Theoretical Analysis and optimization of Thermophoretic and Diffusion Deposition Model in turbulent and Laminar Pipe Flow for Air Pollution Measurement and Control of Diesel Engine Exhaust

Akshay P. Save[1], Siddappa S. Bhusnoor[2]

[1]PG Student, Dept. of Mechanical Engineering, K.J. Somaiya College of Engineering, Vidyavihar, Mumbai, India
[2]Professor, Dept. of Mechanical Engineering, K.J. Somaiya college of Engineering, Vidyavihar, Mumbai, India

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Abstract - *It is necessary to address the nature and mass size distribution of the particles in the atmosphere due to their effect on health and environment. This study focuses on hypothetical investigation and flow examination of Nano particles present in Climate along with their testing strategies. This work likewise examine about different vehicle systems, airborne models and stream elements of particulate matter present in the climate.*

In the present study various theoretical models were analyzed to study diffusion and thermophoretic deposition of particles in the size range of 0.0001 to 2.5 µm, at flow gas temperature of 50˚C≤Tg≤ 400°C and flow rate of 100 < Re < 20000, which is similar to the conditions of exhaust from the diesel engine. From the literature models, a model for laminar and turbulent flow was optimized for improved efficiency by diffusion and Thermophoresis. In the optimized models, particle Thermal conductivity (kp) of 0.5 W m-1 K-1 was taken due to its best match with literature predictions. As per results drawn after theoretical analysis of deposition efficiencies with respect to particle size range of 0.0001-2.5 µm, expression given by Batchelor & Shen et al. (1985) in turbulent flow and C. Tsai (2003) in laminar flow gave best fit among other models in the literature. Diffusion deposition is more dominating for particle size less than 0.01µm and thermophoresis deposition is more dominant for particle size greater than 0.01µm. Variation in temperature dominantly affects to particle deposited by thermophoresis and flow rate variation dominantly affects to particle deposited by diffusion. It also concluded that due to increase in particle size there is decrease in thermal deposition velocity because of thermophoretic mechanism is dominates between particle size 0.05-1 microns, after that inertia dominates.

***Key Words*: Nano particle, Sampling, Dilution, Thermophoresis, turbulent flow, Aerosol, Diffusion**

NOMENCLATURE:

Cp	Specific heat capacity at constant pressure (kJ/kg/˚K)
C	Slip correction factor = 2.347
Cm	Momentum exchange coefficient = 1.146
Cs	Thermal slip coefficient = 1.147
Ct	Temperature jump coefficient = 2.2
Dp	Diameter of the particle (m)
Dti	Inside Tube diameter (m)
Dto	Outside tube diameter (m)
f	Fanning friction factor
kg	Gas thermal conductivity (W/m/˚K)
kp	Particle thermal conductivity (W/m/˚K)
K_{th}	Thermophoretic coefficient
Kn	Knudsen number
L	Tube length (m)
NuD	Nusselt number
Pem	Modified Peclet number
Pr	Gas Prandtl number
Q	Inlet gas flow rate (m^3/s)
Re	Reynolds number
$\bar{T}$	Average temperature of the fluid (˚K)
Te	Gas temperature at tube inlet (˚K)
J	Number flux vector (Particles/m^2s)
J_c	Induced particle flux (Particles/m^2s)
T_{avg}	Mean gas temperature (˚K)
Tw	Wall temperature (˚K)
MW_g	Molecular weight of gas (g/mol)
R	Universal gas constant =8.314(J/mol/˚K)
u_m	Average gas velocity (m/s)
V_{th}	Thermophoretic velocity (m/s)
ṁ	Mass flow rate (kg/s)

n	Particle concentration (g/m^3)
Stk	Stoke's number
hi	Convective heat transfer coefficient of gas on the pipe inner surface (W/m^2/°K)
ho	Convective heat transfer coefficient of air on the pipe outer surface (W/m^2/°K)
	Greek symbols
α	Thermal diffusivity (m2/s)
ϱ	Gas density (kg/m^3)
$ϱ_p$	Density of particle (kg/m^3)
βt	Thermophoretic parameter
ν	Air kinematic viscosity (m^2/s)
μ_b	Viscosity of fluid in the bulk (Ns/m^2)
μ_w	Viscosity of fluid in the wall side (Ns/m^2)
η_{th}	Thermophoretic deposition efficiency in turbulent tube flow
λ	Mean free path of air (m)

1. INTRODUCTION

An aerosol is a stable suspension of solid and liquid particles in a gas. Aerosols are ubiquitous throughout the environment and are very important to public health. It is important that we understand their dynamics so that we can quantify their effects on humans. The field of aerosol science and technology has advanced significantly over the past 20 years, with ultrafine particles gaining particular interest, not only for their health properties but also for their industrial applications.

