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Applied Thermoplastic Screw Plastication Theory: Industry Acceptance and Implications for Plastics Processing Education

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APPLIED THERMOPLASTIC SCREW PLASTICATION THEORY: INDUSTRY ACCEPTANCE AND IMPLICATIONS FOR PLASTICS PROCESSING EDUCATION

by

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APPLIED THERMOPLASTIC SCREW PLASTICATION THEORY: INDUSTRY ACCEPTANCE AND IMPLICATIONS FOR PLASTICS PROCESSING EDUCATION

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Rapid expansion of the thermoplastics processing industry has increased the need for plastics education and training. Screw plastication is the major method of melting plastics in order to mold or extrude them into useful products. Thus, information about the role of plastication is needed to provide guidance for plastics education and training.

This study sought confirmation of suspected differences existing in the amount of knowledge personnel have about thermoplastic screw plastication, dependent upon: (a) the type of plastics process used, and (b) their job classifications. Furthermore, the study collected data in three additional areas: (1) the extent to which persons in given job classifications rely on plastication theory; (2) the importance of elements of this information to their work; and (3) the likelihood that personnel in a given classification will seek additional information about plastication theory.

Conclusions were drawn from a survey instrument which asked respondents to report knowledge about several specific areas of screw plastication. Surveys were submitted to 180 people in all, involved in manufacturing and design engineering, trouble shooting, management, technical sales, research and development. All members of this sample were involved in injection molding, blow molding or extrusion. The instrument was administered to subjects residing within the state of Michigan, as Michigan was determined to be representative of the plastics industry throughout the United States. A 75% return rate of the instrument was achieved.

Some interesting conclusions can be drawn from this study. First, a degree of plastication knowledge is requisite for all people entering production, engineering and managerial positions with no appreciable difference between job classifications. Second, currently, blow molders more actively seek information on plastication than do injection molders. Third, the area of screw design is seen as being very important, but is not well understood by current molders. This knowledge gap provides an array of potential educational interventions, the exact nature of which needs to be determined.

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Paul V. Engelmann

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CHAPTER I

INTRODUCTION AND BACKGROUND

Background of the Problem

Polymers (plastics) will soon be the major manufacturing material used in the world for production of all hard goods and soft goods (T. Richardson, 1983; Society of the Plastics Industry, 1984). Plastics now comprise an important portion of the building construction, textiles, transportation, medical, electronics, housewares and packaging industries (Resins, 1988). In 1987, the U.S. alone used almost 53.7 billion pounds of plastics (Resins, 1988). Furthermore, as of 1984 plastics processing employs the largest percentage of people in U.S. manufacturing (Kern, 1985). In addition, plastics resins, materials and products now comprise the fourth largest manufacturing industry in the U.S. by dollar volume (Kern, 1985). In fact, more manufacturing plants in the U.S. are involved in plastics processing than in any other type of processing by a ratio of almost 2 to 1 (Kern, 1985). The size of the entire plastics industry increased by 9% in 1987 alone, and there are projections for continued substantial growth (Plastics, 1987; Resins, 1988).

The plastics processing industry is extremely diverse. There are over 30 separate types of processing employed within the industry (T. Richardson, 1983). These processes fall into a number of broad categories including extrusion, molding, forming, casting, reinforcement, finishing, decorating, welding and assembly. Of the 30+ processes, extrusion, injection molding and blow molding account for nearly 60% of the plastics industry by volume (Brockschmidt, 1986; Dickard, 1986; Materials, 1987).

All plastics are divided into two groups: (1) thermosets and (2) thermoplastics. Like concrete, once hard, thermosetting plastics cannot be reliquified and can only be reshaped by cutting or breaking. Thermoplastic polymers, on the other hand, are those resins that can be remelted and reshaped like wax. Within each of these two groups there are literally hundreds of different types of polymers and polymer alloys.

Over four fifths of the polymers now in use are thermoplastics (Resins, 1988). A vast majority of all thermoplastics are processed by extrusion, injection molding and blow molding (Dickard, 1986; Materials, 1987). Thus, the major portion of the plastics industry is involved in processing some type of thermoplastic resin by either extrusion, injection molding, or blow molding.

One of the greatest areas of commonality between the major methods of thermoplastic processing is screw plastication. Screw plastication is the method of melting plastics using an auger type screw to provide frictional heat. Study of the behavior of the plastics as a viscous liquid, or "rheology", is critical to understanding the melting process. Plastication governs the way in which the process functions and the majority of requisite problems. Changes in plastication can change the flow of the polymer and in turn, the mechanical properties of the finished part (Schwartz & Goodman, 1982). Thus, these factors have direct bearing on the quality and efficiency of the production of the finished plastic product (P. N. Richardson, 1974; Rosato & Rosato, 1986).

Problem Statement

One of the key issues in manufacturing education is what to teach and how best to teach it (Wells, Caldwell, & Arthur, 1985). Currently, close to 200 colleges and universities across the U.S. and Canada are struggling with the challenge of preparing their students to cope with the major shift toward plastics in manufacturing technology (Engelmann, 1986).

Over the past two decades there has been a steady increase in the emphasis placed on screw plastication mechanisms by educational materials such as text and reference books (Engelmann, In Press; Johnson, 1973;

Milby, 1973; T. Richardson, 1983; Rosato & Rosato, 1986; Schwartz & Goodman, 1982; Steele, 1977). Texts and references from the early seventies either do not discuss plastication at all or handle it in a very superficial manner. In contrast, current books devote as much as one or two chapters to the subject of plastication (Rosato & Rosato, 1986; Schwartz & Goodman, 1982). When searching for a reason for this increase in emphasis on screw plastication, it is noted that a large amount of research has been done over the past 30 years (Amellal & Elbirli, 1987; Lee & Biesenberger, 1987; Sakai, Hashimoto, & Kobayashi, 1987; Tanner, 1987; Yoshimura & Richards, 1987). In fact, screw plastication is far better understood than it was 20 years ago (Crawford, 1982; Frados, 1976; Rubin, 1972). Better understanding of the impact of plastication upon viscosity, pressure, shear stressing and shear rate has shed new light upon the role of the processors (Schwartz & Goodman, 1982). For many years problems with part performance were blamed on the resin suppliers rather than the processor. It has become increasingly apparent in recent years that the way in which a polymer is plasticized during molding has a profound effect upon the chemical structure of the polymer and thus the physical properties of the molded part (Crawford, 1987; Rosato & Rosato, 1986; Schwartz & Goodman, 1982).

At this time the extent to which the plastics industry has acquired and accepted the current scientific understanding of plastication is unclear. Also, unclear is the importance of this knowledge to those in the industry.

It would seem logical to assume that if an understanding of screw plastication is considered unimportant, then the knowledge will neither be sought out nor applied. However, it is clear from the bulk of literature that a good portion of the machinery and resin suppliers see better plastication as a way to achieve better products. It is not evident however, to what extent processors understand or value this information.

To what extent have plastics processing personnel in differing job classifications acquired knowledge about plastication mechanisms, and what value do they place on the knowledge gained?

Operational Definitions of the Variables

Knowledge of Screw Plastication

Knowledge of screw plastication may be defined as the ability to apply or discuss the application of certain principles about any one of several of the following areas. This may also be referred to as a working understanding of screw plastication. Areas of screw plastication knowledge include an understanding of the following five areas: (1) barrel temperature profile, (2) properties of shear, (3) screw design, (4) screw forces and (5) discharge modifiers. The barrel temperature profile is a graph of temperature readings along the barrel of an extruder or molder. The barrel is the sleeve around a plastication screw. As the screw turns inside the barrel, it pumps the polymer resin forward and adds frictional heat. Control of barrel heat determines much about the temperature uniformity and quality of the molten polymer. The relative effects of shear rate and shear stressing on the quality of the melt are a second area of plastication knowledge (Levy, 1981: Rosato & Rosato, 1986; Rubin, 1972; Schwartz & Goodman, 1982). Shear rate is defined as the amount of slippage of polymer molecules over one another in a given measure of time. Shear stressing is the amount of force applied in a given area to produce slippage between the molecules (Schwartz & Goodman, 1982). Melt quality may be more precisely defined in terms of the temperature uniformity pressure profile, molecular weight distribution of the polymer after melting and residual stress caused by plastication.

Third, a working understanding of the effects of screw design on the quality of the melt may also serve as a measure of knowledge (Levy, 1981; Rosato & Rosato, 1986; Rubin, 1972; Schwartz & Goodman, 1982).

Fourth, a working understanding of the effects of screw forces (such as back pressure and screw speed) on the quality of the melt may also serve as a measure of knowledge (Levy, 1981; Rosato & Rosato, 1986; Rubin, 1972; Schwartz & Goodman, 1982). Back pressure may be defined as the force applied to the back of the screw during rotation. Back pressure adds friction to plastication. Screw speed may be defined as the rate of rotation of the screw during plastication, measured in revolutions per minute.

Finally, a working understanding of the effects of discharge modifiers (such as nozzles, adapter plates, screen packs and breaker plates) on the quality of the melt may also serve as a measure of knowledge (Levy, 1981; Rosato & Rosato, 1986; Rubin, 1972; Schwartz & Goodman, 1982). Nozzles, adapter plates, screen packs and breaker plates all serve to add back pressure and conduct the molten resin from the screw to the tooling or mold. The tooling or mold in turn will produce the shape of the finished product.

Measurement of knowledge of screw plastication may be accomplished through questions concerning specific information about each of the aforementioned five areas. Knowledge in all five of these interrelated areas is important. A lack of knowledge in any specific area could have a very detrimental effect on the quality of melt production under certain circumstances (Levy, 1981; Rosato & Rosato 1986; Rubin, 1972; Schwartz & Goodman 1982).

Classification of Job Titles

Job classifications of interest for the purpose of this study shall include the range of individuals involved in thermoplastic processing. These jobs may be divided into six major groups: (1) those involved in production, process, or manufacturing engineering; (2) those individuals involved in design and design engineering, (3) those individuals involved in set-up and trouble shooting, (4) those individuals involved as foremen or in a supervisory position, (5) those individuals involved in general and corporate management and (6) those individuals involved in sales, marketing, purchasing, testing, polymer research and development will be classified under the category of "other". This categorization scheme is consistent with the system used by major plastics publications for data collection e.g. Plastics Technology and Modern Plastics.

Processing Methods

Processing methods of interest in this study shall include extrusion, injection molding, and blow molding (Brockschmidt, 1986; Dickard, 1986; Materials, 1987). Extrusion is the process of forming plastics in a molten semi-liquid state, much like squeezing toothpaste from a tube, to produce products such as plumbing pipe. Injection molding is the process of molding plastics in a molten liquid state by injection into a closed mold to form a finished product like a gear shift knob. Blow molding is the molding of plastics through the formation of a tube or parison that is blown-up within a hollow mold like a balloon, to form a hollow finished product like a bottle.

Research Objectives

This study is designed to explore the existence and magnitude of the differences in the amount of knowledge and perceived importance of screw plastication within the thermoplastics processing industry by job classification.

From the data acquired in this study, inferences about the nature and role of plastication education will be drawn. This information is critical because of the formative state of plastics education. One measure of the relative infancy of plastics education is the evolution of Society of Plastics Engineers (SPE) student chapters. The first student chapter was chartered in 1960, however, over 81% of all the student chapters in the world have been chartered in the last ten years (Bristol, 1987).

Ultimately, this study should shed new light in several specific areas. Conclusions may be drawn as to whether the difference in amount of knowledge acquired is dependent upon the job classification a person holds. Furthermore, a determination will be made about the relative understanding of skilled blue collar employees vs. other employees. In addition, differences in the degree of knowledge acquisition dependent upon the type of thermoplastics processing being performed may be revealed. Given the study data, the appropriateness of elements of current plastics curricula may be determined. In addition, the role of in-plant plastication training may be ascertained. The question of who should be taught what, may effectively be addressed.

Finally, the study will provide data that will be used to determine if knowledge developed in extrusion and injection molding is being transferred to blow molding. Such a determination is especially critical now, since blow molding has only recently started to produce high tolerance structural parts. Injection molding and extrusion have been meeting the demands of high tolerance for quite some time.

Conceptual Framework and Research Goals

Previous work on screw plastication falls into three categories (see Figure 1). First, a large amount of work done on screw plastication falls in the category of basic scientific research in the areas of polymer chemistry and physics. This work has had a profound impact on our understanding of the nature and behavior of screw plastication mechanisms (Lee & Biesenberger, 1987; Maxwell, 1987; Nelson & Lee, 1985; Yoshimura & Richards, 1987). From this work the mathematical and chemical relationships which exist during plastication have been derived. Although flow patterns cannot be completely predicted under certain situations, much of the behavior of a polymer during plastication is understood.

The second area of work in screw plastication has been in applications research, which may well constitute the majority of the work presently being done in screw plastication. This work is principally concerned with the melt quality as it relates to the design of components. Examples of this type of work are comparisons made between several screw designs with a given grade of resin (Amellal & Elbirli, 1987; Kline, 1988; Nazarenico, 1988; Rauwendaal, 1985; Sakai, Hashimoto, & Kobayashi, 1987). Furthermore, research is often conducted to determine the processing limits of a given grade of resin using a standard rheologic model or with instrumentation such as a torque rheometer (Haake Buchler Instruments, 1985; Tanner, 1987).

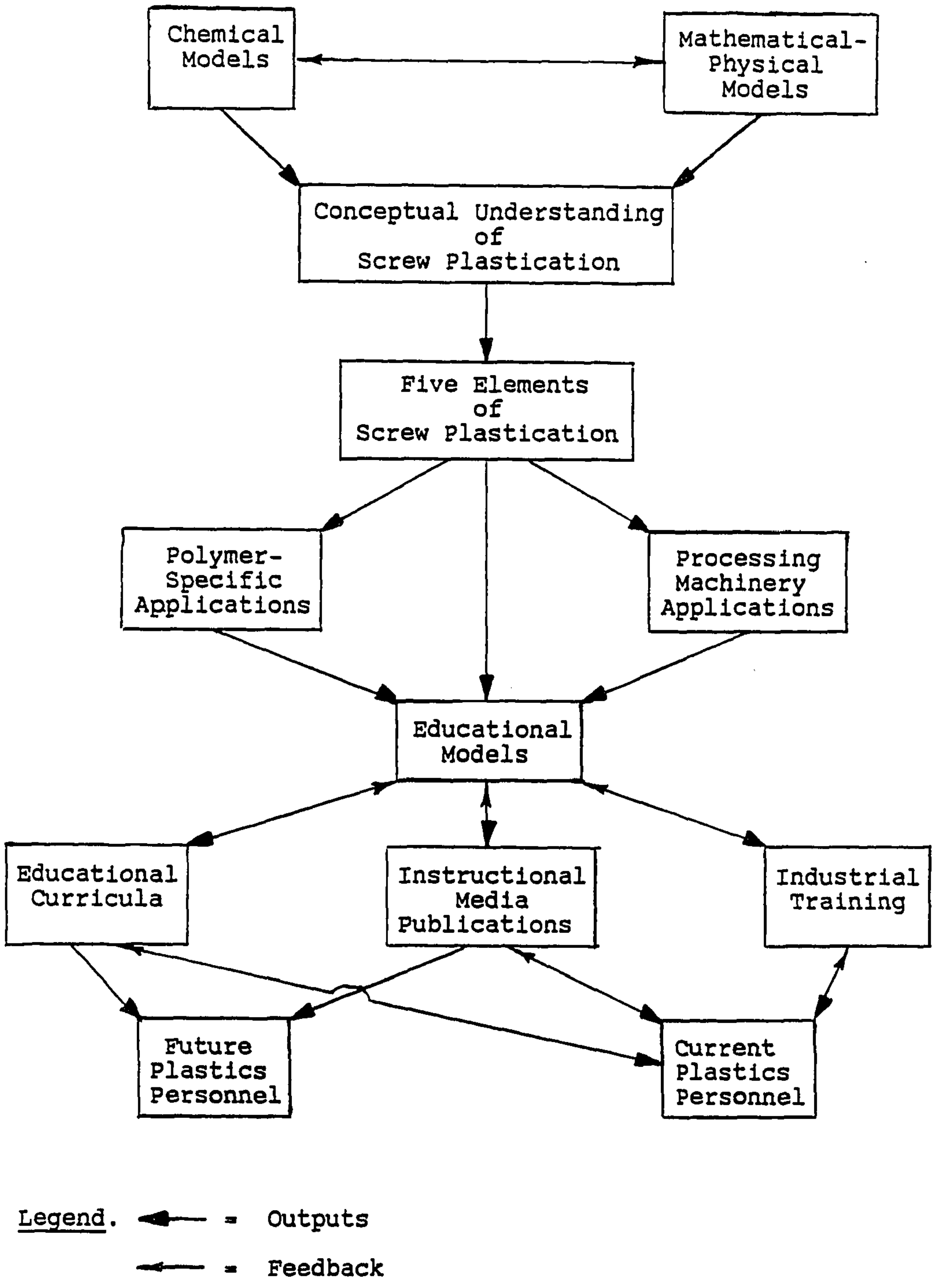


Figure 1. Model of Thermoplastic Screw Plastication Knowledge Flow

The third area of work seeks to synthesize the mathematical and scientific relationships with the applications research into usable forms for consumption and application by a larger audience. The output from this type of work may be in the form of reference books, text books, instructional video tapes, films and model curricula (Bender, 1981; Crawford, 1987; Michaeli, 1984; Olsen, 1971; Paulson, 1979; Rosato & Rosato, 1986; Rubin, 1972).

