3D Finite Elements Simulation of the Single Screw Extruder with Rotational Barrel Segment

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Summary

This paper aims to numerically evaluate a new concept of construction in a single screw extruder design. Rotational barrel segment introduced in 1998 significantly changes the kinematics of movement in a single screw extruder but has not been yet evaluated on numerical or laboratory level. 3D FEM simulation of single screw extruder segment with rotational barrel segment was performed in ANSYS Polyflow, with the adoption of Mesh Superposition Technique. The behavior of melt flow in the segment rotational barrel segment was evaluated and proved the possibility to numerically simulate this problem. 3D FEM CFD simulation was performed on a new type of construction solution of single screw extruder, rotational barrel segment. Results from the simulation demonstrated that the idea of integrating RBS in extruder construction is a correct idea.

Keywords: *single screw extruder, rotational barrel segment, Polyflow*

1 Introduction

Since their massive development in the first half of 20th century, extruders have undergone a continuous growth in all industrial fields, especially in plastic industry. The need to shorten time of developing new products and increase the existent production encourages manufacturers to develop new solution in design of extruder.

Of course, new solutions were focused on redesigning of the rotary working element (screw)[1], new techniques for heating and cooling the plasticizing system were used, but the general design still consisted in placing the screw in a stationary cylinder (barrel).

In 1998 R. Sikora and J.W. Sikora[2] introduced, a completely new concept of the design of a single screw extruder (SSE). This new design was based on kinematic activation of the barrel itself, which meant it could rotate in the direction identical or opposite to the direction of rotation of the screw (fig.1). In this design concept, the barrel of plasticizing system consists of two fixed (stationary) parts and a movable part placed between them, adjoining the fixed parts with its end faces and placed inside an outer housing attached to both fixed parts. The movable part can rotate in accordance with or opposite to the motion of the screw; it is driven by an external motor and performs rotary motion independently of the motion of the screw. The rotary barrel segment (RBS) is preferably located in the central part of the plasticizing system.

Since 1998 another seven patent solution for construction of RBS were registered in Poland, but so far this concept has not been evaluated in laboratory conditions or introduced in production SSE machines. On one side it is due to construction complexity and problems related to it, on the other side the unavailable mathematical model or 3D FEM simulation verifying this concept. As a part of tasks solved within NewEX project, the concept of RBS is numerically evaluated, and a new type of SSE with RBS will be built.

For typical geometry (one or two continuous flights) of the screw in SSE, several researches with numerical 1D models were published e.g.[3,4,5], calculating polymer flow inside an extruder barrel. However, in the case of more complex screw geometry (CRD mixer, pins..), the numerical models encounter their possibilities. They only provide average values of different parameters along extruder screw that are not sufficient to describe flow pattern and mixing. That is why a 3D FEM simulation for evaluating polymer flow in the extruder barrel is used. In recent years, much attention has been paid to full 3D simulation of polymer flow inside the extruder barrel.

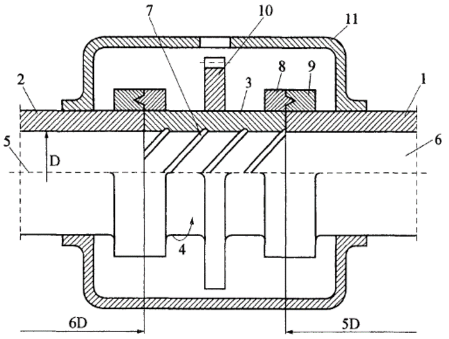

Fig.1. Rotary sleeve of the plasticizing system's barrel: 1, 2 - fixed parts of the barrel, 3 - rotary element, 4 - direction of rotation of the movable part of the barrel, 5 - screw axis, 6 - inner surface of the fixed part of the barrel, 7 - grooves, 8.9 - bearings, 10 - gear drive, 11 -external housing

1.1. Design of RBS

The concept of extruder design with RBS evaluated in this study (fig.2) consisted from the RBS segment (position 3, fig.2) and from specially shaped screw (position 1,fig.2) with the thicker section with no flight at the place where the RBS was placed.