Decrease of motor exhaust molecule outflows stays a significant exploration region for reasons of wellbeing (McClellan, 1987[12]; Kagawa, 2002[8]) and climate (Lloyd and Cackette, 2001[11]). Control of fine particles in the 0.005 to 0.1 µm size range (Burtscher, 2005[2]), were should be tended to, however not thought about by and by for vehicles in future. Montassier N.,1991 [13] utilized information covering a bigger scope of molecule sizes (0.05-8µm in distance across) and contrast that exploratory finding and hypothetical contemplations and to foster a basic model for forecast of thermophoretic molecule testimony in a laminar cylinder stream. To depict molecule transport because of consolidated convection, dispersion and thermophoresis in cooled laminar cylinder streams, dimensional model is being made (Stratmann F., 1994 [16]). Stratmann F., 1994 [16] likewise fostered a trial arrangement to check the dimensional model. Model forecasts are contrasted and the test results.

There is a need to better understand for transport of these particles for better control. Present study involves following types of deposition mechanism for control of Nano particle.

1.1 Deposition by diffusion

Particle diffusion results from its Brownian motion, which is the random motion of the particle in the fluid as a result of its continuous bombardment by gaseous molecules. Diffusion of particles is the net transport under the influence of a concentration gradient. Deposition by Brownian diffusion results from the random motions of the particles caused by their collisions with gas. Unlike deposition by impaction and sedimentation, which increase with increasing particle size, deposition by Brownian diffusion increases with decreasing particle size and becomes the dominant mechanism of deposition for particles less than 0.5 µm in diameter. The particles move from regions of high concentration to regions of low concentration. Fick's first law of diffusion describes Brownian motion in Equation (1); it can be written as:

$$J = -D\Delta n$$

.....Equation (1)

Where J is the number flux vector (particles/m^2s), n the number particle concentration (particles/m^3) and D is a diffusion coefficient (m^2/s) (Drossinos and Housiadas, 2006 [6]). The particle diffusion coefficient can be expressed in Equation (2) (William C. Hinds, 1999 [19]):

$$D = \frac{K_B T C_c}{3\pi\eta D_p}$$

.....Equation (2)

Where K_B=1.381 X 10^{23} is the Boltzmann constant. Equation (2) is called the Stokes-Einstein equation. The dimensionless deposition parameter (μ_p) is given in Equation (3) (William C. Hinds, 1999 [19]),

$$\mu_p = \frac{DL}{Q}$$

.....Equation (3)

Where D is the diffusion coefficient of the particle, L is the length of tube; Q is volume flow rate through tube (William C. Hinds, 1999 [17]). Particle penetration P is a function of μ_p with an accuracy of 1% for all values of μ_p and value of P for laminar is given in Equation (4, 5) (William C. Hinds, 1999 [17]),

$$P = 1 - 5.5\mu_p^{\frac{2}{3}} + 3.77\mu_p \quad \text{For } \mu_p<0.009$$

.....Equation (4)

$$P = 0.819\exp(-11.5\mu_p) + 0.0975\exp(-70.1\mu_p)$$

For $\mu_p \geq 0.009$

.....Equation (5)

Particle penetration P for turbulent flow is give in Equation (6) (William C. Hinds, 1999 [19]),

$$P = \exp\left(\frac{-4V_{dep}L}{D_{ti}u_m}\right)$$

.....Equation (6)

Where d_t= diameter of tube, u = average flow velocity, V_{dep}= diffusive deposition velocity for turbulent flow which is given in Equation (7) (William C. Hinds, 1999 [19]),

$$V_{dep} = \frac{0.04u_m}{\mathrm{Re}^{0.25}}\left(\frac{\rho_g D}{\mu}\right)^{\frac{2}{3}}$$

.....Equation (7)

1.2 Deposition by Thermophoretic

The motion of aerosol particles depends on the external forces that act upon them. The most commonly encountered external forces that influence a particle's mobility, and thus lead to particle transport, are related to thermophoresis and diffusiophoresis. A thermal gradient in a fluid induces a thermophoretic force on aerosol particles, since gaseous molecules exert different impulses to particles on the colder and warmer sides. The thermal gradient results in a net force that moves the particles from the high- to the low-temperature region (Kakac, 2002 [9]).