In Figure 1, large arrows represent output from each of the elements. Small arrows represent feedback by a specific element. For instance, an educational model will output precepts to a curriculum and curricula will feedback based upon those things that are found to be successful with pupils (future and current employees).

However, there is little knowledge about the pattern of consumption and application of screw plastication models by the industrial community. Instead, a series of assumptions are made. First, it is assumed in some cases that since the resin and machinery suppliers have researched the area and designed specific elements into both polymers and processing equipment, the processor does not adversely affect the polymer (Dow Chemical, 1979). Secondly, it is assumed that since information on screw plastication has been included in some recent books, this information has been read and accepted by the processors.

Third, it is assumed that since much of the research, especially applications research is carried by the major plastics publications, such as Modern Plastics, Plastics Technology, Plastics Engineering, and Plastics World, the research is both read and understood by processors. Furthermore, it is assumed that a given percentage of processors have had some coursework in plastics processing, either through college courses or seminars.

In fact, it is not known to what extent knowledge about screw plastication has been acquired by plastics processors. It is not known if there are certain types of processors or job classifications of personnel that have acquired the knowledge and others that have not. Information on who is using the knowledge will hopefully shed some light on the similarities between those individuals. Ultimately, this information may lead to an understanding of how screw plastication theory may be better and more universally applied in the field.

CHAPTER II

REVIEW OF RELATED LITERATURE

Theoretical Understanding of Plastication

This discussion explores the current theoretical understanding of thermoplastic plastication mechanisms. To aid in the discussion of the relationship of variables and constants related to plastication, a number of notations and symbols are used. A comprehensive list of these notations and symbols, along with their definitions may be found in Appendix A.

Further sections will discuss elements of plastication practice and its role in plastics education. Three terms are used in the literature when referring to the process of liquefying polymers: (1) plasticizing, (2) plastifying and (3) plastication. Plasticizing refers to the liquification of polymers generally with a solvent or plasticizer (Whittington, 1978). Plastifying is the softening of a polymer resin by the use of heat alone (Whittington, 1978). Plastication is the softening of a polymer with the application of both heat and pressure (Whittington, 1978). Plastication is central to the discussion of melting polymers for molding and extrusion operations.

Polymer Chemistry

Certain chemical characteristics of thermoplastic resins govern their behavior during plastication. The majority of all thermoplastics are hydrocarbon compounds (Driver, 1979; T. Richardson, 1983). Based upon their chemical structure and the types of atomic bonds present, polymers exhibit three types of structure: (1) crystalline, (2) amorphous and (3) semi-crystalline. Polymers which exhibit crystalline structure are hard, rigid, opaque and often brittle in nature (Schwartz & Goodman, 1982). On the other hand, amorphous polymers tend to be more flexible and may be clear. In order for a resin to be clear, it must be amorphous. However, not all amorphous resins are clear (T. Richardson, 1983). The third type of polymers are semi-crystalline and exhibit characteristics of both amorphous and crystalline polymers, depending upon the degree of crystallinity (Seymour, 1987). Crystalline polymers have a very ordered rigid structure, whereas amorphous polymers have a random structure (Callister, 1985; Driver, 1979).

Dependent upon the chemical composition and structure of a polymer, differing characteristics will be exhibited during the melting process. Two major phase transitions are present in all polymers during the heating process: (1) melting (T_m) and (2) glass transition (T_m) (Driver, 1979; Ulrich, 1982). T_m is a first order transition, characterized by the physical softening of amorphous polymers and liquification of the crystalline polymers. Both are the result of greater freedom of movement and activity of the molecular chains (Callister, 1985; Schwartz & Goodman, 1982). The glass transition temperature is most evident in amorphous polymers. T_g is the point at which the resin begins to soften from a hard solid to a flexible solid material (Callister, 1985; Schwartz & Goodman, 1982). Softening continues over a range of temperatures, and the polymer becomes increasingly rubbery. When T_m is reached, the polymer begins to flow as a viscous liquid (Callister, 1985; Schwartz & Goodman, 1982). Thus, the major difference in the plastication of crystalline and amorphous polymers is that crystalline polymers have a sharp melting point and amorphous polymers soften over a range of temperatures.

Non-Newtonian Fluid Mechanics

The changes in melting rates and fluid viscosities are explained in the area of fluid mechanics known as rheology. Both crystalline and amorphous polymers exhibit decreasing viscosity or resistance to flow as resin temperature increases (Bernhardt, 1959; Han, 1976; Lenk, 1968; Rosato & Rosato, 1986; Severs, 1962). The relationship between the temperature of a resin and its viscosity is non-proportional and non-linear in nature

(Lenk, 1968; Nielsen, 1977; Severs, 1982). This is due to the fact that polymers exhibit non-Newtonian fluid mechanics. A non-Newtonian fluid is one in which changes in the shear stress (τ) are not proportional to changes in the shear rate ($\dot{\gamma}$) (Bernhardt, 1959; Schowalter, 1978; Skelland, 1967).

However, Newtonian fluids provide a more simple model of fluid mechanics with which to understand the factors that affect properties of shear. That is to say that the (τ_{xy}) the shear stress of a Newtonian fluid in the direction of flow (x) and the direction through the cross section of a tube (y) is normally equal to force (F) over area (A) (Schowalter, 1978; Skelland, 1967).

$$\tau_{xy} = \frac{F}{A}$$

The differential of strain ($d\gamma$) over differential in time (dt) is equal to the constant velocity (dv) over the nominal distance traveled (dy) (Schowalter, 1978; Skelland, 1967).

$$\frac{d\gamma}{dt} = \frac{dv}{dy}$$

Thus, shear rate or velocity gradient is expressed as ($\dot{\gamma}$). The dot represents a first derivative with respect to time (Brydson, 1970).

$$\dot{\gamma} = \frac{dv}{dy}$$

Thus, the shear stress is equal to the shear rate multiplied by the slope of the flow curve μ/g_c

(Schowalter, 1978; Skelland, 1967).

$$\tau_{xy} = \frac{\mu}{g_c} \frac{dv}{dy}$$

Or, in simpler terms, the shear stress is equal to the viscosity constant (μ), multiplied by the shear rate (Brydson, 1970).

$$\tau = \mu \dot{\gamma}$$

Calculation of specific values for a Newtonian fluid are relatively easy as compared with the same calculations for a non-Newtonian fluid, such as a molten polymer (Brydson, 1970; Lenk, 1968; Schowalter, 1978; Severs, 1962). The same basic factors are all present when calculating shear stresses and shear rates for non-Newtonian fluids. However, since viscosity is a function of temperature, and the relationship between shear rate and shear stress are no longer linear (μ/g_c is a unique curve), exact calculation affords numerous obstacles (Schowalter, 1978; Skelland, 1967).

Of all non-Newtonian fluids, the polymers as a group have the greatest variance from Newtonian fluids, since the majority of polymers are classed as showing pseudoplastic behavior (Brydson, 1970). A pseudoplastic material is one that thickens as shear rate increases and is independent of time (Collins, 1988). Because of the difficulty of predicting, calculating or measuring the actual viscosity of a pseudoplastic, the viscosity is normally referred to as the apparent viscosity (μ_a) (Brydson, 1970). Since the apparent viscosity of a polymer is the function of the rate of shear and the temperature of the resin, a basic understanding of the thermal properties of plastics is necessary to predict the rate of change of apparent viscosity.

Thermodynamics and Heat Transfer

Thermodynamics involves the study of both the sources of heat and the relative heat transfer or thermal conductivity (Perry, 1984). There are two major sources of heat: (1) control heat and (2) frictional heat. Control heat is provided to the plastication process by electric heaters, such as heater bands or rods, or by a heating fluid such as a hot oil (Levy, 1981; Rosato & Rosato, 1986; Rubin, 1972). Control heat may also employ cooling of the plastication process by the use of a liquid or air coolant (Levy, 1981; P. N. Richardson, 1974). However, the major source of heat for most thermoplastic plastication is frictional heat (Levy, 1981; P. N. Richardson, 1974; Rosato & Rosato, 1986; Rubin, 1972). Frictional heat is the direct result of compressing and shearing resin particles (Jacobi, 1963; Rosato & Rosato, 1986; Rubin, 1972). So much frictional heat may be generated as an extruder screw conveys resin forward and compresses it, that cooling is required to insure both correct temperature and viscosity (Levy, 1981; P. N. Richardson, 1974).

The second important component of thermodynamics is heat transfer. Heat transfer is a function of the type of transfer, the media through which the heat must pass and the amount of heat present. There are three basic types of heat transfer: (1) radiation, (2) conduction and (3) convection (Bernhardt, 1959; Perry, 1984; Pollack, 1964). Radiation is the passage of direct heat energy from one body to another through electromagnetic waves (Bernhardt, 1959). Heat is transferred from the sun to the earth in this way. Conduction is the passage of heat energy due to molecular, atomic or electronic excitement or motion. Conduction may occur between solids, liquids and gasses (Bernhardt, 1959). Conduction is the way a hot piece of steel transfers its heat energy to a countertop upon which it is placed. Finally, convection is the transfer of heat through fluidic movement (Bernhardt, 1959). Convection is the way forced air heat transfers heat from a furnace to the rest of the house.

The majority of all heat transfer that occurs in screw plastication is conduction, with some convection present (Bernhardt, 1959). Thermal conductivity (k) is the term used to explain the rate and efficiency with which heat passes between solids, liquids and gasses (Bernhardt, 1959; Skelland, 1967). The greater the thermal conductivity, the larger the coefficient of heat transfer (h) in a given amount of time (Skelland, 1967). Metals are known for good to excellent thermal conductivity, and polymers are noted for relatively poor thermal conductivity (Callister, 1985; Gregory, 1971; Schey, 1987). Thus, the thermal conductivity of materials present, type of flow, amount of specific heat, type of heat transfer and some rheological constants will determine the rate of heat transfer in the plastication process (Rubin, 1972; Skelland, 1967). The rate of heat transfer is of increasing importance for heating as shear rate and friction decrease.

Thermodynamic principles are some of the major tools used to determine the speed and efficiency of the plastication process. The major drawback to using both thermodynamic and rheological models is the requirement of lengthy calculations. To some extent, the problem of calculating specific values is being addressed by new computer software, such as Moldflow ® and Extrud ® (Austin, 1982; Klein & Klein, 1988; O'Brien, 1988). These programs are capable of calculating predictive values, given a series of measured factors. By understanding the basic factors and relationships present within fluid mechanics, thermodynamics and heat transfer, a usable understanding of the factors affecting the plastication process may be gained.

Elements of Plastication Practice

There are five basic technical areas of screw plastication: (1) barrel temperature profile, (2) properties of shear, (3) screw design, (4) screw forces and (5) discharge modifiers. Each of the five technical areas relates to one or more of the principles outlined in the discussion of polymer chemistry, non-Newtonian fluid mechanics, thermodynamics and heat transfer. These scientific principles form the basis for our understanding of specific technical aspects of plastication.

Barrel Temperature Profile

The first technical aspect of plastication is the barrel temperature profile. An extruder barrel is found on all screw type extruders, injection molders and blow molders. The barrel serves as a cylindrical jacket around the extruder screw (see Figure 2). The tight fit between the screw and the barrel allows the screw to rotate and pump the molten polymer forward, without allowing much leakage of the plastics over the top of the screw flights (Levy, 1981; Rosato & Rosato, 1986; Rubin, 1972).

The barrel temperature profile is the profile of temperature settings from the throat or back to the nozzle or front of an extruder barrel (Figure 3) (Borton, 1984;

Rosato & Rosato, 1986; Rubin, 1972). Generally, the temperature of the barrel throat is set lower than the T_m of the material to prevent premature melting and blockage of the feed throat (P. N. Richardson, 1974). Blockage of the throat is generally referred to as bridging. This is a serious occurrence, since bridging of the throat prevents any further resin from passing from the hopper through the throat and into the extrusion screw (P. N. Richardson, 1974).

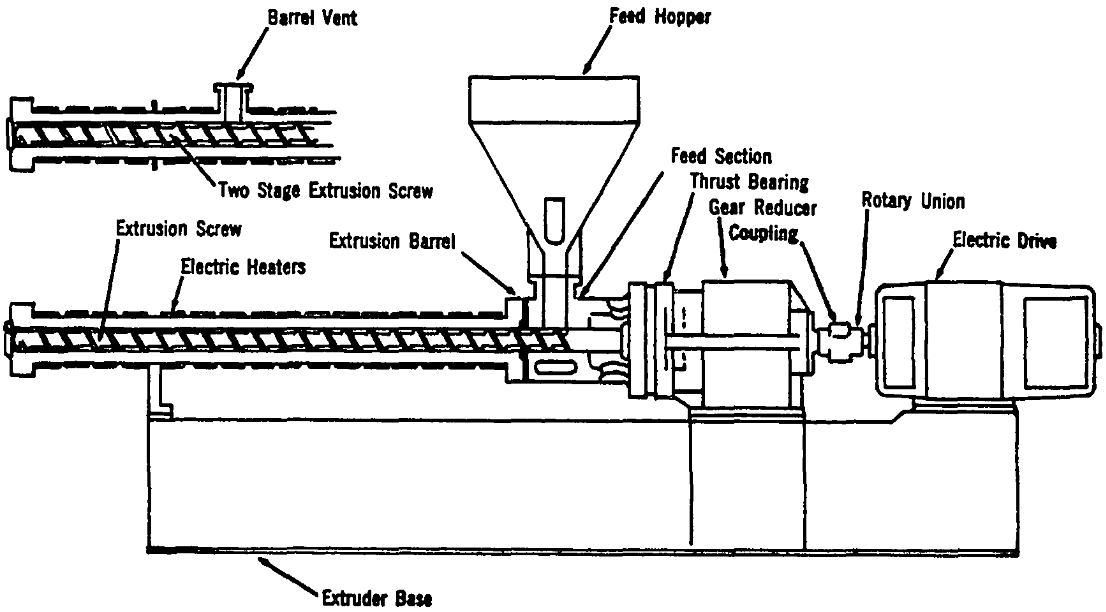


Figure 2. Cross Section of a Screw Type Extruder.

Source: Society of the Plastics Industry (SPI). (1968). Standard nomenclature for single screw extruder: Constant diameter type. Washington: Author. p. 3

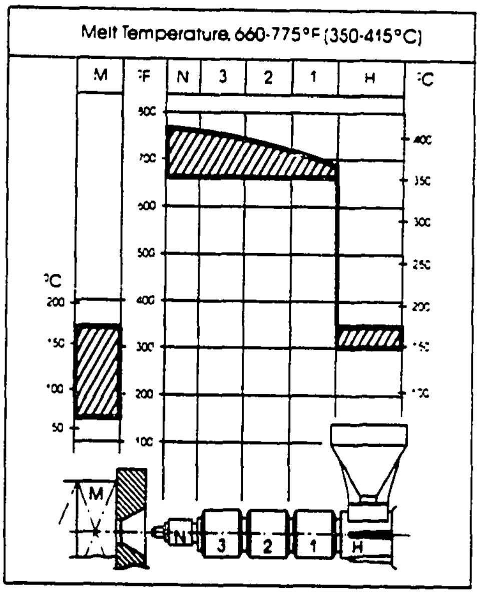


Figure 3. Temperature Profile of an Injection Molding Barrel.

