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Review Article

Potential Investigation on Multiphase Flow of Loaded Dispersion for the Production of Metallized Paper

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Abstract: The current review research's main objective is to develop dispersion models in the multilayer curtain coating with the production of metallized paper. To achieve this, the curtain coating on the paper substrate is employed with respect to multilayer coating of polymers. The first layer of polymer is applied to the paper and then it is subjected to vacuum metallization with aluminum deposition. After it, another second layer of polymer is subjected on it to prevent it from oxidation. These coated polymers are different in nature. The metallized paper will be produced which has high strength will be formulated in this application of curtain coating. The instability of curtain and air entrainment will be minimized from high Weber number, low Reynolds number, Optimum web speed and Coat weights. The above demonstrated process simulation will be modelled in Ansys-CFD. The dispersion of solids in the curtain flow through substrate moving on the web will be evaluated from different numerical methods. Each method has its own characteristics to study the nature of solids dispersion. The high loaded solids dispersion will be investigated from numerical methods including Langrangian Point Particle, Coarse grained molecular dynamics, Stokesian Dynamics, Brownian Dynamics, Point Particle Method Reynolds Averaged Navier Stokes equation, Eulerian Method, Langrangian-Eulerian Point Particle, Large Eddy Simulation point particle, Combined discrete element and Large Eddy Simulation and Discrete Element Methods.

Keywords: Deposition, Impingement, Curtain, Algorithms.

1. INTRODUCTION

The invention of metallized paper has secured importance with its multi-dimensional uses till the recent past. To acquire the polished surface on a metallized paper, it is essential to pre-enamel the surface of the paper substrate. This can only be achieved by refining the paper and making a feasible technology that can work at an optimum rate. Therefore, there comes surprising finding through the motivation of pre-enameling surface with organic solvents and the high gloss on paper surface. The state of art of present research study on metallized paper with different numerical methods is to improve the methodology for an optimum effectiveness to gain desire quality [1-3].

This solution of methodology encompasses with upgraded metallized paper to scrutinize the nature of solid dispersion and to encounter this problem with suitable paths significantly. It is essential to have definite values of applied layers on the paper substrate. Hereafter, we can obtain a composition, which has certain rheological and static surface tension characteristics making it acceptable for metallized paper preparation [3-6].

The metallized paper is manufactured from direct high vacuum metallization. In this technology, the substrate that needs to be metallized is coated with different layers of liquid and metal films. It is settled to accumulate smooth surface on paper substrate. The coated substrate is subjected to a vacuum chamber. The aluminum metal is applied on the surface of the substrate there. There are coated another layer of film to protect the metal

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layer from oxidation and corrosion. Its composition comprises of mineral and synthetic pigments, latex binder and conventional additive. The synthetic polymer pigment should be from Styrene, Acrylic acid, Acrylonitrile, Homo-polyolefin, Co-polymer or Urea-formaldehyde resin of diameter around 0.1-30 um. The added plasticizer amount should be kept up to 25 % with a synthetic polymer agent. Its cast coating layer value is 18-26 g/m2. The Acrylic, Styrenic derivatives, Epoxy resins and Nitrocellulose are used for these purposes. These chemicals have the tendency to form a film when a solvent evaporates.

After the material coating on a substrate, the coating materials pH should be greater than 7. The moisture content is adjusted to 5 to 15 % after the dying operation. There should be mineral pigment to 25-75% and synthetic polymer at 5-25% in coats. These layers have thicknesses from 1 to 3 g/m. It is obligatory to accomplish glass metallized property on metallized paper. We have to reduce the solid dispersion to attain it. There are various metallic papers in usage and their varieties depend on surface smoothness and high adhesion. On that account, there is an advantage for increasing the production rate to 2,000 m/min [7-15].

In the multilayer curtain coating process, the liquid curtain falls from an upward direction on a moving substrate under the gravitational force at a constant height that deposits films, as depicted in Figure 1. The present invention provides a method to manufacture a metallized paper by elaborating different numerical methods for solid dispersion. There are mainly three stages of this process. (i)-Coating of an aqueous layer film on the moving substrate at web. (ii)-Deposition of a metal layer on the substrate. (iii)-Applying the second aqueous film layer on metallized substrate to prevent it from oxidation. So, the correct formulation of this novel process becomes with three zones. (i)-Curtain formation. (ii)- Curtian spreading. (iii)-Impingment. respectively [14].

This technology has two advantages over other coating technologies. This technology has the ability to coat different surfaces with thin liquid films. The second advantage is that the operation has high speed, which causes wetting failure through hydrodynamic pressure produces from liquid near the contact line. On the other hand, there are some challenges in multilayer curtain coating technology that need to address with a serious attention [15].

1.1 Special Issues

Figure 2 (a) represents the space domain of the curtain coating process by demonstration of two dimensionless numbers; (i) Weber number, it is a ratio between inertial and capillary forces based. It is also based on web speed and curtain velocity. (ii) Reynolds number, it is the ratio of inertial force to viscous force. Figure 2 (b) shows that a thin liquid film can be deposited on the solid substrate of limited area under the operating parameters range. It is addressing different issues which are (i)- Air entrainment, (ii)- Bead pulling, (iii)- Heel

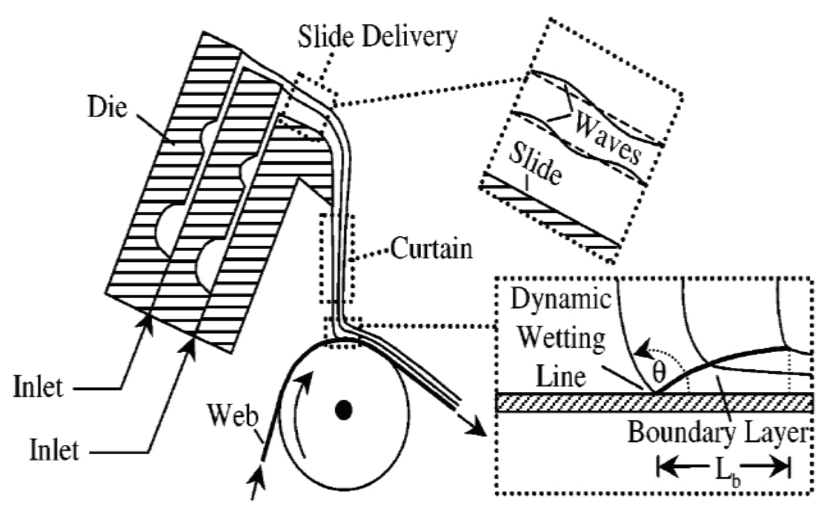

Fig. 1. Schematic diagram of multilayer curtain coating process with moving substrate on web beneath slide deliver [15].

formation and (iv)- Curtain breakup. This limited space is referred as the coating window.