The parameters that influence thermophoretic deposition are the size of the particles, temperature gradient, gas flow rate and gas inlet temperature, flow length and thermophysical properties of gas and the particles. Thermophoretic velocity of an isolated particle in a constant temperature gradient in a pipe flow can be expressed in Equation (8) (Talbot *etal.*, 1980[17]):

$$V_{th} = K_{th}\,\nu\,\frac{\Delta T}{T_{avg}}$$

.....Equation (8)

Where T_{avg} is the mean gas temperature or average gas temperature and Kth is the thermophoretic coefficient, which is a function of gas and particle properties and Knudsen number (Kn).

Among the various expressions for the thermophoretic coefficient available in the literature, the generally accepted expression for a wide range of Knudsen number (Kn) given by (Talbot et al, 1980[17]) was used for the model in the present work, expressed in Equation (9):

$$K_{th} = \frac{2C_s\left(\frac{k_g}{k_p} + C_tK_n\right)C}{(1+3C_mK_n)\left(1+2\left(\frac{k_g}{k_p}\right)+2C_tK_n\right)}$$

.....Equation (9)

Where, Cu, Cm, Cs and Ct are slip correction factor, momentum exchange coefficient, thermal slip coefficient and temperature jump coefficient respectively. kg and kp are the thermal conductivities of the gas and particle respectively. Knudsen number is defined as the ratio of the mean free path of gas molecule to diameter of the particle and expressed in Equation (10):

$$Kn = 2\lambda/Dp$$

.....Equation (10)

where Dp is the particle diameter and λ is the mean free path of gas molecules, which is the average distance the particle travels between collisions with other moving particles. Mean free path is expressed in Equation (11);

$$\lambda = \frac{2\mu}{\rho}\left(\frac{\pi MW_g}{8RT_e}\right)^{0.5}$$

.....Equation (11)

The dynamics of aerosols and more specifically their deposition as they are transported in a flowing fluid is of great importance in technological applications such as aerosol filtration and instrumentation. A thorough discussion of these processes is examined in the scientific literature (William C. Hinds, 1999 [19]; Drossinos and Housiadas,2006[6]). The thermophoretic particle deposition efficiency in the turbulent tube flow is a function of four parameters: the product of the Prandtl number and thermophoretic coefficient, PrKth, the dimensionless temperature (Te -Tw)/Te, the Nusselt number NuD and the modified Peclet number Pe_m.Expression for modified Peclet number is given in Equation (12),

$$Pe_m = \frac{u_m r_o^2}{\alpha L}$$

.....Equation (12)

The objective of this study is to analyze theoretically deposition of fine particle by diffusion and thermophoresis in a pipe flow under simulated engine condition and to optimize best suitable thermophoretic model for turbulent flow and laminar pipe flow in a pipe and use of literature available model for diffusional deposition. Focus of study is analysis of combined effect of thermophoresis and diffusion for wide range of size of particles deposition.

2. MATERIALS AND METHODS

To attain objective, initially we have studied various theoretical models of thermophoretic and diffusion mechanism, and then optimized the model with simulated engine condition, compare them with best suitable theoretical model for deposition of particle by varying temperature, and flow rate of inlet gas to the deposition tube.

The assumptions considered in the model for particle deposition analysis are particles are spherical in nature, at each cross section the concentration of the aerosols is uniform, flow in the pipe is fully developed in terms of both temperature and velocity field and the internal surface of the pipe is smooth. It is also assumed that there is a loss of air-borne particles to the wall in each sub section of the tube by combined Thermophoresis and diffusion mechanisms as per the temperature gradient and diffusion coefficient and other mechanisms have negligible contributions. To attain focus of the study the methodology followed is discussed in below subsection.

2.1 Theoretical Analysis of various thermophoretic deposition mechanisms under laminar flow

Among the various expressions available in the literature for finding the thermophoretic deposition efficiency under laminar flow, Lin and Tsai (2004) [4] in Equation (13) and Stratmann F. (1998) [16] in Equation (14) theoretical laminar models were chosen for present study.

$$\eta_{th} = 78.3\left(\Pr K_{th}\frac{T_e - T_w}{T_w}\right)^{0.94}$$

.....Equation (13)

$$\eta_{th} = 1-\exp\left(-0.845\left(\frac{\Pr K_{th}+0.025}{\frac{T_w}{(T_e - T_w)}+0.28}\right)^{0.9322}\right)$$

.....Equation (14)

