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Thermal Characteristic of Polypropelne Composites with Addition of Fillers : A Study

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Abstract: *The work regards the heat transfer in the polymer composites of solid glass micro-spheres (SGS) or hollow glass micro-spheres (HGS) filled with polypropylene (PP). The net effective thermal conductivities (Keff) of the polymer composites of PP and SGS or PP and HGS are estimated by analytical integral approach and its result was compared with ANSYS model and existed theoretical models. It was observed that the effect of thermal insulation in hollow glass spheres filled polypropylene composites is more than the solid glass spheres filled polypropylene composites and the net effective thermal conductivity (Keff) is linearly decreases with increases of volume fraction (φf) of filler and then decreased somewhat with increasing filler diameter. It was found that the analytical model is very close to ANSYS model and existing analytical models. Furthermore, the net effective thermal conductivity (Keff) of the three dimensional (3D) ANSYS model is lesser than two dimensional (2D) ANSYS model i.e. 3D ANSYS model is fairly closer with the experimental data than 2D ANSYS model. With improved insulation capability and light weight of composites, the solid glass micro spheres (SGS) and hollow glass micro-spheres (HGS) inserted polypropylene composites can be utilized in areas such as building materials, aviation industry and space flight, insulation boards, thermo flasks, food containers etc. Some other properties changed like enhanced wear resistance, increased reflective index, decreased coefficient of thermal expansion and increased the glass transition temperature. Out of the three arrangements, the best thermal performance was given by thin inline ribs whose convective heat transfer coefficient was 1.83 times that of smooth duct.*

Keywords: *Polymer composites, PP, SGM, HGM, volume fraction, Thermal characteristics*

1. Introduction

In last two decades, it has been emerged as subject of most research by ceramic mixed polymer composites. In this current work, my objective is to explore the potential of Solid glass micro spheres (SGM) and Hollow glass micro-spheres (HGM) as are filling materials in polypropylene polymer composites and investigate its thermal characteristics of result composites. In this work an attempt has been taken to find a useful use of SGM and HGM as particulates filler in polymer composites for the development of thermal resistant composites.

Solid glass micro spheres (SGM) and hollow glass micro spheres (HGM) contain outer stiff glass, by which we got some useful properties as light weight, low thermal conductivity, high strength, wear prevention and resistance to salt or organic solvent . Due to having these properties , SGM and HGM have been used for different applications in polymer composites (Khamis and Kim, 2001; Liang, 2002; Zhao, 2007; Liang, 2005). They have other properties like low moisture absorption, high specific compressive

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strength and high thermal stability, due to these properties they more suitable for marine and aeronautical applications (Wouterson et al., 2004; Khamis &Kim, 2001; Nagorny & Gupta, 2006, Plubrai & Kim 2004).

Solid glass micro spheres (SGM) and hollow glass micro spheres (HGM) have require able thermal properties with high softening point (glass transition temperature), low coefficient of thermal expansion, high resistance to water attack, acids attack, halogens, salt and organic solvents.

COMPOSITE MATERIALS

It is combination of two or more materials having different chemical and physical properties. But the composites will have different properties than the parent materials. Generally, composites have improved property than the parent material.

Types of Composite Materials

Composites are classified into different group based on matrix material

a) Metal Composites
b) Ceramic Composites
C) Polymer Composites

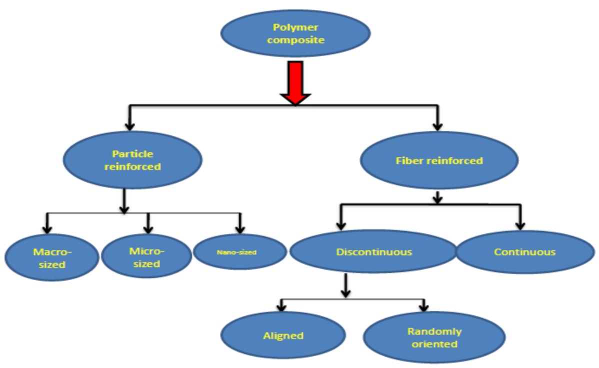

Fig. 1 Classification of Composites Based On Reinforcement Type

Notwithstanding various exploration works reported previously, there is a colossal learning crevice that requests a very much arranged and precise examination here of particulate filled polymer composites. A thorough audit of the distributed writing uncovers that:

