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An Analysis On Thermal Characteristic Of Polypropelne Composites With Addition Of Fillers

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Abstract: *The research focuses on the heat transport in polymer composites made of hollow or solid glass microspheres filled with polypropylene (PP). The analytical integral approach is used to evaluate the net effective thermal conductivities (Keff) of polymer composites made of PP and SGS or PP and HGS, and the results are then compared to those of the ANSYS model and other existing theoretical models. It was found that the effect of thermal insulation in hollow glass spheres filled with polypropylene composites is greater than the effect of thermal insulation in solid glass spheres filled with polypropylene composites. Additionally, the net effective thermal conductivity (Keff) is linearly decreased with increases in volume fraction (f) of filler and then somewhat decreased with increasing filler diameter. It was discovered that the analytical model resembles the ANSYS model and other analytical models fairly closely. Additionally, the three-dimensional (3D) ANSYS model's net effective thermal conductivity (Keff) is lower than that of the two-dimensional (2D) ANSYS model, meaning that the 3D ANSYS model is more in line with the experimental results than the 2D ANSYS model. The solid glass microspheres (SGS) and hollow glass microspheres (HGS) inserted polypropylene composites can be used in areas such as building materials, the aviation industry and space flight, insulation boards, thermo flasks, food containers, etc. thanks to their improved insulation capability and lightweight composites. Other characteristics changed, including improved wear resistance, a higher reflective index, a lower coefficient of thermal expansion, and a higher temperature at which glass transitions. Thin inline ribs with a convective heat transfer coefficient that was 1.83 times greater than that of a smooth duct provided the three designs with the best thermal performance..*

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

1. Introduction

Now a day, polymer composites are the most replacing materials in different structural and engineering utilizations. They have been widely utilized industrial applications, spacecraft 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. By using easily available and low cost fillers having improve properties, they can decrease the overall cost of

components. Metal particulates or ceramic like hard particulates are used now a day, due to their thermal resistance and good wear resistance of the polymer. Addition of such reinforced fillers in polymer materials for the use of domestic applications is mainly focused at the cost decrease and the stiffness betterment. Many researchers have presented that the thermal resistance and wear resistance is improved of polymers due to addition of filler particulates. 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

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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. They have other properties like low moisture absorption, high specific compressive strength and high thermal stability, due to these properties they more suitable for marine and aeronautical applications.
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. However, 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

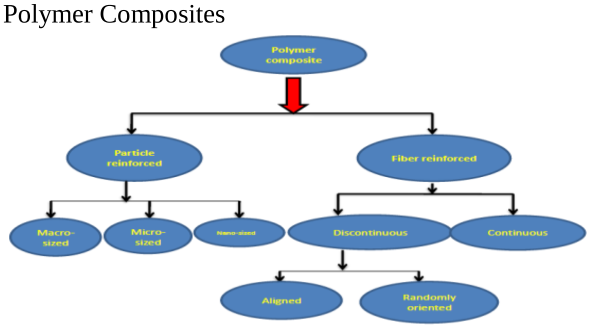

Fig. 1 Classification of Composites Based On Reinforcement Type

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.

MATERIALS AND METHODS

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.

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.

Polypropylene

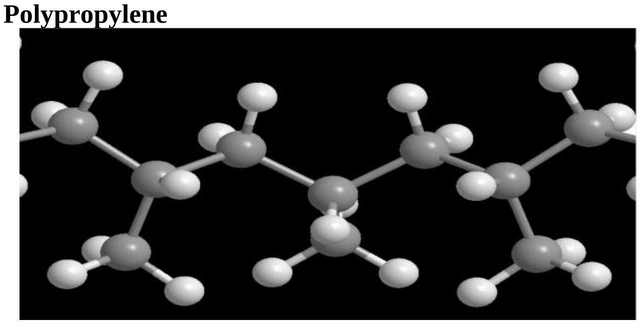

Fig. 2 Polypropylene

Properties of Polypropylene

Table 1 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

Filler Materials: (Solid Glass Micro Spheres)

Micro sized hollow glass micro-spheres (HGM) and solid glass micro spheres (SGMs) of one average sizes (100 μm,) purchased from NICE Ltd. was used as the reinforced filler material in this research work.

Some Important Properties Of Glass Microspheres

Table 2 Properties of Glass Microspheres

PROPERTIES	VALUES
Density	1.50 gm/cc
Thermal conductivity	0.02 W/m-K
Compressive Strength	248.0 MPa
Tensile Strength	56.0 MPa
Micro hardness	6.845 GPa
Electrical conductivity	0.109* 10^{-16} S/cm
Glass transition temperature	400K

2. 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.

