Efficient FEM-FBM for Simulation of Elliptic Particle Sedimentation with Thermal Convection

Antariksha Verma, H. K. Suhas

Abstract: The dynamic sedimentation of large particles including thermal convection gained the significant attentions in various applications using the Direct Numeral Solution (DNS) methods. The current solutions are mainly focused on isothermal suspended particles without the thermal convection separating dissolved particles and enveloping fluids. The systems beside thermal convection having the lack of sufficient investigations like missing the hot and cold elliptic particle in infinity long channels. In this work, we work on two challenges efficient DSN method designing and simulation of elliptic particle in infinity long channel using proposed DNS. The novel approach presented to study and simulates dynamic behaviour of elliptic particle sedimentation using the different settling modes using the Swarm Intelligent (SI) construct Finite Element Fictitious Boundary Method (FEM-FBM) and validates outcomes effectively. The Particle Swarm Optimization (PSO) used as SI to improve the accuracy and efficiency of FEM-FBM model in this work. The PSO based multi-grid FEM-FBM called PFEM-FBM proposed as Direct Numerical Solution (DNS) to simulate and validate fluid flows with thermal convection. The PFEM-FBM method used to understand the progression, energy, and warmth conditions effectively. The re-enactments utilizing PFEM-FBM led to utilizing the three diverse experiments. In the principal case, the relative investigation of cold, hot, and isothermal elliptic particles with thermal convection introduced. In the resulting situation, the estimation of cold elliptic particle improving in an incomprehensibly long channel with its endorsement presented. In the third case, the examination of hot elliptic particle resolve in an incessantly large channel with its support presented. The completion of the study is validated using the simulation outcomes with recent technique at the end.

Keywords: Direct numerical solution, finite element method, fictitious boundary method, particle swarm optimization, sedimentation, thermal convection.

I. INTRODUCTION

The action of strong particle in a gooey liquid has big numbers of applications into the deferent planning areas. For instance, into the re-dox of suspension stream batteries, shape, size & course of action of all powerful elements of material & material conductive particles are typically combined parameters impacting theology & transport characteristics of suspension liquid. Into such programmes, the liquid inertness & thickness has been restricted, director of liquids & solid particles has been unequivocally combined, and thusly, molecule movement demonstrates rich physical wonders [1]. Among various parameters impacting molecule movement, molecule shapes expect a fundamental activity. During the previous quite a few years, the motion of circular particles has attracted much consideration because of the balance of particle shape. As of late, more inquiries about the spotlight in movement of non-round particles to really discover genuine molecule transport structures [2]. For two dimensional (2D) bended molecule or three dimensional (3D) ellipsoid molecule sedimentation, 8 undeniable conditions has been represented: vertical mode, oscillatory mode, flat mode, inclined mode, level II mode, inclined II mode, odd moving mode & winding model. Even mode suggests molecule sediment on a level plane with an enduring speed with centre line of the channels [3] [4]; when flat II mode implies molecule build-up on a level plane with the faltering model. In the accepted style, particle build-up along predictable speed and an unfaltering propensity to level; while in the inclined II mode, inclined molecule leftovers with the influencing structure. Into vertical mode, molecule residue vertically & it will in general seen such a restriction of inclined mode along a propensity purpose ninety degrees. Oscillatory mode suggests molecule squirms fall channel, pushing toward various areas of divider at times & influencing in channel centre line; when atypical moving mode defined as falling elements turns as if it has been coming to & moving up with one of the channel dividers. Winding mode has been surprising into the 3D ellipsoid molecule settlement & it exhibits iota spirals within channel centreline when edge between molecule centre point & channel centreline keeping predictable [5]. As of late referenced modes all things considered result from 2 impacts: 1st is waterway geometry impacts, which has been delineated through stalemate degree such channel width through molecule turn length; 2nd is molecule inertial impact, which has been depicted through molecule Reynolds number like segment molecule size & molecule thickness. By a wide margin the greater part of the assessments talked about above concentrated on just iso-thermal alimented elements where there is no warm convection into alimented elements & consolidating liquids [6] [7]. As warm impacts are not constantly irrelevant in pondering molecule suspension since warmth move may essentially change the particle kinematics, some ongoing works answered to think about the elliptic particle sedimentation with the thermal convection, be that as it may, there is absent of broad investigation of energy trade with thermal consequences for the sedimentation conduct of curved particles Different Settling Modes [8]-[10].

* Correspondence Author

Antariksha Verma* PhD Scholar, Department of Mechanical Engineering, Kalinga University, Raipur, India.

Dr. H. K. Suhas, Department of Mechanical Engineering, Kalinga University, Raipur, India.

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Hence with such motivation, in this research we model, simulate, and validate the sedimentation behaviour of elliptical particles with convention heat transfer using various settling modes.

In this paper we present the study that investigates the design of dynamic behaviour of elliptic particle sedimentation using the different settling modes using the PSO based multi-network Limited Component Invented Limit (PFEM-FBM) strategy. As far as we could possibly know this the first DNS approach in which the SI acquainted with streamline the multigrain issue solver. We planned, mimicked and approved the impacts of warm properties of the liquid, for example, warm enlargement and warm dissipating on the sedimentation of the hot and cold elliptic molecule in limitlessness long channel. In segment II, the short audit of related works exhibited. In area III, proposed strategy and calculations depicted. In segment IV, re-enactment results introduced. In area V, the approval displayed. In segment VI, conclusion and future work described.

II. RELATED WORK

This section presents the various DNS methods introduced for the particular flows simulation followed by the various methods for sedimentation particle analysis presented.

