conduction - Thermal conduction is the transfer of internal energy by microscopic diffusion and collisions of particles or quasi-particles within a body. The microscopically diffusing and colliding objects include molecules, atoms, and electrons. (Definition- Wikipedia)

2. Convection - the transfer of heat by the circulation or movement of the heated parts of a liquid or gas. (Definition- Dictionary)

3. Radiation- Radiation is energy that comes from a source and travels through some material or through space. Light, heat and sound are types of radiation. The kind of radiation discussed in this presentation is called ionizing radiation because it can produce charged particles (ions) in matter. (Definition – Wikipedia)

In this experiment I have used convection to heat 200 ml of water and then transferred the same amount of water into an insulated container (by recycled materials) to allow the liquid to lose heat, which was recorded using logger pro Vernier. Further I have tested the insulation capacity of recycled materials of different densities, to examine the relationship between the density of recycled materials and its heating capacity, which may further lead to the discovery of a material perfect for cooking and insulation. Safety in the investigation. During the experiment I have ensured complete safety of myself, to my peer and to the nature.

2 Design

2.1 Apparatus

1. Thermocol
2. Cardboard
3. Bubble Wrap
4. Polystyrene
5. Vernier Logger Pro
6. Temperature probe
7. Laptop
8. Thermometer
9. One Beaker (200 ml) (big)
10. One small Beaker (100 ml)
11. Tongs
12. Tape
13. Logger Pro 3.8.4 Software
14. Water 200 ml

2.2 Hypothesis

- Statement - The Large number of air spaces in the material, greater the insulation capacity.
- Physics Theory

2.3 Variables

- Independent Variable – density of material
- dependent Variable – rate of cooling
- Controlled Variables - thickness, amount of water used, initial temperature, the surroundings of beaker, layer of insulation, the time interval for which temperature drop was observed.

Variable	**Effect of variable on the experiment**	**How to control the variable?**
The Amount of Water used for the investigation for each material	Energy lost to surrounding due to drop of temperature for different amount of water varies.	The water was measured to 200ml with the help of another beaker before being poured into the insulated beaker..
The initial temperature of Water	Different initial temperatures would result in inaccurate data and unsuitable for comparison among gradient of different materials..	The temperature of the water was measured to be 70 degree Celsius before data collection using Vernier Temperature Probe.
Thickness of the material	Different thickness would strengthen the insulating power of a material and hence would be ineffective for comparison with other materials equivocally.	When the material of the size of beaker is cut out, it is made sure that the thickness is same as other materials. The thickness is roughly measured with a small ruler for high precision of result.
The time interval for which the temperature was observed.	Different time interval time interval or less time interval would result in collection of data unfit for comparison and conclusion.	The time interval was measured by the Logger Pro, hence it was pre set before data collection.
Layer of Materials of similar thickness used	It would affect the insulation capacity of materials, since greater layering would make it a strong insulator.	Only one layer of each material was utilised for the experiment.

2.4 Procedure

- Cut out a piece of cardboard adequate to cover the beaker (200ml). Wrap that piece around the beaker and mark any extra amount of cardboard to be cut out.
- Place the Beaker upside down on another piece of cardboard and trace the shape of the opening of the beaker. Cut out the leaving a margin of 0.5cm.
- Now trace the base of the beaker and repeat second part of step 3.
- Using tape cover the beaker with all the three pieces of cardboard and make a hole for the temperature probe to fit through it.
- Now heat the water in a heater to 80 degrees.
- Meanwhile, set up the Logger Pro equipment and connect it to the laptop. Open the logger pro program, set the sample to 5 and the time to 300 seconds.
- Once the water is heated, Transfer the water using the small beaker to the big one twice, ensuring that the big beaker has 200 ml of water.
- Dip the Temperature probe into the beaker, check, once the temperature is 70 degrees, click on collect button situated at the center of the toolbar of logger pro application.
- Save the data collected.
- Repeat Steps 5 to 9 once more.
- Take a big piece of thermocol big enough to be cut into pieces and cover the beaker. Cut equally medium rectangular size of thermocol and tape it around the beaker without leaving any open gaps between them.
- Place the beaker on another piece of thermocol and trace the opening of the beaker. Cut out that piece leaving a margin of 0.5cm.
- Trace the base of the beaker and cut out that piece.
- Using all the three pieces cover the beaker. Make a hole on the top for the temperature probe to just fit through it.
- Heat the water in a heater to 80 degrees.
- Transfer the water using the small beaker into the big beaker, ensuring that the beaker has no more than 200ml of water.
- Dip the temperature probe, check, once the temperature is 70 degrees, click on the collect button situated at the toolbar.
- Save the data collected.
- Repeat steps 15 to 18 once more.
- Repeat steps 11- 19 with Bubble wrapper.
- Similarly repeat steps 11- 19 with Polystyrene
- Conclude and Evaluate