- Most of works have done on solid glass micro spheres (SGM) but very less work have done on hollow glass micro spheres (HGM).
- Most of the investigations are aimed at enhancing the heat conductivity of the polymer by adding conducting filler rather than attempting to improve its insulation capability.
- Most of the works reported on thermal conductivity of particulate filled polymers are experimental in nature and reports available on numerical and analytical models are few

2. Review of Literature

Hutchings [2020] now a day, polymer composites are the most replacing materials in different structural and engineering utilizations. They have been widely utilized industrial applications, space craft uses due to their low density, good specific strength, good modulus and good wear resistance. Due to they have less weight, those are most preferable material in sensitive weight utilizations. Sometimes their use restricted in general applications due to their high cost.

Unal et al [2019] In last two decades, it has been emerged as subject of most research by ceramic mixed polymer composites. In this current work, my objective is to explore the potential of Solid glass micro spheres (SGM) and Hollow glass micro- spheres (HGM) as are filling materials in polypropylene polymer composites and investigate its thermal characteristics of result composites.

Khamis and Kim[2018] In this work an attempt has been taken to find a useful use of SGM and HGM as particulates filler in polymer composites for the development of thermal resistant composites. Solid glass micro spheres (SGM) and hollow glass micro spheres (HGM) contain outer stiff glass, by which we got some useful properties as light weight, low thermal conductivity, high strength, wear prevention and resistance to salt or organic solvent .

Plubrai & Kim[2018] Solid glass micro spheres (SGM) and hollow glass micro spheres (HGM) have require able thermal properties with high softening point (glass transition temperature), low coefficient of thermal expansion, high resistance to water attack, acids attack, halogens, salt and organic solvents.

Kranthi, G. & Satapathy, A. [2017] Inspired by the biological nervous system, an artificial neural network (ANN) approach is a fascinating computational tool, which can be used to simulate a wide variety of complex engineering problems such as tribo-performance of polymer composites. This paper, in this context, reports the implementation of ANN in analyzing the wear performance of a new class of epoxy based composites filled with pine wood dust. Composites of three different compositions (with 0, 5 and 10 wt.% of pine wood dust reinforced in epoxy resin) are prepared. Dry sliding wear trials are conducted following a well planned experimental schedule based on design of experiments (DOE).

Gregory, S.W., Freudenberg[2016] A solid lubricant composite material was made by compression molding PTFE and 40 nm alumina particles. Prior to compression molding the constituent powders was blended using a jet

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milling apparatus? Composites from 0 to 20 wt. % were prepared. These composites were tested against a polished stainless steel counter face on a reciprocating tribometer. The experimental conditions were a contact pressure of 6.4 MPa, a stroke length of 50 mm, and a sliding speed of 50 mm/s.

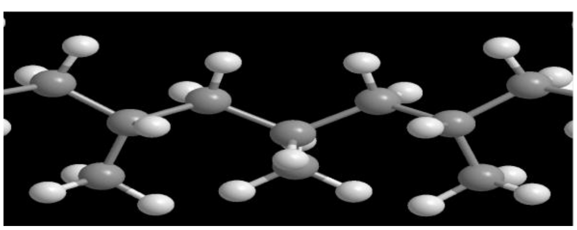
3. Composite Techniques

This part depicts the materials and techniques utilized for preparing and describing the composites under scrutiny. It displays the subtle elements of the tests identified with the physical, mechanical, smaller scale auxiliary, warm and dielectric portrayal of the readied particulate filled polymer composite examples.

3.1 Matrix Material

The material which is used as base material is called as matrix material. It has maximum percentage of volume in composites. Composite's property mainly depends on matrix material. Matrix material is selected according our requirement property. Matrix material should have ability to absorb other material. Here I am using polypropylene as matrix material. It is a thermoplastic material of carbon and hydrogen compound.

3.2 Polypropylene



3.3 Properties of Polypropylene

PROPERTIES	VALUES
Density	.946 gm/cc
Thermal Conductivity	.2 W/m-K
Compressive strength	60-70 Mpa
Tensile strength	30-40 Mpa
Micro hardness (Rockwell)	80-102
Thermal coefficient of expansion	$100 – 150 * 10^{-6}$
Glass transition temperature	100^0 C

4. Proposed Methodology

The calculation of actual properties of the composites is of main important for better design and utilization of the Composite materials. Micro structural properties of composites are essential thing which affect the effective properties of composites. Micro structural means size, shape, orientation and spatial distribution of embedment of matrix.