In [11]-[14], author presented a multi-grid limited component invented limit strategy (FBM) to increase particular streams. Later past, various creamer methodologies is made to re-enact sedimentation of released particles in a liquid, As instance, the cross-zone Boltzmann framework (LBM) is gotten together with other numerical methodology, for example, IBM [15], Limited Component Strategy (FEM) [16] and Discrete Component Strategy (DEM) [17].

In [18] and [19], the creators utilized another cross breed technique CFD & DEM, where calculated fluid components (CFD) has been associated along DEM for analysis of the sediment transportation. Despite the fact that heat move in particulate flows is engaged with numerous modern applications, yet just a couple of results are found in the writing. In [20], the creator proposed an Inundated Limit Technique (IBM) with regards to a Limited Volume (FV) set system plan for the plan of condition move in multiple two-dimensional geometries externally concerning the stable platform movement.

In [21], author displayed the FV-IB system with a non-deadened cross-section methodology for warmth move and liquid stream around fixed particles. Before [22], the creator utilized a compelled volume non-adjusted purpose of control fitted matrices to consider the warm convection around the fixed strong stage. In [23] [24], the writer utilized the Blend imagine for re-enactments of two dimensional molecule sedimentation issues along warmth move among elements & joining liquid.

In [25], the writer used the imagined space procedure to deal with particulate stream issues and loosened up it for analyse heat convection in interface between liquid & strong elements. In [26] [27] writer built up a compelled volume IBM framework for warmth move between liquid & going strong elements in molecule stacked streams. The numerical assessment warm convection in particulate streams is endeavoured through specific various experts too in [28] [29].

In [30] author recognized five contending systems for horizontal relocation of a roundabout particle with thermal convection, in particular, the divider aversion because of grease, the inertial lift identified with sheer slip, the lift on account of particle insurgency, the lift in light of the twist of the regular velocity form also, the journey influenced by thermal convection. Some different scientists have additionally given an account of the numerical investigation of thermal convective particulate flows [31]-[39].

In [40], productive methodology for the precise reproduction of thermal convective particulate flows including countless particles exhibited. Some different scientists have likewise given an account of the numerical investigation of thermal convective particulate flows.

In [41], the writer revealed the main examination wherein the thermal consequences during the sedimentation head of extensive bits by means for particle resolved direct numerical multiplication including created some new approaches for particle's settling.

In [42], contributors analysed results convection of thermal on segments of an elliptic element when improving into impenetrable liquor utilizing multi-network FEM-FBM. The displayed system settles the warmth, force, and coherence conditions all the while.

In this paper, we motivated from the works reported in [40] and [42] to design the PSO construct multigrain FEM-FBM design to recreate the particulate streams with thermal convection.

III. METHODOLOGY

The swarm intelligent technique PSO introduced along with multi-grid FEM-FBM model to form the novel DNS technique called PFEM-FBM in this paper. The proposed model at that point used to re-enact and dissect the thermal convection impacts on the elliptic particle elements while improving in an impenetrable liquid.

3.1. Problem Formulation

To build the problems, we consider the list of parameters mentioned in the table 1. It shows the N solid particles of mass Mi where i = 1, 2 ….N in impenetrable Newtonian vapour.

Table 1: List of parameters in fluid flow

Symbol	Significance
N	solid particles number
Mi	N number of mass
p_f	Fluid density
V	Fluid viscosity
$\Omega_f(t)$	Domain accepted through fluid at time t
$\Omega_i(t)$	Domain accepted through fluid of ith particle at time t
Ω_T	Total domain
U	Fluid velocity
μ_f	Coefficient of viscosity

F	Source term
T	Temperature
c_f	Specific heat
k_f	Thermal conductivity of fluid
σ	Fluid phase total stress tensor

The Ω_T as total domain has been shown by:

$$\Omega_T = \Omega_f(t) \cup \Omega_i(t) \qquad \forall\, i \in (1,2,3,\dots N)$$
(1)

where,

- Ω_T Is an every calculation empire individualistic of t?
- Ω_f & Ω_i be conditional on the time *t,* hence it is denote as $\Omega_f(t) = \Omega_f$ and $\Omega_i(t) = \Omega_i$ release t in the notations.
- $\partial\Omega_i$ Appear for the margins of the ith particle.

Based on this, the fluid flow model and particle motion model are formulated as:

A. Model of Fluid Flow

The incompressible fluid motion with p_f is administered through the conditions of force, vitality, and coherence in the space Ω_f given by:

$$\nabla . u = 0 \quad (a)$$
(2)

$$p_f \left[\frac{\partial u}{\partial t} + u.\nabla u\right] - \nabla.\sigma = \text{f(b)}$$
(3)

$$p_f c_f \left[\frac{\partial u}{\partial t} + u.\nabla T\right] = k_f \nabla^2 T \qquad \forall\, X \in \Omega_T(c)$$
(4)

Where, σ which is given by:

$$\sigma = -pI + \mu_f[\nabla\mu + (\nabla\mu^T)]$$
(5)

B. Model of Particle Motion

After defining the model of fluid flow, this section presents the model of particle motion. As the inflexible particles free, they move in the fluid space which prompts the way that particles furnished with a rotational and translational motion under the activity of gravity and powers, for example, impact powers and hydrodynamic powers. The hydrodynamic powers brought about by fluid and crash powers brought about by associations among particle-divider or particle-particle. To assemble the model the rundown of parameters is given in table 2.

