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Conductivity Test for Plastic Fiber, and Comparison with other Insulating Materials

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Abstract: Era of 21 century study of environment and pollution has become major concern in developing countries like India. Urbanisation and Industrialisation with huge population drag our attention towards practical problems like Waste Management, their scientific solution also to find possibilities to reuse and recycle them to save our resources and energy. With present knowledge and possible resources we have tried to find some of the optimal solution to Non-Biodegradable waste like plastic (specially waste PET Bottles). Also we have find after use solution of products and article. Economical consideration, Social impact, Capacity building and Technical experiments are done during research work on this topic.

The fiber used in test procedure below was mixture partially virgin and partially recycled. So its conductivity was obtained and compared with other available insulating materials with available data. Results were quite satisfactory, which shows that, recycled polyester fiber obtained from waste PET bottles and after their Reuse life can be used in industrial as well as domestic insulation and warm clothes like winter jacket. It can be predicted that 100% recycled fiber will exhibit better insulating properties, because structure of recycled fiber will be deteriorated during recycling process, it will show poor physical and thermal properties than virgin fiber. Poor thermal conductivity will give better insulating properties, which satisfies our aim of converting used PET bottles to fiber, and use them as insulating material.

Also possibilities can be discovered to use them directly convert them to fiber thread to make clothes. Small plant can be setup near municipal cities, it will help rural economy to grow and small level employment generation.

***Keywords*: Biodegradable, Non-Biodegradable, Conductivity, PET bottles, Waste, Recycled Polyester fiber, Insulation.**

I. INTRODUCTION

PET bottles are mainly converted into flakes or fiber after use. Which are used as fibber in winter jackets as an insulating material as well as they can be used in industries and replace asbestos (0.16 W/m ºC), Timber (0.12-0.16 W/m ºC), Wool oak (0.17 W/mºC), Rubber natural (0.13 W/mºC), Sand dry (0.15-0.25 W/mºC), PVC (0.19 W/mºC).; because of its flexibility and low water absorption versatile characteristics. In experiment we have used Polyester fiber available in market which is made from virgin fiber mixed with recycled fiber. Fully Recycled fiber will give us less conductivity value means more resistance to heat flow due to its rearrangement of molecular structure. That will be more useful in insulation purpose.

II. EXPERIMENTAL SETUP

Two co-centric steel cylinders are taken for experiment. The space between these co centric cylinders are filled with insulating material like Cotton and Recycled polyester fiber. Inner cylinder is heated by the apparatus and the consecutive readings of V (voltage) and I (current) are noted down to calculate the value of heat supplied. Heat will be conducted from inner cylinder to outer cylinder by the mode of "Conduction". Temperatures of inner and outer surface are taken by use of thermocouple and at last their average mean value s taken to reduce the possibilities of error during the experiment process.

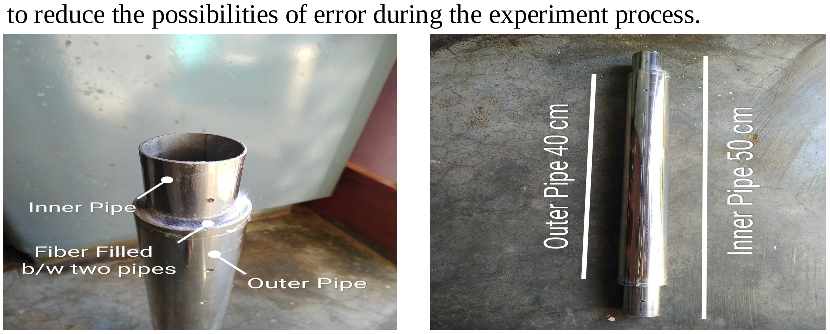

Fig.: Pipe assembly

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Pipe assembly consist of two concentric steel hollow pipe (cylinder). Between their radial spacing fibers is filled. Inner pipe will contain Heater. So heat will flow from inner pipe to outer pipe through fiber. Fiber will resist this heat flow because of its lower thermal conductivity *k*.

