ANALYSIS OF MIXING IN A VARIABLE SPEED CO-ROTATING INTERMESHING TWIN-SCREW EXTRUDER

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Abstract

The flow field and mixing pattern in a variable speed co-rotating intermeshing twin-screw extruder is studied. In this extruder, the two screws have different number of flights and rotate at different speeds. Results from numerical simulations and flow visualization experiments suggest that this extruder exhibits improved distributive mixing in comparison to a regular co-rotating twin-screw in which the screws are identical and rotate at the same speed. In addition, this new screw design exhibits a more positive flow displacement action and a shorter average residence time

Introduction

Co-rotating self-wiping twin-screw extruders are used widely in the polymer industry in applications such as compounding, alloying, reactive extrusion, foaming and devolatilization. The self-wiping action of the screws in these extruders is very important as it eliminates stagnation zones where polymers can degrade. The geometry of these self-wiping co-rotating screws is well documented and it has been described based on kinematic principles[1,2]. The flow characteristics of co-rotating extruders have been the subject of numerous experimental and modeling studies. Numerical simulations have been proven very useful in elucidating flow and mixing in fully-filled (for example see references 3-7) and partially-filled extruders[8]. All commercial co-rotating self-wiping extruders employ screws of identical geometry rotating at the same speed. However, it is possible to use screws rotating at the same speed but having unequal flight lengths. Such a variation is claimed to lead to improved mixing[9]. Our work addresses the flow in co-rotating self-wiping extruders in which the two screws have different number of flights and rotate at different speeds. Although the geometrical characteristics of these screws have been previously described in the literature[2], the flow in screws of this type has not been studied. Results from preliminary visualization experiments and numerical simulations are presented and compared to those from conventional co-rotating screws.

Experimental

Visualization experiments have been carried out using a co-rotating extruder having a transparent barrel made of clear acrylic material and screw elements machined from PVC. The cross-sections of the screws have been constructed according to the theoretical development by Booy[2]. Experiments have been completed using two screw sets. In the first one, bi-lobal screw elements have been used and both screws had the exact same geometry. In the second set, the two screws had different geometries. More specifically, one screw had two flights and the second one had one flight. These screws were self-wiping and they were rotating at 1:2 screw speeds respectively. Typical cross-sections of screws are shown in Figure 1 having unequal (A) or equal (B) number of flights. The screws were driven by a Haake Rheocord unit using different gear boxes. Photographs of the clear acrylic barrel, the screws and the gear boxes are shown in Figure 2. Experiments have been carried out at various screw speeds by using a silicon fluid (Dow Corning 200) and color tracers.

Numerical Simulations

To study the flow in extruders in which the screws rotate either at the same speed (SS) or variable speed (VS), preliminary numerical simulations have been performed using a finite volume method (FVM) based software package ("Screwflow-Multi") developed by Plamedia, Ltd. 300,00 hexahedral elements were used and time-dependent simulations were performed for 3 seconds total flow time with a time step of 0.0042 seconds on a computer having an Intel® Xeon™ CPU 3.2GHz, with 3.4GB memory. The total computation time was approximately four days for each set of conditions. Particle tracer analysis was employed by following streamlines.

The dimensions of the screws are given in Table 1 and the corresponding cross-sections are shown in Figure 3. Simulations were performed for a polypropylene material using a Cross-Carreau model to describe its viscosity curve (Table 2). The operating conditions used in the simulations are listed in Table 3.

Results and Discussion

Overall, the visualization experiments indicate a difference in the flow conveying mechanisms between the same-speed and variable-speed operating modes. During the conference presentation, video clips will be shown to highlight the nature of these differences. Observations from these experiments indicate that the variable-speed operating mode exhibits a shorter residence time and a more positive displacement action.

Overall, the simulations results indicate that the flow field in the variable speed screw configuration exhibits higher pressure drop, higher shear stresses and higher local mixing efficiency. Figure 4 shows results on the axial velocity distribution. It may be appreciated that the VS configuration exhibits a broader velocity distribution compared to that of the SS configuration. Examination of the high velocity tail of the distribution shows that the VS configuration exhibits a small fraction at much higher velocities. In addition, examination of the low velocity end of the distribution shows that the VS configuration exhibits a more significant fraction of back-flow. Figure 5 demonstrates the difference in flow fields between the two screws of the VS configuration. It is clear that the single-flighted screw (left) contributes to forward pumping while the double-flighted screw (right) has more of a reverse pumping action. The residence time distributions (RTD) for the two screw configurations are shown in Figure 6. It can be seen that both distributions are similar, however, the VS configuration has an average residence time about 60% of that of the SS configuration.