Schematic presentation of solid micro glass spheres embedded in a polypropylene matrix having a regular arrangement is shown in below fig. The boundary conditions and the heat flow direction for conduction is shown in the below fig. Here the temperature at top face is 100^0c, convection heat transfer occurs at the bottom face having convection heat transfer coefficient is $25W/m^2$-K and other four faces are insulated. The temperatures on other boundaries and at inside domain are not arrested.

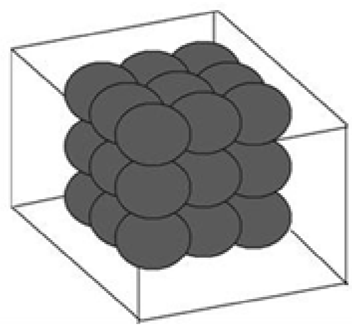


Fig 2 Schematic Presentation of Solid Micro Glass Spheres

4.1 Governing Equations

Analytical model for determination of the net effective thermal conductivity (K_{eff})

Values of the net effective thermal conductivity of the above PP composites of different filler percentage have been estimated analytically by using the Eqn. given below. It is derived on one dimensional (1D) conduction model by integral approach. The assumptions that have taken to solve this Eqn. are

- Heat flows only one direction i.e. other four faces are insulated.
- Both the boundary surfaces are at uniform temperatures throughout the surfaces.
- Heat flows perpendicular to the surfaces.
- Composites are homogeneous in macroscopically.
- Both filler and matrix isotropic in locally.
- Contact resistance between matrix and filler material neglected.

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- No void inside the composites is assumed.
- Uniformity in distribution of filler inside the matrix in a periodic manner.

4.2 For Solid Sphers

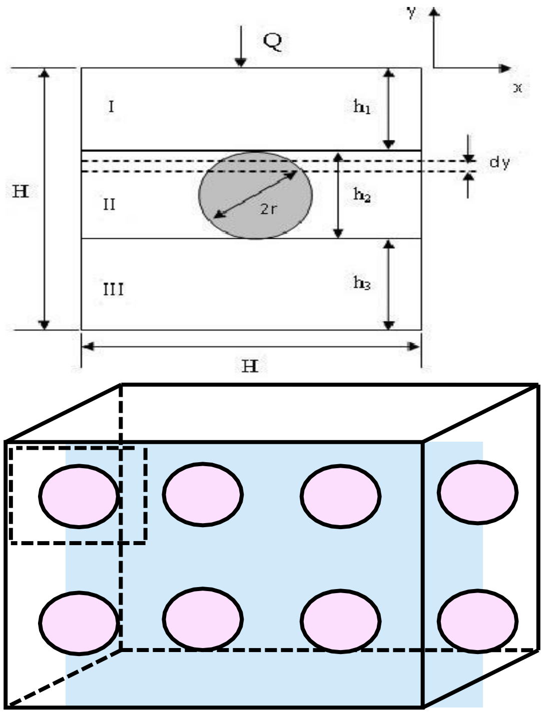

Fig. 3 For Solid Sphers

Above Figure represents the 3-D view of particulate filled composite model and an element is taken is taken into consideration for further study the heat transfer behavior consisting of a miniature cube with a particle is in the center of it.

- The element is subdivided into three parts where Part I and part III represents the only polymer and the thickness is h_1 and h_3 where $h_1 = h_3 = (H-2r)/2$.
- Part II is the combination of the polymer and microsphere and the thickness is h_2 ($h_2=2r$).
- The equivalent thermal conductivity of whole composite is calculated by using the specific equivalent thermal conductivity theory.