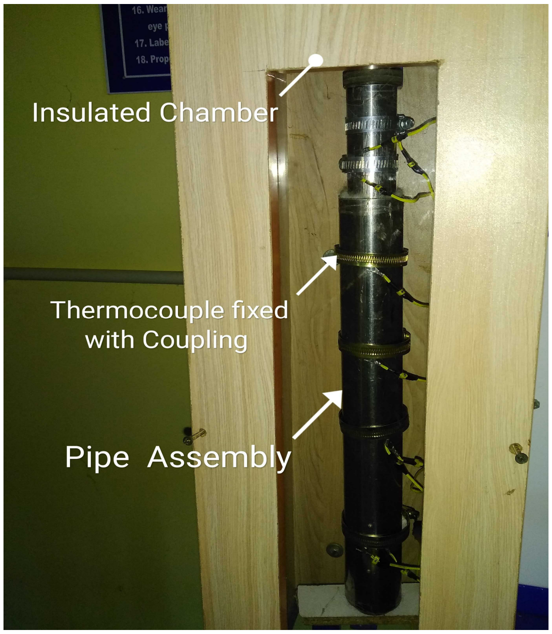

Fig.: Pipe assembly inside experimental chamber. Thermocouples on inner and outer surface

Table: Specifications of experimental arrangements

Material	Steel Pipe and Polyester fiber
Diameter of inner cylinder (pipe)	3.87×10^{-3} m
Diameter of outer cylinder (pipe)	5.15×10^{-3} m
No of thermocouple used	2 on inner cylinder surface 3 on outer cylinder surface

III.THEORY

A. Consider the transfer of heat by mode of conduction through the wall of a hollow cylinder formed of insulating fiber. Consider the pipe is ppipe is insulated at end or it is of sufficient length by which heat loss from end are negligible. If T_i is greater than T_o then heat will flow from inner tube to outer tube. The process will be described by Fourier's law as follow.

$$Q = -kA\frac{dT}{dr}$$

Integrating radius from r_1 to r_2 and corresponding temperature limits of T_i to T_o we get

$$Q\int_{r1}^{r2}\frac{dr}{r} = -k.2\pi L.\int_{Ti}^{To} dT$$

$$Q.\ln\frac{r2}{r1} = -k.2\pi L.(To - Ti)$$

$$Q = \frac{k.2\pi L.(Ti - To)}{\ln\frac{r2}{r1}}$$

So it can be written for conductivity, *k* (in W/mK) as follows

$$k = \frac{Q.\ln\frac{r2}{r1}}{2\pi L.(Ti - To)}$$

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Let,

r_1 = radius if inner cylinder
r_2 = radius of outer cylinder
T_i = average (mean) temperature of inner surface ºC
T_o = average (mean) temperature of outer surface ºC
L = length of the pipe
Q = heat input in watts
k = conductivity of insulator W/mK

B. Assumptions

1) Insulating material is isentropic.
2) Heat flows in one dimensional.
3) Spacing filled with insulating fiber is constant between the cylinders.
4) Density of fiber filled between the cylinders are constant throughout the length.
5) Readings are taken when temperature values are not changing and they reached steady state.
6) Heater efficiency is maximum, so temperature of heater and inner cylinder surface is same.
7) Setup is completely insulated from environment with help of glass covering.

IV. TESTING AND CALCULATION

A. Observation Table

Ambient Temperature
23 ºC for Day-1 (Observation 1, 2) and
21 ºC for Day-2 (Observation 3,4,5)

After first set of reading it is clear that steady state reaches after 90 minutes (approx.) so we decided to take next set readings for 90 minutes with an interval of 30 minutes to check temperature variation. Inner surface average temperature $T_{i\ avg}$ and outer surface average temperature $T_{o\ avg}$ are calculated for last reading which is very close to steady state condition.

