Simulation for Coating process applying CFD packages in a market.

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1. Introduction

Coating Research Association (CRA) in Japan offers CFD Working Group for coating and drying process. This WG was inaugurated on April 2003, consists of 26 companies (July 2008) interested in simulation for such process, and holds meetings periodically to exchange and do research on how to apply field CFD packages in a market for coating and drying process. This report is a summary of this WG activity.

In Japan, field CFD packages have been used for coating and drying simulation since 1990's. Every company participating in this WG also uses field CFD packages for such simulation as designing and analysis tool. Free surface (Air-liquid interface) prediction is important to coating and drying process. ALE(Arbitrary Lagrangian and Eularian) Method is a conventional way, and VOF(Volume of Fluid) Method is becoming more popular for such prediction recently. In addition, FEM(Finite Element Method), FDM(Finite Difference Method) and FVM(Finite Volume Method) are used as discretization methods in field CFD Packages. Since each field CFD package is developed and improved by different software vender, it is crucial for users to evaluate practicality, accuracy and repeatability for particular phenomenon such as in coating. However, it is difficult for a single company to compare and evaluate these field CFD packages, because these packages are still comparatively expensive.

Therefore, in this WG, practicality of field CFD packages for coating simulation was researched and studied with an identical simulation model. In this report, evaluation of slot coating simulation by 3 CFD packages[i] and capillarity simulation by 5 CFD packages[ii] will be presented.

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2. Slot coating simulation

Slot coating is one of the most popular coating methods today. A simulation on an identical slot-coating model with 3 CFD packages was carried out, and then practicality and reliability have been evaluated in comparison with each simulation's coating window and experimental coating window reported in past[iii].

Each CFD packages uses FEM (A), FDM (B) and FVM (C) as discretization method respectively and 4 ways were adopted as shown below.

(A) FEM, ALE, liquid phase only, STEADY
(B1) FDM, VOF, liquid phase and void as air, UNSTEADY (transient)
(B2) FDM, VOF, liquid phase and air, UNSTEADY (transient)
(C) FVM, VOF, liquid phase and air, UNSTEADY (transient)

The simulation model is shown in Fig.1. Coating liquid flows into from slit inlet (velocity inlet), flows out to moving web from slit outlet forming bead as free surface, flows within a fixed gap and finally forms coating film on a moving web. Simultaneously, vacuum (pressure condition) is set at upstream boundary to stabilize bead.

The free-surface shape of coating liquid by (A), (B1), (B2) and (C) is respectively shown in Fig.2. The bead free-surface shapes slightly differ from each other, but are comparatively in good correspondence. Thus, when vacuum pressure is 2100 Pa, bead position is stable at upstream die edge with all 3 CFD packages.