Overall, the velocity field results demonstrate a more positive displacement action for the VS configuration. The particle tracking analysis data shown in Figure 7 demonstrate that the material advances faster in the VS screw configuration. In addition, the VS configuration demonstrates more distributive mixing action as indicated from calculations of the average mixing efficiency[10] (52 for the VS configuration versus 29 for the SS configuration).

Concluding Remarks

It has been demonstrated that variable speed self-wiping co-rotating twin-screw extruders exhibit improved distributive mixing and shorter average residence times. Further experimentation and numerical simulations are currently being performed to fully appreciate the benefits of this operating mode.

References

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Keywords: co-rotating, twin-screw extruders, variable speed, mixing

Table 1. Screw Geometrical Characteristics

Item	Value (mm)
Inner Diameter of Barrel：D1	47
Outer Diameter of Screw：D2	46.25
Inner Diameter of Screw：D3	29 (SS)
	30 (VS)
Distance between Screw Centers：D4	38.5
Flight Tip Width	5.3 (SS)
Screw Lead	44
Total Screw Length	220

Table 2. Cross-Carreau model parameters

$\eta = \eta_o / (1 + (c\,\gamma)^a)^b$			
η_0 (Pa・s)	a	b	c
1170	2	0.28	0.06

Table 3. Operating conditions

Model	Throughput (kg/h)	Screw speed (rpm)		Temperature (℃)		L/D	Cross section area (m^2)
		Left : Single	Right : Double	Inflow	Barrel		
Variable Speed	200	800	400	200	200	5	1.05E-03
Same Speed	200	400					1.26E-03

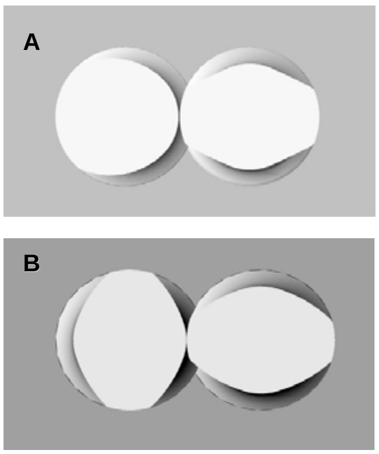

Figure 1 – Screw cross-sections:
(A) Unequal number of flights,
(B) Equal number of flights.

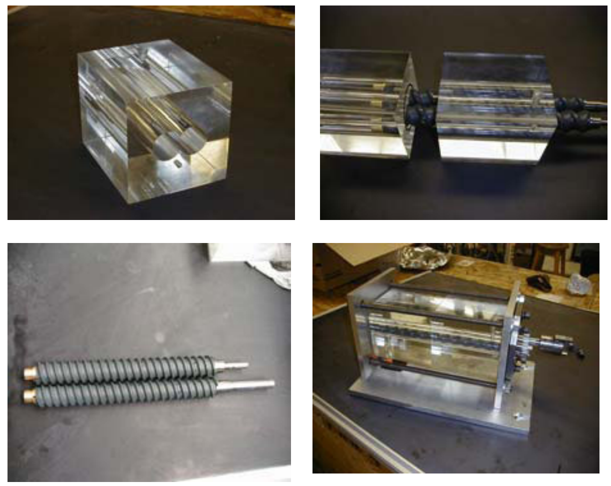

Figure 2 – Photographs of barrel sections, screws and gear box.

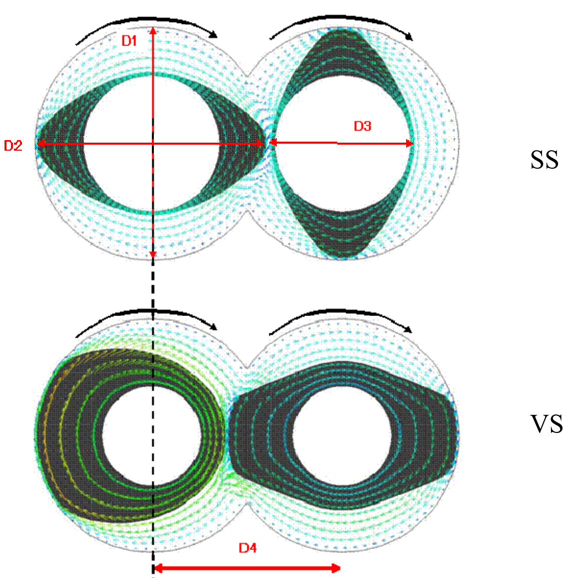

Figure 3 – Cross-section and dimensions of same speed (SS) and variable speed (VS) screws.