From equation values of momentum exchange coefficient, thermal slip coefficient and temperature jump considered in this study are Cm=1.146; Cs=1.147; Ct=2.2 respectively (Lin and Tsai, 2004 [4]). Sieder and Tate in Equation (15) provided a correlation for the Nusselt number for laminar flow heat transfer.

$$Nu_D = 1.86\,\mathrm{Re}^{1/3}\Pr^{1/3}\left(\frac{D}{L}\right)^{1/3}\left(\frac{\mu_b}{\mu_w}\right)^{0.14}$$

.....Equation (15)

Nusselt number methodologies zero as the length turns out to be huge. This is because the Sieder-Tate relationship just applies in the warm passage area. In long cylinders, wherein a large portion of the warmth move happens in the thermally completely created area, the Nusselt number is almost a consistent autonomous of any of the above boundaries. Note that a ratio(μb/μw) shows up in the above laminar stream heat move relationship, It endeavors to unequivocally represent the way that the thickness of the liquid close to the divider is not quite the same as that in the mass at any hub area.

2.2 Theoretical Analysis of thermophoretic deposition mechanisms under turbulent flow

Among the various expressions available in the literature for finding the thermophoretic deposition efficiency under turbulent flow, Byers and Calvert (1969) [3] in Equation (16), Nishio et al. (1974) [14] in Equation (17), Batchelor and Shen (1985) [1] in Equation (18), Romay et al. (1998) [15] in Equation (19), Housiadas and Drossinos (2005) [6] in Equation (20), J-S-Lin et al. (2004) [4] in Equation (21) theoretical turbulent models were chosen for present study.

$$\eta_{\mathrm{th}} = 1-\exp\left(-\frac{\rho C_{pf}\,\mathrm{Re}_D K_{th}\,\nu(T_e - T_w)}{4DhT_{avg}}\left(1-\exp\left(\frac{-4hL}{u_m\rho C_p D}\right)\right)\right)$$

.....Equation (16)

$$\eta_{th} = 1-\exp\left(-\frac{\rho C_p K_{th}\,\nu(T_e - T_w)}{k_g T_{avg}}\left(1-\exp\left(\frac{-4hL}{u_m\rho C_p D}\right)\right)\right)$$

.....Equation (17)

$$\eta_{th} = \Pr K_{th}\left(\frac{T_e - T_w}{T_e}\right)\left(1+\left(1-\Pr K_{th}\right)\left(\frac{T_e - T_w}{T_e}\right)\right)$$

.....Equation (18)

$$\eta_{th} = 1 - \left[\frac{T_w + (T_e - T_w)\exp\left(\frac{-\pi D_{ti} h L}{\rho Q C_p} \right)}{T_e} \right]^{P_r K_{th}}$$

.....Equation (19)

$$\eta_{th} = 1 - \left(\frac{T_w}{T_e} \right)^{P_r K_{th}}$$

.....Equation (20)

$$\eta_{th} = 1 - \exp\left(-0.2 \frac{P_r K_{th} Nu_D}{Pe_m} \left(\frac{T_e - T_w}{T_w} \right) \right)$$

.....Equation (21)

The outflows of (Byers and Calvert, 1969 [3]; Nishio et al., 1974 [14]; and Romay et al, 1998 [15]) were determined utilizing a 1D-control volume approach that included statement effectiveness taking a differential liquid component for a specific line cross-segment. (J S Lin, 2004 [4]) examined thermophoretic transport for temperature range 296 to 315 K and Reynolds number of 640, 960 and 1600 were tried utilizing particles going from 0.01 to 0.04 µm in measurement.

There are several theoretical expressions available in the literature for predicting thermophoretic deposition efficiencies in turbulent pipe flows.In the turbulent flow, the Nusselt number is much higher than that in the laminar flow. Correlation suggested by Gnielinski is that the Nusselt number can be expressed in Equation (22),

$$Nu_D = \frac{\left(\frac{f}{8} \right)(\mathrm{Re} - 1000)\mathrm{Pr}}{1 + 12.7 \left(\frac{f}{8} \right)^{1/2} \left(\mathrm{Pr}^{2/3} - 1 \right)}$$

.....Equation (22)

Where, $f = (0.790 \ln(\mathrm{Re}) - 1.64)^{-2}$, For $10^4 \le \mathrm{Re} \le 10^6$

2.3 Experimental matrix for theoretical analysis

The experimental matrix is decided to study the deposition of the particles in a tube by combined diffusion and Thermophoretic mechanisms at a simulated engine conditions. The deposition tube is of 0.5m in length and of 0.00635 m in ID with 0.75 mm thickness. The experimental matrix of the present study is tabulated in the Table 1.