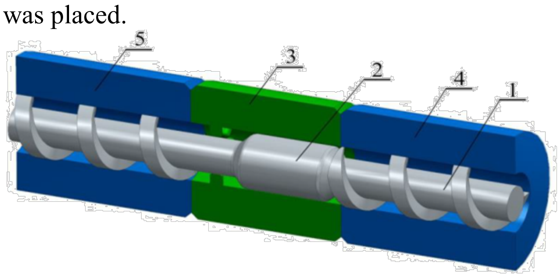

Fig.2 1–screw,2–part of the screw of increased diameter of the root, 3-rotational segment, 4 and 5–immovable barrel elements

The design of the RBS segment (fig. 3) was simplified as much as possible, to avoid issues during meshing. RBS has a shape of a cylinder with through hole of the diameter of 26mm and wall thickness of 1mm. The diameter 26mm is also the diameter of the stationary part of the extruder barrel.

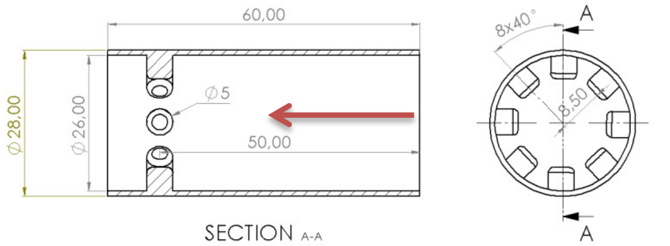

Fig.3 Simplified shape of RBS segment

There are equally placed eight cylindrical pins at the inner wall of the RBS with height 4,5mm and diameter 5mm. The pins are situated at the far end of the RBS(in the direction of flow marked with red arrow).

Another solid part introduced in the simulated system is the screw (fig.4). The total length of the screw is 200mm with the 16,25mm long zones without a flight on both ends. This is due to avoid computational irregularities causing problems with calculation convergence. Instead of the screw in the area where is, the RBS placed a 41mm long section with a diameter of 23mm, leaving a 1,5mm gap between screw and RBS. To reduce the number of elements in FEM simulation, there is a hole with a diameter of 12mm through the whole length of the screw.

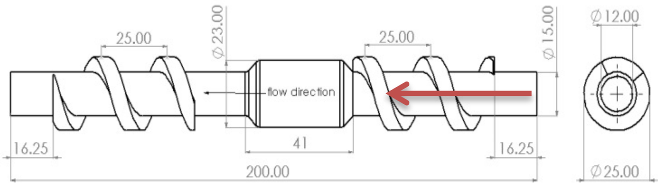

Fig.4.Design of extruder screw used in this study

2 Flow simulation in RBS

2.1. Mesh superposition technique

Calculating a flow pattern in complex geometries is not easy to perform. As the screw (or RBS) rotates, time-dependent boundaries make FEM simulations more difficult. Even in a steady state operating condition (i.e. constant screw speed), due to the rotation of the screw, the polymer inside the barrel flows at a non-steady periodic condition. Methods used in the early days[6] created the mesh only on the volume occupied by the polymer. As the screws rotate, the mesh must be regenerated to take into account the new position between the screw volume and the polymer domain.

Actually, new techniques were developed to overcome this issue, called Mesh superposition technique (MST)[7] or immersed boundary finite element method (IBFEM)[8]. In this study MST incorporated in ANSYS Polyflow 2019 R2® software is used.

2.2. Simulation pre-processing

Based on the shape of the screw and RBS a CAD model of the flow domain was created. Flights from the screw, pins from RBS were eliminated and the Boolean operation was used to obtain the CAD model of flow domain (fig.5). The flow domain was meshed in ANSYS Meshing ® to obtain hexahedral element mesh. To capture accurately the polymer flow in the area between barrel - screw flight and RBS-screw an inflation technique was used ensuring at least five mesh elements through thickness. Screw and RBS were meshed with ANSYS Fluent Meshing® resulting in the tetrahedral mesh. Subsequently, the mesh of the flow domain and the mesh of solid parts were joined and exported into ANSYS Polyflow. The final mesh (fig.6) consisted of 386 075 elements.

