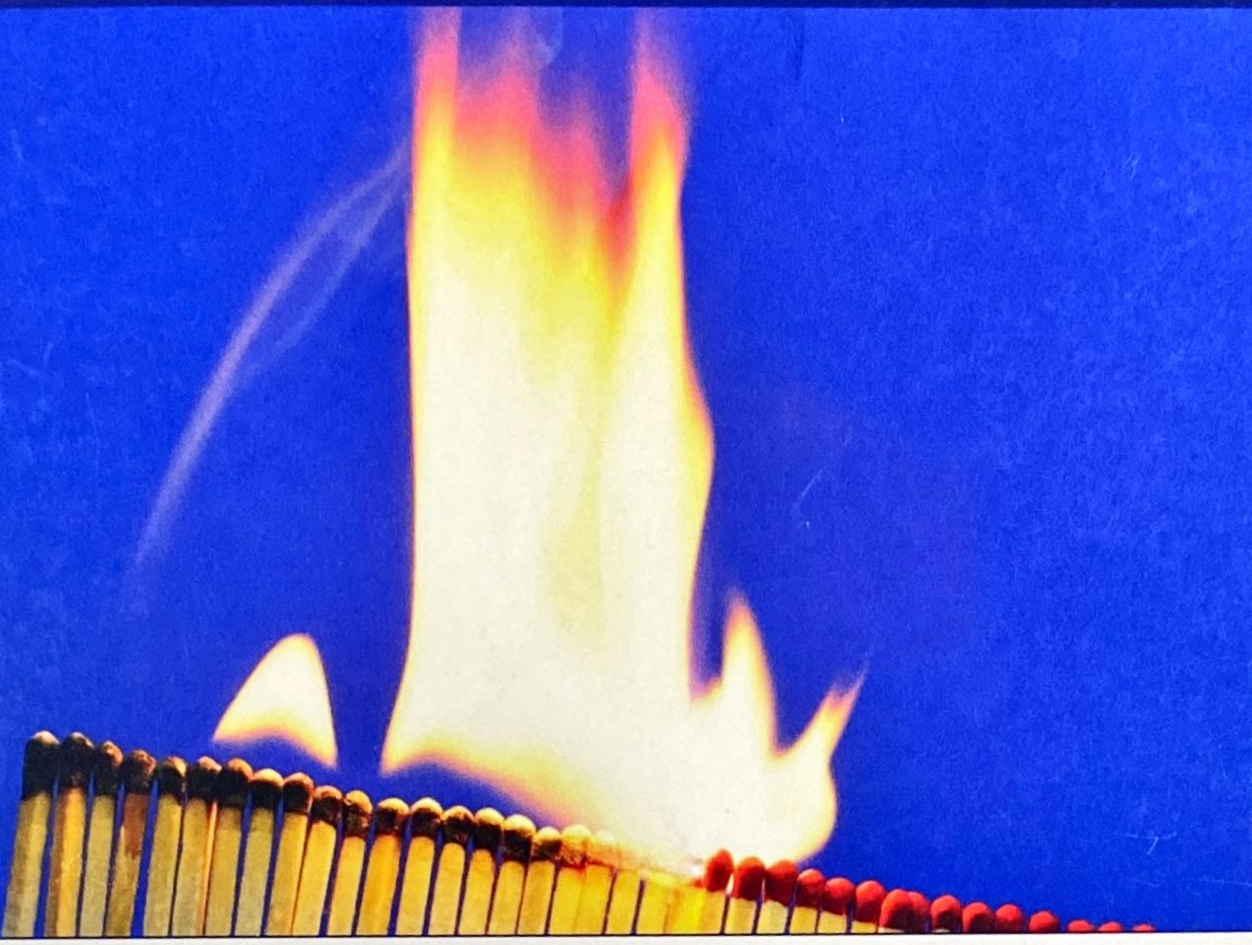

Hamdy HASSAN

Heat Transfer During Injection Molding

Simulation, Analysis and Optimization

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Titles

Introduction

The plastics have always existed in nature and their capacity to change of the form was used by the man since a long time: the Egyptians have already grinded mixtures of bitumen and of clay almost 5000 years ago [Massé 00].

The word "plastic" means substances which have plasticity (the deformation of a material undergoing non-reversible changes of shape in response to applied forces), and accordingly that is formed in a melt state and used in a solid state. Therefore, the origin of plastic forming can be traced back to the processing methods of natural polymers such as lacquer, shellac, amber, tusks, tortoiseshell, as well as inorganic substances such as clay, glass, and metals. Because the natural polymer materials are not uniform in quality and lack mass productivity in many cases, from early times, it has been demanded to process them easily and into better quality and to substitute natural polymers by artificial materials. Celluloid, synthetic rubber, ebonite, and rayon are examples of these artificial materials.

Our perception of the plastics materials has changed since the Eighties where the cheap and not very powerful plastic was used for the articles of down market and leaving the high-speed motorboat of the noble materials such as leather or metals. During those last years, the industry of plastic materials profited from a fast and regular growth, supported in particular by the diversity of the applications. Hence, the plastic materials have important assets compared to traditional materials. They have many functional advantages: lightness, mechanical and chemical resistance, reduced maintenance, free of form. These advantages make them possible to increase the lifespan of certain equipment thanks to their mechanical and chemical properties. These contribute to the reinforcement of the safety thanks to best behavior towards the shocks and fire. They offer a better thermal or phonic insulation compared with many insulation materials and, for some of them, a good electric insulation. They enrich also the possibilities of designing by permitting to lighten the structures and to carry out complex forms, ready to fulfill several functions. In each market of application (automobile, building, electricity, industrial plants...), those remarkable performances are at the origin of innovating technological solutions.