Table -1: Experimental matrix for simulated condition

Parameters	Condition
Inlet tube pressure	1 atm
Gas inlet temperature	T1=50°C , T2=100°C , T3=200°C , T4=300°C , T5=400°C
Particle material	Particulate Matter (Carbon soot)
Particle size (diameter)	0.0001 – 2.5µm
Reynold's number	Re1=100 , Re2=1000, Re3=2000, Re4=5000, Re5=10000, Re6=20000
Tube length ; Inlet diameter ; thk	0.5 m ; 0.00635m ; 0.75mm
Particle source	Atomizer (TSI 3079)
Density of gas	1.2 kg/m^3
Conductivity of tube material ; Particle	398W/(m°k) Copper ; 0.5 W/(m°k)
Ambient temperature.	27°C
Convective heat transfer outside coefficient	20 W/(m^2°K)

3. Results and discussion

Deposition of the simulated engine exhaust particulate matter (carbon) by combined diffusion and Thermophoresis mechanism is analyzed using models available in the literature under both laminar and turbulent flow conditions. Model for Thermophoresis under laminar and turbulent flow is optimized for improved deposition. Influence of effect of flow rate, gas inlet temperature and particle size on deposition mechanisms are discussed in below section.

3.1 Analysis of deposition of Particles by Thermophoretic mechanism using models from literature

Themophoretic deposition efficiency of the particles are studied using literature models under turbulent (Re4=5000; Re5=10000; Re6=20000) conditions and gas inlet temperature of 400°C and results are plotted in chart 1. From the chart 1, it is also clear that among all the turbulent models, all models show maximum variation in between size range of 0.05-6 micron for all flow rates, after that deposition efficiency remains more often constant for all turbulent models.

From the chart 1, it is clear that Batchelor and Shen (1995) [1] model is good for all size range of the particles. Hence it is taken as optimized model in this study under turbulent condition of Re4=5000.

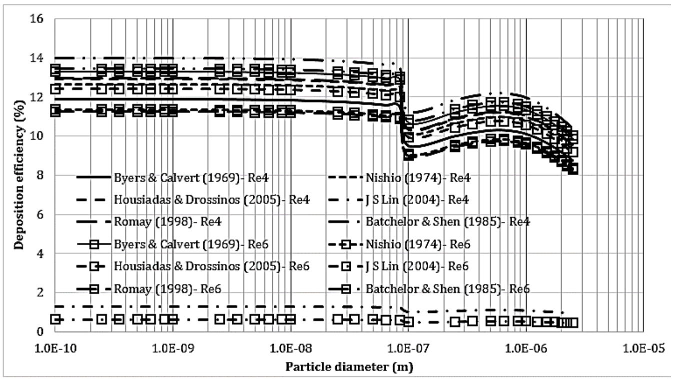

Chart -1: Analysis of Thermophoretic deposition using models from literature under turbulent condition at gas inlet temperature of T5=400˚C

Themophoretic deposition efficiency of the particles are studied using literature models under laminar (Re1=100; Re2=1000; Re3=2000) conditions and gas inlet temperature of 400˚C and results are plotted in chart 2. From the chart 2 it is also clear that among all the laminar models, All models show maximum variation in between size range of 0.05-6 micron for , after that deposition efficiency remains more often constant for all laminar models.

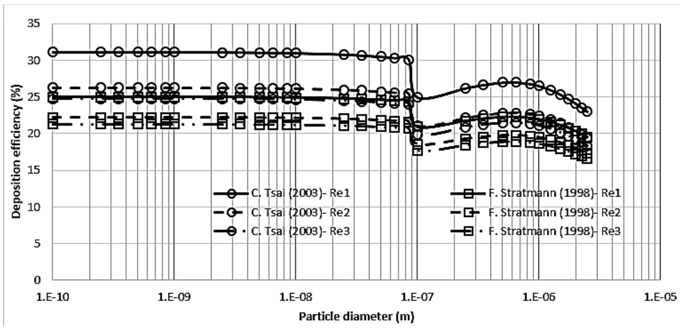

Chart -2: Analysis of Thermophoretic deposition using models from literature under laminar condition at gas inlet temperature of T5=400˚C

From the chart 2, it is clear that C. Tsai (2004) [4] model is good for all size range of the particles. Hence it is taken as optimized model in this study under laminar conditions of Re1=100. From the chart 1 and 2, it is observed that Thermophoretic deposition is independent on the size of the particles up to 0.1 micrometer, beyond which it will changes. As flow rate increases, rate of particle deposited by thermophoresis is increases. Deposition for particle smaller that 0.001µm and greater than 1µm are remained unaffected by variation in temperature and flow rate. From this chart 1 and 2, it is also observed that as per particle size range 0.0001-2.5 µm, thermophoresis deposition is more dominant for particle size less than 0.1µm.