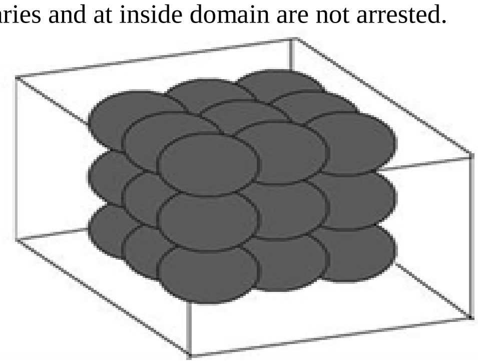

Fig 3 Schematic Presentation of Solid Micro Glass Spheres

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

FOR SOLID SPHERS

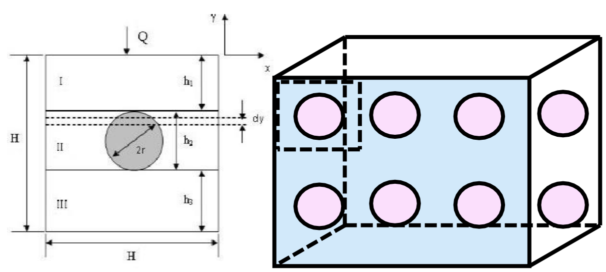

Fig. 4 For Solid Sphers

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

$$K_2 = \frac{Q_p + Q_f}{\left(\frac{dT}{dy}\right)A} = \frac{K_pA_p}{A} + \frac{K_fA_f}{A}$$

Now integrating it over the complete thickness, we will get

$$K_2 = \int_0^{h_2}\left(\frac{K_pA_p}{A} + \frac{K_fA_f}{A}\right)dh\Big/h_2$$

$$= \int_0^{h_2}\frac{\left(\frac{K_pA_p}{A}\right)dh}{h_2} + \int_0^R \frac{Kf}{RA}\pi(2Rh - h^2)dh$$

$$= \frac{K_pV_p}{h_2A} + \frac{\pi Kf}{RA}\left[R^3 - R^3/3\right]$$

$$= \frac{K_pV_p}{h_2A} + \frac{2\pi KfR^3}{3RA}$$

$$= \frac{K_pV_p}{h_2A} + \frac{VfKf}{h_2A}$$

Thermal Resistances are

$$R_1 = R_3 = \frac{h_1}{KpA}$$

$$R_2 = \frac{h_2^2}{KpVp + KfVf}$$

$$K_{eff} = \frac{H}{(R_1 + R_2 + R_3)A}$$

$$K_{eff} = H\Big/\left(\frac{2h_1}{kp} + \frac{h_2^2}{KpVp + KfVf} + \frac{h_1}{KpA}\right)A$$

From fig. 4.2

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

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

But $\emptyset f = \frac{v_f}{v_c} = \frac{4\pi r^3}{3H^3}$

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

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

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

For Hollow Spheres

$$A_f = 2\pi\left(\sqrt{2Rh - h^2}\right)t$$

Total Cross Section

$$=\int_0^R 2\pi\left(\sqrt{2Rh - h^2}\right)t\,dh$$

$$= \int_0^R 2\pi\left(\sqrt{-(h^2 - 2Rh + R^2 - R^2)}\right)t\,dh$$

$$= \int_0^R 2\pi\left(\sqrt{R^2 - (h - R)^2}\right)t\,dh$$

Let $h = R = Z$, $dh = dZ$

$$= 2\pi t\int_{-R}^0 2\pi\left(\sqrt{R^2 - Z^2}\right)t\,dZ$$

$$= 2\pi t\left[\frac{Z}{2}\left(\sqrt{R^2 - Z^2}\right) + \frac{R^2}{2}\sinh^{-1}\frac{Z}{R}\right]_{-R}^0$$

$$= 2\pi t\left(\frac{R^2}{2}\sinh^{-1}(0) = -\frac{R^2}{2}\sinh^{-1}(-1)\right)$$

$$.88\pi tR^2$$

$$K_2 = \frac{KvVp}{h^2A} + \frac{1.762}{h^2A}Kf\pi tR^2$$

Let, Vf=1.762 πtR^2

$$K_1 = K_3 = \int_0^{h_1} Kp\,\frac{dy}{h_1} = Kp$$

$$K_{eff} = H/(R_1 + R_2 + R_3)A$$

$$K_{eff} = H\Big/\left(\frac{h_1}{KpA} + \frac{{h_2}^2}{KpVp} + \frac{h_1}{KpA}\right)A$$