1) Thermocouple T_8 and T_9 were attached to inner surface pipe.
2) Thermocouple T_1, T_3 and T_5 were attached to outer surface pipe.
3) Ambient Temperature

23 ºC for Day-1 (Observation 1, 2) and
21 ºC for Day-2 (Observation 3,4,5)
Set 1: V=17.25 volt, I=0.10 amp

Time interval min	Inner surface (pipe) thermocouple temperature Ti			Outer surface (pipe) thermocouple temperature To			
	T_8	T_9	$T_{i\ avg}$	T_1	T_3	T_5	$T_{o\ avg}$
0	27.6	27		27	27.5	27	
10	29.2	28.4		28.5	28	28.2	
20	30.3	29.1		29.3	28.4	28.9	
30	31	29.8		29.9	28.7	29.6	
40	31.6	30.2		30.4	28.8	30.1	
50	32.1	30.6		30.7	30.6	30.5	
60	32.7	31.2		31.2	28.9	31.1	
70	33.6	31.7		32.0	29.2	31.9	
80	33.8	32.3		32.4	29.5	32.3	
90	34	32.5	33.25	32.6	29.7	32.5	31.6

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Set 2: V=32 volt, I=0.21 amp

Time interval min	Inner surface (pipe) thermocouple temperature Ti			Outer surface (pipe) thermocouple temperature To			
	T_8	T_9	$T_{i\ avg}$	T_1	T_3	T_5	$T_{o\ avg}$
0	34	32.2		31.9	29	32.1	
30	40	39.2		34	29.4	35	
60	41.1	40.9		34.9	35	35.8	
90	44	42.8	43.4	35.6	37	36.8	36.46

Set 3: V=39.6 volt, I=0.25 amp

Time interval min	Inner surface (pipe) thermocouple temperature Ti			Outer surface (pipe) thermocouple temperature To			
	T_8	T_9	$T_{i\ avg}$	T_1	T_3	T_5	$T_{o\ avg}$
0	40.9	39.7		33.3	34.2	33.8	
30	48.5	46.9		37.6	39.5	39.2	
60	53.1	51.3		40	42.3	42.6	
90	55.7	53.7	54.7	41.1	44	44.2	43.1

Set 4: V=49.8 volt, I=0.34 amp

Time interval min	Inner surface (pipe) thermocouple temperature Ti			Outer surface (pipe) thermocouple temperature To			
	T_8	T_9	$T_{i\ avg}$	T_1	T_3	T_5	$T_{o\ avg}$
0	55	53		41	44	44	
30	63.1	60.6		44.4	48.5	48.5	
60	65	62.1		44.9	49.0	49.3	
90	65.2	62.2	63.7	44.8	49.1	49.4	47.76

Set 5: V= 59.8 volt, I=0.40 amp

Time interval min	Inner surface (pipe) thermocouple temperature Ti			Outer surface (pipe) thermocouple temperature To			
	T_8	T_9	$T_{i\ avg}$	T_1	T_3	T_5	$T_{o\ avg}$
0	65.2	62.3		44.7	49.1	49.4	
30	73.6	70.3		48.6	53.6	54.2	
60	77.8	74		50.6	56	57	
90	81	77.2	79.1	52	58.6	59	56.46

B. Calculation

V = Voltmeter reading in volts

I = Ammeter reading in amp

Q = V x I Heat input in watts

r_1 = radius if inner cylinder = 3.87×10^{-3} m

r_2 = radius of outer cylinder = 5.15×10^{-3} m

L =length of inner surface (effective) pipe = 40×10^{-2} m

T_i = Average (mean) temperature of inner surface ºC

T_o = Average (mean) temperature of outer surface ºC

Table ; Calculation table

Set No	Voltage V (volts)	Current I (amp)	Heat Q (watt)	Average inner surface (pipe) temperature ºC	Average outer surface (pipe) temperature ºC	Conductivity k (W/mK)
1	17.25	0.10	1.725	33.25	31.6	0.1188
2	32	0.21	6.72	43.4	36.46	0.11008
3	39.6	0.25	9.9	54.7	43.1	0.09702
4	49.8	0.34	16.932	63.7	47.76	0.1207
5	59.8	0.40	23.91	79.1	56.46	0.1201