3 Gathering Data

At the lab, before collecting the data for each material, the instrument was setup with the laptop and the water was boiled to 80 0C. The instrument used for the purpose of recording the fall in temperature of water was Vernier Logger Pro and The Logger Pro Software. Meanwhile the beaker was prepared by insulating it with one of the four materials. As soon as the temperature of the water rose to 80 degrees Celsius, it was transferred to the insulated beaker. The Vernier temperature probe (used for recording the temperature of water) was dipped into the liquid and sampling rate was set to 300 per minute. When the temperature of the water was 70 degrees Celsius, I started collecting the data with time set to 300 seconds. This process was repeated twice for reducing the uncertainty of data. The Raw data consisted of Time and the Temperature. The following tables represent the raw data collected using the Logger Pro Software and setup. I have however represented a few readings to make it concise and short. Also, since the temperature didn't change drastically within seconds, I have shown the change in temperature every 10 seconds.

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4 Raw Data Table

S.no.	Time (seconds)	Temperature (Degrees Celsius) Cardboard		Temperature (Degrees Celsius) Bubble wrap		Temperature (Degrees Celsius) Thermocol		Temperature (Degrees Celsius) Polystyrene	
1	0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0
2	10	69.9	69.8	69.9	69.9	70.0	69.9	70.0	69.9
3	20	69.8	69.8	69.9	69.8	69.9	69.9	69.8	69.7
4	30	69.5	69.5	69.8	69.8	69.9	69.8	69.7	69.6
5	40	69.4	69.4	69.7	69.7	69.7	69.7	69.5	69.5
6	50	69.3	69.2	69.5	69.6	69.8	69.7	69.4	69.3
7	60	69.2	69.1	69.5	69.6	69.6	69.6	69.3	69.3
8	70	69.0	68.9	69.5	69.5	69.5	69.6	69.3	69.2
9	80	68.9	68.8	69.3	69.4	69.5	69.4	69.1	69.0
10	90	68.8	68.8	69.3	69.4	69.3	69.4	69.1	69.0
11	100	68.7	68.8	69.2	69.3	69.3	69.3	69.0	68.8
12	110	68.5	68.6	69.1	69.3	69.3	69.3	68.9	68.7
13	120	68.4	68.6	69.1	69.2	69.3	69.2	68.8	68.7
14	130	68.3	68.5	69.0	69.2	69.2	69.2	68.8	68.5
15	140	68.2	68.3	68.8	69.1	69.1	69.1	68.7	68.4
16	150	68.1	68.3	68.7	68.9	69.0	69.0	68.6	68.4
17	160	68.0	68.0	68.7	68.8	68.8	69.0	68.5	68.3
18	170	67.8	67.9	68.6	68.7	68.8	68.9	68.4	68.2
19	180	67.7	67.9	68.4	68.6	68.8	68.8	68.4	68.2
20	190	67.7	67.7	68.4	68.6	68.8	68.7	68.3	68.1
21	200	67.5	67.6	68.4	68.5	68.6	68.7	68.2	68.0
22	210	67.4	67.5	68.4	68.4	68.4	68.6	68.1	67.9
23	220	67.3	67.4	68.2	68.4	68.4	68.6	68.0	67.8
24	230	67.1	67.3	68.0	68.3	68.3	68.5	67.9	67.8
25	240	67.1	67.1	68.0	68.3	68.4	68.4	67.7	67.7
26	250	67.0	67.1	68.0	68.3	68.3	68.4	67.6	67.7
27	260	66.9	67.0	68.0	68.3	68.1	68.4	67.5	67.5
28	270	66.8	66.8	67.9	68.2	68.1	68.4	67.4	67.4
29	280	66.7	66.8	67.9	68.1	68.1	68.3	67.4	67.4
30	290	66.6	66.7	67.7	68.0	68.0	68.2	67.2	67.3
31	300	66.5	66.5	67.7	67.9	67.8	68.1	67.2	67.2

5 Processing the Data

To reduce the uncertainty in data and maintain the precision, the data has been processed using excel sheet. The change in temperature was calculated with the formula $\frac{T1+T2}{2}$.