Source: GE Plastics. (1986). Ultem injection molding. (Form no. ULT210). Pittsfield, MA: Author. p.7

For most resins, the barrel temperature is ramped or increased as the resin moves forward in the barrel (GE Plastics, 1986; Rosato & Rosato, 1986; Rubin, 1972; Vickers, 1987). Ramping allows the resin to achieve a desired end processing temperature at a gradual rate. In most cases, the nozzle or output temperature is higher than any of the previous temperature zones on the barrel (Ehritt, 1983). This is because most thermoplastic resins degrade at elevated processing temperatures (Rosato & Rosato, 1986; Schwartz & Goodman, 1982). Less time spent at elevated processing temperatures will lower the potential polymer degradation and thus, the polymer will exhibit less heat history (Rubin, 1972). In some instances, higher temperatures are needed earlier in plastication to drive off moisture or to enhance initial friction of the resin (Borton, 1984; Gregory, 1971).

The barrel temperature settings are achieved by the use of electric heater bands around the barrel. The temperature of the bands is set on a controller and monitored by thermocouples (Steward, 1985). Placement and depth of thermocouples is critical to insure accurate temperature measurement (Bruker, Miaw, Hasson, & Balch, 1987). The temperature of the throat is controlled by passing chilled water through a jacket around the feed throat (similar to the water jacket on an automotive engine). Cooling of the rest of the barrel may be achieved by the addition of a cooling fan jacket. In this instance, the temperature controller may activate either the heater bands or cooling fans of a particular barrel zone (Levy, 1981). In all cases, the temperature controller provides control heating/cooling to achieve the desired resin temperature. However, the majority of the resin temperature comes from the friction and shearing of the plastics (Levy, 1981; P. N. Richardson, 1974; Rosato &

Rosato, 1986; Rubin, 1972).

Properties of Shear

Shear, as discussed in the section on non-Newtonian fluid mechanics, is one of the primary elements in the melting of plastics. Shear is the sliding and tearing of polymer molecules through the application of a force. Generally, shear increases as the friction increases between moving objects. Furthermore, since friction produces heat, and heat lowers the apparent viscosity of a polymer, polymers are said to be shear thinning (Kruder, 1985). Thus, by increasing the amount of pressure on the melting polymer, the shear work can be increased and the polymer will melt faster (Levy, 1981).

Due to these changes in apparent viscosity, the shear rate is critical. By definition, as the shear rate increases, so does the melting rate. However, the relationship between shear rate and melting rate is non-linear due to the fact that polymers are non-Newtonian materials (Brydson, 1970). Another point of consideration is the maximum shear rate limit. The maximum shear rate limit is the point at which the polymer starts to degrade (Austin, 1987). Shear rate limits range from 20,000 to 100,000 reciprocal seconds, depending upon the type of polymer (Austin, 1988). In most cases only 1,000 to 3,000 reciprocal seconds are generated in commercial extruders, far below the shear rate limits (Kruder, 1985). Maximum shear rates are generally not approached or exceeded, except in very restricted areas of discharge modifiers, such as dies.

The other major component of shear is the shear stress. As noted earlier, the shear stress is approximately equal to the shear rate multiplied by the apparent viscosity (Brydson, 1970; Kruder, 1985). The shear stress is a measure of the amount of force applied to a polymer in order to cause slippage between the molecules. In order for slippage to occur, secondary atomic bonds must be broken, and heat is released as a result (Driver, 1979; Richardson, 1983). The heat released in turn causes the polymer to melt. The level of shear stress is instrumental in changing the type of mixing that will take place within a melt (Bikales, 1971).

Polymers may exhibit two types of mixing: (1) distributive and (2) dispersive. Distributive mixing increases the random distribution of polymer particles, without decreasing the ultimate size of the particles (Kruder, 1985). However, if the critical shear stress is reached, a polymer will exhibit dispersive mixing. This type of mixing reduces the ultimate size of polymer particles as well as increasing their random distribution (Kruder, 1985). At some level above the critical shear stress, the maximum shear stress limit is reached. The maximum shear stress limit ranges from 100,000 to 300,000 MPa (Austin, 1988). Above this limit primary atomic bonds are broken and the polymer is said to be over stressed (Austin, 1982). As over stressing occurs, the polymer loses many of its physical characteristics. Its strength and flexibility decrease, brittleness increases and the color of the polymer changes (Austin, 1982; Schwartz & Goodman, 1982).

Clearly, the effects of shear can be both beneficial and destructive to a polymer, dependent upon the amount and type of shear imposed. Careful control of shear through both machine design and operation is critical to the integrity of a given polymer.

Screw Design

Two major components of polymer flow are exhibited in extrusion screws: (1) drag flow and (2) back flow. In a drag flow, the change in pressure (Δ P) due to flow restriction is zero (Jacobi, 1963) (see Figure 4). This provides an unimpeded progression of resin down the screw flights. However, the other extreme of polymer flow is back flow, where the flow is completely restricted and the flow rate (Q) is equal to zero (Jacobi, 1963) (see Figure 4).

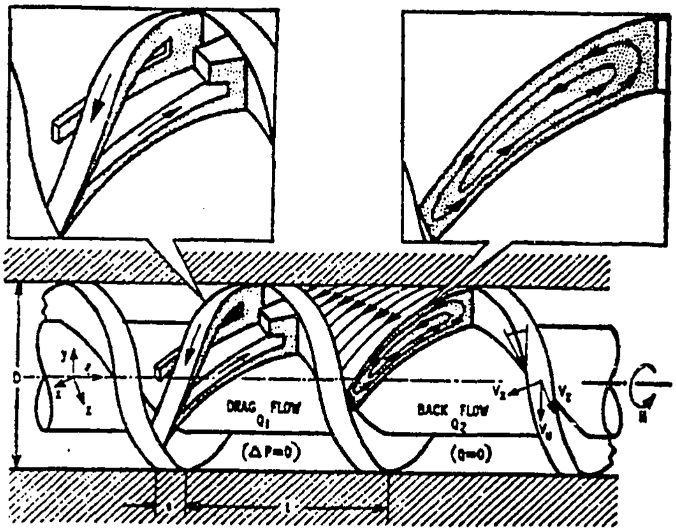


Figure 4. Flow of a Molten Polymer Along the Screw Channel Without Any Losses Due to Leakage.

Source: Jacobi, J. R. (1963). Screw extrusion of plastics: Fundamental theory. London: Iliffe. p. 7

Predictably, very few actual extrusion situations exclusively show either drag or back flow behavior. Instead, flow within an extruder screw exhibits characteristics of both types of flow with the addition of some leakage flow due to wear and increased clearance between the screw and barrel. The importance of this understanding is that the greater the component of drag flow, the higher the rate of output. Conversely, as back flow increases, the amount of mixing and shear will also increase (Bernhardt, 1959; Stevens, 1986).

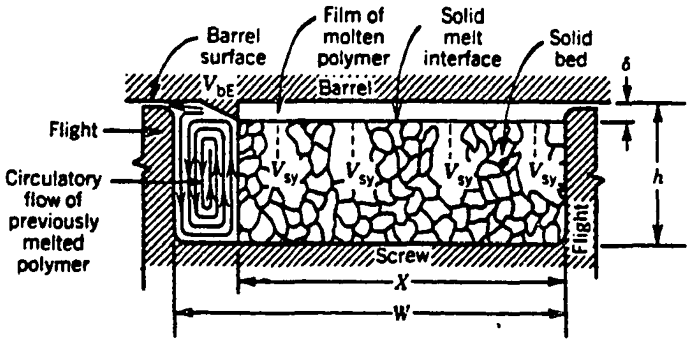


Figure 5. Model of Idealized Polymer Melting in a Screw Channel.

Source: Kruder, G. A. (1985). Extrusion. In H. F. Mark, N. M Bikales, C. G. Overberger, G. Menges, & J. I. Kroschwitz (Eds.), Encyclopedia of polymer science and engineering (Vol 6, p. 576). New York: John Wiley.

An interesting phenomenon occurs due to a resin's circulatory flow characteristics within a screw, and the fact that the resin starts as solid particles and progresses to a molten fluid. The solid bed of resin pellets is transmitted along the front of the screw channel, while the molten fluid collects and circulates at the back of the screw channel (Colby, 1985; Kruder, 1985; Tadmor & Klein, 1970) (see Figure 5). As the ratio of melt to solid increases, the solid bed breaks up and becomes mixed into the melt (Colby, 1985) (see Figure 6). So long as the solid bed stays intact, the melting rate is approximately proportional to the square root of the width of the solid bed (Kruder, 1985). When the solid bed breaks up, the rate of melting decreases. Thus, control of the solid bed becomes one of the key elements in screw design.

Figure 6. Model of Polymer Melting as the Channel Depth of a Standard Screw is Decreased for Compression.

Source: Colby, P. N. (1985). Screw and barrel technology. Youngstown, OH: Spirex. p. 17

Melting action is governed by several aspects of screw geometry (see Figure 7). First, the length to diameter ratio of the screw determines the total length of the path that the polymer will travel down the screw (Rubin, 1972). Second, there are generally three sections of a screw. The sections are named for their function. The feed section feeds resin into the screw and starts to compress the pellets (P. N. Richardson, 1974). Next, the transition section compresses and melts the resin (P. N. Richardson, 1974). Finally, the metering section stabilizes compression and meters a constant flow pressure out the discharge end of the screw (Colby, 1985).

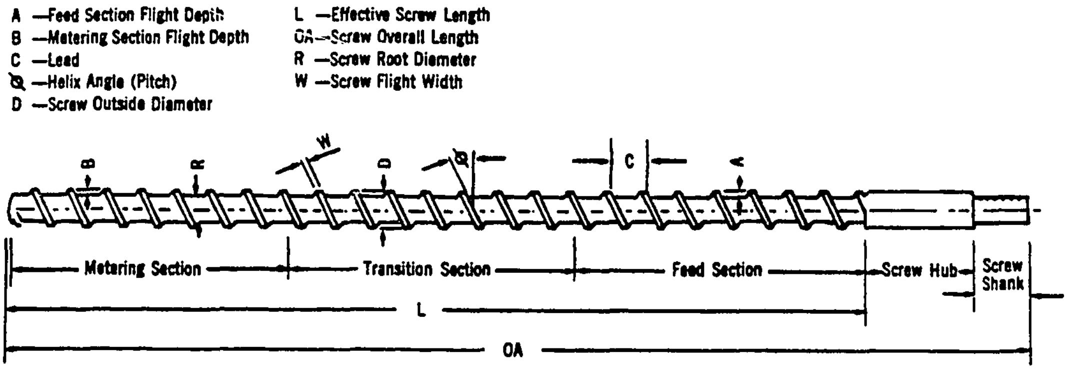


Figure 7. Nomenclature of a Standard Extrusion Screw.

Source: Society of the Plastics Industry. (1968). Standard nomenclature for single screw extruder: Constant diameter type. Washington: Author. p. 5

Compression is a result of the compression ratio between flight, or channel depth, in the feed section and the channel depth in the metering section (Lillienahl, N.D.). The larger the amount of compression, the greater the amount of friction and resulting shear (Gregory, 1971). Finally, the pitch, or helix angle of the screw flight will contribute to the rate at which the resin progresses along the screw. The larger the helix angle, the greater the potential rate of travel (Rosato & Rosato, 1986). However, the rate of travel is ultimately governed by the degree of back flow due to discharge restriction

(Tadmor & Klein, 1970).

There are two main types of screw extruders: (1) single screw and (2) twin screw. Although twin screw extruders have several advantages, they are principly limited to high volume extrusion compounding, sheet and film operations. The majority of all plastication units in the industry today consist of single screw extruders (Engelmann, In Press; T. Richardson, 1983; Schwartz & Goodman, 1982).

A number of single screw designs are currently in use and under study in the industry today. The most common type of screw design is the standard metering screw (Colby, 1985) (see Figure 8). Metering screws work well for many materials, but have several shortcomings which have prompted the four alternate groups of screw designs: (1) two-stage, (2) barrier flight, (3) melt draining and (4) mixing.

Two-stage screws are used to decompress a molten polymer, enabling moisture to escape (Lee & Biesenberger, 1987). In order to decompress the melt, the channel depth is increased after the compression section to allow gasses and water vapor to escape through a vent in the side of the barrel (Levy, 1982) (see Figure 9). Moisture is not able to escape from a polymer in a standard screw and the result is foam or bubbles in the finished product (Dow Chemical, 1979).

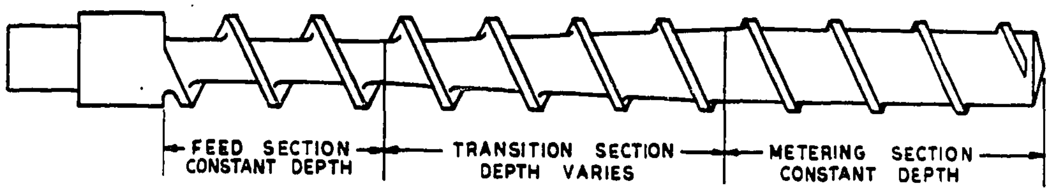


Figure 8. Profile of a Standard Metering Screw.

Source: Colby, P. N. (1985). <u>Screw and barrel technology</u>. Youngstown, OH: Spirex. p. 3

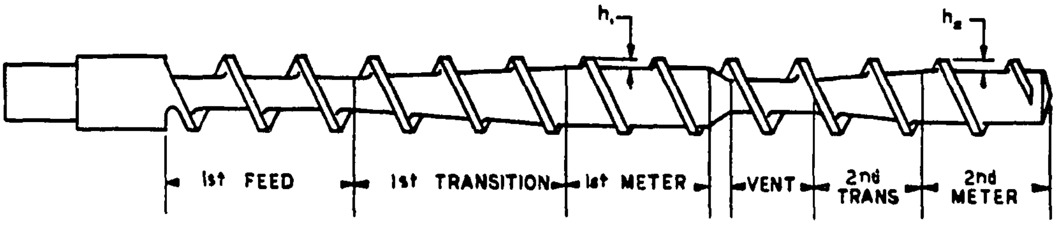


Figure 9. Profile of a 2-Stage Screw.

Source: Colby, P. N. (1985). <u>Screw and barrel technology</u>. Youngstown, OH: Spirex. p. 4

Another problem with the design of a standard screw is that the solid bed breaks up into the melt rather than melting completely (Kruder, 1985). To solve this problem, a group of barrier flight or double flight screws have been developed (Barr, 1988; Colby, 1985; Kim, 1985; Rauwendaal, 1986a; Schlack, 1985) (see Figure 10). The melt is kept separated from the solid bed by an intermediate or barrier flight. The clearance at the top of the barrier flight allows the resin melted in the solid bed to leak back over the barrier flight and flow in a separate channel (see Figure 11). The advantage of this system is that the coefficient of friction is higher in the solid bed, and thus the resin melts faster (Barr, 1988; Kruder, 1985).

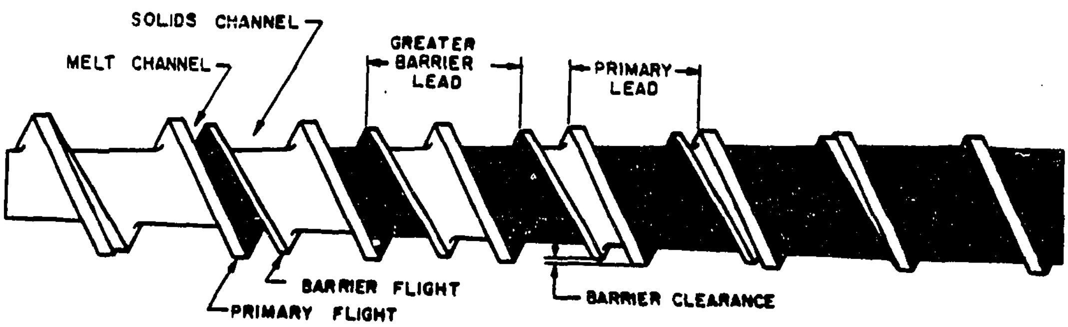


Figure 10. Profile of a Barrier Flight Screw.