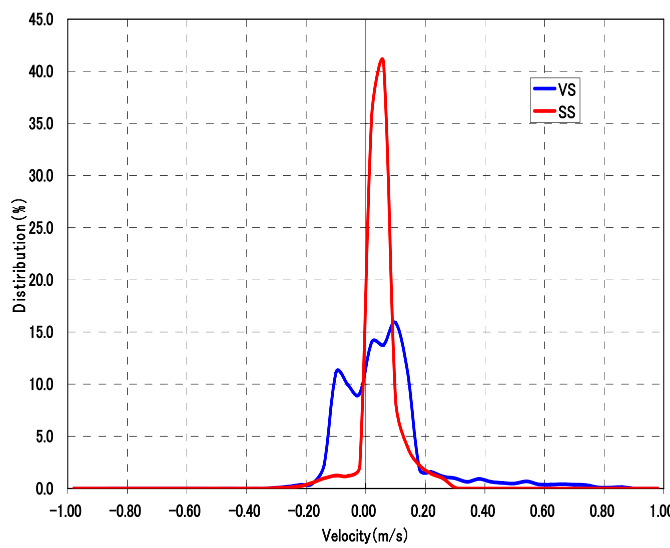

Figure 4 – Comparison of axial velocity distributions of same-speed (SS) and variable-speed (VS) screws

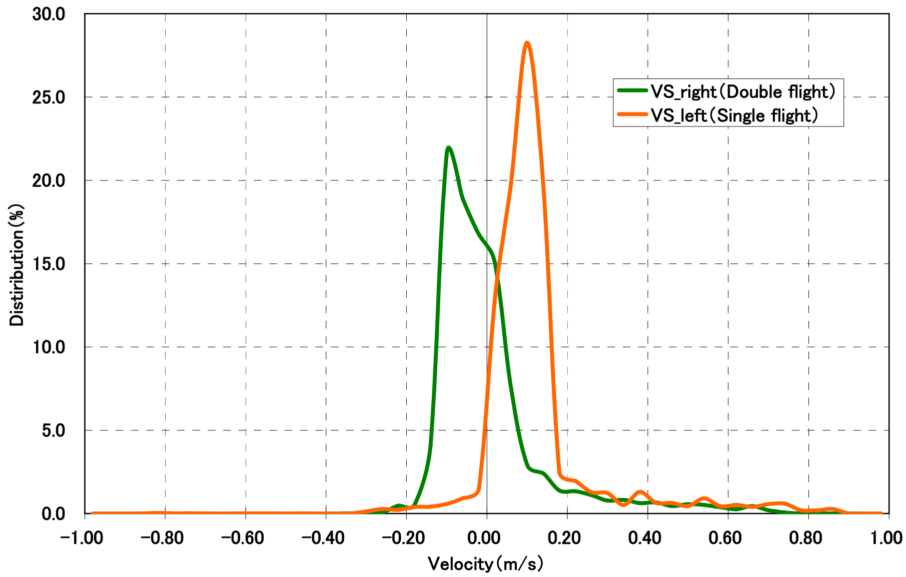

Figure 5 – Comparison of the velocity distributions on the two screws in variable speed (VS) configuration.

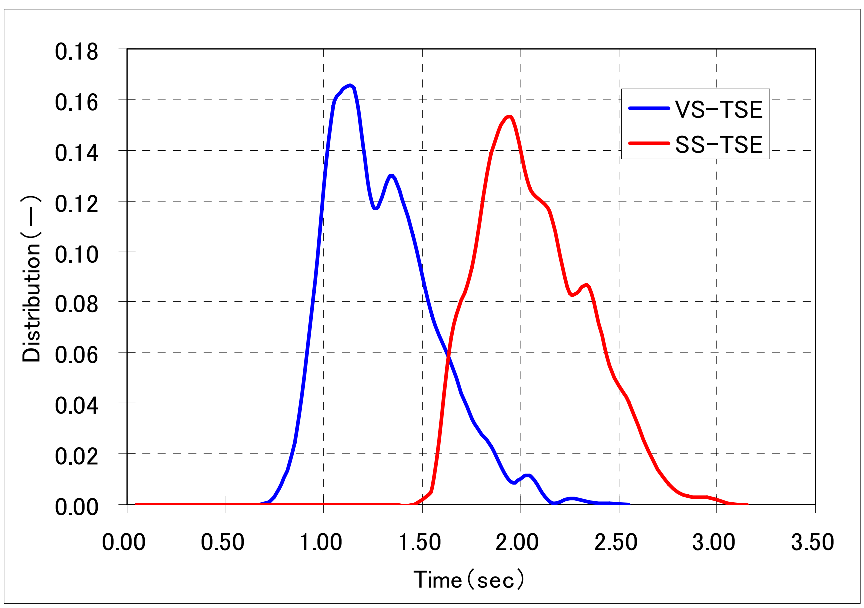

Figure 6 – Comparison of residence time distributions (RTD) between the same speed (SS) and variable speed (VS) screw configurations.