To obtain the change in temperature the average temperature is subtracted from the original temperature. Hence the value of change in temperature vs. time is graphed to derive the rate of cooling from the gradient of the graph. For the purpose of convenient comparison of data I have converted seconds into minute while finding the gradient of the graph as the following example: $G_{\text{cardboard}} = \frac{y1-y2}{x1-x2} = \frac{3.55-0.10}{300-10} = \frac{3.45}{290} = \frac{3.45}{4.833} = 0.71\ Km^{-1}$

Seconds to minute conversion = 1 min= 60 seconds, 1 second = $\frac{1}{60}$seconds

Hence 290 seconds = $\frac{290}{60}$min = 4.833 min.

The similar data processing was carries out for each of the three materials too.

5.1 Why I chose these four materials?

Out of the various recyclable materials, these are the most commonly available or abundant. If needed, it can be provided sufficiently at the required regions. Also, by personal experience, I know that Bubble wrap is most commonly used for packing couriers, fragile materials, and is used ubiquitously, hence this material, if used as insulation will be a greater benefit to society , by reducing carbon footprints. The other three include Thermocol, Polystyrene and cardboard. The materials were uniformly cut out with equal sizes sufficient to cover the beaker. Also the size of the lid was same for each of the materials. I cut out the materials by taking precise measurements of length and width necessary, avoiding uncertainties. At the lab there was Aluminum foil, newspaper, however, since I decided to find out results that would qualify to be applicable in real life, I chose materials with greater density and thickness.

Before beginning my experiment, I tested cardboard to check if it was plausible. The test experiment was successful as per my plan and therefore I continued to starting of with my investigation.

5.2 Processed Data

Measurement of the gradient of the graph

The Maximum and minimum gradient is calculated using the formula for slope of a graph –

$\frac{y1-y2}{x1-x2}$. Here since time was measured in seconds was converted into minutes by - (x1-x2)/2

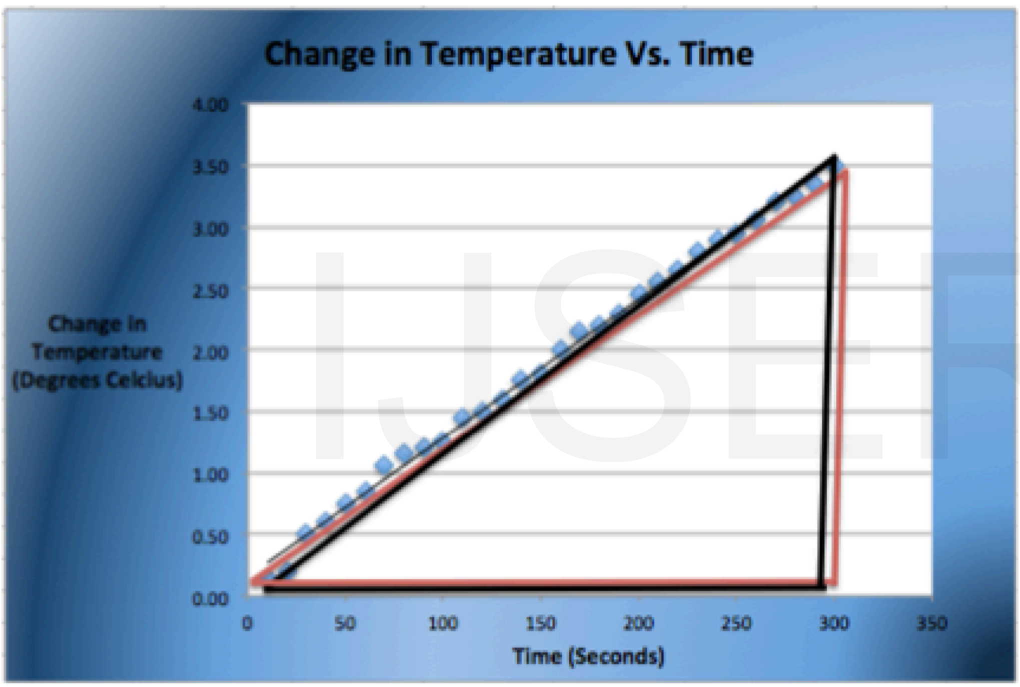
The Gradient of the graph has been measured by calculating the average gradient of maximum gradient and minimum gradient of the graph. Uncertainty of the Gradient is calculated using the formula (max. Gradient – min. Gradient)/2.