The history of plastic forming started with the development of phenol resin in the beginning of the 20th century. Originally, plastics were derived from improvement of natural materials, and therefore, their processing methods also progressed on the extended line of conventional processing methods. Several years after the industrial production of phenol resin, the production of vinyl chloride resin started, and then the production of styrene-based resins started. By the end of the first half of the 20th century, almost all main materials of synthetic resins were developed [Isayev 87]. As to the forming methods, it is said that the first injection molding machine was put to use in Germany in 1921; however, it can be said that this machine was an extension of the die-cast machine. The development and prevalence of plastic forming as shown today can be ascribed to the characteristics of materials, prices, and good process ability arising from the uniformity of artificial materials and, in addition, their mass production and allowance for cost reduction. Nowadays, there are different methods for polymer processing (thermoforming, blow molding, compression molding, transfer molding, extrusion of polymers, etc.), which differs by the methods of fabrications, the used materials, the qualities of the product and the forms of the product produced.

Among these processes of plastic materials forming, injection molding is considered as one of the most prominent of the industrial processes for mass producing plastic parts. More than one third of all plastic products is made by injection molding, and over half processing equipment of the world's polymer is used for the injection molding process [Castro 04]. Injection molding is used in many sectors of industry thanks to its rapidity of execution. It is used for three-dimensional and complex finished plastic parts or simple pre-forms intended to be puffed up, while guaranteeing a good quality of the products (respect of the dimensional tolerances, mechanical resistance, aspects of surface etc.). It is more complex than extrusion or thermoforming, but also more capable of producing very complex components to tight specifications. For instance, injection molding embodies the extrusion process to generate of polymer melt at faster time dynamics than thermoforming over a greater range of temperature and pressure. In injection molding and its variants (co-injection, injection compression, gas assisting molding, etc.), thermoplastic pellets are fed into a rotating screw and melted.

Injection molding consists of several stages: plastication, injection, packing, cooling, and ejection. During injection molding, with a homogeneous melt collected in front of the screw, the screw moves axially to drive the melt into an evacuated cavity. Once the melt is solidified and the molded component is sufficiently rigid to be removed, the mold is opened and the part is ejected while the next cycle's thermoplastic melt is plasticized by the screw. Cycle times range from less than four seconds for compact discs to more than three minutes for automotive instrument panels.

However, in spite of its intense use, the process of injection molding still requests more process control and efficient of machine part design. The design and the manufacture of the mold are always today a delicate moment and it is not certain that the part at exit of the mold has well the form, the dimensions or the aspect of expected surface. The parameters which are possible to modify during the injection molding are numerous (pressure, temperature, cooling fluid, material used, cycle time, etc.) and the experience of the operator plays an important role in the startup of the production.

The complexity of the technical aspects of this process of setting forms places at the confluence of several disciplines: chemistry and material science, with regard to the properties of polymers and their transformation, fluid mechanic, concerning the flow of the cooling fluid and the filling of the mold cavity, solid mechanics, in order to study the constraints and the deformations and of course its thermal behavior within sight of the importance of the thermal transfer through the product, the mold and the cooling channels. In addition to the complexity of polymer processing, polymers present high pressure and temperature dependent viscosity, non linear viscoelastic behavior, low thermal diffusivity, crystallization and solidification kinetics, etc...

In order to manufacture products with specifications in terms of dimensional stability or mechanical behavior, knowledge is required on the processing variables, the properties of the polymer and mold materials, the geometry of the mold, the layout out of the cooling system, etc.. The influence of these parameters on the final properties is far from obvious. It is often a result of a large amount of trials and errors when new products are developed. But, with the help of the numerical tools, product innovation could be speed up, the associated costs could be reduced, the product quality could be improved, and they help us to understand the material behavior along all the process. The numerical simulation of an industrial process as the injection molding is thus very interesting in order to better predict the evolutions and to propose operating conditions likely to give the best results. However, this simulation proves to be delicate within sight of the complexity of the physical phenomena which are taken into account.

Objective

Despite the various research efforts that have been directed towards the analysis, optimization and simulation of injection molding included main parameters of injection molding (pressure, temperature, etc.), material properties, cooling systems, etc., support for the layout design of the cooling system has not been well developed. Most of other studies on the injection molding process, especially the design of the cooling system, have been a two dimensional study without considering all injection molding stages (filling, cooling, ejection etc.) because of the complexity of the process as indicated earlier. The objective of this study is to understand/simulate the heat transfer of injection molding process and the effect of different injection molding parameters on this process to obtain optimum polymer product quality at low cost and high production rate. This work aims at optimizing process time of an important industrial production process and better understanding/developing the intimate operation of the physical phenomena of injection molding process. The study includes an experimental work using an injection molding machine and a numerical simulation of a calculation code by finite volume. During this study, different parameters (cooling system design, material properties, cooling fluid properties, process parameters like injection temperature and filling time, etc.) are considered for the optimization of the injection molding process to reach a high product quality at low cost and high production rate. The design of the cooling system considered during the study aims at reducing cycle time and hence increases the productivity of the process and reduces the process cost. At the same time it achieves uniform temperature distribution through the product to minimize such undesired defects as sink marks, differential shrinkage, thermal residual stress built-up and part warpage. Also, the effect of polymer material properties on the heat transfer process during the filling process is considered. Firstly, a two dimensional models is presented for the effect of polymer properties on the filling process and the effect of the cooling system design on the final product quality. Then, a three dimensional model for the injection molding machine is studied numerically and experimentally. A complete three dimensional model of the