At first, these four special issues during the curtain coating process cause the liquid curtain breakup and raise instability. Further, the stability of the liquid curtain solely dependent on the Weber number. The deep analysis tells us that the curtain meets stability at Weber number >1.5. The impingement zone has some physical operating conditions which elaborate the dynamics of film layer formation and its operation through multilayer curtain coater above the web and substrate. These conditions stand out for the process feasibility. Firstly, there is formed (Heel-Heel) when there does not arise movement in curtain to the web direction. Secondly, there occurs (Strands-Strands) at low flow rate which produces shear in the curtain resulting a break-up. In consequence, a pulled layer forms; it materialized due to coating layer that does not impact on substrate beneath the slot in moving web direction [16].

The stability in curtain has unique role for an effective coating. The curtain instability appears from solid dispersion at coats. Curtain unsteady performance causes by the air boundary layer. There is a need to encounter the curtain instability with relative troubleshooting. The curtain coat weights vary at high speed. These instabilities are recognized from sinusoidal frequency. While, the stability is reached at constant amplitude and variable frequency range.

The other curtain instabilities are termed as splashing and burps. The induced viscosity and surface tension result in these changes. The low values of curtain viscosity and Weber number coat result in splashing and intermittent burps.

The Weber number is varied along x-direction at the surface. The effectiveness of surfactant in multilayer curtain coating process leads towards low Weber number low. The Weber number provides helpful work about uniform liquid curtain. This can control adding surfactant and there comes stability in liquid curtain. The surface tension can also become low with the addition of a suitable surfactant. Hereafter, it becomes constant from the variable. As a result, surfactant has a vital tendency to decrease the surface tension and increase the stability of multilayer curtains effectively. A low liquid flow is found in a curtain due to the break of liquid films, as demonstrated in Figure 3. This transition accounts of forming a liquid film along curtain layers map out.

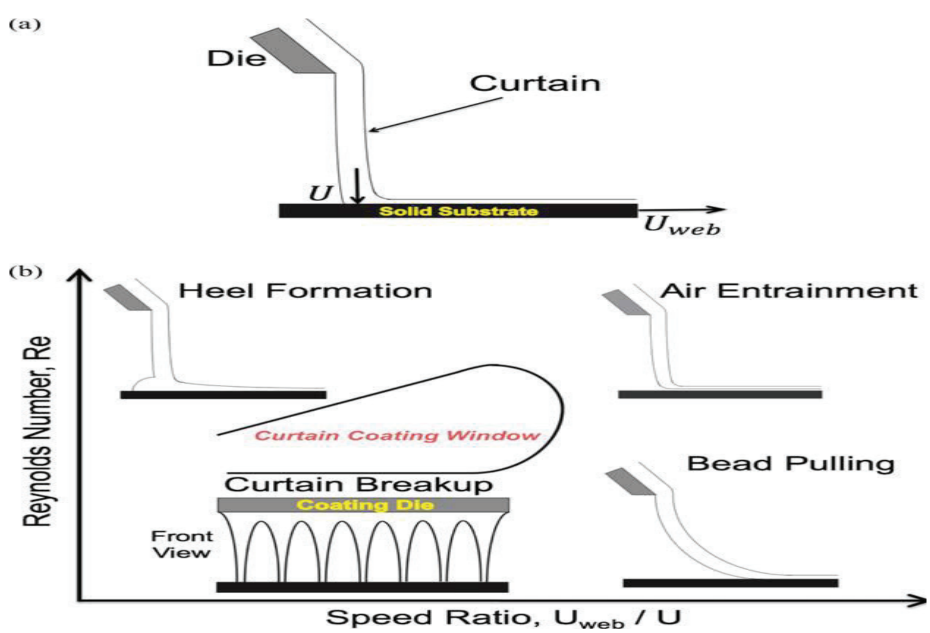

Fig. 2. (a) Illustration on Specific operation from dimensionless numbers, (b) Illustration on liquid film deposition at substrate of curtain coating process [16].

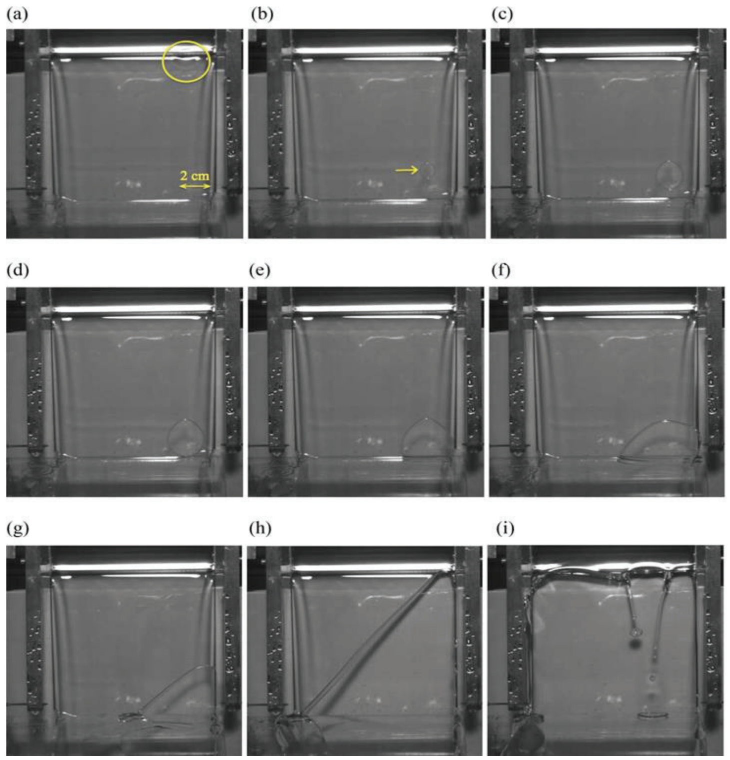

Fig. 3. Illustration on breakage of liquid curtain at 70 wt. % of glycerol/ distilled water with μ = 19.1 mPa.s and variable time intervals at (a) t= 26.5 ms. (b) t= 182.5 ms. (c) t= 186 ms. (d) t=188.5 ms. (e) t=192.5 ms. (f) t= 207 ms. (g) t= 359.5 ms. (h) t=689.5 ms. (i) t =967 ms [17].