Source: Colby, P. N. (1985). Screw and barrel technology. Youngstown, OH: Spirex. p. 20

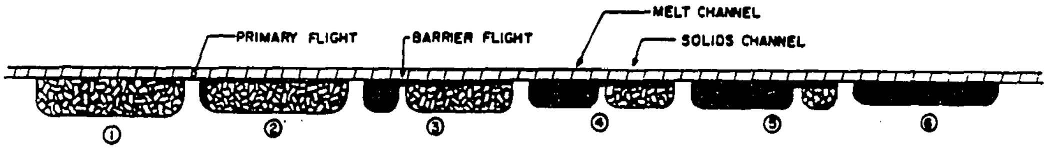


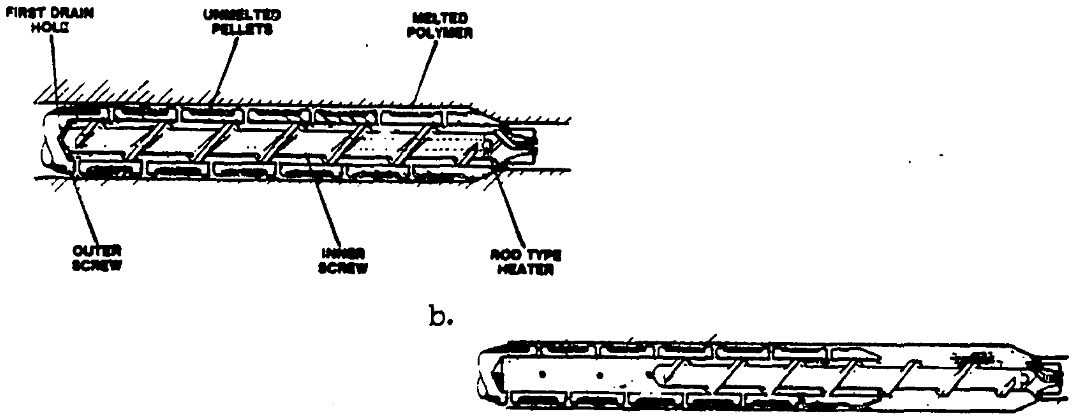
Figure 11. Model of Polymer Melting Along a Barrier Flight Screw.

Source: Colby, P. N. (1985). Screw and barrel technology. Youngstown, OH: Spirex. p. 19

An alternative to the barrier screw is the melt draining screw (Dowling, 1986) (see Figure 12). The melt draining screw drains the molten polymer through a series of holes to the inside of the screw. The molten resin is then conveyed forward by a second internal screw. In some cases, melt draining screws have greater output and better melt quality than conventional barrier screws (Dowling, 1986).

Another variation of standard screw design is the incorporation of a mixing head or mixing section (Kruder, 1985; Nunn & Rakashima, 1988) (see Figure 13). The purpose of the mixing section is to trap and smear semi-melted resin particles. The particles are thus squeezed over the pins, flights or bar, which causes them to melt due to the increased shear rate (Maddock, 1967). The squeezing may cause dispersive mixing which is required with certain polymer additives (Kruder, 1985).

a.



Legend. (a) Forward position prior to plastication,

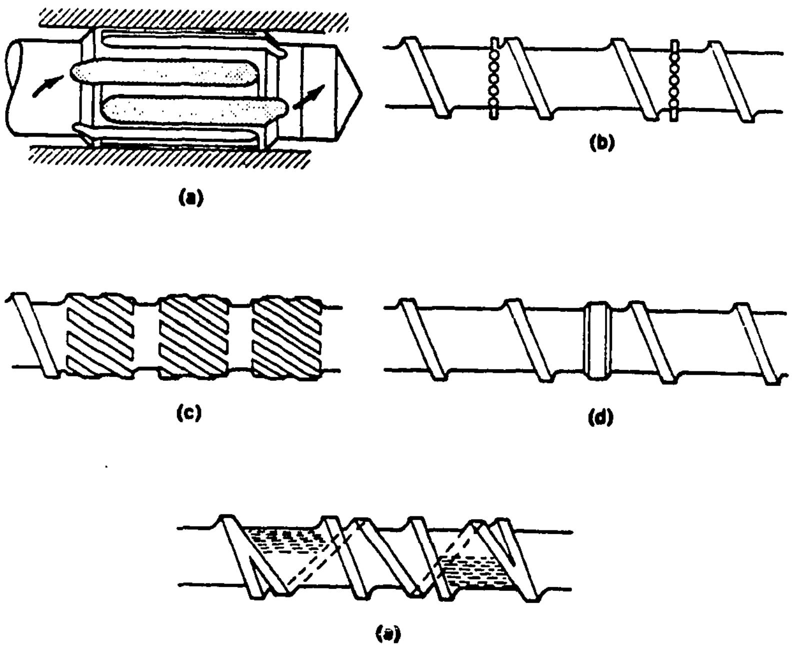
(b) Filled position following screw rotation plastication of the resin.

Figure 12. Diagram of a Melt Draining Screw.

Source: Dowling, E. H. (1986). Screw performance comparison for injection molding. ANTEC '86 Conference Proceedings for the Society of Plastics Engineers, 44, 170.

Screw Forces

Two primary forces are applied by all plasticating screws. Rotary force is applied by turning the screw; whereas, lateral force is applied through back pressure. Thus, the rate of screw rotation, or screw speed, and the amount of back pressure govern the shear rate and the shear stressing, and thus the melting of a polymer.



Legend. a = Union Carbide, b = Mixing Pins,
c = Dulmage Section, d = Ring Barrier,
e = Spiral Barrier

Figure 13. Various Screw Mixing Sections.

Source: Kruder, G. A. (1985). In H. F. Mark, N. M. Bikales, C. G. Overberger, G. Menges, & J. I. Kroschwitz (Eds.), Encyclopedia of polymer science and engineering (Vol 6, p. 587). New York: John Wiley.

Screw speed is often used to determine output rate. However, the output rate increases at a decreasing proportion as the screw speed is increased (Stevens, 1985). This phenomenon occurs for two reasons. First, at higher screw speeds shear rate increases and viscosity decreases (Kruder, 1985). As viscosity decreases, the fluid becomes more compressible and thus, output decreases per unit of work (Brydson, 1970). The second factor is that as viscosity decreases in a fluid, a greater amount of leakage flow and back flow are present (Jacobi, 1963).

Back pressure is the resistance to forward flow of a polymer down the screw flights (Whittington, 1978). This force is the amount of compression applied to the resin. Back pressure is the function of the ratio of the volume of input resin to the size of the output area (Rosato & Rosato, 1986). Therefore, a screw without restriction or discharge modifier will exhibit no compression and no back pressure (Steward & Krammer, 1988).

There are three methods of effectively increasing back pressure. First, if the channel depth is decreased after the feed section of a screw, back pressure is increased as a function of channel depth (Peischl & Bruker, 1988). Second, in the case of injection molding, the screw is permitted to reciprocate backwards in the barrel to allow resin to accumulate in front of the screw for the next shot (Rosato & Rosato, 1986; Rubin, 1972). Resin accumulates between the nozzle at the end of the barrel and the non-return valve on the end of the screw (Rosato & Rosato, 1986; Rubin, 1972). If, however, the screw is not allowed to reciprocate backwards in the barrel, resistance is applied to resin moving down the screw flights. The resistance applied is back pressure (Weir, 1975). In injection molders, this type of back pressure is produced by applying hydraulic pressure to the back of the screw (Rosato & Rosato, 1986; Rubin, 1972; Weir, 1975). The pressure prevents the screw from freely reciprocating, and thus, back pressure is applied on the plasticating resin.

The third method of applying back pressure is through the use of a restrictive discharge modifier such as a nozzle, adapter, die, screw pack or breaker plate. In all cases, these discharge modifiers restrict the flow of resin by decreasing the area of the discharge opening(s) (Levy, 1981; Michaeli, 1984; Rosato & Rosato, 1986; Rubin, 1972).

In the case of both screw design and discharge modifiers, the amount of restriction is fixed at the time the component is manufactured. In the case of hydraulically applied back pressure, the amount of pressure may be varied at any time during the process. This is also true of screw speed, since it may be changed simply by changing the setting on a variable speed control (P. N. Richardson, 1974).

Several studies have shown that back pressure has a greater effect on shear properties than screw speed (Guo &

Chung, 1988; Nelson & Lee, 1985). The reason for the effect is that back pressure adds more shear work as a result of increased friction (Levy, 1981). Furthermore, screw speed is plagued by losses in transmission of energy, as explained earlier (Jacobi, 1963). The correct amount of screw force is an especially critical issue when coupled with the fact that most back pressure in extrusion and blow molding is fixed through the use of discharge modifiers (Levy, 1981; P. N. Richardson, 1974; Schwartz & Goodman, 1982).

Discharge Modifiers

Discharge modifiers serve to conduct the flow of molten plastics from the screw tip to the mold or tooling that will form finished products. Discharge modifiers fall into several categories. These categories represent different specific functions within molding and extrusion. However, most discharge modifiers have one primary function in common. They all restrict the discharge flow to increase back pressure within the screw flights.

The first group of discharge modifiers consist of screen packs, breaker plates and choke plates. All three items may be located just ahead of the screw at the end of the barrel (Levy, 1981). In all cases, these items perform two functions. They straighten the spiral flow off the front of the screw and increase the back pressure

(Levy, 1981; P. N. Richardson, 1974). However, screen packs provide an additional function of filtering impurities in the form of small particles from the melt (Cresta Filtration Technology, 1986; Stevens, 1985; P. N. Richardson, 1974).

Screen packs frequently become clogged, and this type of blockage will provide considerable additional back pressure (Cresta Filtration Technology, 1986). The screen pack, which is supported by the breaker plate, may be changed either manually or automatically (Cresta Filtration Technology, 1986; Levy, 1981) (see Figure 14). In the case of manual changes, it is usually necessary to shut down the extruder to remove the screen pack (Cresta Filtration Technology, 1986; Levy, 1981). In such cases, the plastics inside the extruder are subject to much greater resonance time in the barrel, and the amount of heat transfer is greatly increased (Gregory, 1971). Since heat transfer is increased, so too is the temperature of the resin (Stevens, 1985). Thus, a manual screen change may cause great fluctuations in the thermal characteristics of the extruded polymer.

Unlike screen packs, breaker plates do little filtering, and choke plates do not filter at all. A major function of a breaker plate is to break up and straighten the flow (Levy, 1981). By breaking up the flow into many smaller flows, the spiral flow pattern of the screw is turned into straight line or laminar flow as it enters the adapter plate (Levy, 1981; Luker, 1985) (see Figure 14). A choke plate, on the other hand, mainly adds back pressure and has a less pronounced effect on reducing spiral flow (Levy, 1981).

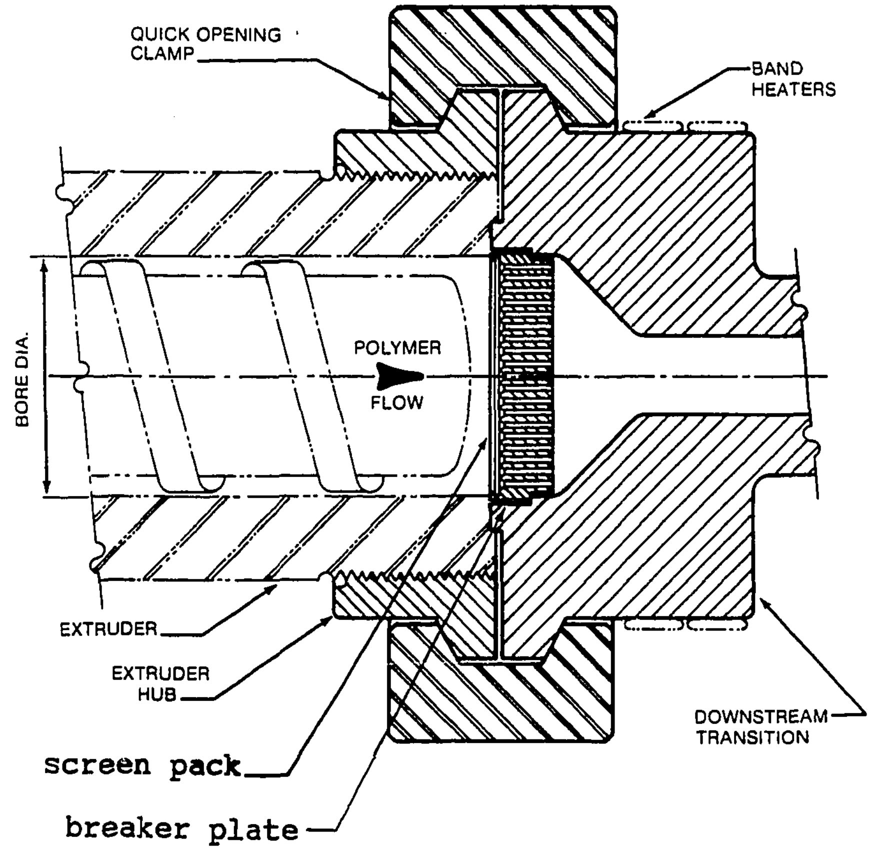


Figure 14. Cross Section of the Front of an Extruder Barrel Showing the Screen Pack and Breaker Plate.

Source: Gala Industries. (N.D.) <u>Quick opening clamp and optional screen pack</u> (Bulletin QOC-2). Eagle Rock, VA: Author. p. 3

The second group of discharge modifiers includes adapter plates and dies. Adapter plates are used to channel the melt from the front of the screw to the die. Adapter plates usually have a fairly steep transition from the inside diameter of the barrel to the inside diameter at the back of the die (Levy, 1981; Michaeli, 1984) (see Figure 14). This transition serves to convey the resin at a uniform pressure profile into the die (Michaeli, 1984). The die further restricts flow through a transition from the inside diameter of the discharge end of the adapter plate to the unique geometry at the discharge end of the die (Luker, 1985). This transition is absolutely critical in order to establish enough back pressure, ensure uniform exit velocity from the die and achieve the desired profile of the extruded part (Luker, 1985). Dies are found in all extrusion operations as well as in extrusion blow molding (Engelmann, In Press).

The final group of discharge modifiers are found exclusively in injection molding and injection blow molding operations. These modifiers include both nozzles and non-return valves. In the case of non-return valves restriction is not always present, whereas nozzles serve the same purpose as adapter plates.

Non-return valves are attached to the discharge end of a screw in injection molding operations. It is the function of the non-return valve to close during forward reciprocation of the screw (Rosato & Rosato, 1986; Weir, 1975). By closing the valve, the screw becomes a piston or ram as it moves forward down the barrel (Engelmann, In Press; Rubin, 1972). The resin is then forced out of the barrel through the nozzle and into the mold (Rosato & Rosato, 1986; Schwartz & Goodman, 1982; Weir, 1975).

Nozzles serve to channel the melt from in front of the screw to the mold where finished parts are produced. Like an adapter plate, the nozzle is characterized by a transition from the inside diameter of the barrel to the orifice diameter of the sprue bushing in the mold (Rubin, 1972).

Nozzles may be divided into several groups: (a) standard nozzles, (b) cut-off and shut-off nozzles and (c) reverse taper or nylon nozzles. A standard nozzle has an open orifice and allows some leakage or drool (Dym, 1987; Rosato & Rosato, 1986; Rubin, 1972) (see Figure 15). Cut-off and shut-off nozzles close internally once an injection is complete to prevent leakage when the mold is opened (Dym, 1987; Rosato & Rosato, 1986; Rubin, 1972). Finally, reverse taper or nylon nozzles first compress the resin with a transition similar to that of a standard nozzle. Then the polymer is decompressed through the use of a reverse taper at the nozzle's discharge orifice (Rubin, 1972). Decompression is desireable with polymers like nylon that achieve very low viscosities and are thus subject to high exit velocities (Rubin, 1972).

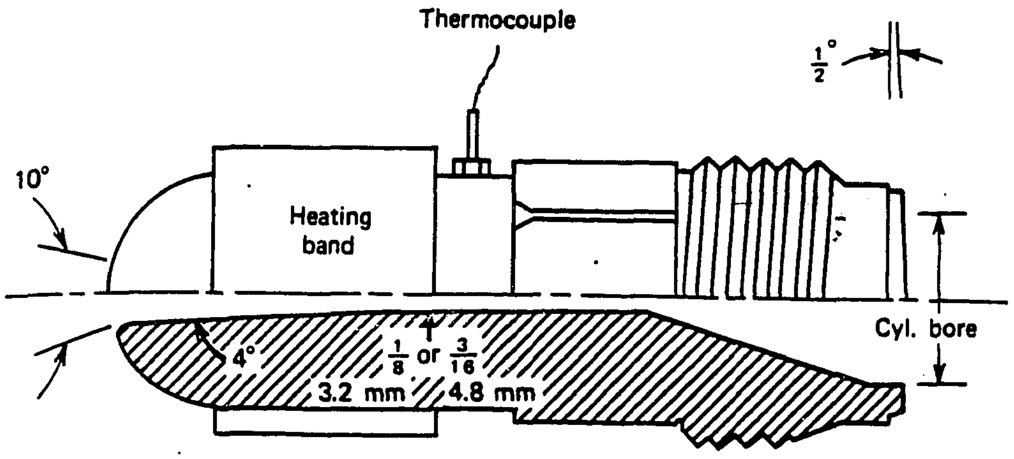


Figure 15. Cross Section of a Nylon Nozzle.

