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Simulation of extrusion of high density polyethylene tubes

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Abstract. The production of extruded polyethylene films rods, tubes and pipes is a typical industrial process that has been extensively investigated over many years. In this study the extrusion of High Density Polyethylene (HDPE) tubes was simulated by using the 3D finite element simulation software StarCCM+®. The simulation was applied in order to examine the influence of design and operational parameters on the characteristics and the soundness of the tube and for optimizing the overall quality of the product. Two alternative die configurations were studied; one with a four inputs head and the other with an eight inputs head. From the results obtained it is concluded that extrusion with the eight inputs head die design results in better overall pipe quality; this design was implemented successfully in an industrial production line.

1 Introduction

High-density polyethylene (HDPE) tubes are typically used in many applications such as to convey potable water, waste water, chemicals, etc. HDPE has high strength, toughness, durability and resistance to chemicals. In order to manufacture solid wall pipes the following steps should be followed: heat, melt, mix, and convey the raw material into a mold to achieve the final form.

Finally, the shape should be kept uniform during the cooling process. All these phases were implemented within a special-purpose designed pipe manufacturing line (Fig. 1).

Figure 2 shows the extruder set-up.

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Fig. 1. A typical pipe manufacturing line [1].

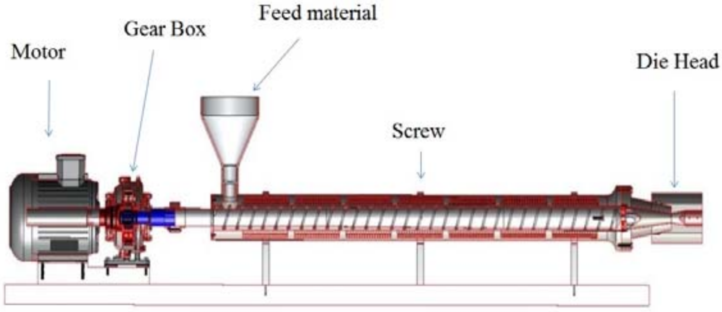

Fig. 2. Extruder set-up.

The design of the die head is one of the most influencing factor that affects the pipe shape quality. The main characteristics of die heads are the number of screw inputs and the geometry of the screw [2-6].

This work studies the extrusion of HDPE tubes (equivalently called pipes) by applying 3D simulation of the extrusion process. Two alternative die configurations were studied; one with a four inputs head and the other with an eight inputs head. From the results obtained it is concluded that extrusion with the eight inputs head die design results in better overall pipe quality; this design was implemented successfully in an industrial production line.

2 Simulation set-up

In order to simulate the process at three dimensions (3D), as the first step the two configurations of head die in a 3D CAD program had to be designed; Solidworks® was used for this job. Figure 3 shows the head components, all of them being designed at 1/1 scale (final dimensions).

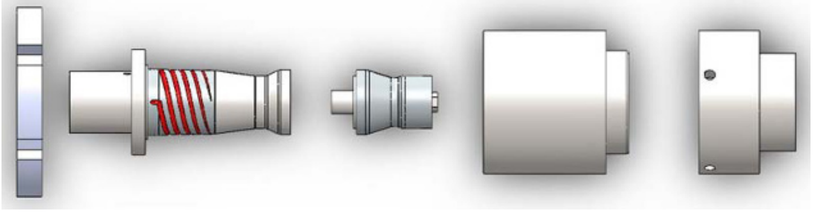

Fig. 3. Components of the four input head die (by Solidworks®).

Figure 4 shows the die with raw material inside (red color) as it placed in extruder line.

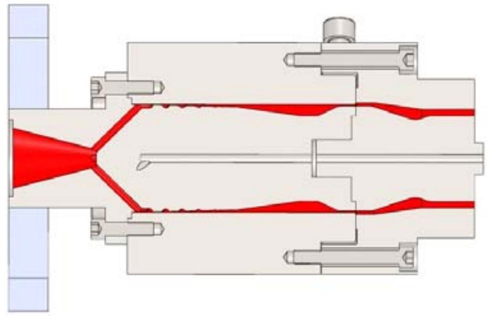

Fig. 4. Head cross section view.

In Figure 5 and 6 the volume of raw material is represented as 3D volume models for the two configurations (four inputs and eight inputs heads) examined.

Fig. 5. Volume of raw material inside the head with four inputs.

Fig. 6. Volume of raw material inside the head with eight inputs.