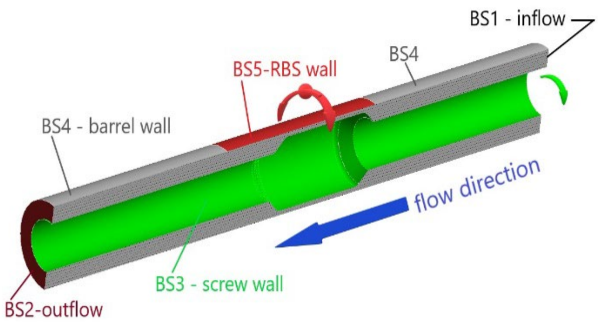

Fig.5 Longitudinal cross section through flow domain CAD model

For the purpose of this study, three scenarios were computed and evaluated. The difference was in the motion of the RBS. In scenario A the RBS was not rotating, in scenario B the RBS is rotating at 80rpm in the same direction as the screw and in the scenario C, the RBS is rotating in the opposite direction at 80rpm.

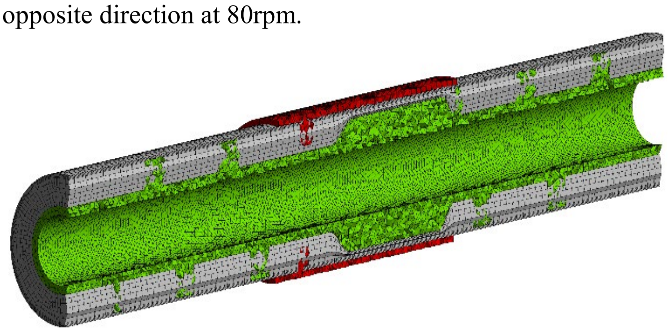

Fig.6 Longitudinal cross section of final FEM mesh

2.3. Boundary conditions

Final scheme of the computational problem is shown in Fig.6 Flow boundary conditions on the mesh at selected boundaries (BS) were applied:

- BS1 – inflow (Q = 5.5kg/h)
- BS2 – normal forces and tangential velocities vanish (fn & vs) = (0, 0),
- BS3 – cartesian velocities imposed (vx & vy & vz) = 8,378 rad.s^{-1} (80 rpm,direction see fig.5)
- BS4 – normal and tangential velocities imposed (vn & vs) = (0, 0)
- BS5- cartesian velocities imposed (vx & vy & vz) = (0 or 8,378 rad.s^{-1} according to scenario)

The first two boundary conditions, BS1 and BS2, imply that pressure may be generated along the screw. The pressure at the end of the flow domain is unknown, so we calculate the pressure gradient, which is relative to the zero pressure at the flow domain exit. Negative pressures resulting from computations do not mean that negative pressures exist in the extrusion process[9]. Computing negative pressure observed in modeling rotating polymer processing machinery has been described[10].

We have used the power-law rheological model for the material from the Polyflow database Extrusion_HDPE_isoth_463K flowing material..

3 Simulation results

A flow analysis has been performed for polymer flow in the area of RBS. Shear rate and velocity fields for all three scenarios are presented.

Shear rate distribution on melt flow domain (fig.7) is mapped on plane parallel with extruder axis.