6 Processed Table 1

S.no	Time (±1 seconds)	Cardboard		Polystyrene	
		Average Temperature	Change in Temperature (±0.05)	Average Temperature	Change in Temperature (±0.05)
1	0	**70.00**	**0.00**	70.00	0.00
2	10	**69.85**	**0.15**	69.95	0.05
3	20	**69.80**	**0.20**	69.75	0.25
4	30	**69.50**	**0.50**	69.65	0.35
5	40	**69.40**	**0.60**	69.50	0.50
6	50	**69.25**	**0.75**	69.35	0.65
7	60	**69.15**	**0.85**	69.30	0.70
8	70	**68.95**	**1.05**	69.25	0.75
9	80	**68.85**	**1.15**	69.05	0.95
10	90	**68.80**	**1.20**	69.05	0.95
11	100	**68.75**	**1.25**	68.90	1.10
12	110	**68.55**	**1.45**	68.80	1.20
13	120	**68.50**	**1.50**	68.75	1.25
14	130	**68.40**	**1.60**	68.65	1.35
15	140	**68.25**	**1.75**	68.55	1.45
16	150	**68.20**	**1.80**	68.50	1.50
17	160	**68.00**	**2.00**	68.40	1.60
18	170	**67.85**	**2.15**	68.30	1.70
19	180	**67.80**	**2.20**	68.30	1.70
20	190	**67.70**	**2.30**	68.20	1.80

21	200	**67.55**	**2.45**	68.10	1.90
22	210	**67.45**	**2.55**	68.00	2.00
23	220	**67.35**	**2.65**	67.90	2.10
24	230	**67.20**	**2.80**	67.85	2.15
25	240	**67.10**	**2.90**	67.70	2.30
26	250	**67.05**	**2.95**	67.65	2.35
27	260	**66.95**	**3.05**	67.50	2.50
28	270	**66.80**	**3.20**	67.40	2.60
29	280	**66.75**	**3.25**	67.40	2.60
30	290	**66.65**	**3.35**	67.25	2.75
31	300	**66.50**	**3.50**	67.20	2.80