Table 2: List of parameters in particle motion

Symbol	Significance
U_i	i^{th} particle Translational velocity
w_i	i^{th} particle Angular velocity
m_i	Mass of ith particle
m_f	Fluid mass accepted similar volume as m_i
F_i	Resultant hydrodynamic (lift & drag coefficients) of ith particle
F_i'	Collision forces action on of ith particle
I_i	i^{th} particle inertia tensor interaction
τ_i	Resultant torque centre of mass of ith particle
g	Gravitational accelerations

The solid particles motion conducted by Newton-Euler formulations, accordingly the particle required to satisfy the equation (6) if the translational and rakish speeds of particle available:

$$m_i \frac{dU_i}{dt} = (\Delta m_i)g + F_i + F_i' , \qquad d_i \frac{dw_i}{dt} + w_i \times (I_i w_i) = \tau_i$$
(6)

Δm_i Is given by:

$$\Delta m_i = m_i - m_f$$
(7)

C. Effects of Fluid Interactions

The particles are free and they move which leads the interactions among the particles and fluid. The effects of such interactions resulted into exertion of the forces on fluid and particles. The trading of vitality and force happens among fluid and particles during the interactions such as hydrodynamic forces, momentum interaction, energy interaction, and Bossiness approximation. The equations of such problems described in [40] [42]. To solve such problems related to interactions the solver model introduced in next section.

3.2. Multi-grid PFEM-FEB

To solve the fluid particle interactions we introduced the multi-grid approach to solve which depends in various networks, gotten by routinely refining the course work? Essentially multi-lattice used to get the best answers to tackle the issue, in this work we utilized the PSO technique in the multi-network solver. In multi-matrix, the PSO imperative is applied to the lingering in the wake of softening on all activity levels, and a straightforward moving through solver is applied to make the course of action in coarsest grid if amount of degrees chance is close to nothing. Further, prolongation has been utilized trailed through post smoothing in PSO health ability to get the best particle plan. These schemes remain continuously the accentuations of multi cross section cycle (V & F cycle, as appearing in calculation 1 and 2) completed as a major aspect of the PSO intermingling step. With the assistance of certain administrators, here we clarified how multi-framework deals with an issue utilizing distinctive network levels. The multi-lattice method to comprehend the straight framework $A_i u_i = b_i$ is presented in the following steps with the *k* number iterations. Figure 1 demonstrates the PSO based multi-grid solver introduced in this work. Using the iterative optimization over the various grid levels, better results obtained to solve the problems. Based on the figure 1, the algorithm 1 and 2 designed to solve the problems caused by the fluid particle interactions. The multi-framework V cycle (MGV), multi network W cycle (MGW) & multi matrix F cycle (MGF) required by using proposed DNS method. The algorithm 1 and 2 shows the steps solving process of MGV and MGF respectively.
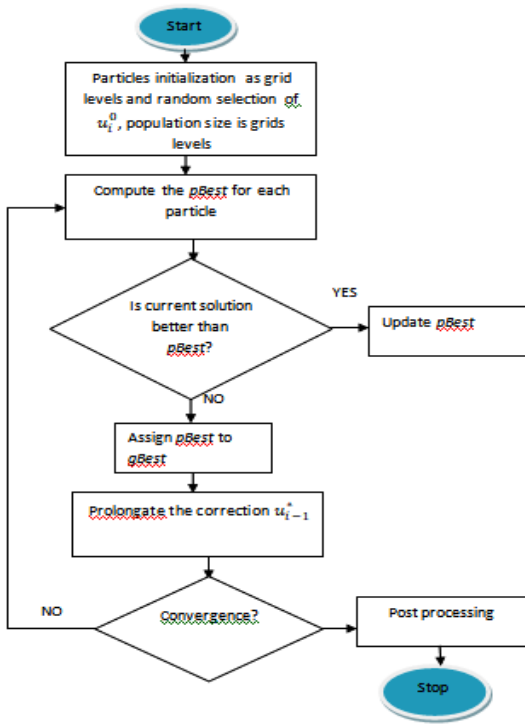
Fig.1. PSO based multi-grid solver

Algorithm 1: MGV
function MGV (b^i, u^i) $i = (1:k)$, k: number of iterations

1. Initialization of population size and random selection of particle
 2. Compute the *pbest* for each particle
 3. Fitness function
    3.1. Rearrange the estimated resolution u^i of the system $A_i u_i = b_i$ among an enhanced clarification
    3.2. if i= 1
      • measure the correct resolution u^i
      • $pbest = u^i$
      • return *pbest*
    3.3 else
      • Computer the fitness function as:
      • $u^i = s(b^i, u^i)$,
      • $r^i = A^i . u^i - b^i$
      • $d^i = p\left(MVG(R(r^i), 0)\right)$,
      • $u^i = x^i - d^i$
      • $u^i = s(b^i, u^i)$
      • $pbest = u^i$
      • return *pbest*
 4. At each iteration, if current solution better than previous *pbest* then update the new *pbest*
 5. Else assign *pbest* to *gbest*
 6. If (finished V cycled)
    • Algorithm converged
    • Return best solution u^i

7. Apply post process on obtained u^i
8. Return final u^i

Algorithm 2: MGF
function MGF (b^i, u^i)
1. Return an accurate solution u^i of the system $A_i u_i = b_i$ 2. solve exactly $A_i u_i = b_i$ to get u^1 3. for i= 2 to k   4. $u^i = MGV\left(b^i, p(u^i)\right)$ 5. end for

After presenting the PSO based multi-grid solver, next we have to present the model of Multi-grid PFEM-FBM solver. This multi-matrix invented limit technique depends on the PFEM foundation framework which covers the entirety computational domain Ω_T as described in [40] [42]. Using the solver model, we further perform the computations to solve the problems related to hydrodynamic forces, torque, drag and lift coefficients, energy balance equations, dimensionless parameters which are used to investigate the dynamic sedimentation behaviour of particle with thermal [42].