Because of the linear distribution of temperature, the average thermal conductivity of each section may first be obtained:

$$Q = KA \frac{\Delta T}{\Delta X}$$

Thermal resistance

$$R = \frac{dx}{KA}$$

For part I and III

$$K_1 = K_3 = \int_0^{h1} K\,p\,\frac{dy}{h1} = Kp$$

For part II

$$K_2 = \frac{Qp + Qf}{\left(\frac{dT}{dy}\right)A} = \frac{Kp\,Ap}{A} + \frac{Kf\,Af}{A}$$

Now integrating it over the complete thickness, we will get

$$K_2 = \int_0^{h2} \left(\frac{KpAp}{A} + \frac{KfAf}{A}\right) dh \,/\, h_2$$

$$= \int_0^{h2} \frac{\left(\frac{KpAp}{A}\right)dh}{h2} + \int_0^{R} \frac{Kf}{RA}\,\pi\,(2Rh - h^2)dh$$

$$= \frac{KpVp}{h2A} + \frac{\pi Kf}{RA}\,[R^3 - R^3/3]$$

$$= \frac{KpVp}{h2A} + \frac{2\pi Kf R^3}{3RA}$$

$$= \frac{KpVp}{h2A} + \frac{VfKf}{h2A}$$

Thermal Resistances are

$$R_1 = R_3 = \frac{h1}{KpA}$$

$$R_2 = \frac{h2^2}{KpVp+KfVf}$$

$$K_{eff} = \frac{H}{(R1+R2+R3)A}$$

$$K_{eff} = H/\left(\frac{h1}{KpA} + \frac{h2^2}{KpVp+KfVf} + \frac{h1}{KpA}\right)A$$

$$K_{eff} = H/\left(\frac{2h1}{Kp} + \frac{h2^2 A}{KpVp+KfVf}\right)$$

From fig $h_1 = \frac{H-2r}{2}$, $h_2 = 2r$

So $K_{eff} = H/\left(\frac{H-2r}{Kp} + \frac{4r^2 A}{KpVp+KfVf}\right)$

But $\emptyset f = \frac{Vf}{Vc} = \frac{4\pi r^3}{3H^3}$

So $H = r\,\sqrt[3]{(4\pi/3\emptyset f)}$

So $K_{eff} = \frac{r\sqrt[3]{(4\pi/3\emptyset f)}}{\frac{r\sqrt[3]{(4\pi/3\emptyset f)}}{Kp} - \frac{2r}{Kp} + \frac{4r^2 A}{KpVp+KfVf}}$

$$K_{eff} = 1/\left(\frac{1}{Kp} - \frac{2}{Kp\sqrt[3]{(4\pi/3\emptyset f)}} + \frac{1}{\sqrt[3]{(4\pi/3\emptyset f)}}\left\{\frac{4rA}{KpVp+KfVf}\right\}\right)$$

Fig. 4 Solid Glass Micro Spheres

Fig 5 Hollow Glass Microspheres

5. Result and Discussion

5.1 Numerical Simulation

Net Effective thermal conductivities (Keff) of polypropylene and Solis glass micro spheres composites are estimated numerically by help of spheres in cube model. Different temperature profiles have been obtained from analysis of FEM of composites of polypropylene and SGM of 100 μm size having different volume fractions .05%, .42%, 1.41%, 3.35% and 5.23% as shown below.

