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Analysis of the effects of wear and tear of gates and runners in the injection molding process for multi-cavity injection molds in natural imbalance

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ABSTRACT

Title of Thesis: *Analysis of the effects of Wear and Tear of Gates and Runners in the Injection Molding Process, for Multi-cavity Injection Molds in Natural Imbalance.*

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Intuition, prior experience, and trial and error experimentation have previously been the key factors in solving the mold design and process optimization problems, when there is a dimensional change in gates and runners due to wear and tear in multi-cavity injection molding. The effect of wear and tear of gates and runners of circular and rectangular geometries, using the flow analysis package MOLDFLOW have been studied. A mold with two rectangular cavities of volume in the ratio 2:1 has been taken as the reference model for the analysis. It is observed that the amount of imbalance due to wear and tear of gates and runners is a function of the rheological properties of the material being processed.

The wear of the gates is more critical than the runners. The effect of circular gate wear is more severe on the flow balance in the multi-cavity mold. It is not possible to bring the imbalanced flow, due to wear and tear of gates and runners, back to the original balanced state.

ANALYSIS OF THE EFFECTS OF WEAR AND TEAR OF GATES AND RUNNERS IN THE INJECTION MOLDING PROCESS, FOR MULTI-CAVITY INJECTION MOLDS IN NATURAL IMBALANCE

BY

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Thesis is submitted to the Graduate School of New Jersey Institute of Technology in the partial filfullment of the requirements for the degree of Master of Science in Mechanical Engineering.

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CHAPTER 1

INTRODUCTION

1.1 HISTORY

Plastics is one of the world's fastest growing industries, ranked as one of the few billion dollar industries. Its two major processing methods are injection molding and extrusion. Approximately 32 percent by weight of all plastics processed goes through injection molding machines

Injection molding has the advantage that molded parts can be manufactured economically in unlimited quantities with little or practically no finished operations. It is principally a mass production method.

The first patent for injection molding was granted in the United States in 1872 to John Hyatt, for what was termed a stuffing machine plunger injection molding machine.

The term injection molding is an oversimplified description of a quite complicated process that is controllable within specified limits. Melted or plasticized plastic material is injected or forced into a mold where it is held until removed in a solid state, duplicating the cavity of the mold. The mold may consist of single cavity or a number of similar cavities, each connected to flow channels or runners that direct the flow of the melted plastic to the individual cavities. The process is one of the most economical methods for mass producing a single item. There are three basic operations exists in injection molding

Raising the temperature of the plastic to a point where it will flow under pressure. This is usually done by simultaneously heating and masticating the granular solid until it forms a melt at an alevated and uniform temperature and uniform viscosity. This overall process is called plasticating of the material.

The liquid molten plastic from the injection unit is transferred through various flow channels into the cavities of the mold, where it is finally shaped into the desired object by the confines of the mold cavity. What makes this simple operation complex is the limitation of the hydraulic circuitry used in the actuation of the injection plunger and complicated flow paths involved in the filling of the mold and cooling action in the mold.

Opening the mold to eject the plastic after keeping the material confined under pressure as the heat is removed to solidify the plastic and freeze it permanently into the shape desired, for thermoplastics.

These three steps are the only operations in which the mechanical and thermal inputs of the injection machine must be coordinated with the fundamental properties of the plastic being processed. These three operations are also the prime determinants of the productivity of the process because manufacturing speed will depend on how fast we can heat the plastic to the molding temperature, how fast we can inject it, and how long it takes to cool the product in the mold.