In addition, there is an observation from results in Figure 3 that sudden break of liquid curtain can also occur due to low flows of liquid layers. There are formed topological structures when liquid layers left the die slot with equally spaced arrays. The purpose of the investigation is to compare curtain layers dynamics with theoretical and experimental observations of formation and steadiness in the inscribed multilayer curtain coating process. There are taken several observations with different liquid properties. The paramount certitude is break-up of the liquid curtain due to the formation of holes that take place before disintegrating liquid film.

(Heel-Heel) sets up when the curtain is not completely moved in the direction of the web, but flows slightly towards opposite direction. (Strands-Strands) founds due to insufficient flow, which causes well establish curtain to break-up and contract into strands. A pulled film forms when the coating fails to impact on substrate surface right below the slot and it is pulled forward together with the web [17].

The particles dispersion in the industrial processes has gained importance from reduced turbulence with upgrading it. These dispersed particles laden flows occur in different processes including pneumatic conveying, particle separation, multilayer curtain coating and fluidized beds. It is necessary to optimize these processes and their corresponding equipment for minimizing any error. This fact accounts of upgrading the process selectivity. There are several numerical simulation methods that can demonstrate the complex fluid flows and relative solid characteristics. The Computational fluid dynamics (CFD) techniques show the wide ranges of fluid flows from it salient tools. These CFD models are showing the particle-fluid and particle-particle interaction with quite precision. The present research paper is focused to compare the investigation on different CFD models to review comprehensively the nature of solid dispersion for the production of metallized paper using multilayer curtain coating technology. The identification of the correct optimum multilayer curtain coating model with physical parameters is a future need which is intensively described at the end of paper.

In general, there occurs coupling between dispersed and continuous phase. It is evaluated from the volume fraction of the solids. It is based on degree of particle scale time τP= ρPdP and Kolmogorov time scale τp=(ν/ε)1/2 simultaneously. This carrier fluid flow affects the particle dynamics, although these solids do not affect the flow turbulence.

1.2 Economic Value

Till the recent past, the curtain coating has become an emerging technology from its high speed. It has attained commercial success as the pre-metered and non-impact coating process. This technology has attained potential impact due to its ability to imply low coat weights on moving substrate. This process follows the non-impact and non-contact type operation. Multilayer curtain coating is referred to as a defect free coating surface process because there does not occur split patterns as the lamination comes above the base sheet. This process possesses uniqueness from various ranges of coating and coat weights through a single coating head [18].

There is a paramount need to address the multilayer curtain coating mechanism and identify the specific reasons why the process fails? The designed experimental tests have a key role as the testing will show its viability with any theory or hypothesis. The performance can only be enhanced by elucidating the errors which grow inaccuracy. While the CFD analysis is costly but the hydrodynamic dispersion mechanism is vital to upgrade the multilayer coating process. This process design is critical for increasing product reliability. The phase visualization with its brief mechanism is inaccessible to scientists working on this process. It is due to geometric features and non-transparent liquids. The evaluation of the configurations can be done with experimental tests. To save the cost and time with the permission of exploring the parameters have a key for real process effectiveness.

The CFD can simulate the phase interaction accurately. It offers a wide range to upgrade the full-scale model with reliable configurations. Scientists have gained interest in estimating the nature of solids with other phase interactions for optimization. Further, validation comes from the data. A different mathematical model can approach the nature of solid dispersion (Particle-particle, Gas-particle and Liquid-particle). In dilute systems, the Eulerian-Eulerian mathematical model has the capacity to trace the particles in the continuous phase with its low computational cost. The CFD has proved its utility to simulate the solid-particle interaction in the curtain at isothermal conditions too [19].

The present research study is focused on seeing the validity factor of this process. In the beginning, the performed mathematical models with their recommended features can be modified for testing, or their differences can be reduced with any combination, if required. There are available different simulation softwares such as (Ansys-CFD, Ansys-CFX, Star-CCM and Open-Foam). There is a serious need to compare the accuracy of these mathematical models through the nature of dispersion with relative troubleshooting. The critical evaluation of various numerical models will describe the process parameters optimization. It will keep a focus on the nature of flow with interphases dispersion. We will be able to obtain the most reliable mathematical model which can express multilayer curtain coating optimization in contrast to other simulation models [20-22].

In Langrangian-Particle mathematical model, it solely describes the diffusion and transportation of solid tracers in a medium. It combines with trajectories of large number of particles. The major advantage of this model is that there is no numerical diffusion takes place.

On the other side, in other models; a solid released from its point source instantaneously. While, the Langrangian-mathematical model is independent of the computational grid. In general, it has an infinitesimally small resolution. This model has a wide range. So, it can simulate the meso-scale transport, diffusion, dry and wet deposition.

Besides other models, the Eulerian-Langarangian mathematical approach can evaluate the interphase dispersion. This combined modeling approach has the ability to capture a wide range of particles in various forms, including concentrated and dilute flows, linear and non-linear and multiphases interaction in non-equilibrium state. To achieve it, the Reynolds Averaged Navier Stokes equation is used at continuous phase which is called carrier.