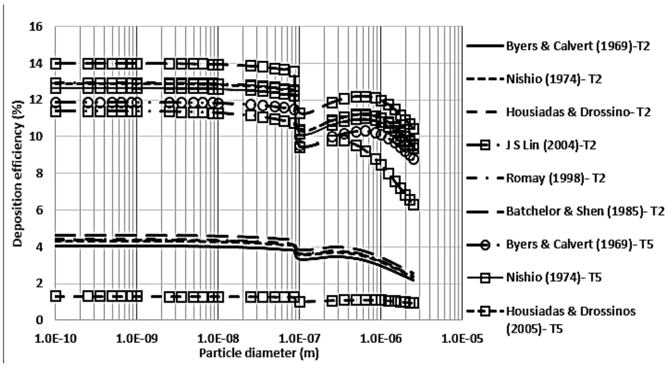

Chart 3 Analysis of Thermophoretic deposition using models from literature under turbulent condition at flow rate of Re4=5000 and gas inlet temperature of T2=100˚C & T5=400˚C

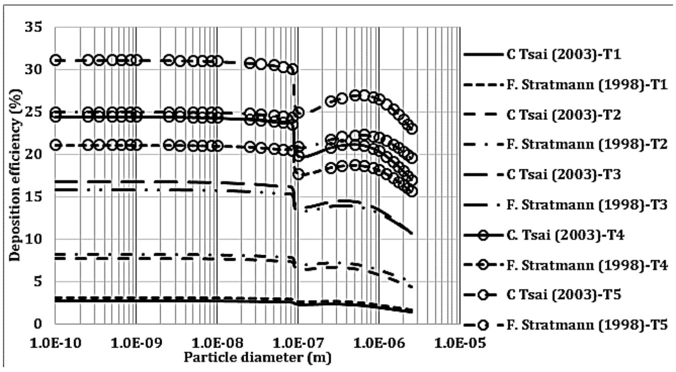

Chart 4 Analysis of Thermophoretic deposition using models from literature under laminar condition at flow rate of Re1=100 and for all gas inlet temperature

Themophoretic deposition efficiency of the particles are studied using literature models under optimized turbulent conditions of Re4=5000 and gas inlet temperature of T2=100˚C & T5=400˚C and results are plotted in chart 3. Themophoretic deposition efficiency of the particles are studied using literature models under optimized turbulent conditions of Re1=100 and gas inlet temperature of T2=100˚C & T5=400˚C and results are plotted in chart 4. From the chart 3 and 4 it is also clear that among all the turbulent and laminar models, All models show maximum variation in between size range of 0.05-6 micron under various gas inlet temperature, after that deposition efficiency remains more often constant for all models. From the chart 3 and 4, it is also observed that Thermophoretic deposition is independent on the size of the particles up to 0.1 micrometer, beyond which it will changes.

3.2 Analysis of Thermophoretic deposition using Optimized model at various gas inlet temperature under turbulent and laminar condition

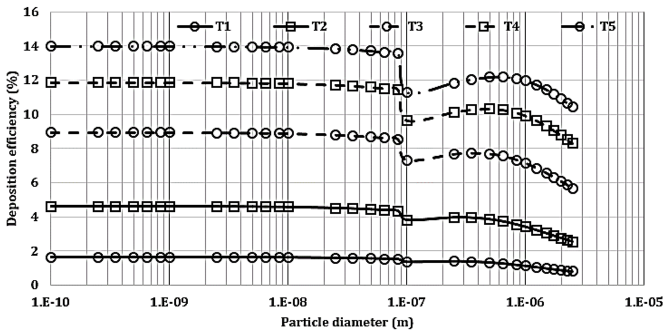

Chart 5 Analysis of Thermophoretic deposition using optimized turbulent model Batchelor& Shen (1985) from literature under turbulent condition at flow rate of Re4=5000 and all gas inlet temperature