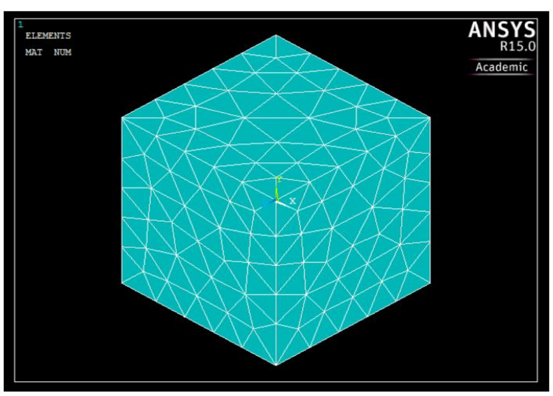

Fig 6 Meshing for .05% Filler Solid

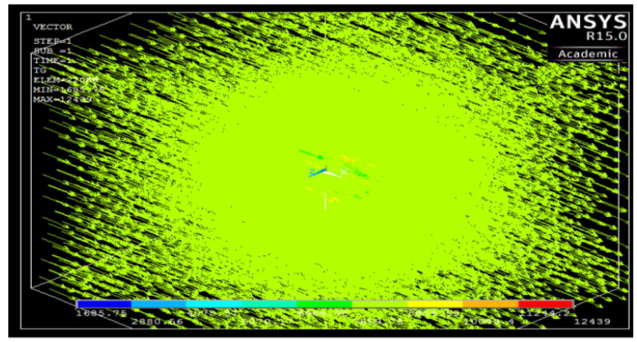

Fig 7 .05% Hollow Filler Temp Counter

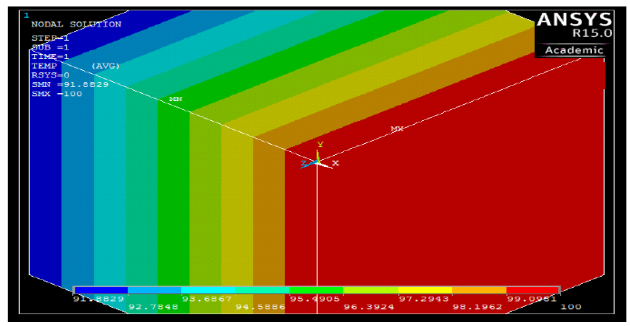

Fig 8 0.05% Filler Solid

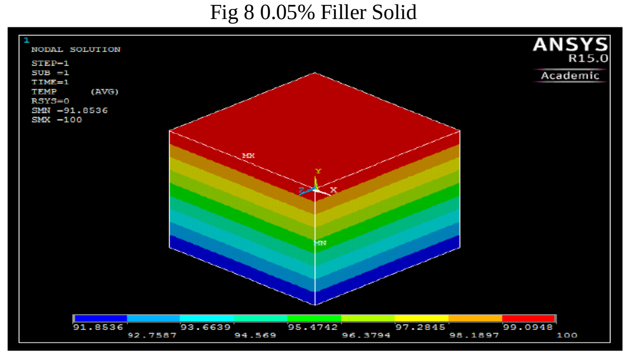

Fig 8 0.42% Filler Solid

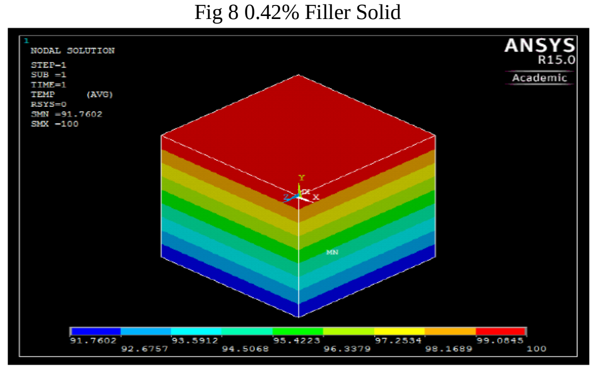

Fig 10 1.41% Filler Solid

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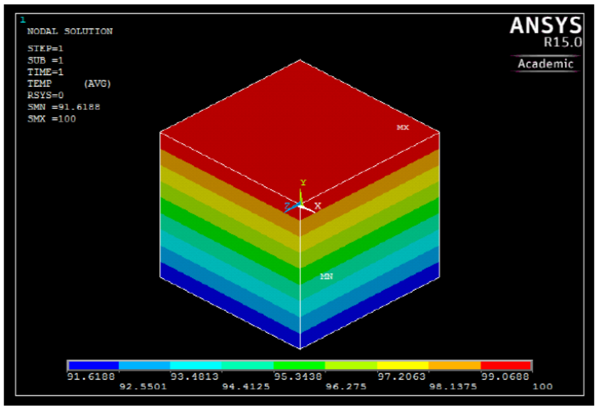


Fig 11 3.35% Filler Solid

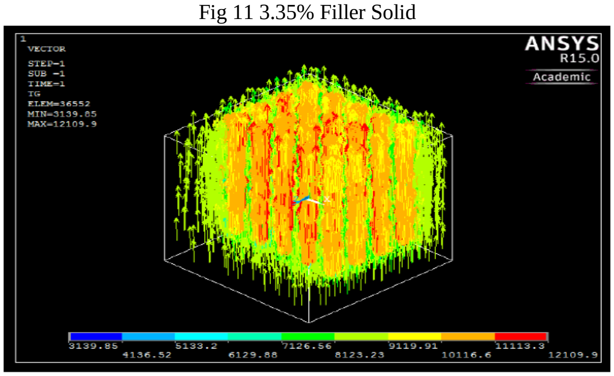
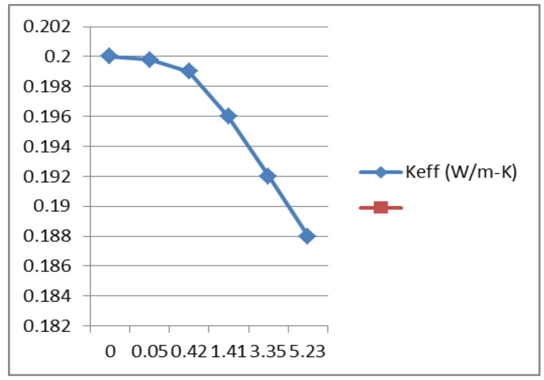