6.1 Cardboard



Gradient

Maximum Gradient

G = $\frac{y1-y2}{x1-x2} = \frac{3.55-0.10}{300-10}$ = 0.71 Km^{-1}

Gradient =

$\frac{max.gradient+min.gradient}{2}$

= $\frac{0.71+0.67}{2}$

= 0.69 Km^{-1}

Minimum Gradient

G = $\frac{y1-y2}{x1-x2} = \frac{3.45-0.20}{300-10}$ = 0.67 Km^{-1}

Uncertainty in the Gradient =

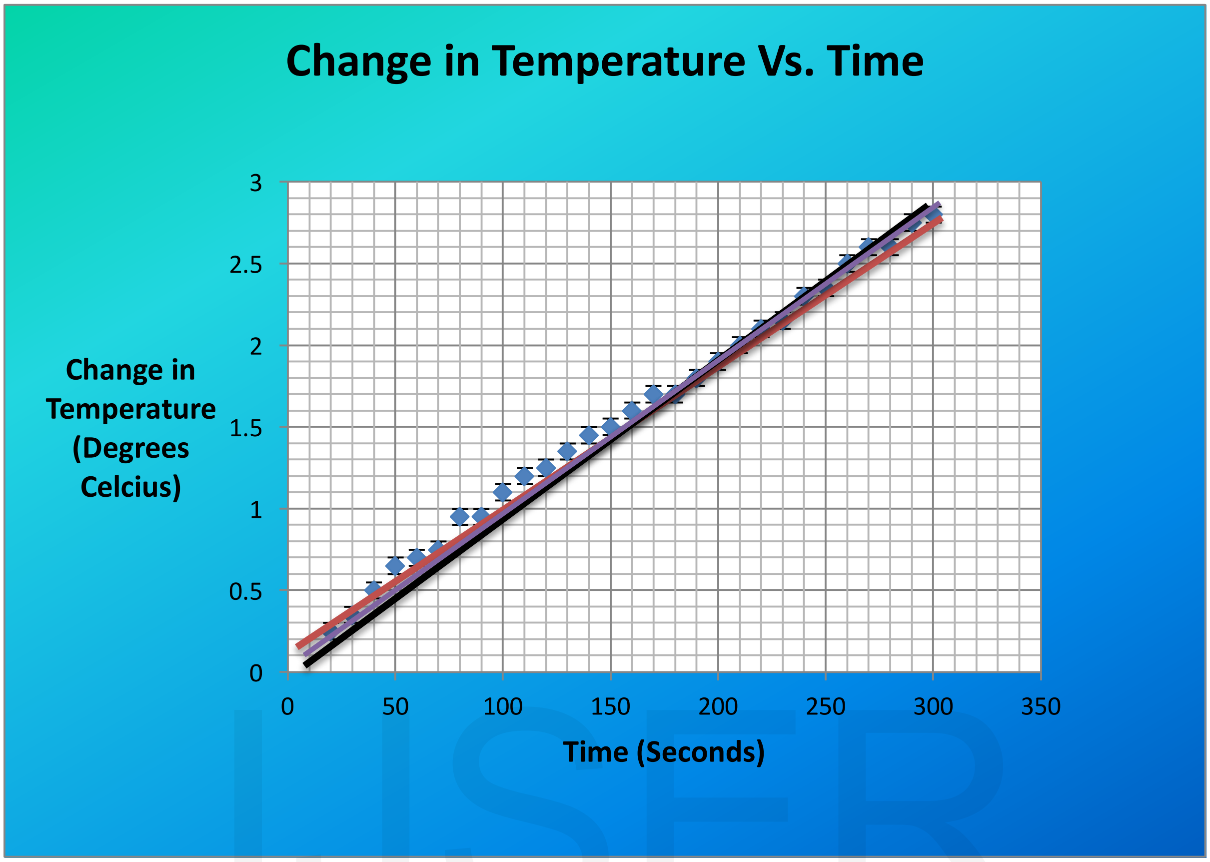
$\frac{max.gradient-min.gradient}{2}$

=(0.71-0.67)/2

= ±0.02 Km^{-1}

Gradient - 0.69 ± 0.02 Km^{-1}

6.2 Polystyrene



Gradient of the Graph (Polystyrene)

Gradient of the Graph = Rate of change of Temperature

Maximum Gradient

$$G = \frac{y1-y2}{x1-x2} = \frac{2.75-0.10}{300-10} = \frac{y1-y2}{x1-x2} = 0.55\,Km^{-1}$$

$$\frac{max.gradient+min.gradient}{2}$$

$$\frac{0.59+0.55}{2}$$

0.57 Km^{-1}

Minimum Gradient

$$\frac{y1-y2}{x1-x2} = \frac{2.85-0.00}{300-10} = 0.59\,Km^{-1}$$

Uncertainty in Gradient

$$\frac{max.gradient-min.gradient}{2}$$

= (0.59-0.55)/2

= **± 0.02 Km^{-1}**

Gradient of the Graph = 0.57 ± 0.02 Km^{-1}

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7 Processed Table 2:

S.no	Time (±1)	Thermocol		Bubble Wrap	
		Average Temperature (Degree Celsius)	Change in Temperature (±0.05)	Average Temperature (Degrees Celsius)	Change in Temperature (Degrees Celsius)
1	0	70.00	0.00	70.00	0.00
2	10	69.95	0.05	69.95	0.05
3	20	69.90	0.10	69.90	0.10
4	30	69.85	0.15	69.85	0.15
5	40	69.70	0.30	69.75	0.25
6	50	69.75	0.25	69.65	0.35
7	60	69.60	0.40	69.60	0.40
8	70	69.55	0.45	69.60	0.40
9	80	69.45	0.55	69.40	0.60
10	90	69.35	0.65	69.40	0.60
11	100	69.30	0.70	69.35	0.65
12	110	69.30	0.70	69.25	0.75
13	120	69.25	0.75	69.25	0.75
14	130	69.20	0.80	69.15	0.85
15	140	69.10	0.90	69.15	0.85
16	150	69.00	1.00	69.00	1.00
17	160	68.90	1.10	68.90	1.10
18	170	68.85	1.15	68.80	1.20
19	180	68.80	1.20	68.70	1.30
20	190	68.75	1.25	68.60	1.40
21	200	68.65	1.35	68.60	1.40
22	210	68.50	1.50	68.55	1.45
23	220	68.50	1.50	68.50	1.50
24	230	68.40	1.60	68.45	1.55
25	240	68.40	1.60	68.40	1.60
26	250	68.35	1.65	68.30	1.70
27	260	68.25	1.75	68.25	1.75
28	270	68.25	1.75	68.20	1.80
29	280	68.20	1.80	68.15	1.85
30	290	68.10	1.90	68.05	1.95
31	300	67.95	2.05	68.00	2.00