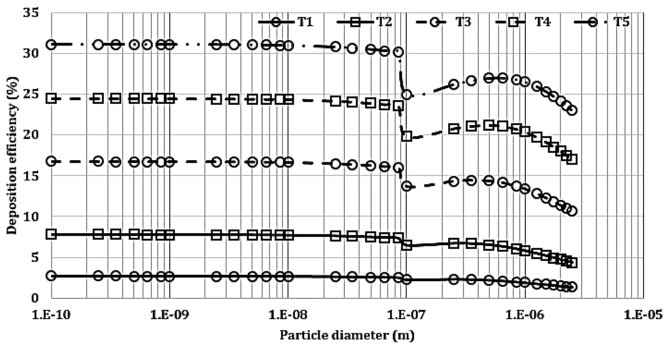

Chart 6 Analysis of Thermophoretic deposition using optimized laminar model C. Tsai (2003) from literature under laminar condition at flow rate of Re1=100 and at all gas inlet temperature

Chart 5 shows the Effect of temperature on thermophoretic efficiency due to optimized turbulent Reynold number Re4=5000 and optimized turbulent model Batchelor& Shen (1985) [1]. From chart 1 and 3, all turbulent thermophoresis models are compared and found Batchelor and Shen (1985) [1] model which gives maximum efficiency among all turbulent thermophoresis models with optimum flow rate of Re4=5000. Chart 6 shows the Effect of temperature on thermophoretic efficiency due to optimized laminar Reynold number Re1=100 and optimized turbulent model C. Tsai (2003) [4]. From chart 2 and 4, all turbulent thermophoresis models are compared and found C. Tsai (2003) [4] model which gives maximum efficiency among all laminar thermophoresis models with optimum flow rate of Re1=100.

Thermophoretic deposition efficiency of the particles are studied using literature models under optimized laminar and turbulent conditions of respective Re1=100 and Re4=5000 and at all gas inlet temperature of (T1=50˚C, T2=100˚C, T3=200˚C, T4=300˚C, T5=400˚C) and results are plotted in chart 5, 6 respectively. Thermophoresis deposition efficiency is directly proportional to the temperature. Efficiency remained constant up to particle size 0.1 micron. Then after sudden change happens due to value of particle size and mean free path of particle is mathematically equal. The thermophoretic deposition efficiencies also agree very well with the theoretical expressions of Batchelor& Shen et al. (1985) [1] in turbulent flow (chart 1, 3, 5) and C. Tsai (2003) [4] in laminar flow (chart 2, 4, 6) with optimized respective flow rate of Re4=5000 (Turbulent flow) and Re1=100 (Laminar flow) and at gas inlet temperature T5=400˚C. The present experimental data suggest that in both turbulent and laminar flows, Talbot's formula for the thermophoretic coefficient is accurate.

3.3 Analysis of deposition of Particles by diffusion mechanism using model from literature

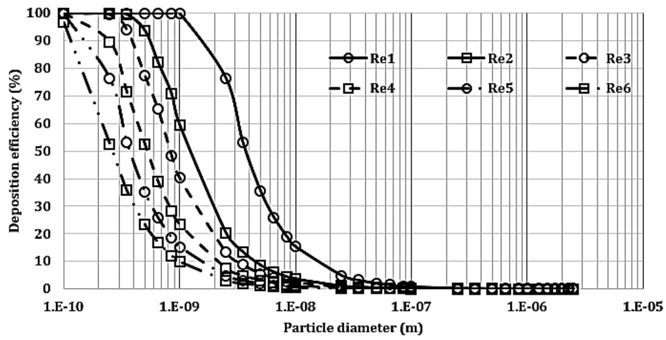

Chart 7 Analysis of diffusion deposition using optimized models from literature under laminar and turbulent condition at constant gas inlet temperature of T5=400˚C

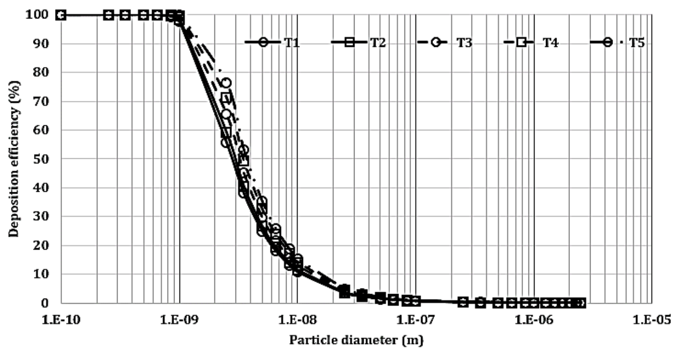

Chart 8 Analysis of diffusion deposition using models from literature under laminar condition at flow rate of Re1=100 and for all gas inlet temperature