The solid dispersion is shown from tracked particles in gas flows. There is momentum exchange which causes an interaction. The large particles are idealized as point particles. In this mathematical modeling approach, the particle boundary, flow region and meso-scale particle range can not be approached. These features can be simulated from functional correlations which have empirical parameters. The Point-Particle model can be evaluated through a continuous phase. It is achieved by using the different mathematical models including Langrangian Point Particle, Coarse-grained molecular dynamics, Stokesian Dynamics, Brownian Dynamics, Point Particle Method Reynolds Averaged Navier Stokes equation, Eulerian Method, Langrangian-Eulerian Point Particle, Large Eddy Simulation point particle, Combined Discrete Element-Large Eddy Simulation and Discrete Element Methods.

Consequently, the present research study aims to stabilize the curtain coater at an optimum speed which will develop a novel investigation of the multilayer curtain coating process from theoretical numerical methods. There is a comprehensive research plan to evaluate the various features, which comprise substrate, curtain stability, runnability and quality of metallic film intensively.

1.3 Applications

Curtain coating technology has tremendous applications in different industrial sectors, which include Optical films, Metallized papers, Steel sheets for home appliances, Utensils, and Specialty film formation [23].

2. Literature Review:

2.1 Assessment of Particles Tracking Model

The Eulerian-Langrangian point particle method is used to explore the solid dispersion in a turbulent flow. There are used CFD and Open-foam softwares for the direct simulation. The precise investigation on solid dispersion in multilayer coating for metallized paper can be performed in the future. It will be really helpful for scientists who are undergoing any troubleshooting on multilayer coating of metallized paper. The dispersion model is evaluated from particle motion. In order to get simulation on the steady and unsteady state modes; These effects will rise to investigate the coupling between continuous and dispersed phase. The combined modeling effect of Eulerian and Langrangian models will give a conclusion that the dispersed phases is in agreement with simulation runs and experimental tests. The Ansys-Fluent software does not provide exact measurements on the dispersed phase. On the other hand, the Open-foam software overestimates the dispersion. These differences are due to low values of mass and solid volume fraction and mass [24].

The precise dispersed flow is being obtained with Langrangian-Eulerian combine network related to conservation equations. The prevailed conditions at Newtonian fluid are isothermal and incompressible. The Reynolds Averaged Naviers Stokes equation is able to demonstrate the mass and momentum transport. The simulation of Reynolds force is performed with the eddy-viscosity approach. For this purpose, two turbulence models are used, which are (($k - \varepsilon$) and ($k - \omega$-SST)). These are based on eddy viscosity approach. Their coding has been performed in the Ansys-Fluent and Open-foam. The solid particle's motion gets traced from the differential equation. The paramount significance of these approaches is that it can locate the solid particles independent of their velocity and shape [25].

2.1.1 Langrangian Point Particle Method

The Langrangian model is able to find the precise trajectories of solid particles with small air samples. It enables to find the transport and diffusion of small solid particles. The basic advantage of the current method beside Eulerian method; this method has key to demonstrate the numerical diffusion. Moreover, the Langrangian method is independent from computational grid and has infinite small resolution. The Flexpart tool is able to simulate the small sized solid particles in meso-scale through transport, diffusion, dry and wet deposition and also radioactive decay of solid particles from a single source with Langrangian method. It can also find the solid particle in domain filling mode from where the entire region is presented by solid particles of equal mass. It enables the simulation of the solid dispersion from their releasing source in backward time to show the valuable contribution from their receptors. The weather prediction model of the European Center Forecast uses Flexpart software for numerical weather prediction [26-28].

2.1.2 Demonstration for Dispersed and Continuous Phases:

There is a need to define the coupling of dispersed and continuous phases for simulating the solid dispersion. The major work function of coupled phases is based on the volume fraction. The solids in diluted flows are affected by aerodynamic forces acting on them. When the solid particle's interaction and its notable effect on dispersed phase with fluid dynamics increase. [29].

2.1.3 Dispersed Phase Mathematical Simulation

The validation of the particle laden dispersed phase comes out from profiles of solid particles. The solid particle profile is plotted against the continuous phase. These profiles are generated according to experiments. The solid particles are traced in the form of slices bar of thickness around 0.15 H. Its center is lying at the measurement points exactly. Figure 4 depicts the date sets of experimental and numerical runs in order of one and two-way coupling. There is an injection at a time of around 0.07 s. There is also an observation that particle's velocity lies in x-direction and particle's clouds in the y-direction. The results are demonstrated in Figure 4 with two-dimensional meshes A and B and C explicitly.

The gathered data sets from the experimental tests reveal that the particles follow the fluid dynamics. Their shape and magnitude is identical to the fluid dynamics profiles. The simulation results indicate that there is a difference in the experimental reading by a spatial dimension. The problem of data sets is kept in Ansys-Fluent with a mesh A. It depicts the velocities with profile distribution which is non-realistic. While, the experimental tests show that particle cloud do not follow the span-wise path. There does not occur the dispersion of the solid particles in the recirculation zone.

Furthermore, there are high magnitudes of velocities in all these profiles. The two-way coupling detects that there are no particles at x/H = 2 at a specified time. The most suitable results come through simulation on mesh C using Ansys-Fluent. It has cell layers in a z-direction span wise. The results match with the experimental tests. The magnitude and shape of the solid particle velocities are in good agreement. The simulated solid particles are higher at the first four positions and then these profiles become block-shaped. At the position x/H = 12, these velocities curves in mesh C do overlapping. The two-way simulation coupling from Ansys-Fluent undermines the expansion of solid particle clouds at the position x/H = 2, 5, 7. The one-way coupling enables the particles to spread on the second measuring value [30-32].

To conclude, the computational domain of Ansys-Fluent should be three dimensional to facilitate the solid particle's turbulent dynamics.