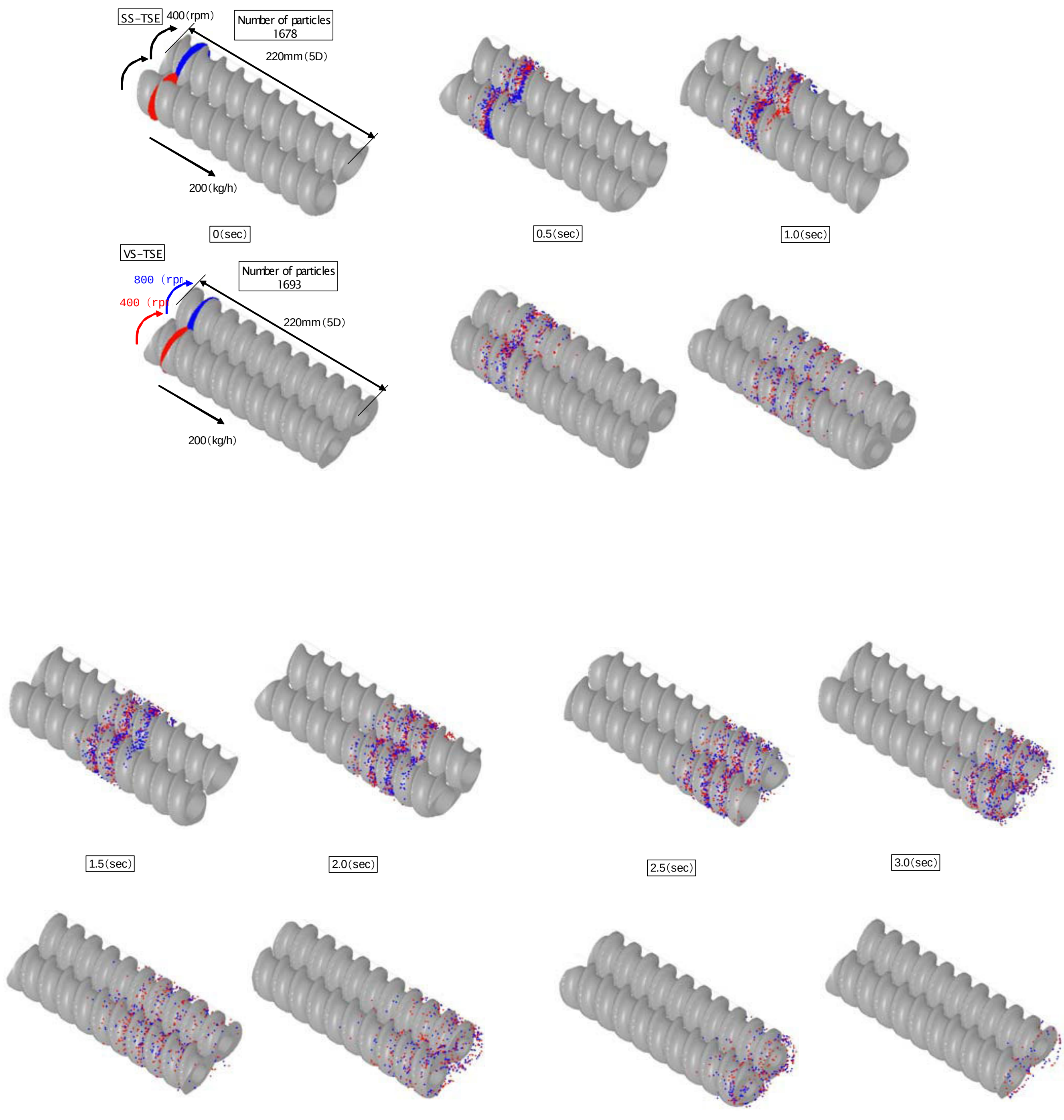

Figure 7 – Particle tracking analysis results.