Source: Rubin, I. I. (1972). Injection molding theory and practice. New York: John Wiley. p. 23

Plastics Education

The first plastics education on record was conducted in 1906 at North Dakota State University with a course in paint technology (Carraher, 1985). From that date forward, plastics education has taken an increasingly large and diverse role in post-secondary education (Carraher, 1985; Deanin & Nascimento, 1986).

It was estimated in 1974 that approximately 136,000 college graduates were doing technical work in the plastics industry (Deanin, 1974). At that time it was estimated that less than 1% had completed any coursework in plastics (Deanin, 1974). The number of college graduates working in the plastics industry has risen since 1974 (Carraher, 1985). However, the ratio of coursework to students is still quite low (Carraher, 1985). Historically, activity in plastics education has fallen into three curricular categories: (1) chemistry, (2) engineering and (3) technology.

Curricula in chemistry and related fields include: (a) chemistry, (b) chemical engineering and (c) polymer science (Carraher, 1985; Deanin & Martin, 1981b; Winding & Brodski, 1968). As early as 1951 graduate courses of study in chemical engineering included courses devoted to polymeric materials (Winding, 1957). At that time 31 universities were offering between 1 and 20 credit hours of polymer coursework (Winding, 1957). By 1960, some schools were even offering coursework in rheology (Winding, 1960). The 1960s saw substantial growth in the area of rheology coursework. Over 40 schools became actively involved in both classes and research involved with polymer rheology (Winding & Brodski, 1968). However, specific application of rheology to processing was still quite limited.

Engineering coursework includes programs in mechanical engineering and materials science engineering. No significant activity was reported in this area until 1956 (Winding, 1957). At that time, some elective courses were offered at the graduate level with almost no undergraduate coursework (Winding, 1957). Concern has been expressed that even as late as 1970, polymers were not being introduced into mechanical engineering coursework (Marovitz, 1971). Furthermore, mechanical engineering coursework in polymers has not been as carefully tracked as the coursework in polymer and materials science engineering. However, the role of polymer and materials science engineering has been well documented since about 1960 (Deanin & Martin, 1981b; Winding, 1960; Winding & Brodski, 1968; Winding & Wald, 1964). This area has sustained steady growth through the last three decades (Winding, 1960; Deanin, 1988). In 1987, approximately one third of the degree programs in plastics/polymers were programs in materials/polymer science and engineering (Deanin, 1988).

The third area of polymer coursework involves those programs with classes in plastics technology. Plastics technology courses may be found in engineering technology, industrial technology, industrial arts and education programs (Deanin, 1988). The first record of plastics technology coursework was in the 1960 SPE survey of polymer courses (Winding, 1960). Since that time, the number of technology degree programs has increased to over 30 (Deanin, 1988; Engelmann, 1986).

Two areas of technical education which are very poorly documented are industrial training and vocational programs. There is some mention of specific examples of programs across the U.S., but little data on the number of programs, courses or enrollment (Lavin, 1986; Paulson, 1986; Deanin, 1988). The impact of these programs should be felt where skilled hourly workers are needed in the plastics industry (Lavin, 1986; Paulson, 1986).

Of major interest to this study is the role of processing coursework in polymer/plastics education. The number of degree programs at all levels with coursework in plastics processing has risen from one or two in 1957 to 66 in 1988 (Winding, 1960; Deanin, 1988). In addition, processing coursework is more common in plastics engineering, engineering technology and technology programs than in polymer science and chemical engineering programs (Deanin, 1974, 1988). Furthermore, many processing courses include discussion of screw plastication as a portion of both laboratory and lecture material (Deanin, 1988; Deanin & Martin, 1981). However, at this time the exact number of students involved in plastication coursework is not known. The best and most recent study failed to include a number of schools with plastics coursework, including Kalamazoo Valley Community College and Western Michigan University (Deanin, 1988). The omission of over 20 other schools surveyed in 1986 makes the 1988 findings seem conservative (Engelmann, 1986). Thus, it may be concluded that between 70 and 90 schools are presently offering plastics processing coursework (Deanin, 1988; Engelmann, 1986).

The total number of degree programs has increased about 34% between 1980 and 1987, to about 160 programs (Deanin, 1981, 1988; Engelmann, 1986). In that same time frame, credit hours of processing coursework increased 44% (Deanin, 1981, 1988). Thus, about one half of all the plastics programs in the U.S. are currently offering plastics processing coursework (Deanin, 1988; Engelmann, 1986). Furthermore, it is reasonable to assert that the majority of these schools are teaching coursework in plastication (Deanin, 1988; Engelmann, 1986). The rapid increase in processing coursework provides the basis for questioning the relative importance of plastication to the personnel in the thermoplastic processing industry. Without industrial feedback, technical and engineering education may or may not produce graduates with the correct knowledge base (Wood & Davis, 1978).

CHAPTER III

DESIGN AND METHODOLOGY

Sample Population

The population under study consisted of personnel in engineering, set-up, design, supervision and management involved in extrusion, injection molding and blow molding within the state of Michigan. A stratified random sample was drawn from the Society of Plastics Engineers (SPE) members involved in the aforementioned three processing areas.

Roles of the SPE and the SPI

By its nature, the SPE attracts members which represent a cross section, of both the job classifications and processing types requisite in this study. Michigan, on the whole, represents about 10.1% of the total SPE International membership (Bristol, 1988). According to the international office of the SPE, society membership reached 28,984 in June of 1988 (J. Toner, personal communication, July 27, 1988). This represents just under one third of all of the people eligible for membership in the U.S. The SPE estimates that between 90,000 and 100,000 people in the U.S. currently hold positions that make them eligible for membership in the society.

The SPE is one of two major organizations in the plastics industry. The second organization is the Society of the Plastics Industry (SPI). Membership in the SPI is not open to individuals. SPI membership is by company only, and dues are assessed by gross annual corporate dollar volume. Thus, if a company attains SPI membership, all of the employees in the company are served by the society. The function of the SPI is to research and promote products of the plastics industry. Thus, the SPI has been extensively involved in work to improve product reliability in areas such as flammability (Warren, 1988). The SPI has also served as lobbyist for the plastics industry over the past 50 years (Leaversuch, 1987a).

The role of the SPE is quite different from that of the SPI. The stated objective of the SPE is to "promote scientific and engineering knowledge related to plastics" (Constitution, 1983, p. 1). This makes the SPE the logical choice to use when gathering information about the level of current understanding of plastication by skilled and professional personnel within the plastics industry. In fact, the membership of the SPE should afford a conservative read-out of knowledge gaps present in the industry. This is due to the additional technical information provided to SPE members. For this reason, any knowledge gaps found by this study should be and probably are, of a greater magnitude than indicated by the data.

Demographics of the Great Lakes Area

The East North Central or Great Lakes states of Illinois, Indiana, Michigan, Ohio, and Wisconsin comprise 29% of the injection molding plants, 24% of the extrusion plants, and 22% of the blow molding plants in the U.S. (Brockschmidt, 1986; Kreisher, 1986; Naitove, 1986b). This distribution represents only a 1% decline for injection molding and stable performance for extrusion over the past decade (Kreisher, 1986; Naitove, 1986b). Furthermore, "in the mid-1980s alone, Michigan accounted for half of all new plastics-related jobs in the Great Lakes States and one quarter of plastics job growth nationally" (Ross, 1988, p. 10). In addition, the average hourly machine rate for the Great Lakes states is about 5% below the national average of $49.02 per hour, making the Great Lakes the closest region to the national average (Custom, 1988). The Southeast region is least expensive at 15% below the national average, and the Western states are most expensive at 22% above the national average (Custom, 1988).

The following conclusions were drawn about the Great Lakes states after the 1986 census of molding and extrusion. It was noted that in spite of the slight loss of growth in injection molding in the Great Lakes, the region still is over twice as active as the Southeast and Sunbelt combined (Naitove, 1986b). Furthermore, "The Great Lakes region remains extrusion's center of gravity with little change overall (from 1980)" (Kreisher, 1986, p. 97). In addition, the Great Lakes were heralded as "the single largest concentration of blow molding plants" in the nation (Brockschmidt, 1986, p. 79). Thus, the Great Lakes region comprises the center of the molding and extrusion industry, both in terms of capacity and cost of production. Michigan is thus a logical representative sampling area for the study of the molding and extrusion industry.

Make-Up of the Sample Group

A stratified random sample was selected, because the three processing types account for 33% of Michigan SPE Divisional membership, with injection molding accounting for about 26%, extrusion at 4%, and blow molding at 3%. These numbers reflect those SPE members affiliated with either the Detroit, Mid-Michigan or Western Michigan Sections and showing a primary affiliation with injection molding, extrusion, or blow molding divisions (Bristol, 1988). Sectional membership is determined by the geographic area in which a member resides. Divisional membership is chosen by each member based upon the type of process or products with which the individual works. By using a stratified random sample, enough blow molders and extruders will be surveyed to minimize the effects of radically different sample sizes of the three groups. In addition, this will ensure large enough samples of extruders and blow molders to minimize the problems associated with small sample sizes.

Three groups were surveyed. Sixty individuals were selected from each of the three processing areas: 1) injection molders, 2) extruders and 3) blow molders. The number of 60 individuals was selected, because 60 is the highest multiple of ten that may be drawn equally from all three target populations in the Michigan sections of the SPE. Blow molding, where divisional membership has fluctuated between 67 and 81 people, is the smallest of the three groups.

Research Design and Procedures

A custom instrument was designed, and a pilot study was conducted to establish instrument validity and reliability. First, a pilot study was run with members of the SPE Western Michigan Section Board of Directors, which from this point forward will be referred to as "the industrial pilot group." At the time of nomination for board membership candidates are screened to ensure diversity of both job position and process area. Thus, this group provided wide ranging feedback about potential problems with the sampling instrument and procedures.

The instrument consisted of content items, which correspond to the five areas outlined in the operational definitions of knowledge of screw plastication in Chapter One. These areas have been selected because they are the well accepted and documented framework of plastication (Crawford, 1987; Levy, 1981; P. N. Richardson, 1974; Rosato & Rosato, 1986; Rubin, 1972; Schwartz & Goodman, 1982). The participants were asked to respond to three basic questions: How much do you know about this area of screw plastication? How important is this information to you? Will you seek additional information in this area? (see Appendix B).

Each of the responses were made on a Likert scale (see Appendix B). The Likert scale was selected to measure the responses for several reasons. Primarily, the scale provides a range large enough to accommodate respondent opinion differences without causing a forced decision between two responses.

The instrument was administered twice to the industrial pilot group, first as a group and second by mail. This procedure established the degree of consistency in responses. Following collection of the data from the pilot study, an item analysis was run to establish item reliability. In addition, the participants in the pilot study were asked to respond to several questions in a standardized, free response phone interview (R. A. Richardson, Dohrenwend & Klein, 1965) (see Appendix C). The clarity of items and directions were explored to further enhance reliability. Secondly, the breadth and comprehensiveness of the question content were addressed. The aim of this line of questioning was to uncover any content gaps which might bias the results of the survey, and thus jeopardize measurement validity (Isaac & Michael, 1981). Following a summary of the responses to the phone interviews, the survey instrument was modified where required (Patton, 1980).

In addition to the industrial pilot group of SPE members, a second pilot group consisting of engineering and technology students in a non-plastics area was given the instrument to provide base line data. This group of students was selected because of their ability to understand technical concepts. Engineering Graphics (ET-142) is the only technical course required for virtually all of the engineering, engineering technology and management curricula in the College of Engineering and Applied Sciences at Western. This group of degree programs is representative of the job classifications present in the study. Responses of this group were compared with the industrial pilot group to establish item validity. The industrial pilot group would be expected to score higher on the instrument than the base line pilot group, if the survey items are valid.

After the questions were revised as necessary, the survey instrument was printed on high quality paper to improve the initial response rate from the sample groups. A cover letter conveying SPE sponsorship and the economic benefit of the results of this research was also used to increase initial response rate (see Appendix D). In addition, $1.00 was included with each cover letter, both as a token of appreciation for participating in the study and to increase the rate of response. The cover letters, $1.00, stamped return envelopes, and instruments were mailed in mid summer. A follow-up letter was sent to all participants two weeks later. The follow-up letter both thanked the participants for their help and made positive statements about the response rate (see Appendix E). Included with the follow-up letter was a duplicate survey and second stamped return envelope for all those who had not yet responded.

The external validity of the data is enhanced by several factors. The fact that the state of Michigan is strategically located in one of the major areas for thermoplastics processing is of key importance (Brockschmidt, 1986; Kreshler, 1986; Naitove, 1986). This circumstance of geography makes the data from this study applicable to the U.S. plastics industry. Furthermore, the processing population of Michigan spans industries of molding firms. Surveying this population should take into account differences due to plant size. In addition, the sample group represents the cross section of skilled blue collar and white collar professionals, which should measure and account for differences due to job classification.

This study has several potentially limiting factors. First, since the instrument relies on self reported data, there is always the chance that some participants may provide inaccurate responses. Furthermore, since the number of subjects is only 60 per group, and each group will be divided up by job classification, there is the potential for low cell numbers and sampling errors associated with small sample sizes. A potential solution for the problem of low cell numbers is outlined in the section on data analysis in this chapter. Finally, this study does not specifically measure differences in working knowledge dependent upon plant size. Basic data collected in this study may provide a platform for future investigation of differences in personal knowledge due to plant size. However, an investigation of these differences seems unwarranted at this time.

Data Analysis

The objectives of this study are to investigate both knowledge and value differences between job classifications within thermoplastics processing, and knowledge and value differences between differing processing methods. For this reason, a phased data analysis has been selected to alleviate potential problems with low cell numbers. First, sixteen one-way analyses of variance (ANOVA) were run between injection molding, extrusion, and blow molding and the five areas of screw plastication. The first group of one-way ANOVAs measured differences in five areas of knowledge of plastication as described in Chapter One. The second group of one-way ANOVAs measured differences in attitude about plastication knowledge. The third group of one-way ANOVAs measured desire to pursue additional knowledge in these areas. Since the data relied on isolating differences between processing types, a number of subjects were eliminated from the analysis. First, all subjects responding that they were not involved in processing, or involved in some other process, were removed from the sample group. Second, all subjects who listed a given process as a primary SPE division, but marked a different type of processing on the survey were removed from the sample group. Their removal was based on the probability that they were involved in more than one process and would thus give a compromised response between two of the processes listed. In order for the data to be accurate, each response needed to reflect information about a single discrete process.

An alpha level of .05 was chosen, because the consequences of committing a Type I error are approximately as detrimental as committing a Type II error. If a Type I error was committed, it would have been the assumption that either there is no difference between process types or between job classification. However, if a Type II error was committed, then it would have been assumed that some area of plastication knowledge is deficient, when in fact it was not. In either case, a misallocation of training and educational resources could result. Thus, an alpha of .05 provides equal protection from making Type I and Type II errors.

Furthermore, each of the questions was analyzed for the differences among the job titles with regard to plastication knowledge. For this reason, sixteen successive one-way ANOVAs were run, one analysis for each question concerning knowledge, attitude and desire for continuing education. For this analysis all 135 respondents were used, since working with more than one process would not affect a person's job classification. Cell sizes were judged to be too small to run reliable two-way ANOVAs simultaneously taking into account both job title and processing type. This decision is due to underlying assumptions about uniform sample size and normality which would have been jeopardized. Furthermore, since the successive one-way ANOVAs showed no significant differences at an alpha level of .05 in 15 of the 16 question areas, the two-way ANOVAs were deemed unwarranted.