IV. SIMULATION RESULTS

The simulation and validation of PFEM-FBM approach performed using the MATLAB tool in this paper by considering the three test cases described as below:

4.1 Investigation of Different Elliptical Particle Sedimentation

In this test case, settling practices of a the hot elliptic molecule, the whole distance open to the fierce segments liquid, a cool molecule in the hot liquid, and an isothermal molecule in a vertical liquid channel are re-enacted using the diversion parameters depicted in the table 3. The article is from the start arranged at the point (2, 10), and its course is with the ultimate objective that the genuine centre of oval creates the edge of θ= 0^Oto the horizontal centre point of channel. For host and cold particle, the distinct the dimension less temper of particle & fluid has been 1. The differentiation in temperatures is 0 for the isothermal particle.

Table 3: Simulation parameters in case study 1

Parameter	Value	Significance
b	0.5	Ellipse minor axis
A	2b	Major axis of ellipse
W	4a	Width of channel
H	12a	Height of channel
L	$\sqrt{ab}$	elliptic particle length of characteristic

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V	0.1	Fluid kinetic viscosity
p_r	1.1	density ratio of solid fluid
Re	40	Dimension less flow number values
Pr	0.7	Prandtl number
c_r	1	solid & liquid Heat power ratio
T	1	particle surface dimension less temperature
T_f	0	Fluid temperature
G_r (hot)	500	Grashof number for hot
G_r (cold)	-500	Grashof number for cold
G_r (isothermal)	0	Grashof number for isothermal

Figure 2 shows the cold particle similarly increases a lot big possible velocity than hot & isothermal particle & therefore, there is an immense variation between drag coefficients Album of hot moreover cold elliptic particles when spot achieve most extreme speeds like appeared in figure 3. From these outcomes of cold particle, it is seen that the trademark convection improves the compelled convection, and thusly, the settling speed of the molecule is incredibly high. The eventual outcomes of hot molecule settling in a chilly liquid exhibit that molecule goes about as a glowing source and the glow streams from the molecule for including liquid. Both drag control & delicacy power shield molecule via reviving at a higher space toward gravity, & molecule settles influenced by compete between warm convection & compelled convection. Appropriately, settled speed of hot molecule in chilly liquid low appears differently in relation to the cool molecule into hot liquid and that of iso-thermal molecule.
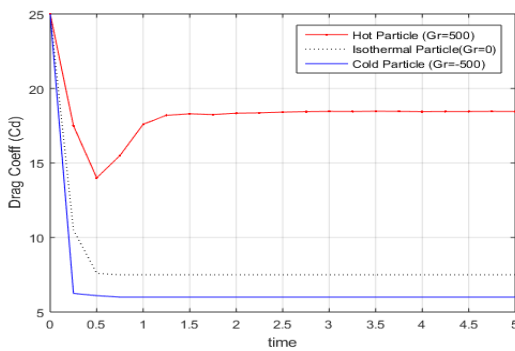

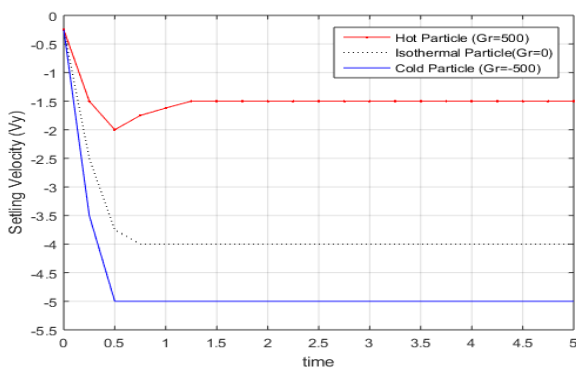**Fig.2. Drag coefficient of the particles with respect to time**

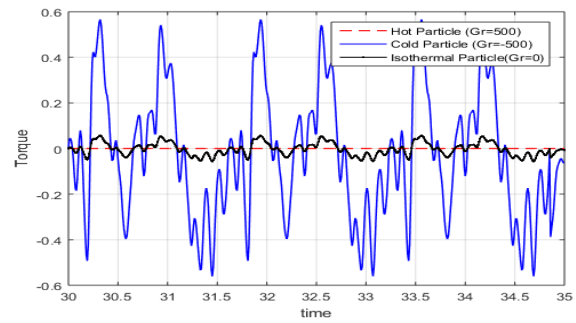**Fig.3. Settling velocity of the particles with respect to time**

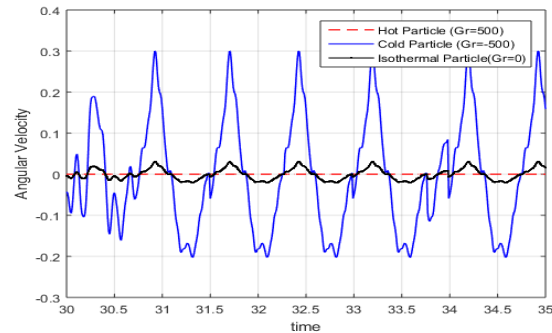**Fig.3. Torque of particles with respect to time**

Fig.5. particles Angular velocity along respect to time

The isothermal particle sedimentation results show that all fluid & particle are at a comparable steady heat; along these lines, power in light of thermal convection is excluded. The particle settles simply influenced by obliged convection in light of the way that no glow change happens among the liquid and molecule that makes the sophistication control. Further, in figures 4 and 5, it is seen that in light of big settled speed of the chilly molecule, plentifulness of torque powers following up on molecule as a result of hydrodynamic investment is higher showed up distinctively in connection to the hot and isothermal particles. Similarly, the isothermal molecule faces a torque of little monstrosity, in any case, the level of torque powers following up on the hot molecule is just around zero because of more slow settling velocity.