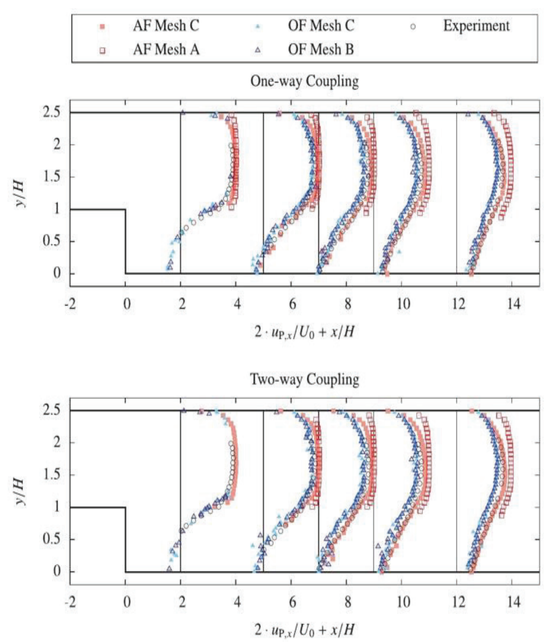

Fig. 4. Illustration on velocity profiles of the dispersed solid phase with main direction uP,x(y) behind from simulations in Ansys-Fluent on meshes A, B and C and experimental tests [32].

2.2 Dimensionless Numbers for Solid Dispersion

It is convenient to write the differential equations and their boundary conditions in terms of dimensionless groups. Dimensionless groups may have a smaller numerical values which certainly facilitates a numerical solution. These analyses of the system are described in a more convenient manner. The investigation on liquid curtain can be critically monitored at low value of dimensionless Weber number. The Weber number is able to distinguish the liquid curtain flow on a moving substrate meticulously. There are surface waves that are generated due to pressure gradient from meniscus on the substrate. The effects of gravity and pressure have a paramount role for the stability of liquid curtain to achieve the optimum multilayer coating; described in Figure 5 [33-35]. In multilayer curtain coating, there are developed dispersion models for the production of metallized paper. To achieve this, the curtain coating on the paper substrate is employed with respect to the layered coating of polymers. The main gain of the present research is to study the highly loaded dispersion of coating polymers on the first coating on a paper substrate moving on a web. Secondly, aqueous film deposits on said metallized paper. This would be characterized on the basis of shear viscosity and static surface tension. The first curtain polymer will be chosen from Acrylic group, an Acrylic-styrene polymer and colloidal dispersion polymer is formed from it simultaneously.

The first curtain polymer will be chosen from the Acrylic group, an Acrylic-styrene polymer and colloidal dispersion polymer is formed from it simultaneously. This is also called a modified Acrylic polymer. The second polymer is colloidal dispersed and its size varies. It is prepared conventionally and it contains Acrylic polymer with an Amine hydroxyl group. These two curtain layer polymers quantities are selected. There are added Pigments, Surfactant, Polyurethane and Acrylic-acrylamide thickener for upgrading metallized paper quality in this multilayer curtain coating application [36-38]. Henceforth, the solid particles visualization has become a crucial part of providing strength on said metallized paper. These die particles velocities are being monitored by a high-speed camera. Their velocities are calculated with a rate of change of position with time. These velocities are varied from K= (0.8-1) m/s shown in Figure 6. The measured thickness is varied from 0.07-0.3 mm.

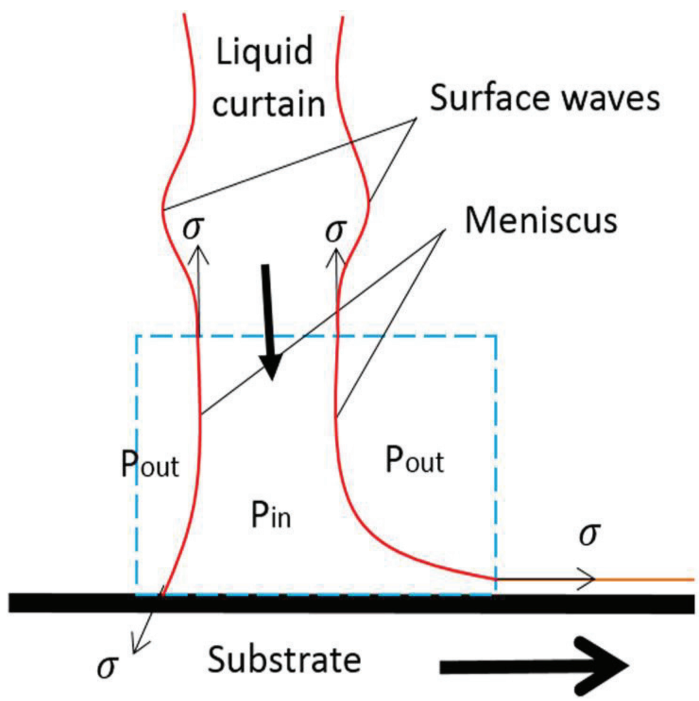

Fig. 5. Illustration on pressure gradient and surface tension at meniscus [33].