Finally, the data were analyzed on the basis of blue collar vs. white collar views. For this purpose, set-up, trouble shooting, foremen and supervisory personnel were grouped together as a blue collar composite. Engineering and management personnel were grouped together as a white collar (production) composite. Finally, those in sales, finance, marketing, technical support, research and development were grouped as a white collar (support services) composite. The blue collar and white collar groups were then compared. Sixteen successive one-way ANOVAs were run, one for each question concerning knowledge, attitude, and desire for continuing education.

Underlying assumptions of the statistical procedures were met in the following ways. Observations were made from independent random samples, which is requisite for ANOVAs. Measurement of the dependent variable was made on an interval Likert scale. The samples selected were from large enough groups to approximate normal distributions.

CHAPTER IV

DATA & FINDINGS

Pilot Study

The pilot study was administered in four phases: (1) base line data gathering, (2) initial data gathering with the industrial group, (3) follow-up data gathering with the industrial group and (4) follow-up interviews with the industrial group. Protection of human subjects forms were filed and approved prior to data collection (see Appendix F).

Base Line Data

Base line data on the survey instrument were gathered from a group of potential plastics industry employees. This group consisted of the 14 members of the ET-142 Engineering Graphics class present on June 14, 1988.

Questions 3 through 17 on the survey gathered specific information in three areas: (1) knowledge of the subject, (2) perceived importance of the knowledge and (3) likelihood of seeking additional information (see Appendix B). Questions 3 through 17 were ranked on a 5 point Likert scale. All data for the three pilot studies may be found in Appendix G. Mean scores for the five questions dealing with knowledge of the subject area had a range of $\bar{x}$ = 1.143 to 1.500 with a standard deviation range of s = .363 to 1.092. The range of mean scores for the five questions about perceived importance was $\bar{x}$ = 1.500 to 1.929 with a standard deviation of s = .941 to 1.439. Finally, mean scores for those five questions dealing with the likelihood of seeking additional information had a range of $\bar{x}$ = 1.929 to 2.071 with a standard deviation range of s = 1.385 to 1.542. The range of the standard error of the mean for all cases was .097 to .412.

Industrial Pilot Data

The industrial group was made up of nine board members from the Western Michigan Section of the SPE. The survey was first administered on May 24, 1988. The range of mean scores for the questions dealing with knowledge of the subject was $\bar{x}$ = 3.00 to 4.00 with standard deviations ranging from s = .50 to 1.00. For those questions dealing with perceived importance of the knowledge, means ranged from $\bar{x}$ = 3.444 to 4.000 with standard deviations ranging from s = .866 to 1.424. Finally, means for the likelihood of seeking additional information ranged from $\bar{x}$ = 3.333 to 3.777 with a range of standard deviations of s = .866 to 1.201. Furthermore, the standard error of the mean for all 15 questions ranged from .167 to .475.

In mid-June the survey was re-administered to the

In mid-June the survey was re-administered to the industrial pilot group in order to correlate results on specific questions. Pearson Product Moment correlation coefficients ranged from r = .739 to .943 with one exception. The exception was Section IV, question number five with a correlation of r = .555. The result was puzzling, because the mean scores between the two administrations of the survey for this question were only separated by .222. Upon scrutiny of the raw data, it was noted that six respondents had given the same response each time. However, one person had radically changed his response. Upon interviewing the respondent, it was learned that his desire for knowledge about discharge modifiers significantly increased, following a problem at the place of employment. The problem had occurred just prior to the second administration of the instrument.

Thus, it may be concluded from the correlation data, that the wording of the questions was neither ambiguous, nor did it produce random answers.

Comparison of the Pilot Data

As expected, the industrial pilot group scored much higher in all question areas than the base line pilot group. The average difference between the mean responses for the industrial pilot group and mean responses for the base line pilot group was 2.02 on a five point scale.

Furthermore, the average standard error of the means for the industrial pilot group was .315 and for the base line group was .293.

Due to the wide separation of means, coupled with the relatively small standard error of the means, the following conclusion may be drawn. There is a real difference between the industrial and base line pilot groups both in knowledge level and attitude about the five elements of screw plastication. Furthermore, it may be concluded that information measured by the survey instrument is not universal between technical disciplines and is of greater interest and importance to those involved in plastics.

Industrial Pilot Group Follow-Up Interviews

Included with the second mailing of the instrument were copies of the proposed initial and follow-up letters to be used during the next phase of data gathering. Each participant was instructed to review the letters and survey prior to the interview. Following the second administration of the survey instrument to the industrial pilot group, a phone interview was conducted with all industrial participants. On July 11, 1988 all members of the industrial pilot group were called and asked ten interview questions (see Appendix C).

between five and ten minutes to complete. Second, the instrument was judged to be complete in terms of its content. However, the section dealing with importance was judged to cause some confusion. Participants asked the question, "Important in what context--my job specifically, or my effect on those whom I supervise?" An additional question about the importance of plastication to a person's job position was proposed by the group and appears as Section III of the final survey instrument (see Appendix H).

The group consensus was that including the $1.00 as a token of appreciation, would provide the necessary incentive to fill out the survey. Some minor changes were suggested for both letters. Although the content of the letters was considered to be both complete and appropriate by the group, several group members said they had never received a follow-up letter before to any survey they had responded to. They stated that the follow-up letter increased the professionalism of the study as far as they were concerned. The only major concern expressed by about half the group was the apprehension about achieving more than 50% participation.

Administration of the Data Collection

A stratified random sample was selected, as discussed in Chapter III. Following selection of the sample group, data collection was undertaken.

The survey instrument, cover letter, stamped self addressed return envelope and $1.00 were mailed to each member of the sample group from Western Michigan University on July 15, 1988. Approximately 42% of the surveys were returned in the first week following the survey mailing. An additional 16% of the surveys were received in the second week.

On July 29, 1988 follow-up letters were mailed to all members of the sample group. In addition, surveys and return envelopes were sent to those 79 individuals who had not responded by Thursday, July 28, 1988. An additional 10% of the entire group responded in the week after the follow-up letter. Furthermore, a 4% return was received in the second week following the letter. Finally, an additional 3% of the surveys were returned in the last two weeks of August. A total of 135 of the 180 members of the sample group responded between July 19, 1988 and August 25, 1988. These replies brought the final return rate to a respectable 75%. On September 19, 1988 the 136th survey arrived from Calenzano, Italy. Since the respondent was apparently no longer working in Michigan, the data were not used in the analyses.

Analysis of the Data by Process

For the remainder of this chapter all statistical values judged to show real differences between groups at the stated alpha level will be reported in the following manner: The type of statistic (degrees of freedom) = value of the statistic, probability, or alpha level.

The level of plastication knowledge between the differing processing types was basically uniform on four out of the five questions (see Table 1). The exception to this was knowledge about the effects of screw design on product quality. In this case, blow molders showed a higher level of expertise in screw design ($\bar{x}$ = 3.556) than injection molders ($\bar{x}$ = 1.095), $F(116) = 2.680$, $p < .05$.

Analysis of the degree to which a person's job relied on screw plastication knowledge did not show any difference at an alpha level of .05. The responses from blow molders, injection molders and extruders were quite close, and the means were separated by only .361 (see Table 2).

Analysis of the importance of screw plastication knowledge to each process revealed several interesting points. The responses taken together showed uniform importance placed on the five aspects of plastication knowledge ranging from ($\bar{x}$ = 3.299 to $\bar{x}$ = 3.385) (see Table 3). However, the blow molders uniformly afforded greater importance to screw plastication

Table 1

Successive One Way ANOVAs of
Screw Plastication Knowledge
by Processing Type

Knowledge Area	Processing Type			
	Blow Molding	Extrusion	Injection Molding	Row Total
Barrel Temp. Profile	$\bar{x}$ = 3.806 s = .980 n = 36	$\bar{x}$ = 3.486 s = 1.246 n = 35	$\bar{x}$ = 3.435 s = 1.167 n = 46	$\bar{x}$ = 3.564 s = 1.140 n = 117
Properties of Shear	$\bar{x}$ = 3.334 s = 1.171 n = 36	$\bar{x}$ = 3.028 s = 1.404 n = 35	$\bar{x}$ = 3.000 s = 1.211 n = 46	$\bar{x}$ = 3.111 s = 1.258 n = 117
Screw Design	$\bar{x}$ = 3.556 s = .969 n = 36	$\bar{x}$ = 3.371 s = 1.262 n = 35	$\bar{x}$ = 3.000 s = 1.095 n = 46	$\bar{x}$ = 3.282 s = 1.128 n = 117
Screw Forces	$\bar{x}$ = 3.667 s = 1.195 n = 36	$\bar{x}$ = 3.314 s = 1.278 n = 35	$\bar{x}$ = 3.630 s = 1.000 n = 46	$\bar{x}$ = 3.547 s = 1.148 n = 117
Discharge Modifiers	$\bar{x}$ = 3.472 s = 1.108 n = 36	$\bar{x}$ = 3.543 s = 1.172 n = 35	$\bar{x}$ = 3.348 s = 1.100 n = 46	$\bar{x}$ = 3.444 s = 1.118 n = 117

Table 2

One-Way ANOVA of the Dependence of a Person's Job on Screw Plastication Knowledge by Processing Type

	Processing Type			
	Blow Molding	Extrusion	Injection Molding	Row Total
Dependence on Plastication Knowledge	$\bar{x}$ = 3.000	$\bar{x}$ = 3.143	$\bar{x}$ = 2.782	$\bar{x}$ = 2.957
	s = 1.373	s = 1.574	s = 1.397	s = 1.440
	n = 36	n = 35	n = 46	n = 117

knowledge than the injection molders (see Table 3). In fact, in two cases the difference between blow molders and injection molders was found to be significant at the stated alpha level. In the case of barrel temperature profile, blow molders showed a mean for importance of ($\bar{x}$ = 3.722), whereas injection molders only rated importance at ($\bar{x}$ = 3.087), $F(116) = 2.485$, $p < .05$. Furthermore, blow molders rated the importance of screw design higher at ($\bar{x}$ = 3.611) than injection molders at only ($\bar{x}$ = 2.957), $F(116) = 2.9437$, $p < .05$.

The largest area of disagreement about screw plastication knowledge was in the area of desire to gain additional knowledge. Once again, taken together,

Table 3

Successive One-Way ANOVAs of the Importance of Screw Plastication Knowledge by Processing Type

Knowledge Area	Processing Type			
	Blow Molding	Extrusion	Injection Molding	Row Total
Barrel Temp. Profile	$\bar{x}$ = 3.722	$\bar{x}$ = 3.314	$\bar{x}$ = 3.087	$\bar{x}$ = 3.350
	s = 1.233	s = 1.301	s = 1.313	s = 1.350
	n = 36	n = 35	n = 46	n = 117
Properties of Shear	$\bar{x}$ = 3.533	$\bar{x}$ = 3.343	$\bar{x}$ = 3.045	$\bar{x}$ = 3.299
	s = 1.131	s = 1.413	s = 1.316	s = 1.302
	n = 36	n = 35	n = 46	n = 117
Screw Design	$\bar{x}$ = 3.611	$\bar{x}$ = 3.457	$\bar{x}$ = 2.957	$\bar{x}$ = 3.308
	s = 1.179	s = 1.314	s = 1.349	s = 1.310
	n = 36	n = 35	n = 46	n = 117
Screw Forces	$\bar{x}$ = 3.639	$\bar{x}$ = 3.257	$\bar{x}$ = 3.261	$\bar{x}$ = 3.376
	s = 1.175	s = 1.421	s = 1.340	s = 1.318
	n = 36	n = 35	n = 46	n = 117
Discharge Modifiers	$\bar{x}$ = 3.528	$\bar{x}$ = 3.486	$\bar{x}$ = 3.196	$\bar{x}$ = 3.385
	s = 1.159	s = 1.197	s = 1.240	s = 1.202
	n = 36	n = 35	n = 46	n = 117

processors showed little difference in desire to seek knowledge about each of the five elements of screw plastication. Mean scores for the likelihood of seeking additional information ranged from $\bar{x}$ = 3.259 to $\bar{x}$ = 3.393 (see Table 4). However, the difference in likelihood of seeking additional information was sharply different between blow molders and injection molders in all five areas. Furthermore, sharp differences were also revealed between extruders and injection molders in the areas of screw design and discharge modifiers.

The following differences in means for likelihood of seeking additional information were found. Blow molders reported a greater likelihood of seeking information about barrel temperature profile ($\bar{x}$ = 3.500) than did injection molders at ($\bar{x}$ = 2.783), $F(116) = 3.563$, $p < .05$. Furthermore, blow molders rated the likelihood of seeking additional information about the properties of shear at ($\bar{x}$ = 3.583), whereas injection molders only rated their likelihood at ($\bar{x}$ = 2.978), $F(116) = 2.244$, $p < .05$. In the area of screw design, blow molders ($\bar{x}$ = 3.667) and extruders ($\bar{x}$ = 3.943) both reported a greater likelihood of seeking additional information than did injection molders at ($\bar{x}$ = 2.935, $F(116) = 6.296$, $p < .05$. In addition, the likelihood of seeking information on screw forces was greater for blow molders ($\bar{x}$ = 3.444) than for injection molders ($\bar{x}$ = 2.761), $F(116) = 3.217$, $p < .05$.

Table 4

Successive One-Way ANOVAs of the Likelihood of Seeking Additional Screw Plastication Knowledge by Processing Type

Knowledge Area	Processing Type			
	Blow Molding	Extrusion	Injection Molding	Row Total
Barrel Temp. Profile	$\bar{x}$ = 3.500	$\bar{x}$ = 3.229	$\bar{x}$ = 2.783	$\bar{x}$ = 3.137
	s = 1.254	s = 1.262	s = 1.190	s = 1.259
	n = 36	n = 35	n = 46	n = 117
Properties of Shear	$\bar{x}$ = 3.583	$\bar{x}$ = 3.286	$\bar{x}$ = 2.978	$\bar{x}$ = 3.256
	s = 1.273	s = 1.227	s = 1.342	s = 1.301
	n = 36	n = 35	n = 46	n = 117
Screw Design	$\bar{x}$ = 3.667	$\bar{x}$ = 3.943	$\bar{x}$ = 2.935	$\bar{x}$ = 3.462
	s = 1.414	s = 1.211	s = 1.357	s = 1.393
	n = 36	n = 35	n = 46	n = 117
Screw Forces	$\bar{x}$ = 3.444	$\bar{x}$ = 3.229	$\bar{x}$ = 2.761	$\bar{x}$ = 3.111
	s = 1.362	s = 1.285	s = 1.139	s = 1.278
	n = 36	n = 35	n = 46	n = 117
Discharge Modifiers	$\bar{x}$ = 3.639	$\bar{x}$ = 3.514	$\bar{x}$ = 2.848	$\bar{x}$ = 3.291
	s = 1.356	s = 1.222	s = 1.173	s = 1.287
	n = 36	n = 35	n = 46	n = 117

Finally, both blow molders ($\bar{x}$ = 3.639) and extruders ($\bar{x}$ = 3.514) reported greater likelihood of seeking information on discharge modifiers than did injection molders ($\bar{x}$ = 2.848), $F(116) = 4.875$, $p < .05$.

Analysis of the Data by Job Title

The level of plastication knowledge differed little between job title groupings. In fact, no real difference in knowledge was shown between job titles (see Table 5). It is interesting to note that the least amount of knowledge about plastication was in the area of shear. Taken as a group, the amount of knowledge in the area of shear properties constituted a mean of only ($\bar{x}$ = 3.059). This finding is in contrast to the entire group's seemingly greater knowledge about barrel temperature profile at a mean of ($\bar{x}$ = 3.489).

When asked to rate the dependence of their job on screw plastication knowledge, all groups responded uniformly. Once again, no real difference was found at a .05 alpha level. Job dependence was rated highest by manufacturing engineers and lowest by managers, but the mean scores were separated by only .511 (see Table 6)

When ratings were analyzed for differences in the stated importance of screw plastication knowledge, a trend emerged. Managers and others afforded the least importance to all five areas of screw plastication.