4.2 Investigation of Cold Elliptical Particle Settling

In this segment, we further exhibited the re-enactment after-effects of the third experiment where the examination of cold curved particle settling in hot fluid performed under the unmistakable settling strategies for a roundabout particle with the impact of compelled and thermal convection. Table 4 exhibits the once-over of re-enactment parameters for this test. The elliptic particle has been added at centreline of channel with the intention which has been outstanding centre of particle creates edge of θ= ⟦45⟧^o to level centre of the flow.

Table 4: Simulation parameters in case study 2

Parameter	Value	Significance
b	0.5	ellipse small axis
a	2b	Major axis of ellipse
W	0.4	Width of channel
H	2	Height of channel
L	$\sqrt{ab}$	elliptic particle Characteristic length

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v	0.1	kinematic viscosity of the fluid
p_r	1.001	fluid-solid density ratio
Re	100	dimensionless flow number values
Pr	7	Prandtl number
c_r	1	solid and liquid Heat capacity ratio
T	0	dimensionless temperature
T_f	1	Fluid temperature
G_r	{-200, -600, -1000}	Set of Grashof numbers
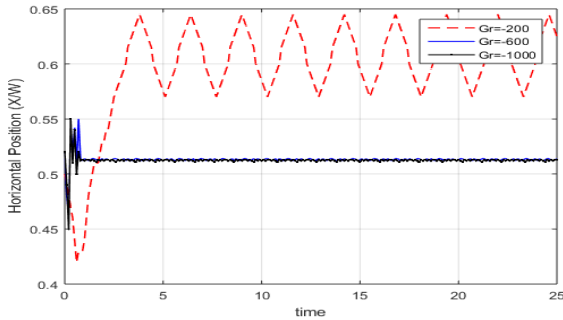
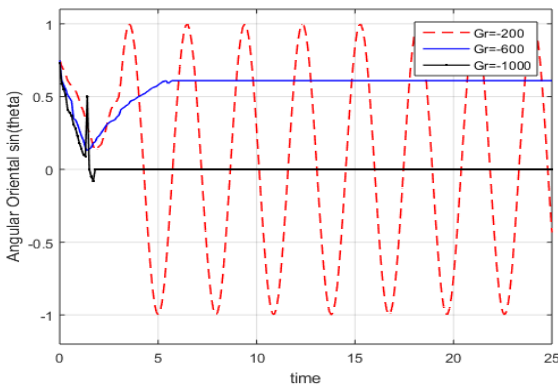**Fig.6. Horizontal position of settling cold particle w.r.t time**

Fig.7. cold particle w.r.t time Angular orientation of settling

Figures 6 and 7 are showing the results of three unmistakable sedimentation methods of the cold elliptic particle with changing Gr numbers. For the instance of Gr = -200, it is seen that the settled elliptic particle shows the tumbling method. For occurrence of Gr = - 600 particle improves continually in inclined method close centreline of pipe along reliable list to regular accomplishment of flow. For the case of Gr = - 1000, the elliptic particle settled frequent with centreline in horizontal mode with a predictable purpose of θ= 0° to the horizontal rotate. The modes change to ensure that the effect of ordinary thermal convection over particle sedimentation increases as the Grashof number augmentations.

Figure 8 shows that particle settling velocity in the tumbling mode moreover demonstrates standard irregular motions with a little abundance, while particles covered along enduring velocity in tending mode & horizontal mode. From this result, it is perceived that descending velocity has been big in inclined mode appeared differently concerning horizontal mode, in like manner, settled velocity of rolling

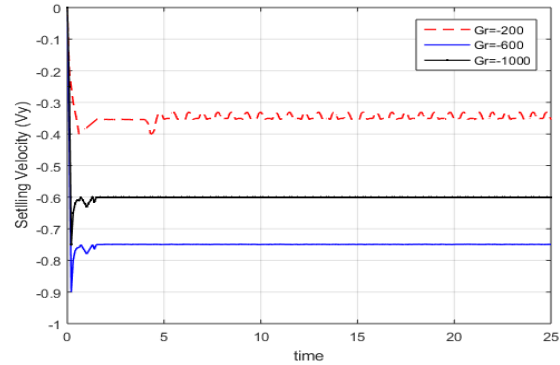particle influences, as rolling mode particle demonstrates steady rotational movement.