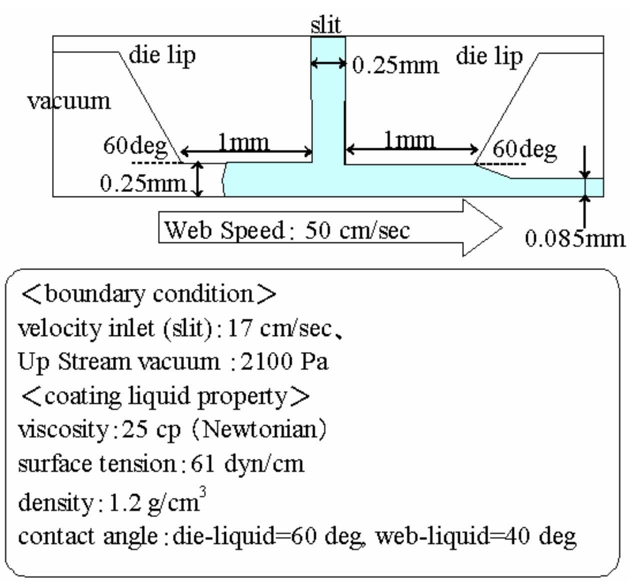

Fig.1 Slot-coating model and condition

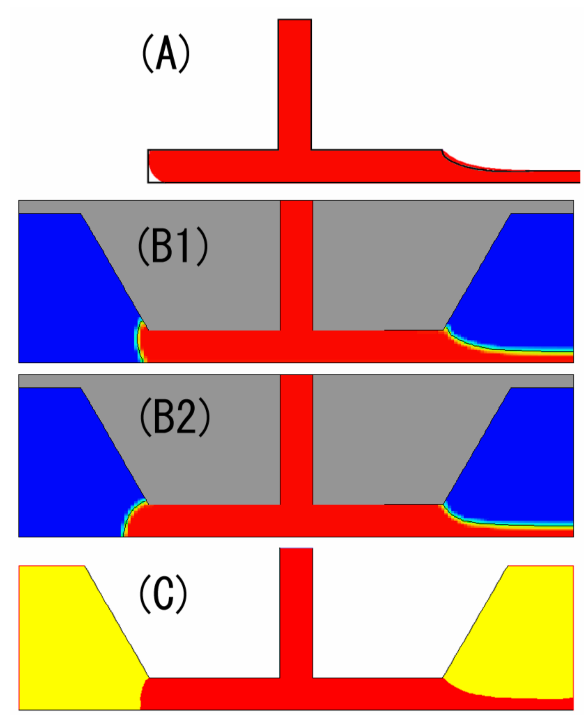

Fig2. Free-surface shape by each package (vacuum = 2100 Pa)

3. Capillarity simulation

Each CFD package's practicality and reliability on slot coating simulation are explained about, but not on specific free-surface shape. A surface tension of liquid is important physical parameter for slot coating simulation as well. Therefore, simple capillarity simulation was carried out to evaluate how surface tension effects free-surface shape with 5 CFD packages. When a glass tube is dipped into liquid surface, liquid surface in the tube rises to h. The surface rising height h is given from theoretical equation below.

$h = 2\sigma\cos\theta / \rho g r$

where

ρ : liquid density

σ : liquid surface tension

θ : contact angle

g : gravity force

r : radius of glass tube

Accuracy of 5 CFD packages for capillarity simulation is evaluated in comparison with this equation value. Fig.3 shows simulation model used by VOF method. Right-side boundary is axisymmetric model of cylindrical glass tube. Contact angle of the inside tube wall, which is important for capillarity, is 60 degree, and that of other wall is 90 degree tentatively. Upper boundary is pressure-constant outlet and the gauge pressure is set as zero. On the other hand, with ALE method, only liquid flow is considered, so simulation area is set only within this tube, and a gauge pressure is set as zero on it's bottom end. 5 CFD packages are adopted as shown below.

(A) FEM + ALE, liquid phase only, STEADY

(B) FDM + VOF, liquid phase and void as air, UNSTEADY (transient)

(C) FVM + VOF, liquid phase and air, UNSTEADY (transient)

(D) FVM + VOF, liquid phase and air, UNSTEADY (transient)

(E) FVM + VOF, liquid phase and air, UNSTEADY (transient)

