Abstract

ABSTRACT

Plastic materials are very important in our daily life. They are superior to many conventional materials, in both their physical properties and variety of ways in which they could be processed. An extra-ordinary large number and variety of applications could be made due to the particularly useful chemical and physical properties of plastics. This fact became recognized particularly during the period of great economic growth after 1950, and led, during the rapid development since then, to the present world production of over 50 million tons annually. Despite this large amount, sufficient quantities of raw materials are available to meat foreseeable future demands of plastics.

Many plastic products are made through extrusion. The processing involves creating a melt from a resin, which is initially in the solid state. The quality of the part made from the melt depends on the homogeneity of the melt, which in turn is closely related to the geometry of the screw which delivers the melt to the die. Thus it is essential to use a screw which is best suited to the given properties of the resin and operating conditions of the extruder.

The usual method used in the past to design a screw was empirical and based on trial and error. The screw was designed on the bases of data gathered over years and tested. If the experiment did not give the expected results, certain geometric changes are made on the screw and the experiment repeated. In this way the screw is more or less, so to say, fitted to the resin concerned. Although this method could lead to positive results, the experimental effort involved could be considerable.

Furthermore this method had no scientific background and could neither be scaled up or down with certainty. Quality products could be made from resins by structuring them through controlled processing which requires a homogeneous melt at a uniform temperature. This could be accomplished only by accurately designed screw. Here again the trial and error method has serious limitations.

These limitations could be avoided by the help of computer-aided simulation and design. The general steps involved in designing any machine element used to polymer processing with the computer could be outlined as follows:

1. Forming a physical picture of the process.
2. Mathematical formulation of the physical process (model).
3. Putting the model into the computer language (program).
4. Testing the program with various input variables on a computer (process simulation).
5. Evaluation of output data and comparison with physical picture.
6. Checking the computer predictions with experiment.
7. Feedback of experimental results into the model (improvement of the model).

This work gives a picture of how solid plastic granules are being converted into melt in the extruder, the effect of various factors on extrusion process, and the necessary changes to be made in the screw geometry and operating conditions in order to attain complete and uniform melting. The objective of the work is to achieve a best performance for plastic extruder screw, through a successful extrusion process.

The thesis is organized as follows:

Chapter 1: Introduction about the development of single screw extruders, plastic products, and standard conventional extruder screw. Review of previous work in the various extrusion sections, such as solid conveying, melting, melt conveying, and die forming.

Chapter 2: Extruder Hardware including extruder drives, thrust bearing assembly, barrel and feed throat, feed hopper, extruder screw, die assembly, and heating and cooling systems.

Chapter 3: The Mathematical Model including a description of the geometry of the extruder screw and equations of the pressure profile at each extrusion region.

Chapter 4: Extrusion Pressure Analysis including the parameters of a selected reference case, and the parameters, which affect the extrusion process.

Chapter 5: discussions about the effect of some parameters on the pressure profile.

Chapter 6: The conclusions that were gained from the work, including some recommendations for getting a good performance for the plastic extruder screw.

الملخص العربي

ملخص البحث

تلعب المواد البلاستيكية دورا هاما جدا في حياتنا اليومية، فهي تمتاز عن بقيــة المــواد التقليديــة بخواصها الفيزيائية الممتازة واختلاف الطرق التي يمكن إنتاجها بها، ولقد أمكن إنتاج العديد و العديد من المنتجات والتطبيقات الهندسية بواسطة هذه المواد بحيث أصبحت لا تكاد تخلو آلة أو معدة أو منتج من البلاستيك بأنواعه المختلفة.

و لقد زادت أهمية المواد البلاستيكية تحديدا خلال النهضة الصناعية الكبرى بعد عام ١٩٥٠ والتي رفعت الاستهلاك العالمي من البلاستيك إلى أكثر من ٥٠ مليون طن سنويا، وتزداد الحاجة إليه عاما بعد عام مما أدى إلى ظهور أنواع مختلة من المواد البلاستيكية لكي تغطي الزيــادة المســتمرة للاحتياجــات المستقبلية لها في العديد من المنتجات والتطبيقات الهندسية المختلفة.

و يمكن إنتاج المواد البلاستيكية بطرق عديدة من أهمها عملية البثق،حيث يتم فيها تحويل الحبيبــات البلاستيكية الصلبة إلى مصهور في الحالة السائلة، و تعتمد جودة المصهور على مدى تجانسه والتي تعتمد بدورها بشكل كبير على هندسية شكل عمود بثق البلاستيك الذي يوصل هذا المصــهور إلى محطتــه الأخيرة داخل الاسطمبة لتعطي الشكل النهائي للمنتج.