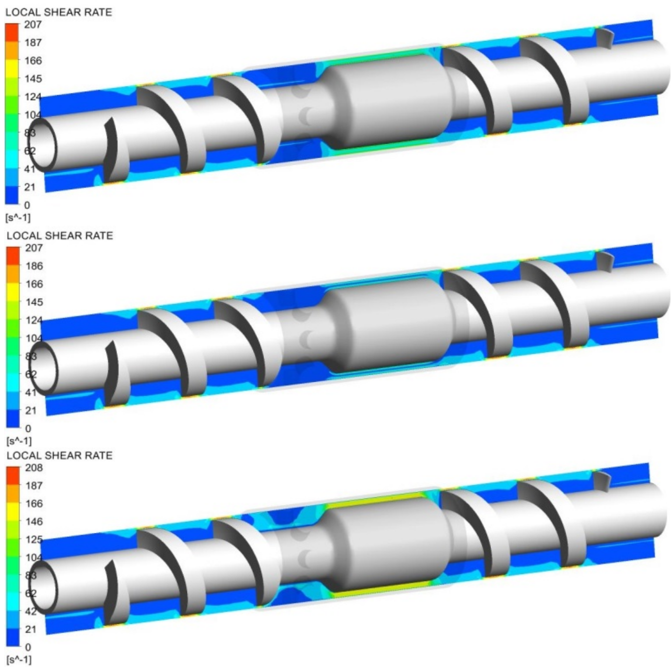

Fig.7 Shear rate distribution for scenario A,B and C (top to down)

As the expected peak of shear rate value in all scenarios is located in the area between screw flight and barrel wall. The peak value for all cases is at a value about 208s-1. However, at the location of the RBS clear difference in shear rate value between scenarios is visible. In the scenario A, where the RBS is not rotating, values of shear rate at the area of the highest diameter of screw reach from 55s^{-1} to 120s^{-1} close to the screw surface. When the RBS is rotating with the same speed and in the same direction as the screw (scenario B) the shear rates at the location of RBS are lowest among simulated cases, ranging from $33s^{-1}$ to $87s^{-1}$. The results are as expected because the relative angle speed between the RBS and the screw is zero, thus the velocity gradient in the area is very small and caused mostly by the melt flow in the Z direction (screw axis). Highest values of shear rate in the area of RBS are observed in scenario C with evenly distributed shear rate (about $160s^{-1}$) through the polymer flow domain at the gap between screw and RBS.

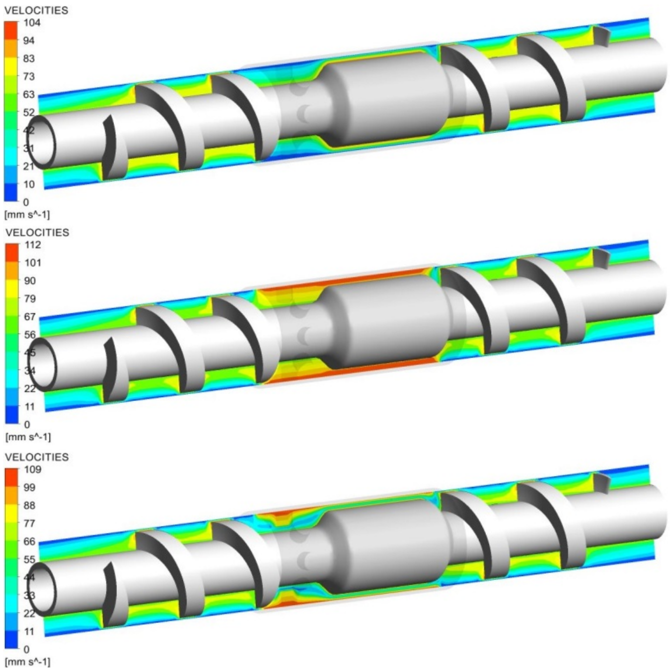

Fig.8 Velocities distribution for scenario A,B and C (top to down)

Distribution of the velocities fields is presented in the Fig.8. The results are as predicted because a stick condition at BS5 and BS3was set at pre-processing stage. Highest velocity values of the velocities in the RBS region are observed in scenario B, at the inner wall of the RBS. In scenario C local velocity peaks are observed at the pins location.

4 Conclusion

It is highly challenging to simulate and analyze polymer melt flow inside extruder barrel with complicated geometry shape with mathematical models for single flight screw since strong simplifications required. These challenges can be solved with 3D FEM CFD simulation, which provides access to local data (velocity, shear rate) with virtually no limited geometry shape of rotating parts. 3D FEM CFD simulation was performed on a new type of construction solution of single screw extruder, rotational barrel segment. Results from the simulation demonstrated that the idea of integrating RBS in extruder construction is correct and investigation of further shapes with CFD simulation is needed before evaluating RBS in a laboratory environment.

Acknowledgement

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