Fig. 5 Solid Glass Micro Spheres

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Fig 6 Hollow Glass Microspheres

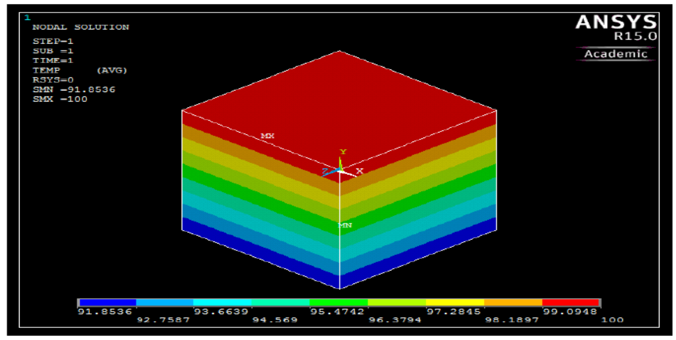

Fig 9 0.42% Filler Solid

3. Result and Discussion

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.

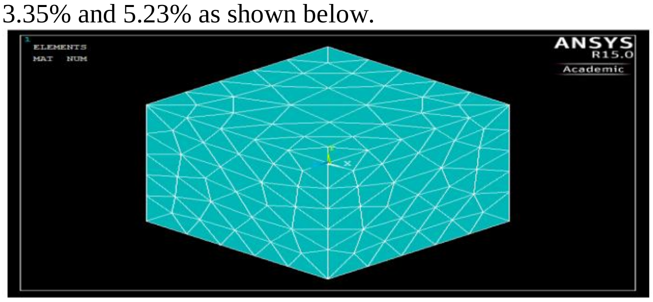

Fig 6 Meshing For .05% Filler Solid

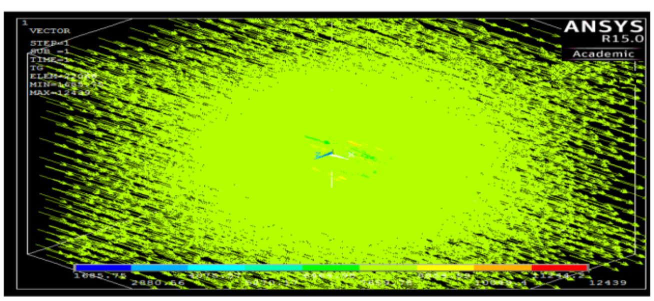

Fig 7.05% Hollow Filler Temp Counter

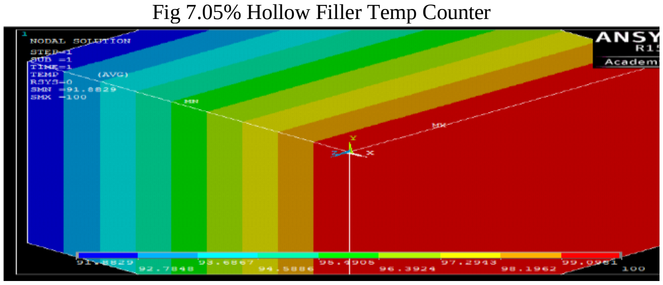

Fig 8 0.05% Filler Solid

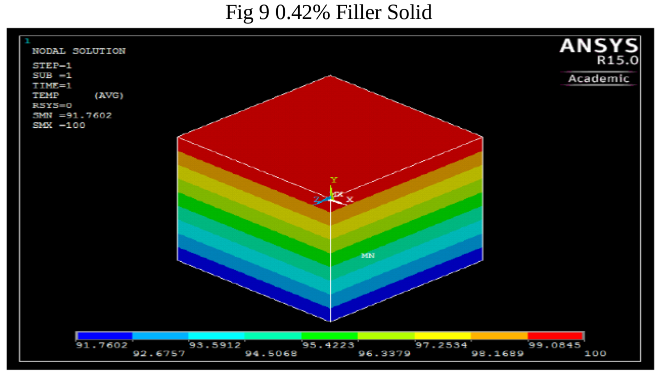

Fig 10 1.41% Filler Solid

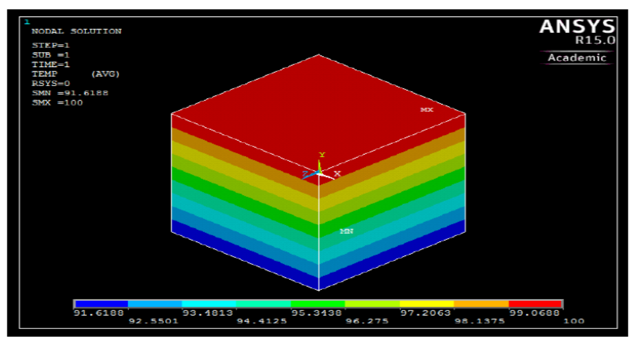

Fig 11 3.35% Filler Solid

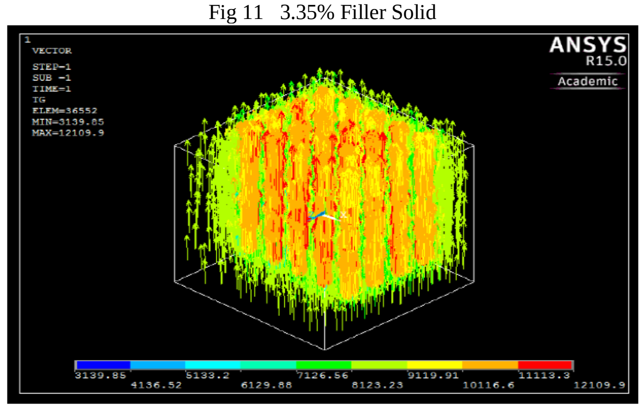

Fig 12 Vector Field of Temperature

Table 5.1 Comparison of SGM with K_{eff}

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

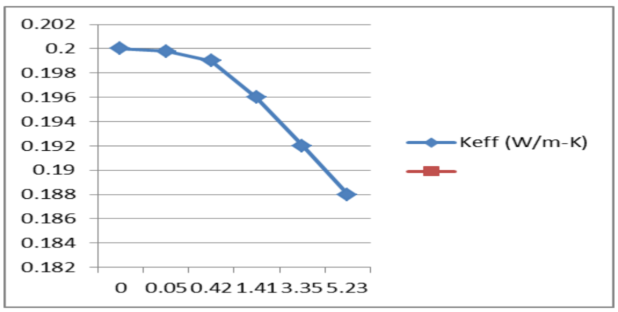

Fig.13 Comparison graph between SGM with Keff

From the above fig. 13 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 5.1 and above fig.5.8 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%.

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.

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

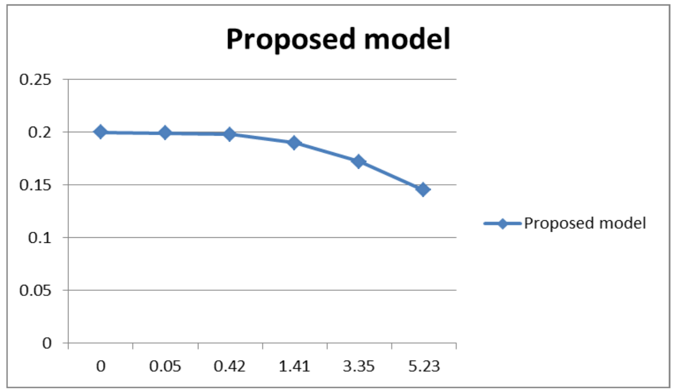

Fig. 14 Graph of Proposed Model

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.

Table 2 Proposed model comparison with existing model