Table 5

Successive One-Way ANOVAs of
Screw Plastication Knowledge
by Job Title

Knowledge Area	Job Title: Engineering	Design	Set-up/ Troubleshooting	Supervisory	Management	Other	Row Total
Barrel Temp. Profile	$\bar{x}$ = 3.353	$\bar{x}$ = 3.565	$\bar{x}$ = 3.429	$\bar{x}$ = 3.750	$\bar{x}$ = 3.438	$\bar{x}$ = 3.556	$\bar{x}$ = 3.489
	s = 1.115	s = 1.308	s = 1.134	s = .500	s = 1.165	s = 1.319	s = 1.196
	n = 17	n = 23	n = 7	n = 4	n = 48	n = 36	n = 135
Properties of Shear	$\bar{x}$ = 3.177	$\bar{x}$ = 3.261	$\bar{x}$ = 2.714	$\bar{x}$ = 2.750	$\bar{x}$ = 3.042	$\bar{x}$ = 3.000	$\bar{x}$ = 3.059
	s = 1.015	s = 1.356	s = 1.254	s = .957	s = 1.202	s = 1.493	s = 1.274
	n = 17	n = 23	n = 7	n = 4	n = 48	n = 36	n = 135
Screw Design	$\bar{x}$ = 3.177	$\bar{x}$ = 3.261	$\bar{x}$ = 3.286	$\bar{x}$ = 3.250	$\bar{x}$ = 3.188	$\bar{x}$ = 3.111	$\bar{x}$ = 3.185
	s = .951	s = 1.214	s = .951	s = .500	s = 1.179	s = 1.410	s = 1.186
	n = 17	n = 23	n = 7	n = 4	n = 48	n = 36	n = 135
Screw Forces	$\bar{x}$ = 3.706	$\bar{x}$ = 3.217	$\bar{x}$ = 4.000	$\bar{x}$ = 4.000	$\bar{x}$ = 3.313	$\bar{x}$ = 3.333	$\bar{x}$ = 3.407
	s = 1.105	s = 1.347	s = .817	s = .817	s = 1.274	s = 1.287	s = 1.242
	n = 17	n = 23	n = 7	n = 4	n = 48	n = 36	n = 135
Discharge Modifiers	$\bar{x}$ = 3.294	$\bar{x}$ = 3.522	$\bar{x}$ = 3.429	$\bar{x}$ = 3.750	$\bar{x}$ = 3.292	$\bar{x}$ = 3.167	$\bar{x}$ = 3.319
	s = .920	s = 1.310	s = 1.397	s = .500	s = 1.237	s = 1.230	s = 1.195
	n = 17	n = 23	n = 7	n = 4	n = 48	n = 36	n = 135

Table 6

One-Way ANOVA of the Dependence of a Person's Job on Screw Plastication Knowledge by Job Title

Knowledge Area	Job Title						
	Engineering	Design	Set-up/ Troubleshooting	Supervisory	Management	Other	Row Total
Dependence on Plastication Knowledge	$\bar{x}$ = 3.118	$\bar{x}$ = 2.826	$\bar{x}$ = 3.000	$\bar{x}$ = 3.000	$\bar{x}$ = 2.604	$\bar{x}$ = 2.861	$\bar{x}$ = 2.807
	s = 1.453	s = 1.466	s = 1.414	s = .817	s = 1.349	s = 1.676	s = 1.453
	n = 17	n = 23	n = 7	n = 4	n = 48	n = 36	n = 135

However, set-up, trouble shooters and supervisors reported the greatest amount of importance placed on screw plastication. Although the trend seemed evident in mean ratings, at no point did a real difference occur at an alpha level of .05 (see Table 7).

Data on the likelihood of seeking additional information about the five elements of screw plastication were also analyzed by job title. In the analysis real differences did occur between several job titles in the area of screw design (see Table 8). Both set-up and trouble shooters ($\bar{x}$ = 4.286) and supervisors ($\bar{x}$ = 4.500) stated a greater likelihood of seeking additional information about screw design than did managers ($\bar{x}$ = 2.944), $F(134) = 1.762$, $p < .05$. In all other cases, differences in the likelihood of seeking additional information were not found at an alpha level of .05.

Analysis of the Data by Job Classification

For this analysis, all job titles were divided into blue collar, white collar (production) and white collar (support services) as explained in Chapter III. For the most part, there was little difference in the reported knowledge of screw plastication among the three groups. To this end, the means among the groups differed little for each of the five areas of screw plastication. The only exception to this uniformity was a difference of over

Table 7

Successive One-Way ANOVAs of the Importance of
Screw Plastication Knowledge
by Job Title

Knowledge Area	Job Title: Engineering	Design	Set-up/ Troubleshooting	Supervisory	Management	Other	Row Total
Barrel Temp. Profile	$\bar{x}$ = 3.353	$\bar{x}$ = 3.217	$\bar{x}$ = 3.857	$\bar{x}$ = 3.750	$\bar{x}$ = 3.250	$\bar{x}$ = 3.028	$\bar{x}$ = 3.244
	s = 1.272	s = 1.536	s = .690	s = .500	s = 1.392	s = 1.483	s = 1.379
	n = 17	n = 23	n = 7	n = 4	n = 48	n = 36	n = 135
Properties of Shear	$\bar{x}$ = 3.000	$\bar{x}$ = 3.261	$\bar{x}$ = 3.571	$\bar{x}$ = 3.750	$\bar{x}$ = 3.146	$\bar{x}$ = 3.222	$\bar{x}$ = 3.207
	s = 1.000	s = 1.573	s = .787	s = .500	s = 1.353	s = 1.532	s = 1.356
	n = 17	n = 23	n = 7	n = 4	n = 48	n = 36	n = 135
Screw Design	$\bar{x}$ = 3.118	$\bar{x}$ = 3.174	$\bar{x}$ = 3.714	$\bar{x}$ = 3.750	$\bar{x}$ = 3.146	$\bar{x}$ = 3.028	$\bar{x}$ = 3.163
	s = 1.111	s = 1.586	s = .951	s = .957	s = 1.368	s = 1.540	s = 1.389
	n = 17	n = 23	n = 7	n = 4	n = 48	n = 36	n = 135
Screw Forces	$\bar{x}$ = 3.529	$\bar{x}$ = 3.261	$\bar{x}$ = 4.000	$\bar{x}$ = 3.750	$\bar{x}$ = 3.125	$\bar{x}$ = 3.056	$\bar{x}$ = 3.244
	s = 1.375	s = 1.453	s = .817	s = .500	s = 1.347	s = 1.530	s = 1.385
	n = 17	n = 23	n = 7	n = 4	n = 48	n = 36	n = 135
Discharge Modifiers	$\bar{x}$ = 3.294	$\bar{x}$ = 3.391	$\bar{x}$ = 3.714	$\bar{x}$ = 3.750	$\bar{x}$ = 3.270	$\bar{x}$ = 3.000	$\bar{x}$ = 3.259
	s = 1.160	s = 1.438	s = 1.113	s = .500	s = 1.216	s = 1.493	s = 1.304
	n = 17	n = 23	n = 7	n = 4	n = 48	n = 36	n = 135

Table 8

Successive One-Way ANOVAs of the Likelihood of Seeking Additional Screw Plastication Knowledge by Job Title

Knowledge Area	Job Title: Engineering	Design	Set-up/ Troubleshooting	Supervisory	Management	Other	Row Total
Barrel Temp. Profile	$\bar{x}$ = 3.177	$\bar{x}$ = 2.957	$\bar{x}$ = 3.286	$\bar{x}$ = 3.750	$\bar{x}$ = 2.958	$\bar{x}$ = 2.889	$\bar{x}$ = 3.007
	s = .951	s = 1.364	s = 1.254	s = 1.258	s = 1.304	s = 1.545	s = 1.330
	n = 17	n = 23	n = 7	n = 4	n = 48	n = 36	n = 135
Properties of Shear	$\bar{x}$ = 3.353	$\bar{x}$ = 3.217	$\bar{x}$ = 3.714	$\bar{x}$ = 4.000	$\bar{x}$ = 2.875	$\bar{x}$ = 3.000	$\bar{x}$ = 3.104
	s = 1.115	s = 1.380	s = 1.113	s = 1.414	s = 1.315	s = 1.512	s = 1.356
	n = 17	n = 23	n = 7	n = 4	n = 48	n = 36	n = 135
Screw Design	$\bar{x}$ = 3.471	$\bar{x}$ = 3.174	$\bar{x}$ = 4.286	$\bar{x}$ = 4.500	$\bar{x}$ = 3.208	$\bar{x}$ = 2.944	$\bar{x}$ = 3.259
	s = 1.328	s = 1.466	s = 1.113	s = 1.000	s = 1.414	s = 1.567	s = 1.456
	n = 17	n = 23	n = 7	n = 4	n = 48	n = 36	n = 135
Screw Forces	$\bar{x}$ = 3.412	$\bar{x}$ = 2.957	$\bar{x}$ = 3.286	$\bar{x}$ = 3.000	$\bar{x}$ = 2.896	$\bar{x}$ = 2.833	$\bar{x}$ = 2.978
	s = 1.121	s = 1.364	s = 1.254	s = .817	s = 1.292	s = 1.540	s = 1.335
	n = 17	n = 23	n = 7	n = 4	n = 48	n = 36	n = 135
Discharge Modifiers	$\bar{x}$ = 3.471	$\bar{x}$ = 3.087	$\bar{x}$ = 3.286	$\bar{x}$ = 3.750	$\bar{x}$ = 3.042	$\bar{x}$ = 2.944	$\bar{x}$ = 3.126
	s = 1.068	s = 1.240	s = 1.134	s = 1.258	s = 1.443	s = 1.473	s = 1.352
	n = 17	n = 23	n = 7	n = 4	n = 48	n = 36	n = 135

.635 between the means of blue collar and white collar employees in the area of knowledge of screw forces (see Table 9). However, even this difference in the means was not judged to be real at an alpha level of .05.

Even less difference was reported in the dependence of a classification of jobs on screw plastication knowledge. Only .239 separated the means of the jobs most dependent and those least dependent on screw plastication knowledge (see Table 10). In all cases, respondents reported moderate dependence of their job on screw plastication knowledge.

In the analysis of the importance of screw plastication knowledge by job classification, a trend appeared to be present. In all five areas, means for importance were higher for blue collar workers than for both classifications of white collar workers (see Table 11). The most striking example of this trend is the .903 difference in the means for screw forces between blue collar and white collar (support services). However, once again the difference in the means was not great enough to be significant at an alpha level of .05

When data were analyzed pertaining to the likelihood of a classification of employees seeking additional information about the five areas of screw plastication, the same trend appeared. Blue collar workers exhibited a greater mean likelihood of seeking information than did

Table 9

Successive One-Way ANOVAs of
Screw Plastication Knowledge
by Classification of Job

Knowledge Area	Classification of Job			
	Blue Collar	White Collar (Production)	White Collar (Support Services)	Row Total
Barrel Temp. Profile	$\bar{x}$ = 3.546 s = .934 n = 11	$\bar{x}$ = 3.455 s = 1.183 n = 88	$\bar{x}$ = 3.556 s = 1.319 n = 36	$\bar{x}$ = 3.488 s = 1.196 n = 135
Properties of Shear	$\bar{x}$ = 2.727 s = 1.104 n = 11	$\bar{x}$ = 3.125 s = 1.202 n = 88	$\bar{x}$ = 3.000 s = 1.493 n = 36	$\bar{x}$ = 3.059 s = 1.274 n = 135
Screw Design	$\bar{x}$ = 3.273 s = .786 n = 11	$\bar{x}$ = 3.205 s = 1.136 n = 88	$\bar{x}$ = 3.111 s = 1.410 n = 36	$\bar{x}$ = 3.185 s = 1.186 n = 135
Screw Forces	$\bar{x}$ = 4.000 s = .775 n = 11	$\bar{x}$ = 3.364 s = 1.261 n = 88	$\bar{x}$ = 3.333 s = 1.287 n = 36	$\bar{x}$ = 3.407 s = 1.242 n = 135
Discharge Modifiers	$\bar{x}$ = 3.546 s = 1.128 n = 11	$\bar{x}$ = 3.352 s = 1.194 n = 88	$\bar{x}$ = 3.167 s = 1.231 n = 36	$\bar{x}$ = 3.319 s = 1.195 n = 135

Table 10

One-Way ANOVAs of the Dependence of a Person's Job on Screw Plastication Knowledge by Classification of Job

Knowledge Area	Classification of Job			
	Blue Collar	White Collar (Production)	White Collar (Support Services)	Row Total
Dependence on Plastication Knowledge	$\bar{x}$ = 3.000	$\bar{x}$ = 2.761	$\bar{x}$ = 2.861	$\bar{x}$ = 2.807
	s = 1.183	s = 1.398	s = 1.676	s = 1.453
	n = 11	n = 88	n = 36	n = 135

white collar workers (see Table 12). Furthermore, once again in all but one instance, the differences in the means were not large enough to be considered valid at an alpha level of .05. However, in the case of screw design, the likelihood of blue collar workers' seeking information ($\bar{x}$ = 4.364) was considerably different than either white collar (production) ($\bar{x}$ = 3.250) or white collar (support services) ($\bar{x}$ = 2.994), $F(134) = 4.201$, $p < .05$. Thus, it may be concluded, blue collar workers are more likely to seek information on screw design than are white collar workers.

It should also be noted that the standard deviations for blue collar workers, on the whole, were 35% lower than white collar (support services) and 25% lower than white

Table 11

Successive One-Way ANOVAs of the Importance of
Screw Plastication Knowledge
by Classification of Job

Knowledge Area	Classification of Job			
	Blue Collar	White Collar (Production)	White Collar (Support Services)	Row Total
Barrel Temp. Profile	$\bar{x}$ = 3.818 s = .603 n = 11	$\bar{x}$ = 3.261 s = 1.394 n = 88	$\bar{x}$ = 3.028 s = 1.483 n = 36	$\bar{x}$ = 3.244 s = 1.379 n = 135
Properties of Shear	$\bar{x}$ = 3.636 s = .674 n = 11	$\bar{x}$ = 3.148 s = 1.344 n = 88	$\bar{x}$ = 3.222 s = 1.532 n = 36	$\bar{x}$ = 3.207 s = 1.356 n = 135
Screw Design	$\bar{x}$ = 3.727 s = .905 n = 11	$\bar{x}$ = 3.148 s = 1.369 n = 88	$\bar{x}$ = 3.028 s = 1.540 n = 36	$\bar{x}$ = 3.163 s = 1.389 n = 135
Screw Forces	$\bar{x}$ = 3.909 s = .701 n = 11	$\bar{x}$ = 3.239 s = 1.373 n = 88	$\bar{x}$ = 3.006 s = 1.530 n = 36	$\bar{x}$ = 3.244 s = 1.385 n = 135
Discharge Modifiers	$\bar{x}$ = 3.727 s = .905 n = 11	$\bar{x}$ = 3.307 s = 1.254 n = 88	$\bar{x}$ = 3.000 s = 1.493 n = 36	$\bar{x}$ = 3.259 s = 1.304 n = 135

Table 12

Successive One-Way ANOVAs of the Likelihood of Seeking Additional Screw Plastication Knowledge by Classification of Job

Knowledge Area	Classification of Job			
	Blue Collar	White Collar (Production)	White Collar (Support Services)	Row Total
Barrel Temp. Profile	$\bar{x}$ = 3.455 s = 1.214 n = 11	$\bar{x}$ = 3.000 s = 1.250 n = 88	$\bar{x}$ = 2.889 s = 1.545 n = 36	$\bar{x}$ = 3.007 s = 1.330 n = 135
Properties of Shear	$\bar{x}$ = 3.818 s = 1.168 n = 11	$\bar{x}$ = 3.057 s = 1.299 n = 88	$\bar{x}$ = 3.000 s = 1.512 n = 36	$\bar{x}$ = 3.104 s = 1.356 n = 135
Screw Design	$\bar{x}$ = 4.364 s = 1.027 n = 11	$\bar{x}$ = 3.250 s = 1.400 n = 88	$\bar{x}$ = 2.944 s = 1.567 n = 36	$\bar{x}$ = 3.259 s = 1.456 n = 135
Screw Forces	$\bar{x}$ = 3.182 s = 1.079 n = 11	$\bar{x}$ = 3.011 s = 1.282 n = 88	$\bar{x}$ = 2.853 s = 1.540 n = 36	$\bar{x}$ = 2.978 s = 1.335 n = 135
Discharge Modifiers	$\bar{x}$ = 3.636 s = 1.120 n = 11	$\bar{x}$ = 3.136 s = 1.323 n = 88	$\bar{x}$ = 2.944 s = 1.473 n = 36	$\bar{x}$ = 3.126 s = 1.352 n = 135

collar (production). This lower standard deviation is present in spite of the small number of blue collar respondents. Thus, this information suggests that the views of the blue collar group are more homogenous than are the views of both white collar groups.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Overview of the Results

The most striking aspect of the data was that in spite of differences in certain areas, an underlying universality of knowledge prevailed. Overall, the groups possessed moderate knowledge in all areas. Furthermore, all job classifications in the three process types expressed a moderate amount of job dependence on their knowledge of plastication. This response is most important, since no group showed either low knowledge base or low job dependence. In all of the white collar job titles some individuals responded that either their knowledge was low or their position did not require use of screw plastication knowledge. However, when discussing projected trends in the population, it must be concluded that knowledge of screw plastication is both important and necessary for workers to be effective in the plastics industry. This finding is of major importance, since it validates the current practice of including the study of plastication in most types of plastics education at all academic levels.