Then, the 3D CAD representations were transfer in the StarCCM+ software in order to configure the tessellation parameters and to produce the tessellations models (Fig. 7). The models that used for the tessellations were: polyhedral mesher, prism layer mesher and surface mesher. The "base size" for the tessellation process was selected to 5μm.

For solving the problem, a number of assumptions were made:

- first that the flow is in a steady state and second that
- the heat flow is adiabatic (adiabatic head wall; (see figure 8).

The initial conditions for the simulation were:

- Mass Flow Rate at the entrance: m = 0.05556 kg/s
- Fluid Temperature: T = 200^{o}C
- Physical Model: isothermal process.
- At the exit the pressure is set at one atmosphere.

The material properties were set as follows:

- Density: 950 kg/m^3
- Viscosity follows the Carreau-Yasuda model:

$$\mu = \mu_\infty + (\mu_0 - \mu_\infty)\ (1 + \lambda\gamma)\text{^}[(\nu - 1)/2] \quad (1)$$

Where μ_∞=0.
Therefore, the viscosity was calculated by the formula:

$$\mu = \mu_0(1 + \lambda\gamma)\text{^}[(\nu - 1)/2] \quad (2)$$

It has the following parameter values:

- μ_0 = 2100 Pa-s; Zero Shear Viscosity
- μ_∞ = 0.0 Pa-s; Infinite Shear Viscosity
- ν = 0.28612; Power Constant:
- λ = 0.058 s; Relaxation Time
- γ: Shear Rate: This value was obtained by the program in order to calculate the viscosity

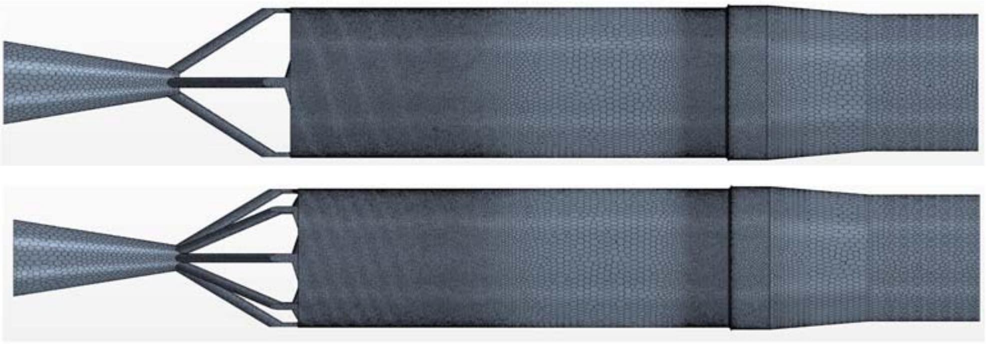

Fig 7. Tessellation model of the two models (four and eight inputs respectively).

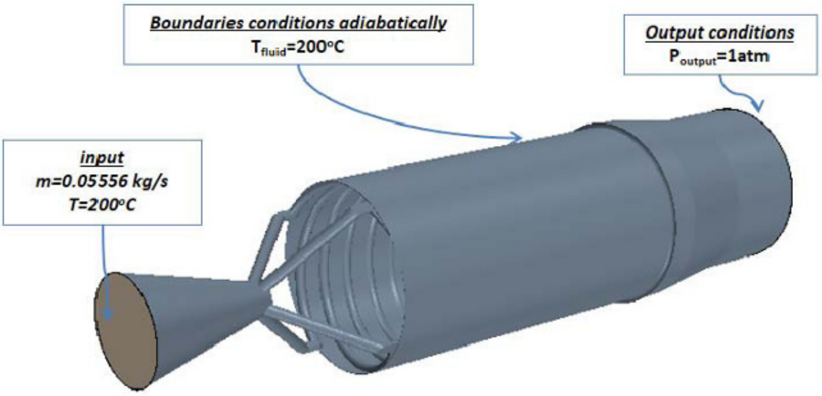

Fig. 8. Boundary conditions of the FE model.

3 Simulation results and discussion

After the FEA simulations of the two different setup the following are observed:

- The use of the 4 inputs head resulted in higher values of the pressures and the velocities in comparison to the ones estimated for the 8 inputs head (see Figs 9, 10 &11).

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- The topology of these values forms a polygon (see Figs 10 & 11). This, is an indication that the shape of the pipe at the exit should be more precise at 8 input head than that of 4 input head.
- At 8 input head the pressure increased in a general way with uniformity along the head; moreover, we observe lower velocities of the fluid material in this case that the ones with the 4 inputs head.