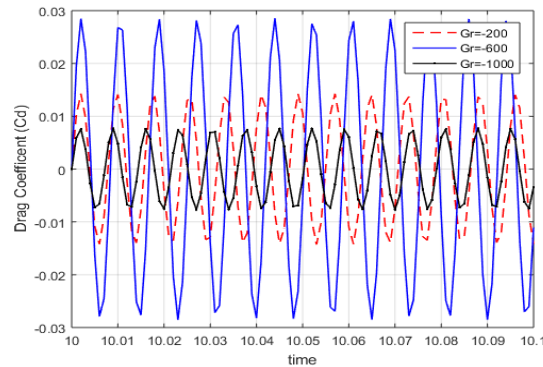**Fig.8. Settling velocity of cold particle w.r.t time**

Fig.9. Drag coefficient of cold particle w.r.t time

Figure 9 demonstrates the outcome of drag coefficient following up on the particle in various modes, for example, tumbling mode, slanted mode, and even mode. These outcomes guarantee that the ampleness of the drag coefficient in the slanted mode is higher stood apart from the other two modes by righteousness of the higher settling speed. Drag coefficient plentifulness in the tumbling mode is higher than that in the flat mode positioning in light of a higher recurrence of sideways motions and precise pivots.
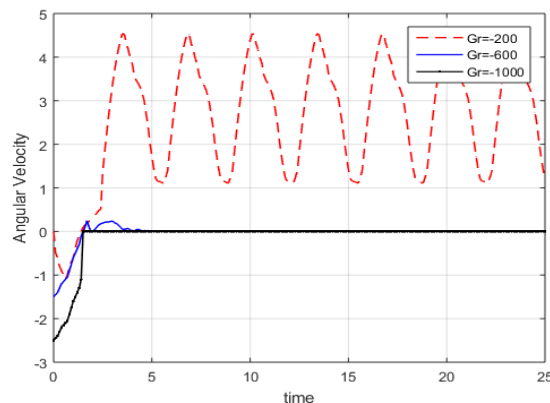

Fig.10. Angular velocity acting on settling cold particle w.r.t time

Finally in investigation of cold elliptic particle settling, the angular velocity and torque measured in figures 10 and 11 respectively. The results show that greatness of torque is practically steady zero on account of flat mode and slanted mode positioning,

and thus the rotational speed of the molecule in these two modes is zero. As appearing in figure 10, the cool elliptic molecule in the tumbling mode settling encounters a solid coupled power the counter-clockwise way. Figure 11 exhibits that jaunty expanding pace created & particle turns with exact velocity whose significance changes sometimes along every turn of particle.
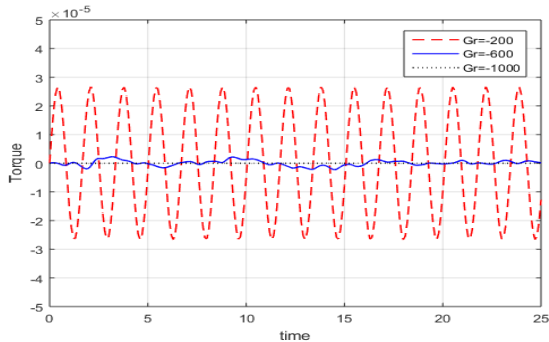

Fig.11. Torque acting on settling cold particle w.r.t time

4.3 Investigation of Hot Elliptical Particle Settling

The final investigation of this research work presented in this section in which analysis of hot elliptic particle sedimentation exposed to the harsh elements fluid considered. The re-enactment parameters are exhibited in table 5. As talked about before the sedimentation of hot elliptic particle is investigated in three modes such as vertical, rolling, and horizontal. In subsections we analyze the simulation results in each mode using the PFEM method.

Table 5: Simulation parameters in case study 3

Parameter	Value	Significance
b	0.5	Minor axis of ellipse
a	2b	Major axis of ellipse
W	0.4	Width of channel
H	2	Height of channel
L	$\sqrt{ab}$	Characteristic length of the elliptic particle
v	0.1	kinematic viscosity of the fluid
p_r	1.001	fluid-solid density ratio (vertical position and velocity analysis)
p_r	1.04	fluid-solid density ratio in vertical mode settling
p_r	1.07	fluid-solid density ratio in rolling mode settling
p_r	1.7	fluid-solid density ratio in horizontal mode settling
Re	100	dimensionless flow number values
Pr	7	Prandtl number
c_r	1	solid liquid Heat capacity ratio
T	1	particle surface dimensionless temperature
T_f	0	Fluid temperature
G_r	200	Grashof number (vertical position and velocity analysis)
G_r	400	Grashof number in vertical mode settling
G_r	600	Grashof number in rolling and horizontal mode settling

A. Vertical Mode

In vertical mode, examinations performed utilizing the estimation of pr=1.04 and Gr = 400 with every other parameter comparative as delineated in Table 5. The particle settles affected by the challenge between the regular convection and the constrained convection.
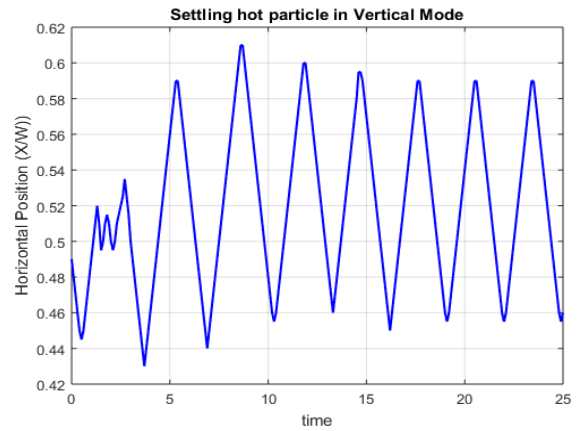