SGM Concentration (Vol %)	Maxell's Model	Bruggmen's model	Lewis & Nielsen's model	Kanari's 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

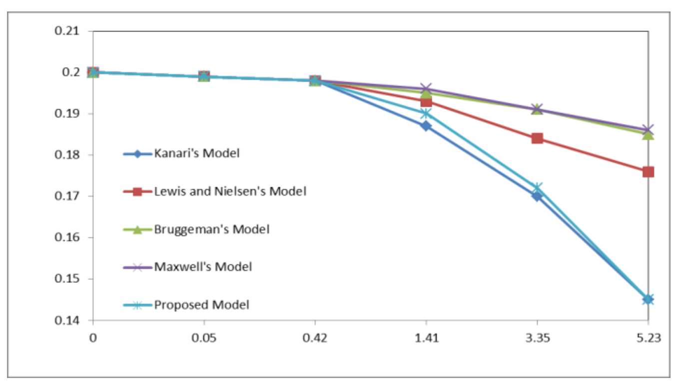

Fig. 5.15 Comparison Graph of Proposed Model with existing model

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. However, 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. Conclusion

- Based on the creation of 1-D heat conduction models, two theoretical correlations of solid glass microspheres (SGM) and hollow glass microspheres (HGM) filled polymer composites are presented for determining the effective thermal conductivity (Keff). It is discovered that theoretical mathematical models serve as very good, acceptable empirical models for spherical (solid or hollow) inclusions, and that the derived relationships from the mathematical models that have been proposed may be very effectively employed to compute Keff for composites.
- It is fortunate that polypropylene composites' capacity for thermal insulation increases greatly when SGM or HGM are added to the PP matrix material. It has been shown that the value of net effective thermal conductivities (Keff) falls as reinforced filler HGM or SGM content increases.
- The net effective thermal conductivities (Keff) of polypropylene composites fall more when hollow glass microspheres (HGM) are added than when solid glass microspheres are added (SGM).