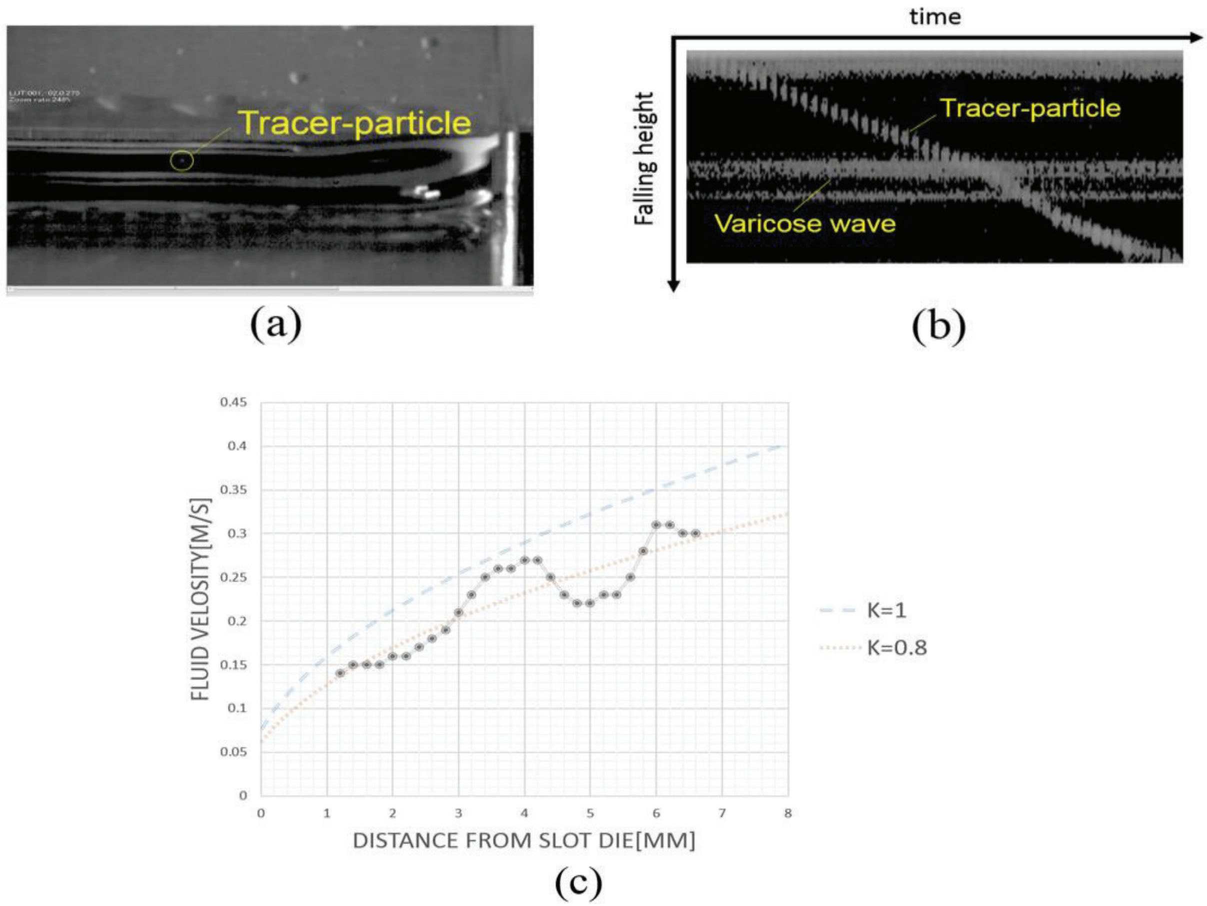

Fig. 6. Illustration on liquid velocities a) Tracer particles in liquid curtain with particle diameter 15 µm b) Solid tracer in liquid [38].

The wave number is dependent on dimensionless Reynolds and Weber numbers. On the other side, amplitude decay gets affected by capillary numbers. These numbers are changeable from the ambient condition, coat thickness and liquid curtain falling height.

There accumulate variable solutions of the curtains dynamics profiles from its curvature at low boundary value. The instability in liquid curtain increases with the effect of surface waves which have staggered and peak valley patterns. These waves are solely dependent on Reynolds and Weber numbers. There do not appear surface waves at low Weber number of 1, low substrate value and low viscosity of liquid curtain die [39,40].

2.2.1 Growth Dynamics of the Hole within the Liquid Curtain

There is breakup in the liquid curtain due to a hole. Firstly, this hole has a circular shape. The capillary force causes to make hole larger. There comes evaluation about curtain flows in a downward direction with an elliptic shape. It was measured using different liquids curtain dynamics. Figure 7 depicts the liquid solutions with a variable viscosity range from (19.1, 54, 92.8, and 177) mPa.s. At (177 mPa.s) liquid viscosity solution value, there is high resistance on hole expansion. The experimental observation on liquid curtain dynamics presents conservation of momentum with effect from solids dispersion. The 70 % solution of Glycerol is fed in liquid curtain and there generates variable effects of hole expansions in both x and y direction at different viscosities. It raises hole expansions, as shown in Figure 7 [40].

The solid particle in liquid curtain die accounts of increase in liquid film curtain viscosity. Furthermore, formation of holes near the edges causes this increase. The high-speed image analysis has proved this hypothesis a truth. The drawbacks of hole are that it slows downs the multilayer coating process due to un-stabilization and it keeps lowering the curtain speed. The other experimental tests have shown that converging edge guides decrease the applied curtain width. Hence, a need to stabilize the curtain with multiple features has achieved importance in multilayer curtain coating process with solids dispersion investigation modes. [41,42].

2.3 Multi-Particle Collision Dynamics

The meso-scale particles simulation can notice the extent of their dispersion. The multi-particle collision dynamics simulation method has progressed as an emerging tool. The coarse-grained molecular dynamics (CGMD) are introduced between this method. Its characteristics can be procured from the multi-particle collision dynamics method coincides with to a stochastic process. The stochastic process comprises of point-particle interaction. From Figure 9, there is appeared that the algorithm is based on two steps; (i)-Streaming and (ii) Collision. In the streaming process, there is an updated particle position with the ballistic movement accompanied by their position. It has proved correct from the written mathematical correlation in Equation 1;

ri(t+h) = ri(t)+hvi(t) →Eq. 1

whereas; ri and vi(t) are the position and velocity of particle i, simultaneously. The collision time is denoted by h. The collision step consists of sorting the particles into the cubic cells. These particles are rotated with an angle α along the axis.

vi(t+h) = vcm(t)+R(α)[vi(t)−vcm(t) →Eq. 2

vcm is mean velocity at cell and α is the angle of rotation. The numbers of particle in cell are designated with NC. In addition, the mass, momentum and energy values are conserved. It facilitates the current hydrodynamics interaction in the current solid dispersion system.

2.4 Hydrodynamics Interactions

2.4.1 Brownian Dynamics

The solid particle motion in liquid curtain seeds the variation in their velocities. This interaction is known as inter-particle hydrodynamics interaction. Additionally, the hydrodynamics interaction is upraised from inducing diffusion. In addition, it is essential to simulate particle dynamics. There are stochastic differential equations with Brownian dynamics and their hydrodynamic interaction is nj(t) is a random vector satisfying [43].