From above equation for conductivity we can simplify with values of r1, r2 and L, we get

$$k = \frac{Q.\log_e \frac{r2}{r1}}{2.\pi.L.(Ti - To)}$$

$$k = \frac{Q.\log_e \frac{5.15}{3.87}}{2.\pi.(0.4).(Ti - To)}$$

$$k = \frac{Q.(0.2857422)}{(Ti - To).(2.513274)}$$

$$k = \frac{V.I.(0.113693)}{(Ti - To).}$$

We will put various values of V,I,Ti, and To to get value of *k* (conductivity) in above equation
Here, *k*= conductivity of plastic fiber in W/mK

V. RESULTS AND DISCUSSION

A. Here we will plot graph between steady state average inner surface pipe temperature "$T_{i\ avg}$" and conductivity "*k*". To get a clear vision that how conductivity behaviour of plastic fiber changes with varying temperature conditions

Thermal conductivity is thermodynamic property of material. Thermal conductivity of solid and liquid is largely independent of pressure and depends on temperature only. It can be concluded that-

K= k (T)

Value of observation 3 differs from other values, it may be because on 2nd day pre heating time given to instrument was 30 minutes lesser than first day which was approx. 90 minutes because of setup arrangements. So the air particles were heated well on first day and less deviation is obtained in 1st and 2nd reading. Whereas 3rd reading which is first set of reading for second day is showing less conductivity because fiber and air particles were not heated properly also the atmospheric temperature of second day(21 ºC) was lesser than first day(23 ºC). so these initial parameters caused deviation in 3rd observation.

Table: Temperature v/s Conductivity value

Set no	Average inner surface (pipe) temperature Ti ºC	Conductivity *k* (W/mK)
1	33.25	0.1188
2	43.4	0.11008
3	54.7	0.09702
4	63.7	0.1207
5	79.1	0.1201