Diffusion deposition efficiency of the particles are studied using optimized literature models under laminar and turbulent (Re1=100; Re2=1000; Re3=5000; Re4=5000; Re5=10000; Re6=20000) conditions and gas inlet temperature of 400˚C and results are plotted in chart 7. Diffusion deposition efficiency of the particles are studied using optimized literature models under laminar Re1=100 condition and for all gas inlet temperature of (T1=50˚C, T2=100˚C, T3=200˚C, T4=300˚C, T5=400˚C) and results are plotted in chart 8. From the chart 7 and 8, it is observed that diffusion deposition is dependent on the size of the particles up to 0.1 micrometer, beyond which it will not, changes. From the chart 7 and 8, it is also clear that for respective optimized turbulent model (Batchelor and Shen,1985 [1]) and laminar model (C. Tsai,2003 [4]), both models show maximum variation in between size range of 0.0001-0.1 micron for all flow rates, after that deposition efficiency remains more often constant and tends to zero.

3.4 Analysis of deposition of particles by combined Thermophoresis and Diffusion Mechanism

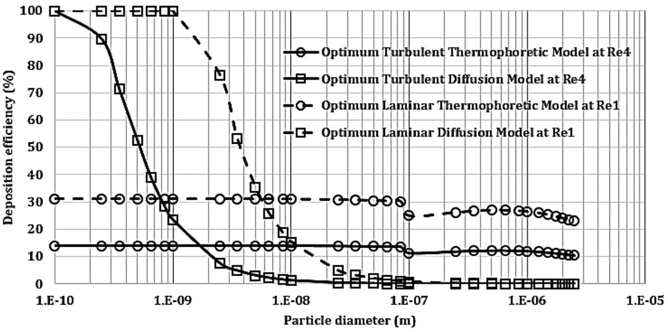

Chart 9 Analysis of thermophoretic and diffusion deposition efficiency using optimized laminar and turbulent models from literature under respective simulated conditions of flow rate (Re1=100; Re4=5000) and temperature (T5=400˚C)

Chart 9 show the Effect on thermophoretic and diffusion deposition efficiency due to optimized simulated conditions of flow rate (Re1=100; Re4=5000) and temperature (T5=400˚C) for optimized laminar model C. Tsai (2003) [4] and turbulent model Batchelor & Shen (1985) [1] respectively. Thermophoresis and diffusion deposition efficiency is depends on temperature. As temperature decrease, thermophoresis and diffusion deposition efficiency also decreases gradually as particle size increases. As per the temperature change, thermophoretic deposition efficiency shows greater variation than diffusion deposition efficiency. As per particle size range 0.0001-2.5 µm, diffusion deposition is more dominating for particle size less than 0.01µm and thermophoresis deposition is more dominant for particle size greater than 0.01µm. Variation in temperature dominantly affects to particle deposited by thermophoresis and flow rate variation dominantly affects to particle deposited by diffusion.

4. CONCLUSIONS

With detailed analysis of data as per methodology and result and discussion following points are summarized,

It is observed from the theoretical analysis that The thermophoretic deposition efficiencies is more by expression given by Batchelor & Shen et al. (1985) [1] in turbulent flow (chart 1, 3, 5) and C. Tsai (2003) [4] in laminar flow (chart 2, 4, 6).

From the present study, it is observed that in both turbulent and laminar flows, Talbot's formula for the thermophoretic coefficient is accurate.

It is observed that due to increase in flow rate there is decrease in efficiency and hence increase in flow velocity as compared to deposition velocity. It also observed that due to increase in particle size there is decrease in thermal deposition velocity because of thermophoretic mechanism is dominates between particle size (0.05-1) microns, after that inertia dominates (chart 1, 2).

From the analysis it is observed that due to increase in gas inlet temperature there is increase in deposition rate due increase in temp gradient.(chart 5, 6)

Thermophoresis deposition efficiency is depends on temperature. As temperature decreases, thermophoresis deposition efficiency also decreases gradually as particle size increases (chart 3, 4, 5, 6). As per the temperature change, thermophoretic deposition efficiency shows greater variation than diffusion deposition efficiency. As per particle size range 0.0001-2.5 µm, diffusion deposition is more dominating for particle size less than 0.01µm and thermophoresis deposition is more dominant for particle size greater than 0.01µm (chart 7, 8, 9).

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