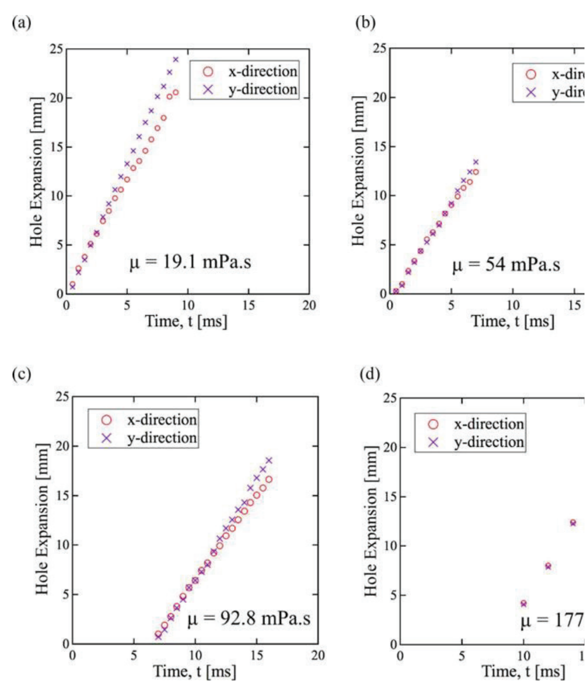

Fig. 7. Illustration on The hole evolution within the liquid curtains for (a) 70 wt % Glycerol solution (l519:1 mPa.s), (b) 79.5 wt % Glycerol solution (l554 mPa.s), (c) 85 wt % Glycerol solution (l592:8 mPa.s and (d) 90 wt % Glycerol [40].

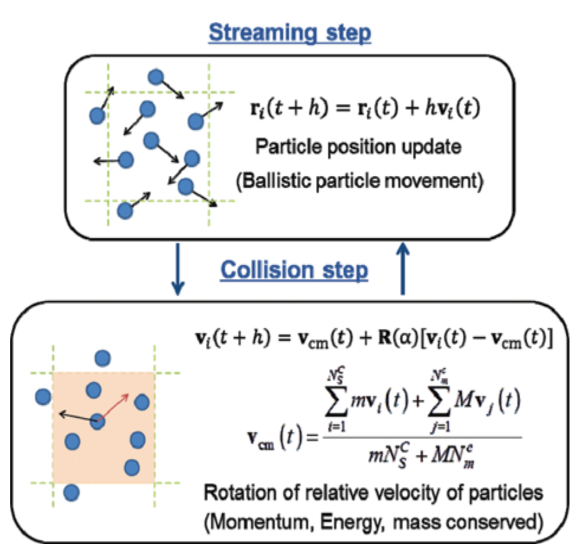

Fig. 8. Illustration on the solid particle hydrodynamic with theoretical approach [43].

There are used Brownian dynamics to expand the physical features of meso-macro molecules in a liquid curtain. The calibrated study on inter-particle hydrodynamic interaction is simply approximated to Stokesian friction as a term. It is inferred that Brownian dynamics cannot find an accurate hydrodynamics interaction. The coarse-grained molecular dynamics have been introduced to overcome these issues. The lubrication force is insufficient near the hydrodynamics particles interaction. However, despite this fact, the Brownian dynamics have a strong role in the investigation of solid dispersion, e.g. colloidal gel, colloidal glass and multilayer coating systems. In Brownian dynamics, inter-particle hydrodynamic interaction is less. In the case of multilayer curtain coating system, the solid particle movement is influenced from non-hydrodynamics inter-particle interaction. It is appeared from Van der Waals and depletion attractions. Consequently, the motion of solid particles is distinguished from volume effects. The theoretical calculations on inter-particle hydrodynamics have proved whole multilayer curtain coating process with non-uniform solids dispersion can be simulated by Brownian dynamics effectively [43].

Finally, the start-up of shear force shows non-rheological characters from overshooting. The Brownian dynamics can work for inquiring of microstructure change on the substrate. It has a deciding role to reveal the microstructural change on a substrate in a non-equilibrium state. It has also reproduced exact information about the microstructural change that denotes the source of stress fluctuation.

To conclude, the analysis on Brownian dynamics optimizes the solid dispersion in multiphase flow of loaded dispersion with the production of metallized paper explicitly [44].

2.4.2 Stokesian Dynamics

The Stokesian dynamics do not have a clear solution of the solid dispersion. Though, indicted mathematical correlation in Figure 8 authorizes to find the inter-particle hydrodynamic interaction rigorously. The Inter-particle and resistance tensors root into torque and stochastic displacement.

While this disturbance causes the change of drag force on solid particles to mention as inter-particle hydrodynamic interaction. The most accurate value of inter-particle hydrodynamics can be obtained from Stokesian dynamics due to the absence of diffusion tensor. It has multi-body far-field interaction and lubrication force which is assembled from resistance tensor R and mobility tensor M. Figure 8 mainly reveals the forces acting on solids dispersion [45].

2.5 Point Particle Reynold Averaged Navier Stokes Equation method

The Reynolds Averaged Navier Stokes equation is time dependent. The foremost theme of the equation is used to inspect fluid dynamics with relative time. The instantaneous quantity is converted by averaged time and fluctuating fluid dynamics. The fluid dynamics can be explored from it absolutely. The time dependent solution can be acquired which is based on the physical properties of fluid.

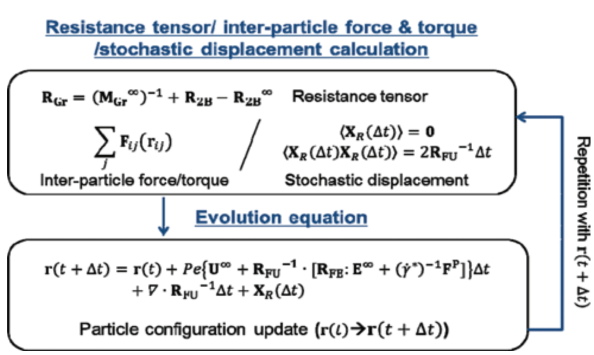

Fig. 9. Illustration on particle configuration update with respect to resistance tensor, inter-particle force torque and stochastic displacement calculations [45].

It can also resolve the dispersion in incompressible turbulent fluid dynamics which is a workhorse of CFD. There is a machine learning framework that enlarges the prognosis about steady-state turbulence. The eddy viscosity is interpolated with parametric studies of pressure and velocity. Hereafter, the exploration on dispersed particles in multilayer curtain coating is executed.