Implications for Current Assumptions

As stated in Chapter I, several assumptions are made about knowledge levels of personnel in the plastics industry. Two assumptions were addressed by this study. First, it was noted that some portion of the industry believes that if the resin and processing equipment are correctly made, the processor cannot adversely affect the polymer. Based on the discussion in Chapter II, adverse effects may be produced in many areas of the plastication process. Based upon the results of this study it is unlikely that any sizeable number of plastics employees believe that they cannot adversely affect the polymer during plastication. This assertion is made because of the uniform level of importance placed on plastication, coupled with the reported level of plastication knowledge.

The second assumption addressed by this study was that current knowledge had been acquired by processors. In all five areas of plastication knowledge the assumption would appear to be correct based upon the moderate level of knowledge reported by all groups. One aspect of knowledge acquisition the study did not address was the source(s) of information used by plastics employees. Since this study has indicated a moderate and uniform level of knowledge, further assessment of the relative impact of various methods of information dissemination within the plastics industry does seem warranted. Until further assessment is made the full impact of research articles and seminars can be only speculative.

Implication of Job Position on Knowledge Acquisition

The data give little indication that the position a person holds in the thermoplastic processing industry will radically alter dependence on screw plastication knowledge. Review of the raw data revealed that some individuals in every white collar job title considered plastication information to be of low importance. However, it should be noted that manufacturing engineers did not respond below a two out of five in four of the five questions about the importance of plastication knowledge. Conversely, in all of the white collar job titles some individuals indicated that plastication is highly important. Thus, it may be concluded from the findings of this study that a moderate amount of knowledge about screw plastication is required for white collar employees in thermoplastics processing.

Although the mean blue collar scores for amount of knowledge and importance of knowledge did not show any real difference at an alpha level of .05, several points are worth noting. First, in all but one question the lowest rating given by blue collar employees was either a two or a three out of five. Second, even though the differences between blue collar and white collar means were not significant at an alpha level of .05, a trend for higher blue collar means was present. In fact, this trend was most pronounced in questions about desire for additional knowledge.

However, several factors are present in the blue collar group which make drawing any definitive conclusions risky in all but one area. It should be noted that the relative sizes of the blue collar group and white collar composites were radically different. Furthermore, the number of individuals in the blue collar composite was too small to approximate a normal distribution. Finally, the differences between blue collar and white collar ratings were indeed not large enough to be considered real at an alpha level of .05. Thus, it can be concluded only that screw plastication knowledge may be of greater importance for blue collar employees. Furthermore, since the desire for additional knowledge in the area of screw design was greater for blue collar employees than for white collar employees at an alpha level of .05, there is probably a need for blue collar training in this area. Without further data collection from blue collar employees no other definitive statement can be made.

Implication of Process Type on Knowledge Acquisition

Although all three process types appear to have nearly identical levels of knowledge of screw plastication, those involved in blow molding affirm both greater interest in and importance of plastication than do those involved in injection molding. This finding supports several conclusions. First, blow molders are more likely to employ the precepts of screw plastication theory than are injection molders. This statement is based on the conclusion that, since personnel in blow molding assign more importance to plastication than do injection molders, the former group are likely to use concepts they judge to be important. Second, personnel involved in blow molding are more likely to seek additional information on screw plastication than would those involved in injection molding. Third, those involved in extrusion are more likely to seek information on screw design and discharge modifiers than would personnel involved in injection molding.

Another area that this study addresses is the question of technology transfer. The findings of this study suggest that a very active technology transfer does exist between research in injection molding and extrusion and use of the findings in blow molding. This conclusion is based on the uniform knowledge levels between processes and greater activity in seeking knowledge on the part of blow molders. These findings stand in spite of the fact that: (a) there are no books published in the English language dedicated to blow molding and (b) few articles have been written about plastication in blow molding. Thus, a logical conclusion is that the personnel in blow molding are transferring knowledge from work done in injection molding and extrusion. Once again, a definitive conclusion may not be drawn without assessment of the relative impact of various methods of information dissemination.

Recommendations for Training and Education

Present inclusion of screw plastication information in plastics curricula is appropriate, based upon the uniform importance attached to plastication by the thermoplastics processing industry. Consideration should be given to the inclusion of plastication theory in management degree programs with technical, manufacturing or engineering specializations. This recommendation is based on the revelation that managers in thermoplastics processing plants report that to a moderate extent their jobs rely on knowledge of plastication.

This study indicates the probability of a need for plastication training of employees involved in blow molding. Furthermore, there would appear to be a need for a seminar or training in the area of screw design and screw forces, targeted at blow molding and extrusion employees. However, the exact form of these interventions should be verified in one of several ways.

A study should be conducted to determine the most effective and desireable methods of disseminating information within the thermoplastics processing industry. Furthermore, a needs analysis should be undertaken to determine which specific areas of screw design knowledge skilled blue collar workers need to improve product quality. Finally, additional plastication information should be channeled to blow molding personnel by whatever means the SPE can employ.

APPENDICES

Appendix A

Notations and Symbols

NOTATIONS AND SYMBOLS

Symbol		Definition
A	--	area
df	--	degrees of freedom
dt	--	differential in time
dv	--	constant velocity
dy	--	nominal distance traveled
$d\gamma$	--	differential of strain
F (physics)	--	force
F (statistics)	--	F - ratio of mean squares between to mean squares within
h	--	coefficient of heat transfer
K	--	coefficient of thermal conductivity
p	--	probability at a given alpha level
Q	--	flow rate
r	--	Pearson Product Moment Correlation Coefficient
s	--	sample standard deviation
T_g	--	glass transition temperature of a resin
T_m	--	melting point of a resin
$\bar{x}$	--	sample mean
γ (gamma)	--	strain
$\dot{\gamma}$	--	shear rate

ΔP (delta)	--	change in pressure
ΔT	--	change in temperature
μ (mu)	--	viscosity constant
μ_a	--	apparent viscosity
μ / g_c	--	slope of the flow curve
τ (tau)	--	shear stress
τ_{xy}	--	shear stress of a fluid normal to the x and y directions

Appendix B

Pilot Survey Instrument

THE ROLE OF PLASTIFICATION IN THE PLASTICS PROCESSING INDUSTRY

Directions: The following questions are designed to gather information about your views of plastics processing. Please answer all the questions by circling the appropriate letter or number.

Section I

1. Plastics process which constitutes the majority of your activity (circle only one)

   A. Blow Molding
   B. Extrusion
   C. Injection Molding
   D. Other (please specify)____________________________
   E. Not involved with plastics processes

2. Your primary job function (circle one)

   A. Production and manufacturing engineering
   B. Design and design engineering
   C. Set-up and trouble shooting
   D. Foreman and supervisory
   E. General and corporate management
   F. Other (please specify)____________________________

Section II

Using the rating scale below, rate your knowledge about the effects of each of the following five areas.

(1) low knowledge
(2)
(3) moderate knowledge
(4)
(5) high knowledge

		Low				High
1.	Relationship of the temperature profile of a machine barrel to product quality...........	1	2	3	4	5
2.	Relationship of shear rate and shear stressing during melting to product quality......	1	2	3	4	5
3.	The effects of screw design on the product quality..............................	1	2	3	4	5
4.	The effects of back pressure and screw speed on the product quality...........................	1	2	3	4	5
5.	The effects of nozzles, adapters, dies, screen packs and breaker plates on the product quality..	1	2	3	4	5

Section III

Using the rating scale below, rate the importance of your knowledge about each of the following five areas.

(1) low importance
(2)
(3) moderate importance
(4)
(5) high importance

		Low				High
1.	Effects of barrel temperature profiles.........	1	2	3	4	5
2.	Effects of shear rate and shear stressing......	1	2	3	4	5
3.	Effects of screw design.......................	1	2	3	4	5
4.	Effects of back pressure and screw speed.......	1	2	3	4	5
5.	Effects of nozzles, adapters, dies, screen packs and breaker plates................	1	2	3	4	5

Section IV

Using the rating scale below, rate the likelihood of seeking additional information in the following five areas.

(1) low likelihood
(2)
(3) moderate likelihood
(4)
(5) high likelihood

		Low				High
1.	Effects of barrel temperature profile..........	1	2	3	4	5
2.	Effects of shear rate and shear stressing......	1	2	3	4	5
3.	Effects of screw design.......................	1	2	3	4	5
4.	Effects of back pressure and screw speed.......	1	2	3	4	5
5.	Effects of nozzles, adapters, dies, screen packs and breaker plates................	1	2	3	4	5

Appendix C

Interview Questions

Interview Questions

1. How long did it take you to complete the survey?
2. Were there any unclear areas in the survey?
3. Was the survey content complete in terms of plastication?
4. If you were sent the proposed cover letter with $1.00 and knew nothing else about why the survey was being done, would there be enough incentive for you to fill out the survey?
5. Is the $1.00 a good idea?
6. Was the cover letter too long?
7. Did the cover letter convey the correct message?
8. Was the content of the follow-up letter appropriate?
9. What changes would you make in the letters?
10. Comments

Appendix D

Cover Letter

Society of Plastics Engineers
Western Michigan Section

Date

Name
Address
City, State, Zip

Dear:

The 1980's have brought rapid advances in the plastics industry. Along with these advances have come increased demands for higher quality products, in less time, at less cost. Many of us are left wondering how to best use the advances in resins and processing machinery to meet these consumer demands.

This study is being sponsored by the Western Michigan Section of the Society of Plastics Engineers. Its purpose is to gather some specific information about the current level of industrial understanding of the melting of plastics. This study will produce specific recommendations to both the SPE and college programs.

Your help is critical. In order to get accurate results, I need approximately a 90% return of these surveys. For this reason, I am enclosing $1.00 bill for a cold soft drink while you take the several minutes to fill out this survey.

Please call me at (616) [illegible] if you have any questions about this study or if I may be of help in some other way. Thank you.

Sincerely,

Paul Engelmann, Plastics Instructor
Dept. of Engineering Technology
Western Michigan University

"The objective of the Society shall be to promote scientific and engineering knowledge relating to plastics"

Appendix E

Follow-Up Letter

Society of Plastics Engineers
Western Michigan Section

July 27, 1988

^F1^

Dear ^F2^:

I would like to take this opportunity to thank you for completing the survey on "The Role of Plastication in Product Quality". I am encouraged by the response that I have received. The early responses look good; however, many surveys have not yet been returned.

If you have not taken the time to finish the survey, I would greatly appreciate your efforts in doing so. I cannot emphasize how important each response is. Approximately 90% of the surveys need to be returned for the findings of this study to be accurate. Thus, each response is a significant voice in this survey.

Your input will help our industry and should provide you with some opportunities to improve your business.

Sincerely,

Paul Engelmann, Plastics Instructor
Department of Engineering Technology
Western Michigan University

"The objective of the Society shall be to promote scientific and engineering knowledge relating to plastics"

Officers and Directors are listed on the back.

Appendix F

Protection of Human Subjects Approval

WMU

Western Michigan University
Kalamazoo, Michigan 49008-3899

Human Subjects
Institutional Review Board

TO: Paul Engelmann

FROM: Ellen Page-Robin, Chair

RE: Research Protocol

DATE: May 10, 1988

This letter will serve as confirmation that your research protocol, "Applied Thermoplastic Screw Plastification Theory: Its Acceptance and Effects on the Plastics Processing Industry" has been approved as exempt by the HSIRB.

If you have any questions, please contact me at 387-2647.

Appendix G

Pilot Study: Data and Statistics

Pilot Study: Data and Statistics

Section & Question Number	Means: Base	Means: Ind 1	Means: Ind 2	Standard Deviation: Base	Standard Deviation: Ind 1	Standard Deviation: Ind 2	Standard Error of the Mean: Base	Standard Error of the Mean: Ind 1	Pearson r: Ind 1 / Ind 2
S1 Q1	1.143	4.000	3.667	.363	.707	.707	.097	.236	.750
S1 Q2	1.286	3.000	3.111	.825	.866	.782	.221	.289	.739
S1 Q3	1.500	3.333	3.222	1.019	.866	.972	.272	.289	.941
S1 Q4	1.500	4.000	3.667	1.092	.500	.866	.292	.167	.866
S1 Q5	1.143	3.333	3.222	.363	1.000	.972	.097	.333	.943
S2 Q1	1.500	4.000	4.000	.941	1.118	1.000	.251	.373	.894
S2 Q2	1.714	3.667	3.556	1.267	.866	.882	.339	.289	.764
S2 Q3	1.929	3.444	3.556	1.439	1.424	1.130	.385	.475	.915
S2 Q4	1.571	3.889	3.778	.852	.928	.972	.228	.309	.940
S2 Q5	1.571	3.667	3.667	1.016	.866	1.118	.272	.285	.904
S3 Q1	1.292	3.333	3.111	1.385	.866	.928	.370	.289	.881
S3 Q2	1.292	3.778	3.556	1.439	1.202	1.130	.385	.401	.930
S3 Q3	2.071	3.667	3.333	1.542	.866	.866	.412	.289	.833
S3 Q4	2.000	3.444	3.000	1.414	1.130	1.000	.378	.377	.885
S3 Q5	2.071	3.333	3.111	1.492	1.000	.601	.399	.333	.555

Legend. Base = 14 Member Base Line Pilot Group

Ind 1 = 9 Member Industrial Pilot Group, First Survey Administration

Ind 2 = 9 Member Industrial Pilot Group, Second Survey Administration

Appendix H

Final Survey Instrument

THE ROLE OF PLASTICATION IN PRODUCT QUALITY

Directions: The following questions are designed to gather information about your views of plastics processing. Please answer all the questions by circling the appropriate letter or number.

Section I

1. Plastics process which constitutes the majority of your activity (circle only one)

   A. Blow Molding
   B. Extrusion
   C. Injection Molding
   D. Other (please specify)____________________
   E. Not involved with plastics processes

2. Your primary job function (circle only one)

   A. Production and manufacturing engineering
   B. Design and design engineering
   C. Set-up and trouble shooting
   D. Foreman and supervisory
   E. General and corporate management
   F. Other (please specify)____________________

Section II

Using the rating scale below, rate your knowledge about the effects of **each** of the following five areas.

(1) low knowledge
(3) moderate knowledge
(5) high knowledge

	Low				High
1. Relationship of the temperature profile of a machine barrel to product quality...........	1	2	3	4	5
2. Relationship of shear rate and shear stressing during melting to product quality......	1	2	3	4	5
3. The effects of screw design on the product quality.............................	1	2	3	4	5
4. The effects of back pressure and screw speed on the product quality..........................	1	2	3	4	5
5. The effects of nozzles, adapters, dies, screen packs and breaker plates on the product quality..	1	2	3	4	5

Section III

1. To what degree does your job depend upon knowledge of the effects of screw plastication (melting)?

Low Degree				High Degree
1	2	3	4	5

Section IV

Using the rating scale below, how important is your knowledge about each of the following five areas as it relates to producing quality products?

(1) low importance
(3) moderate importance
(5) high importance

	Low				High
1. Effects of barrel temperature profiles.........	1	2	3	4	5
2. Effects of shear rate and shear stressing......	1	2	3	4	5
3. Effects of screw design........................	1	2	3	4	5
4. Effects of back pressure and screw speed.......	1	2	3	4	5
5. Effects of nozzles, adapters, dies, screen packs and breaker plates................	1	2	3	4	5

Section V

Using the rating scale below, rate the likelihood of seeking additional information in each of the following five areas.

(1) low likelihood
(3) moderate likelihood
(5) high likelihood

	Low				High
1. Effects of barrel temperature profile..........	1	2	3	4	5
2. Effects of shear rate and shear stressing......	1	2	3	4	5
3. Effects of screw design........................	1	2	3	4	5
4. Effects of back pressure and screw speed.......	1	2	3	4	5
5. Effects of nozzles, adapters, dies, screen packs and breaker plates................	1	2	3	4	5

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