To develop 3D analytical model by considering lattice structure, effect of voids, contact resistance between filler & matrix and considering reflection at the boundary of matrix & filler.

References

[1] Hutchings, I.M. (2020). Tribology: friction and wear of engineering materials. CRC Press.
[2] MS Nurul and M Mariatti, “Effect of thermal conductive fillers on the properties of polypropylene Composites”, Journal of Thermoplastic Composite Materials, 2011, 26(5) 627–639.
[3] Altay L, Sarikanat M, Saglam M, Uysalman T, Seki Y. The effect of various mineral fillers on thermal, mechanical, and rheological properties of polypropylene. Res. Eng. Struct. Mater., 2021; 7(3): 361-373.
[4] Leontiadis, K.; Tsioptsias, C.; Messaritakis, S.; Terzaki, A.; Xidas, P.; Mystikos, K.; Tzimpilis, E.; Tsivintzelis, I. Optimization of Thermal and Mechanical Properties of Polypropylene-Wollastonite Composite Drawn Fibers Based on Surface Response Analysis. Polymers 2021, 14, 924. https://doi.org/ 10.3390/polym14050924.
[5] Mohd Izwan, S.; Sapuan, S.M.; Zuhri, M.Y.M.; Mohamed, A.R. Thermal Stability and Dynamic Mechanical Analysis of Benzoylation Treated Sugar Palm/Kenaf Fiber Reinforced Polypropylene Hybrid Composites. Polymers 2021, 13, 2961. https://doi.org/10.3390/polym13172961.
[6] Gurushanth B Vaggar et al., “Effect of Filler Materials on Thermal Properties of Polymer Composite Materials: A Review”, International Journal of Engineering Research & Technology (IJERT), Vol. 10 Issue 08, August-2021.
[7] Kranthi, G. & Satapathy, A. (2017). Evaluation and prediction of wear response of pine wood dust filled epoxy composites using neural computation. Computational Material Science. 49, 609-614.
[8] Gregory, S.W., Freudenberg, K.D., Bhimaraj, P. & Schadler, L.S. (2016). A study on the friction and wear behavior op PTFE filled with alumina nanoparticles. Wear, 254(5-6),573- 580
[9] Rothon, R.N. (1999). Mineral fillers in thermoplastics: filler manufacture and characterization. Advances in Polymer Science, 139, 67-107.
[10] Suresha, B., Ramesh, B.N., Subbaya, K.M., Ravi Kumar, B.N. & Chandramohan, G. (2010). Influence of graphite filler on two-body abrasive wear behavior of carbon fabric reinforced epoxy composites. Materials and Design, 31, 1833-1841.
[11] Mohan, N., Natarajan, S. & Kumaresh Babu, S.P. (2015). Abrasive wear behavior of hard powders filled glass fabric epoxy hybrid composites. Materials and Design, 32, 1704-1709.
[12] Hong J, Park DW, Shim SE (2014). A Review on Thermal Conductivity of Polymer Composites Using Carbon-Based Fillers: Carbon Nanotubes and Carbon Fibers. Carbon Letters, 11: 347-356.
[13] Schwartz, C.J. & Bahadur, S. (2001). The role of filler deformability, filler–polymer bending, and counterface material on the tribological behavior of polyphenylene sulfide. Wear, 251, 1532–1540.
[14] Nayak, R., Dora, P.T. & Satapathy, A. (2010). A computational and experimental investigation on thermal conductivity of particle reinforced epoxy composites. Computational Materials Science, 48, 576-581. doi: 10.1016/j.commatsci.2010.02.025
[15] Liang, J.Z. (2002). Tensile and impact properties of hollow glass bead-filled PVC composites. Macromolecular Materials and Engineering, 287(9), 588–591. doi: 10.1002/1439-2054(20020901)287:9<588::AID-MAME588>3.0.CO;2-6.
[16] Liang, J.Z. (2005). Tensile and flexural properties of hollow glass bead-filled ABS composites. Journal of Elastomers and Plastics, 37(4), 361–370. Doi :10.1177/0095244305054674