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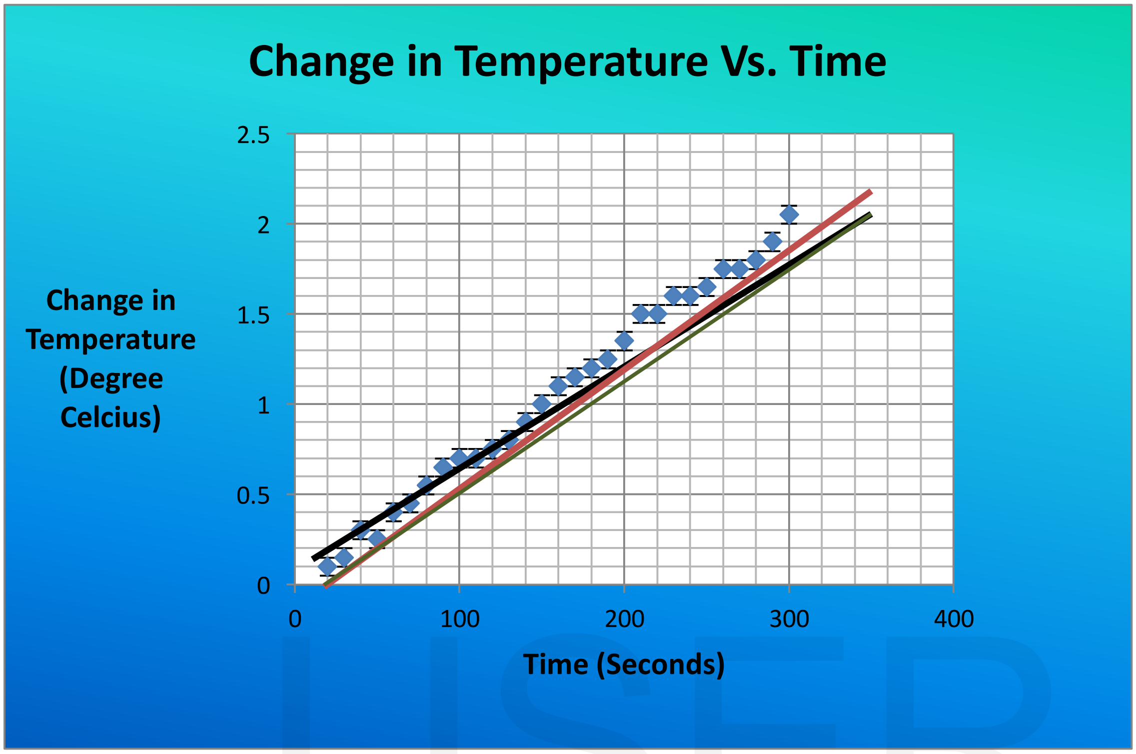
7.1 THERMOCOL



Gradient of the Graph (Thermocol)

Gradient of the Graph = Rate of change of Temperature

Maximum Gradient

G = $\frac{y1-y2}{x1-x2} = \frac{2.10-0.00}{300-10}$ = 0.44 Km^{-1}

Gradient =

$\frac{max.gradient+min.gradient}{2}$

$\frac{0.44+0.40}{2}$

0.42 Km^{-1}

Minimum Gradient

G = $\frac{y1-y2}{x1-x2} = \frac{2.00-0.10}{300-10}$ = 0.40 Km^{-1}

Uncertainty in Gradient =

$\frac{max.gradient-min.gradient}{2}$

$\frac{0.44-0.40}{2}$

= ±0.02 Km^{-1}

Gradient =0.42 ±0.02 Km^{-1}

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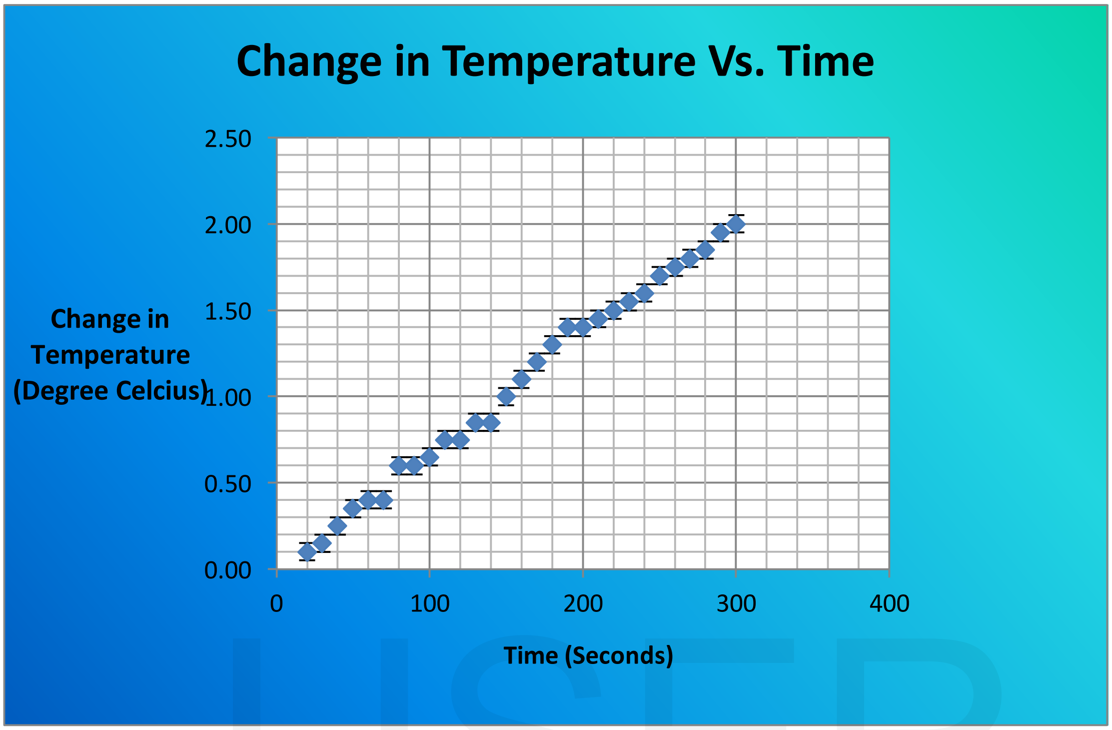
7.2 Bubble Wrap