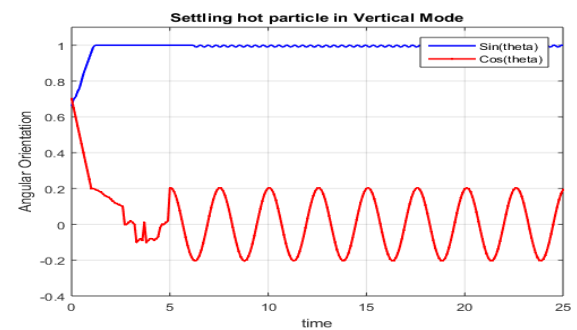**Fig.12. Horizontal position of settling hot particle w.r.t time in vertical mode**

Fig.13. Angular orientation of settling hot particle w.r.t time in vertical mode

Figure 12 demonstrate that particle indicates motions of a little extent about the inside line while settling in vertical mode. Figure 13 demonstrates that the particle residue by keeping up its upstanding direction with the end goal that the point between the real hub of the oval and the horizontal course is pi/2.
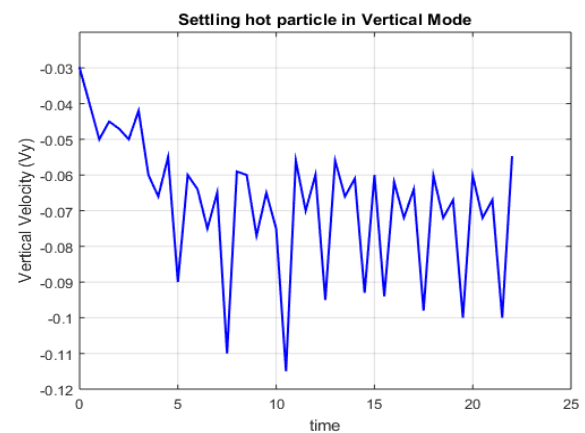

Fig.14. Vertical velocity of settling hot particle w.r.t time in vertical mode
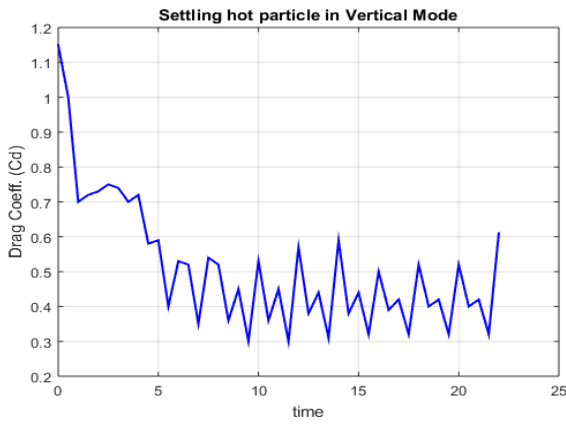
Fig.15. Drag coefficient of settling hot particle w.r.t time in vertical mode

In figure 14, the motions in the settling velocity of particle have been consequence of test among normal convection and compelled convection as discussed previously. In figure 15, drag coefficient Compact disc following up on characterised in inclined mode demonstrates comparable motions because of the changing settling velocity.

B. Rolling Mode

After the simulation of vertical mode, we further investigated the rolling mode results using the $p_r = 1.07$ and $Gr = 600$. Figure 16 and 17 demonstrated the outcomes of direction and precise directions of the hot particle in rolling mode. From the results, it is seen that the particle settled from centre line close to one side divider along motions of little degree & edge between genuine centre point of particle & flat course modifications discontinuously from 0 to 2pi.
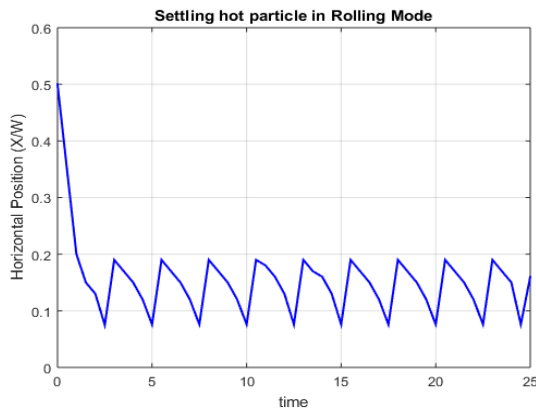

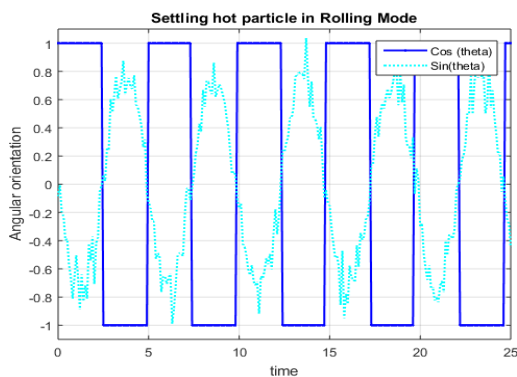**Fig.16. Horizontal position of settling hot particle w.r.t time in rolling mode**

Fig.17. Angular orientation of settling hot particle w.r.t time in rolling mode

C. Horizontal Mode

Finally the horizontal mode case where we increased the density ratio $p_r = 1.7$ with same Gr number as used in rolling mode.
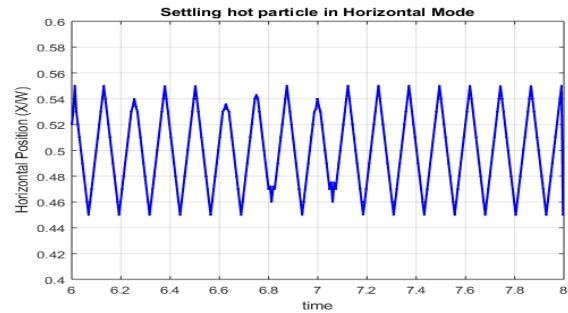