This evolution has been proved functional with this methodology by speed and accuracy properties. These closure optimizing strategies have progressed with upgrading model selection to get high selectivity and efficiency [47].

2.6 Eulerian Method

The Eulerian based methods have different phases which are based on interpenetrating continuous. The single phase does not come over on other one. There is being established a volume of fraction after implementing it. The Eulerian based methods vary continuously with time and space. There are conservation equation of mass, energy and momentum for each phase. These equations are similar to the constitutive relation of empirical investigation.

The Eulerian-Eulerian method consists of three models that are Volume of fluid (VOF), Mixture and the Eulerian [48].

2.6.1 Optimization of Solid Dispersion

The Eulerian method has a different mode for optimization besides other methods. The methods have a focus on shape optimization. For instance, shape node does not move. The assigned function is proportional to state function with respective grid coordinates.

The one side of shape once assigns a positive value at the grid. It comes to inside of the shape after zero is assigned at the boundary. When there is assigned a negative value, it comes on outside of shape. Whenever the shapes evolve, their function is updated from the state change with every node.
The Eulerian method is identical to the Finite element method. Its operating marks coincide into the fundamental features of Level set method. They can be used for process optimization of solids dispersion in multilayer coating process to produce metallized paper of high quality [49,50].

2.7 Langrangian-Eulerian Point Particle Method

The Lagrangian-Eulerian point-particle method uses both Langrangian and Eulerian frameworks. This is also called a Hybrid method. When the boundary conditions become different, the Chimera mesh is a suitable tool for analyzing large solid dispersion. The two sets of meshes are known as Langrangian and Eulerian ones. The moving boundary is surrounded by Lagrangian mesh. The solid dispersion in the region is characterized by the Euler method. When the two meshes do overlapping, a transition region is formulated. The meshes that are in Eulerian mesh are computed as flow variables. Chimera mesh is able to interchange the solid dispersion value using an overlapping zone. It is cost effective in comparison to the mesh regeneration method. While, it is capable of measuring high solids dispersion. A comparison between the experimental and theoretical indicates that they are well expressed. The slight defect comes to rise from errors generated from the coupling of two meshes. There generates some difficulty with digging a hole on Eulerian mesh when the geometry structure is moving [51].

2.8 Large Eddy Simulation Point Particle Approach

The Large-eddy simulation can be performed for the inspection of solid particle interaction in the continuous phase of multi-layer curtain coating process. There is a finding that fluid dynamics (Solid dispersion) is observed from a theoretical correlation. This correlation is derived from filtering the Reynolds Averaged Navier Stokes and continuity equations. When this Large-eddy simulation method is applied on the continuous phase to know the rate and nature of solid dispersion, the empirical correlation of solid dynamics needs substantial parameters. For example, pressure gradient, phase's velocities and mass [53-55].

2.8.1 Combined Discrete Element Method and Large Eddy Simulation Method

This combination of the Large eddy and Discrete element method can deploy the intense exploration of solid particles dispersion. In this mathematical technique, the Hertz-Mindlin approach related to Johnson-Kendall-Roberts cohesion takes on mathematical simulation. The effects of various particle-particle energy interactions cause turbulence. Consequently, it advances the analysis on solid particles interaction in close channels and regions of high concentration [56].

2.9 Discrete Element Method

A Discrete element method is a numerical tool which is in a position to integrate the dispersion processes most accurately. It is also called the distinct element method. There are granular particles that move in various industrial processes. There is a specific need to store and transport them. The CFD coupled with the Discrete element method demonstrates these complex solid dispersion processes effectively beside other mathematical correlations and models. CFD-DEM coupling designates the strength of the open simulation source. It also guides the installation and setup processes. These software tools highlight the solid dispersion in multilayer curtain coating through its functional framework.
The method can expedite the molecular dynamics from rigid elements. Local deformation permits the operating condition requirements. Laterally, distinct numbers of models are formulated for solid materials in discrete element method [57].

The discrete element algorithm is based on conceptual straightforward. It also remains equally with the computational sequence of DEM. This mathematical model boundary gets updated with contact forces act on.

2.9.1 Operating Principle

The high value of dispersion is found in multilayer curtain coating process. It can be reduced from Weber number, Reynolds number and Web speed. The nature of solid dispersion can be inquired into series of calculation of traced particles. In this numerical method, the interaction of the solid particles monitored from the equation of linear motion closely. Their rotational motions are observed from forces drawn on it. The basic methodology stands up with an assumption that disturbances do not breed from one solid particle to other. These solid particles are not in direct contact at a single time frame. These solid particles are simulated from the governing equations of Newton's second law of motion and their dynamics with time-based algorithms coded in DEM [58].

This feasible calculation aims to provide acute study on particulate processes; (i)- Solid-particles. (ii)-Particle-fluid interaction. Its significance escalated in powder technology. This technology has a key role in mixing, blending, the powder flows and dies etc. Contrarily, the population balance models are not effective in contrast to DEM. Hence, the numerical method has a detailed representation of complex solid dispersion for increasing the yield of metallized paper from multilayer curtain coating process [59,60].

3. SUMMARY

The current review study has identified a study for the solid dispersion study in the multilayer curtain coating process for metallized paper production. The pressure gradient is responsible for surface waves at liquid curtain. It can be minimized from Weber number, Reynolds number and Capillary number. The instability in the production of metallized paper from curtain coating only arises from surface waves, liquids boundary condition, falling heights, substrate speed, meniscus angle and curtain curvature surface. A simple and accurate technique to study the irregularity in solid dispersion for this process is providing an obvious guideline from Langrangian Point Particle, Brownian dynamics (BD), Stokesian dynamics (SD), multi-particle collision dynamics (MPCD) and Self-consistent particle dynamics (SC), Eulerian, Langrangian-Eulerian Point Particle, Large Eddy Simulation Point Particle, Combined Discrete Element-Large Eddy Simulation and Discrete Element Methods.

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5. CONFLICT OF INTEREST

The authors declare no conflict of interest.

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