Gradient

Maximum Gradient

$G = \frac{y1-y2}{x1-x2} = \frac{2.05-0.00}{300-10} = 0.42\ Km^{-1}$

Minimum Gradient

$G = \frac{y1-y2}{x1-x2} = \frac{1.95-0.10}{300-10} = 0.38\ Km^{-1}$

Gradient =

$\frac{max.gradient+min.gradient}{2}$

$\frac{0.42+0.38}{2}$

0.40 Km^{-1}

Gradient - 0.40 ± 0.02 Km^{-1}

Uncertainty in Gradient =

$\frac{max.gradient-min.gradient}{2}$

$\frac{0.42-0.38}{2}$

= ± 0.02 Km^{-1}

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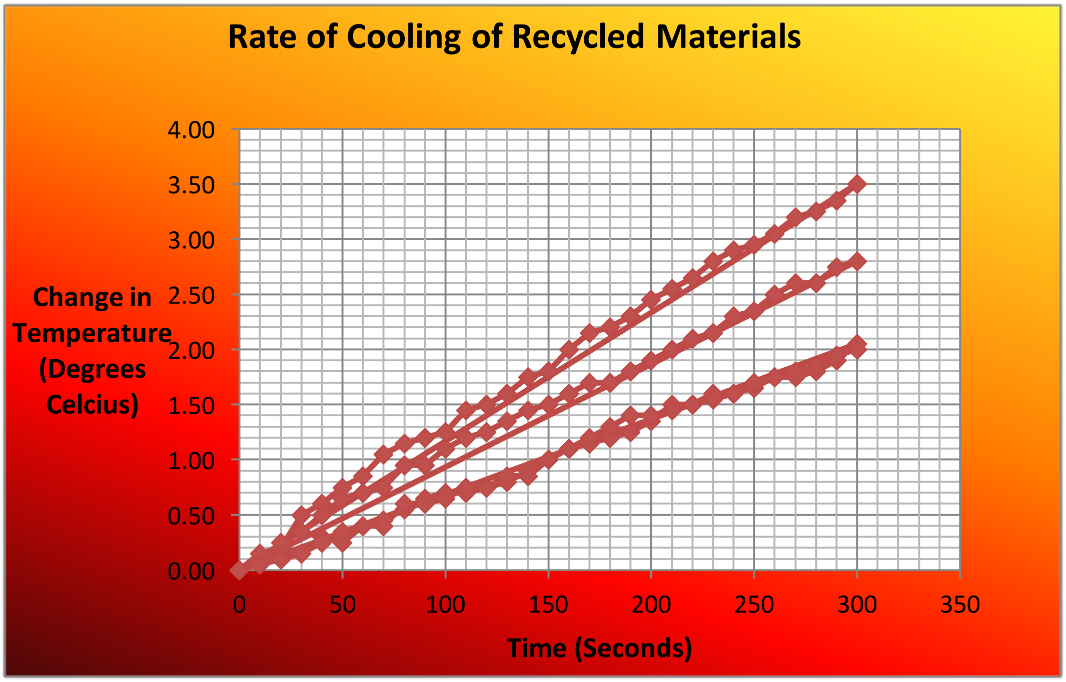

A – Graph of Bubble Wrap B – Graph of Thermocol C – Graph of Polystyrene D- Graph of Cardboard

8 Conclusion and Evaluation

For each material Change in Temperature vs. Time was plotted, whose gradient was the rate of cooling of the material. All the graphs were more or less linear, which indicates that there were no fluctuations in change in temperature, therefore eliminating the presence of great uncertainties and proving that recycled materials qualify for utilisation as insulators. Also, it also proves them to be stable in losing heat to the surroundings. Hence the experiment was successful in keeping up with the expectations of the results.