Fig 12 Vector Field of Temperature

SGM (vol %)	K_{eff} (W m-K)
0	.2
.05	.1998
.42	.199
1.41	.196
3.35	.192
5.23	.188

From the above fig.12 it is observed that the temperature variation between the top and bottom surface areas of the cubes increases with volume fraction percentage of the SGM. It is because of opposition of heat flow by the micro glass spheres along the conduction way. The above table and above fig. represent the variation of K_{eff} with SGM content in composites obtained from finite element method.

It is noticed that, with increase in filler percentage in the composites, the value of K_{eff} decreases gradually. By addition of 5.23% of solid glass micro sphere, the net effective thermal conductivity of polypropylene composites

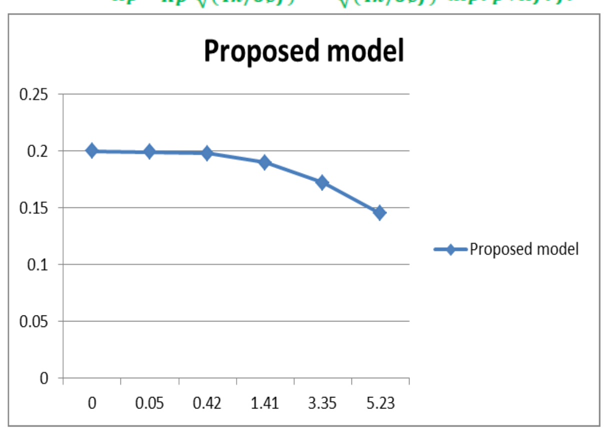


decreased by 6% and by addition of 3.35% of SGM, thermal conductivity decreased by 4%.

5.2 Theoretical Model For Determination Of Effective Thermal Conductivity (K_{eff})

Below table represents the values of the net effective thermal conductivities (K_{eff}) of composites of PP- SGM obtained through proposed theoretical model with different volume percentage of SGM and results obtained through ANSYS by finite element model models.

$$K_{eff} = 1/\left(\frac{1}{Kp} - \frac{2}{Kp\sqrt[3]{(4\pi/3\emptyset f)}} + \frac{1}{\sqrt[3]{(4\pi/3\emptyset f)}}\left\{\frac{4rA}{KpVp+KfVf}\right\}\right)$$



By the help some existing theoretical models, I have calculated the effective thermal conductivity of polypropylene composites with SGM concentration varying from 0 to 5.23 vol. %. Then I compared the values of proposed analytical model with existing model.

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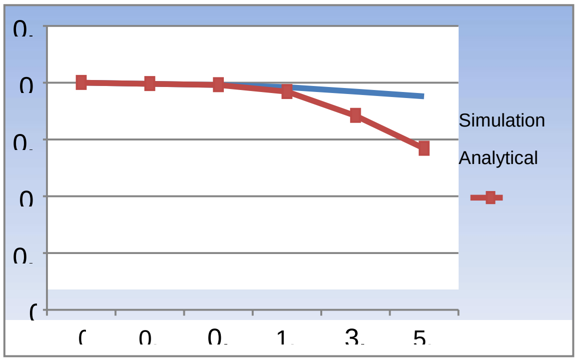
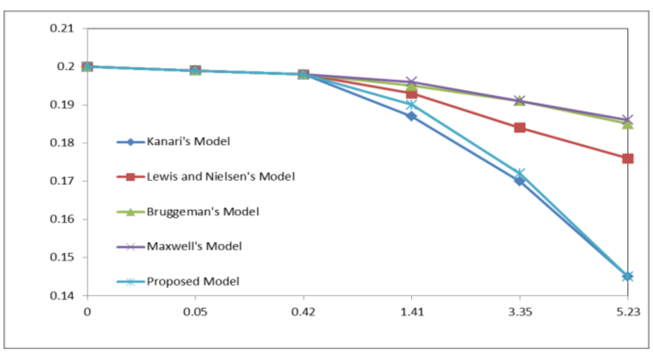
SGM (Vol %)	Analytical Model	FEM Results
0	.2	.2
.05	.199	.1998
.42	.198	.199
1.41	.192	.196
3.35	.172	.192
5.23	.145	.188