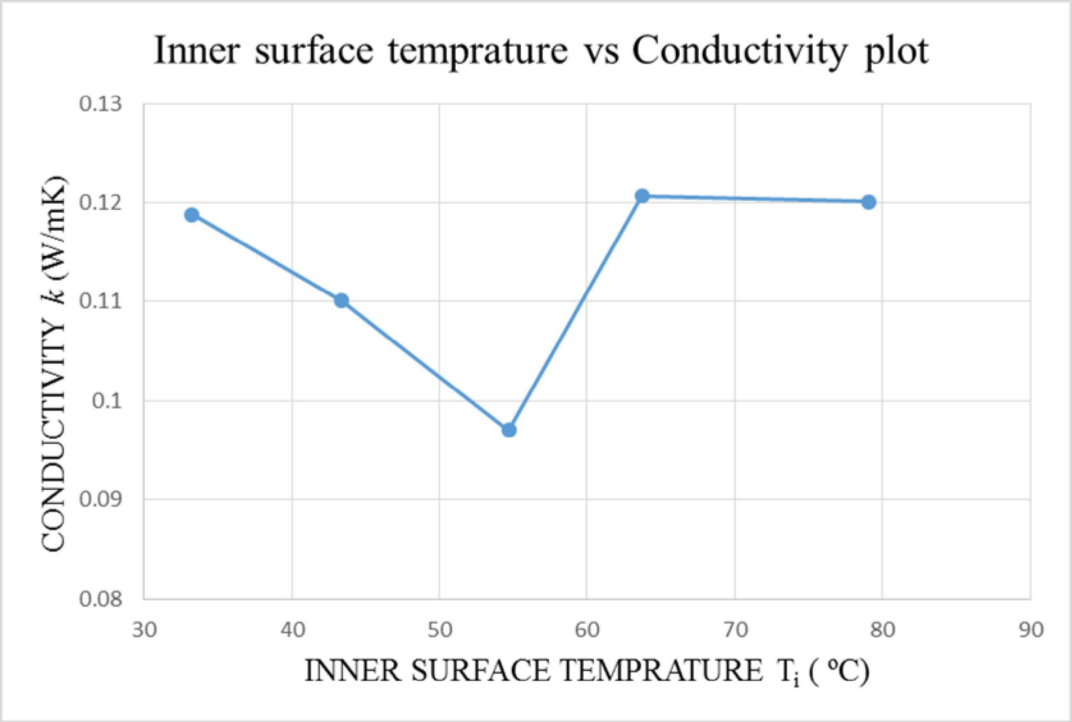

Fig: Plot between Average Inner surface temperature Ti (ºC) and Conductivity k (W/mK).

B. Validation of Result

We can conclude that our Test value for conductivity *k* ranges from 0.097 to 0.1207 W/mK. Which falls in range (approximately) as author calculated in their experiment shown below.

Table: Various material and their Conductivity obtained by experiment.

Material	Jacket Type	Conductivity k (W/mK)
NYLON RIPSTOP	NF-D-J	0.157
RECYCLED POLYESTER	PT-D-J	0.124
RECYCLED POLYESTER	PT-D-V	0.178
POLYESTER	MT-D-V	0.161
RECYCLED POLYESTER	PT-NP-JW	0.105
RECYCLED POLYESTER	PT-NP-JM	0.114
NYLON	PT-NA-J	0.107
THERMOBALL NYLON	NF-TB-J	0.120

Source: Emma Steinhardt.2015.Determing an easily measured factor of merit for the thermal performance of jackets. MIT. USA Measurement and Instrumentation. [2.671]-2015

C. Justification To Convert Plastic Waste To Fiber

Plastic is an outstanding product and versatile in use. But still it is causing harmful effect for both human and environment. That's why we are focusing on Reuse and Recycling of plastic waste. Which is thoroughly analysed during this project work with best of my knowledge and availability of resources.(Report: SRI India)

1) *Employment:* No special skills are required for collection, sorting, packing the bulk. Both men and women can be employed. Number of employees may vary as per availability of waste at particular city and size of the recycling plant.
2) *Salary:* As per report mentioned above salary of employees ranges from 200-700 Rupee per day.

3) *Profit:* From report above and the research done on various internet sources it can be concluded that 50000 to 100000 Rupee per month profit can be generated.
4) *Fiber and Fake Characteristics:* Recycled fiber shows better quality and versatile weather usability than natural cotton fiber. It can replace natural cotton from winter jackets because it is water resistance and light in weight. It can replace asbestos as insulator because of its flexibility and usability in any shape. Flakes are used as raw material to make new plastic products.

D. Future Scope Of This Project

Skilled and unskilled workers can use both suggestions given in our research work. Recycling plant of Flakes and Fiber will need some small amount of investment which can be funded by government by many available schemes. Chhattisgarh state government is going to set up Plastic Park in Rajnandgaon district near Khairjhiti village. It is clear that recycled flakes and fiber will generate a great start-up opportunity in upcoming future in our state.

Our research work can be further extended by finding more Reuse options to other Non-Biodegradable waste which we did not included in our research work. Articles made by us (Stool, Table) can be tested with furniture testing machine for better technical understanding of possible failures also possibilities can be investigated to reduce overall cost.

Also mechanical properties of fiber and flakes can be investigated more deeply and mixed with natural cotton fiber can be compared with fiber only. These can be used with cement mortar and its effects can be investigated for daily life usage. These fibers and flakes can also be used to make roads because of less abrasive property.

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