From the rate of cooling of different recyclable materials, an average rate of cooling of insulating materials can be obtained using the formula

$$= \frac{\textbf{\textit{Sum of the rate of cooling of different materials}}}{\mathbf{2}}$$

Therefore the average rate of cooling = (0.40+0.42+0.57+0.69)/4

= **0.52 K $\mathbf{m^{-1}}$ ± 0.06** (Adding all the uncertainties)

The average rate of cooling is low, therefore being a good insulator which can be useful in rural area for a variety of purposes such as cooking; insulating food, liquids etc. This rate of cooling is only for one thin layer of insulation of the recycled materials, With increase in the layers , the insulation capacity will be greater this, which is quite suitable for implementing for crucial aspects in our daily lives.

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9 Uncertainties

Analysing the environment in and process with which the experiment was carried out, the uncertainty for each of the below mentioned quantities have been considered by taking into account possible systematic errors and other factors, which may have minutely affected the experiment. It is critical to consider any possible uncertainty to understand the limitation and the scope of results applicable in real life situations. Although , it was very much taken care of for minimal uncertainty, however , it is salutary for considerations of external properties.

9.1 Uncertainty for Temperature

The uncertainty for temperature is taken to be $\pm 0.05^0$ C. various factors account for this uncertainty of the value. Since The value was measured by Vernier Logger Pro, the possibility of uncertainty is minimal.

- Systematic error- calibration problem in the instrument. Possibility of the instrument of being internally faulty.
- The Temperature of the Surrounding – Varying conditions of the surrounding result in unpredictable consequences.
- The slab on which the experiment is conducted may affect the out result.
- Variable Thickness of the materials, since it was cut out physically, there is a fair chance of inaccuracy of the thickness of each of the four materials.
- Possibility of leakage of heat due to holes or gaps in the insulating materials
- The presence of minute cracks in the material during the experiment.

9.2 Uncertainty for Time

The Time was also measured by the Logger Pro software, hence there is minimum uncertainty in its value but several factors such as Systematic error- due to calibration problem in the instrument or faulty device could contribute to additional uncertainty. Therefore considering the above mentioned factors, the uncertainty for time is taken to be ±1sec.

10 Analysis of Data

The Graph of Change in Temperature vs. Time of each material indicates the rate of cooling. The Gradient of the graph is the average rate of cooling of each of the materials. The usual insulation of substances are.......compared to that ....the recycled materials have given surprising results which make viable for usage at rural areas.

The insulation capacity is almost the same for all the materials, indicating its potential of conserving energy and aiding the poor with several household and daily works.

All the graphs are linear, indicating a steady rate of cooling, therefore these materials do not allow heat to escape quickly, and rather they resist the rate of the heat lost uniformly to the surrounding. The absence of fluctuations or sudden decrease or increase in rate of cooling certifies them to be reliable sources of insulation.

11 Limitations and Scope of the Investigation

- The no of trials were 2 and each trial consisted of 1 reading at every 10 second time interval, this is would not have been able to produce a perfect data. With greater data collection, the result would have been more precise.
- Heat loss by water is not equal to heat loss by other food items or high density liquid, so trials with different liquids or food items could magnify the insulating capacity of recycled materials
- Experiment carried out for greater time interval would have improved its results.
- Since materials such as Thermocol and polystyrene do not perfectly insulate the container de to their shape and inflexibility to bend , there was fair possibility of varying results of these two materials.
- The amount of water should be measured properly in order to avoid misleading results. Since the Water was directly poured after heating , there are fair chances of inaccuracy in the measurement of amount of water used. However, the water was roughly measured before poured into the beaker.
- The thickness of the materials could be maintained with greater accuracy by paying considerable attention to the thickness of each material.
- In conclusion the density of the liquid affects the insulation capacity of the recyclable materials.

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12 NEWTON'S LAW OF COOLING

- This law states that Newton's Law of cooling states that the rate of change of the temperature of an object is proportional to the difference between its own temperature and the ambient temperature (i.e. the temperature of its surroundings).
- Therefore this could have affected my investigation due to minute changes in temperature of the room.

THE EXPERIMENT CAN BE IMPROVED BY:

1. Calibration of the instrument to check for systematic error
2. Increasing the no of trials to find out change in temperature along with time could decrease the uncertainty of the experiment; in addition it would widen the scope of the investigation.
3. Increasing the time period for which the readings are collected could bring about some improvement too.
4. Testing the software 's accuracy with all the four materials before using it to record the data
5. Maintaining a constant temperature of the surrounding room or area by carrying out the experiment in a closed box.