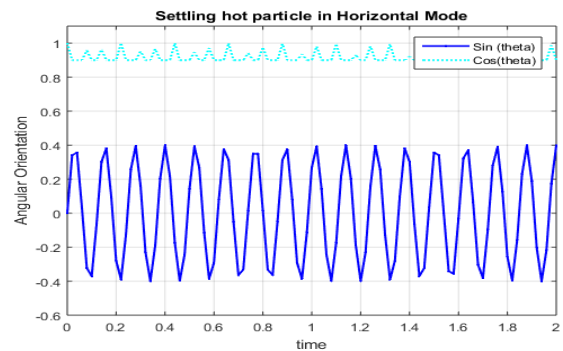**Fig.18. Horizontal position of settling hot particle w.r.t time in horizontal mode**

Fig.19. Angular orientation of settling hot particle w.r.t time in horizontal mode

From the analysis of all three modes, it is seen that by expanding the estimation of pr the particle direction and direction changing from vertical to rolling mode & next to horizontal mode. Figures 18 and 19 are showing the outcomes of trajectories and angular orientation hot elliptical particle in horizontal settling mode respectively. Among all the modes investigation of trajectory and orientations, the variations observed for the hot elliptical particle.

V. VALIDATION

The validation study presented to verify the effectiveness of proposed PFEM-FBM as compared to recent method FEM-FBM [42]. The validation is performed through the comparative analysis of simulated test cases in terms of maximum and minimum values to claim the effective implementation of energy balance equation as well as to claim effectiveness of proposed model.

5.1 Validation of Different Elliptical Particle Sedimentation

In this case study we have simulated and investigated the settling behaviour of hot, cold, and isothermal elliptical particles. In this section we validated their outcomes for drag coefficient, torque velocity, and angular velocity in tables 6, 7 and 8 respectively. As table 6 it shows that for hot settling particle its takes higher drag coefficient velocity and for isothermal it's minimum. Using the PFEM-FBM, the outcomes of drag coefficient velocity shows the more

efficiency as compared to FEM-FBM as the PSO introduced to select the optimum solution in grid solver algorithm.

Table 6: Validation of drag coefficient for hot, cold, and isothermal particles

Gr no	Max [FEM-FBM]	Min [FEM-FBM]	Max [PFEM-FBM]	Min [PFEM-FBM]
500 (Hot)	25	14.04	25	14
-500(Cold)	25	7.6	25	7.5
0 (Isothermal)	25	6.04	25	6

Table 7: Validation of torque for hot, cold, and isothermal particles

Gr no	Max [FEM-FBM]	Min [FEM-FBM]	Max [PFEM-FBM]	Min [PFEM-FBM]
500 (Hot)	0	0	0	0
-500(Cold)	0.573	-0.5503	0.5662	-0.5608
0 (Isothermal)	0.0569	-0.0545	0.0566	-0.0561

Table 8: Validation of angular velocity for hot, cold, and isothermal particles

Gr no	Max [FEM-FBM]	Min [FEM-FBM]	Max [PFEM-FBM]	Min [PFEM-FBM]
500 (Hot)	0	0	0	0
-500(Cold)	0.3012	-0.2021	0.3002	-0.2023
0 (Isothermal)	0.0309	-0.0200	0.0300	-0.0202

5.2 Validation of Cold Elliptical Particle Settling

The third case study belongs to study of sedimentation of cold elliptic particle has been hot fluid. For validation purpose, we validated the drag coefficient values as compared using different Grashof numbers in table 9.

Table 9: Validation of drag coefficients of settling cold particle in hot fluid

Gr no	Max [FEM-FBM]	Min [FEM-FBM]	Max [PFEM-FBM]	Min [PFEM-FBM]
-200	0.0506	-0.0472	0.0543	-0.0243
-600	0.0893	-0.0868	0.0785	-0.0685
-1000	0.0227	-0.0194	0.0177	-0.017

Table 10: Validation of settling velocity of the settling cold particle in the hot fluid

Gr no	Max [FEM-FBM]	Min [FEM-FBM]	Max [PFEM-FBM]	Min [PFEM-FBM]
-200	0	-0.39	0	-0.4
-600	0	-0.88	0	-0.9
-1000	0	-0.73	0	-0.75

The validation outcomes justifies that PFEM-FBM is solid for the thermal convection recreation in particulate flows with the circularly formed particles as compared to FEM-FBM.

VI. CONCLUSION AND FUTURE WORK

The PFEM-FBM introduced over the recent FEM-FBM method so as to improve productivity by presenting the PSO for the best arrangement determination. The re-enactment results exhibited for the diverse experiments of examinations in this work. In the primary examination, the relative investigation regards heating, cold & isothermal elliptic particle settling exhibited which presume that torque and hydrodynamic powers following up on cold, hot & isothermal elliptic particles demonstrates the various practices. In second and third contextual investigations, cold elliptic particle and hot elliptic particle settling into the big channels explored under the diverse settling modes. As indicated by the conduct of particle settling, distinctive settling strategies for the cold and hot particle investigated in this work, for instance, inclined mode, tumbling mode, a vertical mode, rolling more & horizontal mode. Endorsement results legitimize that PFEM-FBM is strong for the thermal convection diversion into particulate flows along circularly shaped particles. For future work we suggest to investigate the various optimization methods in place of PSO for DSN methods.

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