وتعتمد الطرق التقليدية المختلفة لتصميم عمود بثق البلاستيك على الخبرة المعملية ومــا يســمى بعملية التجربة والخطأ، حيث يتم تجميع البيانات المختلفة عن التصميم من خلال سنوات تجارب عديــدة أجريت على أنواع وأحجام وأشكال مختلفة لعمود بثق البلاستيك تحت ظروف تشغيل متعددة، ثم تدون نتائج أداء هذه الأعمدة لكي تستخدم كمرجع يعتمد عليه أثناء أي عملية تصميم جديدة.

ويعيب هذه الطرق الكم الضخم من الوقت والتكلفة والمجهود المبذول من أجل الوصول إلى أفضل أداء لعمود بثق البلاستيك، حيث يلزم تغيير هندسية شكل عمود بثق البلاستيك أو ظروف التشــغيل أو حتى نوع مادة البلاستيك المستخدمة، ويمكن أن يحتاج الأمر إلى تغيير جميع العوامل السابقة سويا، و قد يصل المصمم إلى المراد من هذه التجارب وقد لا يصل، و حتى لو وصل إلى المراد فإنه بذلك يكون قــد صمم عمودا يصلح لنوعية معينة من المواد البلاستيكية، فإذا ما أراد تغيير أيا من العوامل التي تؤثر علــى أداء عمود بثق البلاستيك، أو أراد مثلا عمل تصميم أكبر أو أصغر فإنه قد يلجأ إلى عمليــة التجربــة والخطأ مرة أخرى.

و من هنا ظهرت الحاجة إلى المحاكاة باستخدام الحاسب الآلي لدراسة العوامل التي تؤثر على أداء عمود بثق البلاستيك، حيث يمكن بواسطتها تغيير أحد أو جميع العوامل السابقة سويا، وذلك داخل نموذج رياضي قد سبق التأكد من دقة نتائجه و قربها من القيم الناتجة من التجارب المعملية، ثم رؤية النتائج التي يظهرها الحاسب إما على شكل أرقام أو على شكل رسم بياني أو كلاهما بحيث يمكن للمصمم أن يحصل على ما يريد من هذه التجارب في وقت وتكلفة ومجهود أقل.

و تتكون عملية المحاكاة لأداء أي عنصر هندسي باستخدام الحاسب الآلي من الخطوات الآتية :

١- عمل تصور هندسي و فيزيقي للعملية المراد عمل المحاكاة لها.

٢- عمل نموذج رياضي ينظم و يحكم العلاقات المختلفة بين العوامل المؤثرة على هذه العملية.

٣- عمل برنامج بواسطة أحد لغات الكمبيوتر يحوي في داخله النموذج الرياضي.

٤- اختبار صلاحية برنامج الكمبيوتر بتجربته، و ذلك بإدخال العديد من المتغيرات إليه و دراسة النتائج الخارجة منه.

٥- مقارنة النتائج الخارجة من برنامج الكمبيوتر مع التصور الهندسي و الفيزيقي للعملية المراد عمل المحاكاة لها.

٦- مقارنة دقة نتائج برنامج الكمبيوتر و قربها من القيم الناتجة من التجارب المعملية.

٧- التغذية العكسية من التجارب المعملية لبرنامج الكمبيوتر لتحسين دقة هذه النتائج.

و هذا العمل يعطي صورة عن كيفية تحول الحبيبات الصلبة للبلاستيك إلى مصهور، وعن العوامل التي تؤثر على أداء عمود بثق البلاستيك، والمتغيرات التي قد يلزم تغييرها سواء لهندسية الشكل، أو لظروف التشغيل من سرعة دوران و درجات حرارة ... الخ، و ذلك للوصول إلى أفضل أداء لعمود بثق البلاستيك.

وقد نُظم البحث كالتالي:

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مقدمة حول تطور عمود البثق ذو الباب الواحد، المنتجات البلاستيكية، عمود البثق النمطي التقليدي، مراجعة للأبحاث السابقة في مجال البحث حول مختلف مقاطع عمود البثق مثل منطقة نقل حبيبات البلاستيك الصلب، منطقة الصهر، منطقة نقل المصهور، ومنطقة تشكيل البلاستيك داخل الاسطمبة.

الفصل الثاني :

المكونات الرئيسية للبثق وتشمل المحرك، تجميع كرسي المحور، ماسورة البثق وعنق التغذية، قـلدوس التغذية، عمود البثق.

الفصل الثالث :

النموذج الرياضي، ويشمل شرح لهندسية شكل عمود بثق البلاستيك، والمعادلات الخاصة بتوزيـع الضغط خلال مراحل عملية البثق، وعلاقات معدل سريان البلاستيك.

الفصل الرابع :

تحليل الضغط الناتج من عملية البثق، ويشمل العوامل المختارة كمرجع للقياس، وكذلك العوامـل التي تؤثر في عملية البثق.