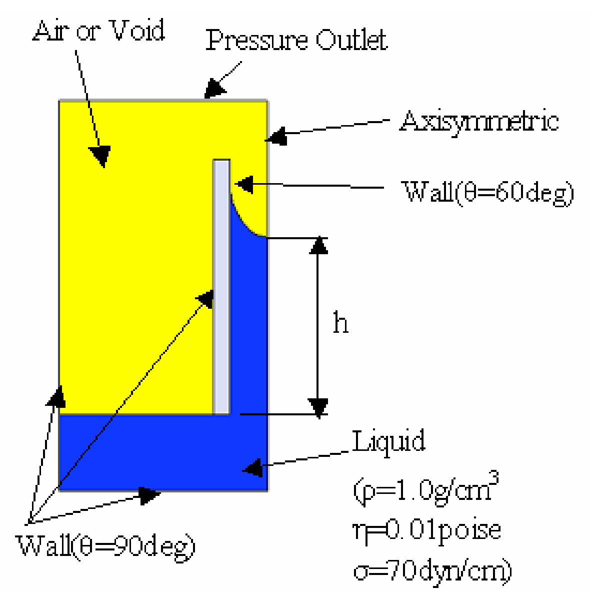

Fig.3 Capillarity simulation model

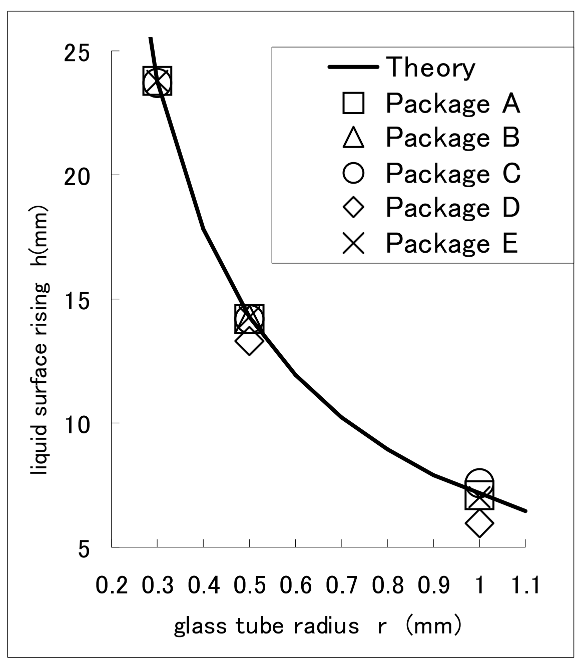

Fig.4 Theory and each package's result

Fig.4 shows theoretical value and each package's result. Those results correspond quantitatively, and all 5 packages have good accuracy in capillarity simulation. On the other hand, calculation time is comparatively short by ALE method, however, by VOF method, it requires lot of effort for us to optimize geometry area, element(mesh) size, initial condition and calculation setting so on. Therefore, we, WG members, share and exchange practical know-hows for coating simulation using field CFD packages.

4. Conclusion

Firstly, slot-coating simulation is practical with every field CFD package and also a simulated operable window is in good correspondence with the experimental. Two-dimensional slot-coating simulation is reported in this paper, and three-dimensional simulative result was reported by M.Yasuhara[iv].

Secondly, 5 field CFD packages have good accuracy for capillarity simulation, however, in some cases particular know-hows are required. Some of these know-hows were reported, S. Ota reported about package B[v], Y. Ozeki reported about package C[vi], and H. Kizaki reported about package D[vii].

Finally, all experimental field CFD packages are practical for coating simulation. Both ALE method and VOF method offer good accuracy and reliability for such simulation, however, optimum size and quality of each element, optimum time step size for unsteady simulation and calculation time depend on each package.

In this WG, we will share information of each package as mentioned in this paper, and we will make a continuous effort on developing technology of coating and drying simulation.

References

[i] CRA CFD WG, "Simulation for slot coating bead applying field CFD packages in a market", Proceedings of SCEJ Autumn Annual Meeting, E2P08, Sendai, 2003 (in Japanese).

[ii] CRA CFD WG, "Evaluation of accuracy for surface-tension simulation applying field CFD packages in a market", Proceedings of SCEJ Autumn Annual Meeting, J215, Sapporo, 2007 (in Japanese).

[iii] L.Sartor, L.E.Scriven, "Limits of operability in slot coating", AIChE Spring Meeting, 1998.

[iv] M.Yasuhara, "Current and future prospect of CFD Technology for coating process", Proceedings of SCEJ Autumn Annual Meeting, E3A01, Sendai, 2003 (in Japanese).

[v] S.Ohta, F.Yoshida and Y.Iino, "Evaluation of accuracy for surface-tension simulation applying a field CFD package in a market (VOF+FDM method)", Proceedings of SCEJ Autumn Annual Meeting, J217, Sapporo, 2007 (in Japanese).

[vi] Y.Ozeki and M.Yasuhara, "Evaluation of accuracy for surface-tension simulation applying a field CFD package in a market (VOF+FVM method)", Proceedings of SCEJ Autumn Annual Meeting, J216, Sapporo, 2007 (in Japanese).

[vii] H.Kizaki, "Evaluation of accuracy for surface-tension simulation applying a field CFD package in a market (VOF+FVM method)", Proceedings of SCEJ Autumn Annual Meeting, J218, Sapporo, 2007 (in Japanese).