SGM Concentratic (Vol %)	Maxwell’ Model	Bruggmen’ model	Lewis & Nielsen’ model	Kanari’ model	Proposed model
.05	.199	.199	.199	.199	.199
.42	.198	.198	.198	.198	.198
1.41	.196	.195	.193	.187	.19
3.35	.191	.191	.184	.17	.172
5.23	.186	.185	.176	.145	.145



From the above comparison, I found that the effective thermal conductivity of proposed model is fairly closed to Kanari’s Model, which is revised of Bruggmen’s model. Thus it is noticed that proposed mathematical model is a acceptable theoretical model for 1-D analysis of composite materials. Below fig. represents the comparison of the net effective thermal conductivities (Keff) results obtained through proposed theoretical model and results from FEM simulation of composites having different volume concentration. From the graph it is found out that the values of effective thermal conductivity of proposed theoretical model is fairly closed with the FEM model. But with higher percentage of SGM the FEM model deviates from proposed analytical model, because it is difficult to find the effective node in ANSYS due to course meshing.

5.3 Polypropylene Composites Mixed With Hollow Glass Micro- Spheres (HGM)

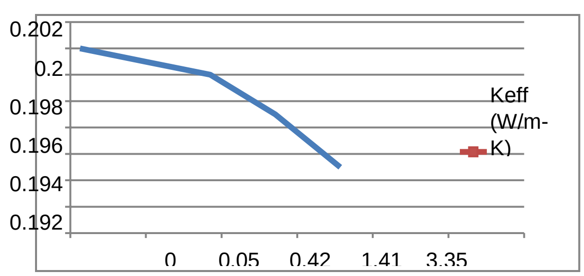
In this part I am presenting the values of effective thermal conductivity (K_{eff}) obtained through proposed analytical model and FEM simulation model for polypropylene composites mixed in different percentage of hollow glass micro-spheres.

Simulation Method

Here the finite element of ANSYS program is utilized for thermal analysis of conductive heat through polypropylene (PP)-HGM composites. For carry out this analysis,3- D models of the hollow spheres in cube (HGM in PP matrix) lattice array has been utilized to simulate the microstructure of PP-HGM composites of different concentration of hollow glass micro spheres. For these composites having hollow glass micro spheres concentrations of .05, .42,

Keff values of composites from FEM of HGM-PP composites

SGM (vol %)	Keff (W/m-K)
0	.2
.05	.199
.42	.198
1.41	.195
3.35	.191



From the above fig. it is observed that the temperature changes between the top and bottom surfaces of the cube

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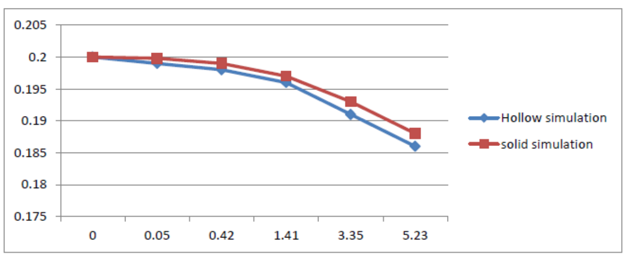
composite increases with volume fraction percentage increase of the HGM. It is because of opposition of heat energy flow by micro-hollow glass spheres along conduction way. Due to hollowness of hollow glass spheres at the center there no heat conduction taking place at the center but radiation may take place, but as the operating temperature of polymer composite is around less than 1000C, we can neglect the effect of radiation.

The above table and above fig. represent the variation of Keff obtained from FEM with HGM concentration in composites. It is noticed that, with increase in reinforced filler percentage in polymer composites, the value of Keff decreases gradually. And with addition of 3.35% of HGM, net effective thermal conductivity of polypropylene composites decreased by 4.5% but for SGM with addition of 3.35% of SGM, thermal conductivity decreased by 4%. So it is preferable to use hollow glass microspheres than the solid glass micro spheres, when we required high insulation and it also reduces the overall weight of component.



5.4 Analytical model for determination of net effective thermal conductivities (Keff) of PP-HGM composites

Values of net effective thermal conductivities of above PP composites have been calculated analytically by using the Eqn. given below.