الفصل الخامس :

المناقشة حول تأثير بعض العوامل على منحنى توزيع الضغط، ومعدل سريان البلاستيك.

الفصل السادس :

الاستفادات المستخلصة من البحث، وتتضمن بعض التوصيات للحصول على أداء جيد لعمود بثق البلاستيك.

فهرس الأبحاث:

ويحتوي على أسماء الأبحاث المراجع التي تم الاستعانة بها للقيام بهذا البحث.

الملحق (أ):

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Mansoura University
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Prod. & Mech. Design Dept.

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A Thesis

Submitted In Partial Fulfillment for the Degree of

Master of Science

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By

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Supervisors

Thesis Title:

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NOMENCLATURE

ψ	Dimensionless melting parameter
η	Viscosity
γ	Shear rate
ϕ	Melting parameter
ω	Rate of melting per unit down-channel distance
$\theta(r)$	The angle formed between the flight and the plane normal to the screw axis.
ρ_b	Bulk Density
θ_b	The helix angle at the barrel surface
δ_f	The radial clearance between the crest of the screw flight and the inner barrel surface
δf	Effective angle of friction of the solid particles
α_H	Hopper half angle
ρ_m	Melt Density
η_r	Viscosity of the melt in the clearance
ρ_s	Slid Density
θs	The helix angle at the screw surface
a	Parameter expressing the temperature dependence of viscosity.
A	Taper in compression section.
$b_{(r)}$	The width of the screw flight in the axial direction
B(r)	Axial distance between Flights
b_b	Width of the screw flights in the axial direction at the barrel surface

b_s	Width of the screw flights in the axial direction at the root of the screw
C	index relates to convergent sections
C_m	Specific heat of the polymer melt
C_s	Specific heat of the Solid bed
D_b	The inside diameter of the barrel
D_s	The root diameter of the screw
E	The width of the screw flight perpendicular to the flight
F_b	Coefficient of friction at the barrel surface
f_c	Coefficient taking into account the effect of the curvature of the screw channel on the melting rate
F_{fd} , F_{fP}	Correction factors for the effect of the flight clearance
f_h	Coefficient taking into account the effect of the flight clearance on the melting rate
F_{HD} , F_{HP}	Corrections for the influence of the varying channel height on the drag and pressure flow respectively
F_s	Coefficient of friction at the screw surface
Fw	Coefficient of friction at the hopper surface
g	The gravitational acceleration
G	Mass flow rate
h	Thickness of the film
H	The distance between the root of the screw and inner surface of the barrel (Channel depth)
H1	Channel depth at the entrance to an axial increment
H2	Channel depth at the exit from an axial increment
H_s	Height of solids
$K_2(z)$,	Factors depending on the dimensions of the die and step

$K_3(z)$	length z.
K_m	Thermal conductivity of polymer melt
Ks	Thermal conductivity of Solid bed
l	Axial distance
L	The axial distance of one full turn (screw lead)
m	Power Low Constant
n	Power Low Index
N	Frequency of screw rotation
p	Number of channels in parallel. (No. of starts)
P	Pressure
P0	Pressure Atmospheric
Q	Volumetric flow rate of the extrudate
R_H	Hydraulic radius of the hopper
T	Temperature
T_{av}	Average temperature of the polymer in the melt film
T_b	Temperature of the barrel inner surface
T_m	Melting point
Ts	Temperature of the solids fed to the hopper
V_b	Tangential velocity of the barrel surface relative to screw
V_j	Vectorial difference between V_b and V_{sz}
V_{sz}	Velocity of solid bed in down channel direction
W	Width of the melt pool (in the melting zone) or the width of the channel (in the metering zone)
$W_{(r)}$	The channel width or the distance between the flights along a helical line, which is perpendicular to the flights
W_b	The width of the channel perpendicular to the flights at the

	barrel surface
W_s	The width of the channel perpendicular to the flight at the root of the screw
X , X_1	Widths of the solid bed at the distances z and z_1
y	Downward coordinate along the height of the
Z	Coordinate in the down- channel direction
z(r)	Helical length at a given radius
Z_D	Length of the delay zone

Abstract

ABSTRACT

Plastic materials are very important in our daily life. They are superior to many conventional materials, in both their physical properties and variety of ways in which they could be processed. An extra-ordinary large number and variety of applications could be made due to the particularly useful chemical and physical properties of plastics. This fact became recognized particularly during the period of great economic growth after 1950, and led, during the rapid development since then, to the present world production of over 50 million tons annually. Despite this large amount, sufficient quantities of raw materials are available to meat foreseeable future demands of plastics.