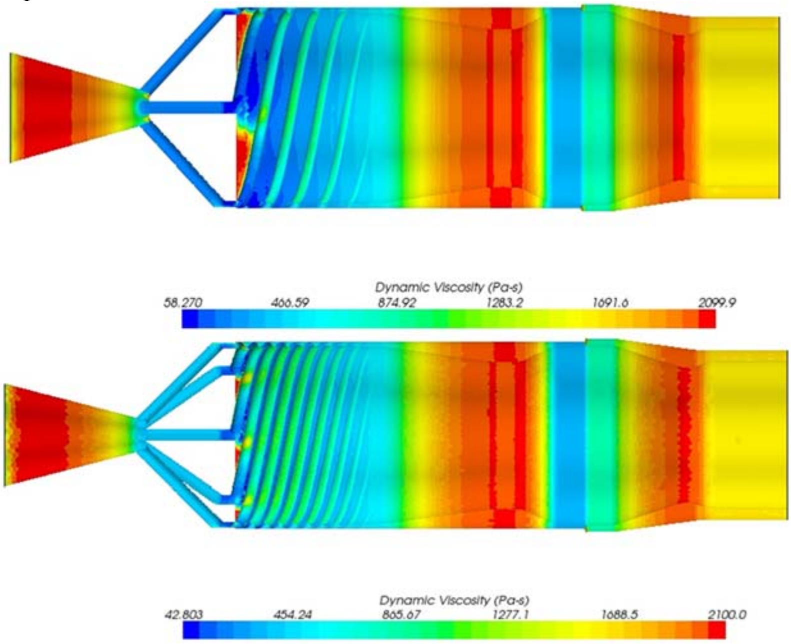

Fig. 9. Dynamic viscosity of fluid material along the die length (4 and 8 inputs head respectively).

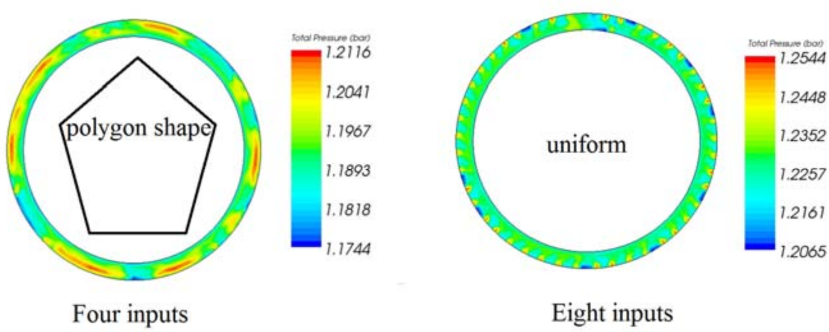

Fig. 10. Output pressure.

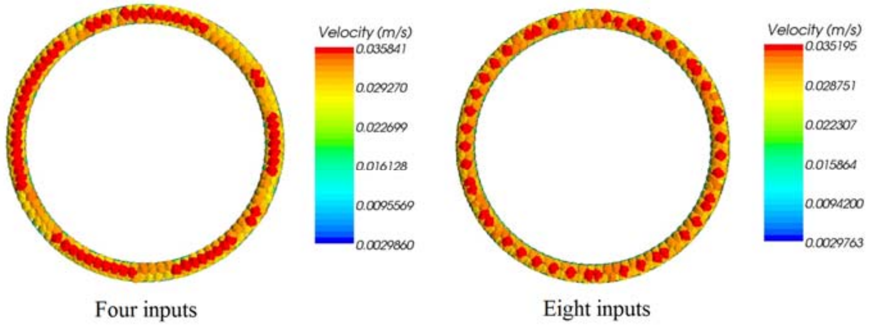

Fig. 11. Velocity distribution.

The 8 inputs head is manufactured and gave better quality pipes in the production line. The quality indicators measured were the wall thickness of the pipes and the precision of the profile.

4 Conclusions

This paper studies the thermo-mechanical behavior of HDPE plastic pipes extrusion. The conclusions drawn are:

The rheological results were better when the 8 inputs head was used for plastic HDPE pipe extrusion since, in general, lower pressures, velocities, and viscosity were obtained. The polymeric fluid material flux possessed better characteristics than that of 4 inputs head.

The quality and the soundness of the pipe product was improved when the 4 input head was replaced by the 8 inputs head in the production line.

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