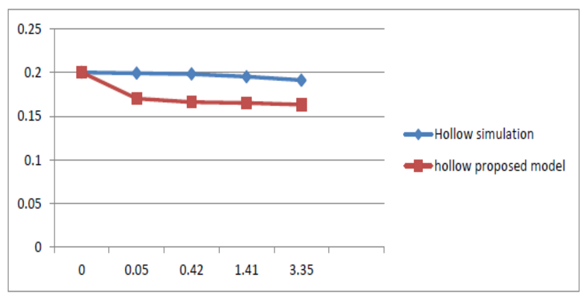
$$K_{eff} = H/(\frac{h1}{KpA} + \frac{h2^2}{KpVp+KfVf} + \frac{h1}{KpA})A$$

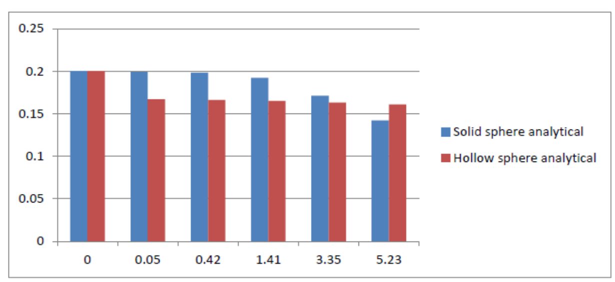
It is derived on one dimensional (1D) conduction model by integral approach. The assumptions that have taken to solve this Eqn. are

- Heat flows only one direction i.e. other four faces are insulated.
- There is vacuumed inside hollow portion of HGM.
- There is no radiation and convection inside the hollow portion of HGM.
- Both the boundary surfaces are at uniform temperature throughout the surfaces.
- Heat flows perpendicular to the surfaces.
- Composites are homogeneous in macroscopically.
- Both filler and matrix isotropic in locally.
- Contact resistance between matrix and filler material negleted.
- No void inside the composites is assumed.
- Uniformity in distribution of filler inside the matrix in a periodic manner.

Below table represents the values of net effective thermal conductivities (K_{eff}) of composites of PP- HGM obtained through proposed theoretical model with different volume percentage of HGM and results obtained through ANSYS by FEM model.

SGM (Vol %)	Analytical Mode	FEM Results
0	.2	.2
.05	.167	.199
.42	.166	.198
1.41	.165	.195
3.35	.163	.191





From the above comparison, I found that the effective thermal conductivity of proposed model is fairly closed to FEM model, but at higher volume percentage concentration of filler there is deviation of proposed analytical model from FEM model, because to select all node points by fine meshing in FEM model is difficult. Thus it is noticed that proposed mathematical model is an acceptable theoretical model for 1-D analysis of composite materials.

6. Conclusion

A two-dimensional numerical study was done to predict the influence of transverse rectangular cross-sectioned ribs on a solar air heater's convective heat transfer properties. A rectangular duct was constructed and numerical analysis was carried out on square and thin (high aspect ratio) rib shapes arranged in different fashion, namely single wall, staggered and in-line ribs arranged on two opposite walls including the absorber plate. Air was the working fluid and constant heat flux was applied only on the absorber plate's top surface. The output of numerical simulations drew the following conclusions

- Out of the three arrangements, the best thermal performance was given by thin inline ribs whose convective heat transfer coefficient was 1.83 times that of smooth duct.
- When ribs/baffles are introduced just beneath the collector plate, there was a considerable alteration in the heat transfer coefficient of air.
- Two methods were used to calculate the average Nusselt number in which one method extracted the local Nusselt number at many points and on averaging these, gave the average Nusselt number and the other method resembled the one used in the existing experimental work. Good matching between existing experimental results and numerical outputs was spotted, when the second method was adopted to calculate the Nusselt number, thereby proving that CFD can be effectively applied for the design of solar air heaters. However the Nusselt number calculated using first method yielded values lower than the existing ones.
- The results revealed that the thin ribs yielded better performance than the squared ones. Similar results were also observed by Skullong et al. in their experimental work.

Since, it was observed that high aspect ratio ribs allow higher convective heat transfer, hence it would be interesting to conduct research work on triangular shaped ribs having very low apex angles. The present work is expected to be very helpful for carrying out the new future project.

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