Many plastic products are made through extrusion. The processing involves creating a melt from a resin, which is initially in the solid state. The quality of the part made from the melt depends on the homogeneity of the melt, which in turn is closely related to the geometry of the screw which delivers the melt to the die. Thus it is essential to use a screw which is best suited to the given properties of the resin and operating conditions of the extruder.

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Chapter 1

Literature Review

CHAPTER 1

LITERATURE REVIEW

1. Introduction

Plastic extruded products play a very important role in our daily life. They are used as major components in many devices and machines. As a beginning, the word *extrude* originates in the Latin word *ex* (out) and *truder* (to thrust). This closely describes the process itself as *shaping by forcing through a die*. The screw extruder efficiently and continuously converts solid polymer into melt and pumps it through a die at high pressure.

Plastic Extruder Screws range from 1`` to 12`` in barrel diameter (Although extruders with 36`` barrel diameter have been built)[1]. These machines extrude a tremendous variety of products at high rates.

2. Plastic Extruded Products:

Plastic extruded products could be classified as follows:

- Plastic film for bags for packing bags for baking, and construction of roads and buildings.
- Plastic pipe for water, gas, drains and vents, and chemical plants.
- Plastic tubing for garden hose, automobiles, control cable housings, laboratories, medical uses, and soda straws.

- Plastic insulated wire for homes, automobiles, appliances, telephones and electric power distribution.
- Plastic filaments for brush bristles, rope and twin, and fishing line.
- Plastic coated paper (film and foil) for milk cartons, meat packaging, and moisture barriers.
- Plastic sheeting for formed products, signs, lighting, and glazing.
- Plastic profiles for home siding, storm windows, and gaskets etc [2].

3. Standard conventional extruder screw:

The performance of the extruder depends on many factors, such as the screw design and operating conditions. In most recent technical papers dealing with plastic extrusion screws, reference was made to a so-called standard conventional extruder screw. This screw consists mainly from three main sections. The first section is called the feed section. The second is called the transition section, and the third is the metering section. The general characteristics of the standard conventional extruder screw [3] are:

- Total length 20 D_b -30 D_b.
- Length of feed section 4 D_b -8 D_b.
- Length of metering sections 5 D_b -10 D_b.
- Number of parallel flights 1.
- Flight pitch 1 D_b (helix angle 17. 66°).

- Flight width 0.1 D_b.
- Channel depth in feed section 0.01 D_b -0.15 D_b.
- Channel depth ratio 2-4.

Where D_b is the barrel inside diameter.

These dimensions are approximate, but the majority of the extruder screws in use today have the general characteristics listed above. Based on these guidelines, the geometry of a standard extruder screw could be determined in a minimum length of time.

The frequency of screw rotation at which the extruder will operate depends on the size of the extruder and production rate requirements. Nowadays, plasticating extruder operate mostly in the speed range of 20-200 rpm and, depending on their size. The limiting factor here is the quality. Higher screw speeds will produce higher throughput, but will usually result in deterioration of quality. In this higher range the operation and mechanism of extrusion are different from that at low screw speeds. Barrel temperature setting is selected according to the polymer extruded. The temperature has to be high enough to melt the polymer without causing thermal degradation.

4. Development of Single Screw Extruders:

The idea of screw pumps is very old, often being attributed to Archimedes. The development of single screw extrusion machines occurred in the latter years of the 19th century roughly contemporary to non-intermeshing counter-rotating twin screw extruders. An 1871 US patent to Sturges has a spirally arranged flange on a shaft or screw for pumping soap. An 1877 U.S. patent to Higbie described the use of a screw for conveying and drying grain.

The first patent on screw extrusion of polymers is an 1879 patent of M. Gray on extrusion with specific application to wire coating. There have been many applications of single screw extrusion by industrial firms without patents or publications. Some authors indicate the Hamburger Gummiwerke used screw extruders for rubber compounds in 1873. In any case it is clear that screw pumps became common to the process industries in the last 30 years of the 19th century.

Variations in screw and screw extruder design have a long history. Desgoff and DiGiorgio within a few years of Higbies and Grays patent described a single screw extruder with decreasing screw pitch in the machine direction which was to give both mixing and kneading. The rubber industry was an early user of screw extrusion

There was considerable activity to develop capability for continuous compounding of rubber. As early as 1919, single screw extruders were developed with multiple entry parts, just before each of which there would be a pressure reducing aperture. The necessity of kneading and mixing rubber and early plastics led in the 1920s to segmented screw designs and in 1930s to threaded and grooved barrel liners. Pin barrel designs had along history. The basic ideas were developed though they were to be often forgotten and subsequently re-invented.

The patents described above roughly cover the period 1880-1940 during which many companies around the world became deeply involved in the manufacture of screw extruders. These involve firms such as Royle and

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