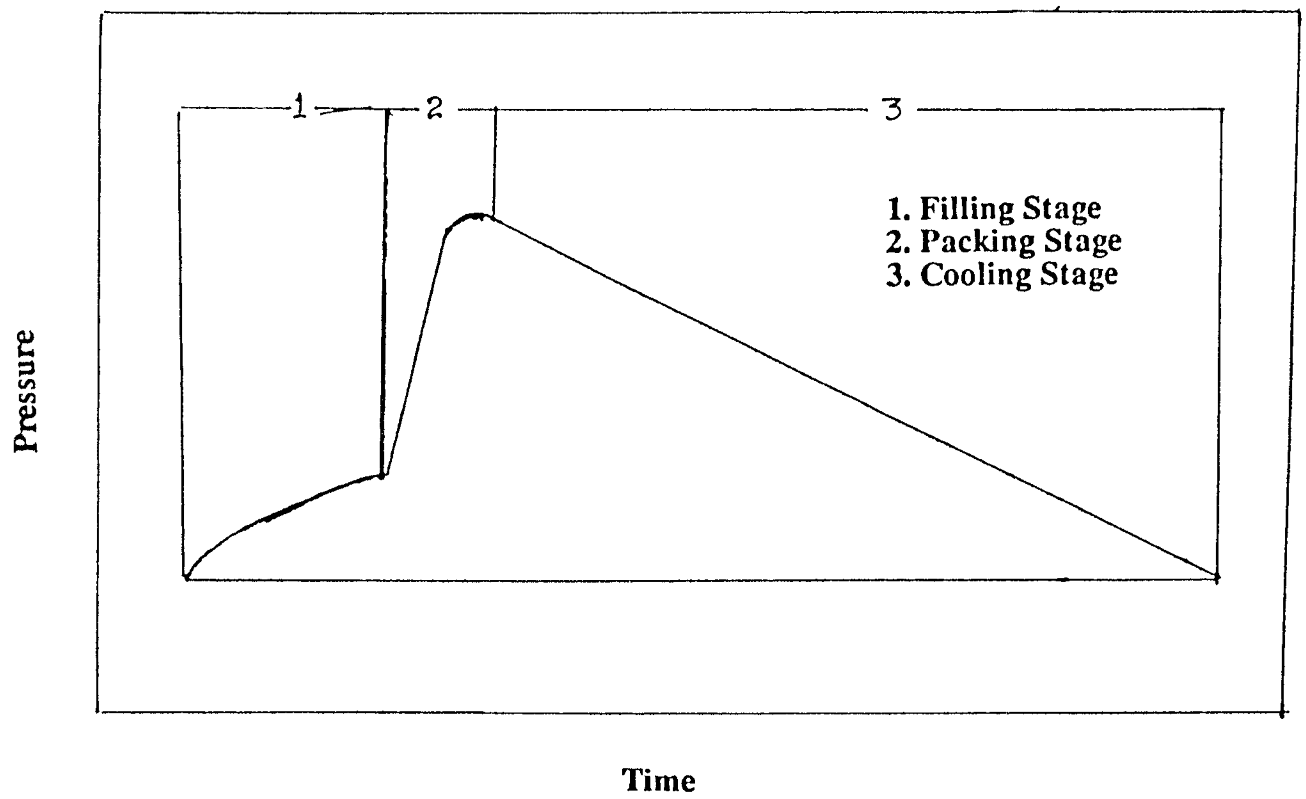


Fig. 1 Injection Pressure variation during one injection molding cycle (From: ref.[6])

The basic components of an injection molding system are: blending, drying, hoppering, metering, plastication, injection, cooling and ejection. Plastic is purchased in pellet form and heated in the injection heating chamber until it reaches a viscous melt state in which it can be forced into mold cavities. Each plastic differs in its ability to flow under heat and pressure.

1.2 MOLDING SEQUENCES

The injection molding process is basically divided into three stages they are:filling, packing and cooling. The injection pressure variation with the time, during one injection cycle is shown in Fig.1

1.3 FILLING STAGE

The filling stage is represented by the unsteady state flow of a hot, non-newtonian melt into an empty cavity, which is held at a temperature below the solidification temperature of the polymer.

1.4 PACKING STAGE

Two factors compete with regard to pressure variation in the cavity during the packing stage. The first is the flow of the polymer into the mold which leads to an increase of pressure corresponding to the increase of density of polymer in the cavity. The second factor is the cooling of the polymer which continues during all stages of injection molding processes. Cooling acts to reduce the pressure in the cavity, very little work is reported in the literature regarding the analysis of the packaging stage.

1.5 COOLING STAGE

After packing is complete, cooling of the polymer continues by virtue of the lower temperature of the mold. Cooling, without flow, continues until the polymer has solidification to a point when it can ejected from the mold without mechanical damage. Ideally, solidification occurs in the conditions of constant mass and volume so that the molded article retains the shape and dimensions of the mold.

1.6 PROCESS CONTROLS

Process controls for injection molding machines can range from unsophisticated to extremly sophisticated devices. There are different kinds of process controls which have closed loop control of temperature and/or pressure, maintain preset parameters for the screw ram speed, ram position, and /or hydraulic position, monitor and/or correct the machine operation, constantly fine tune the machine and provide consistency and repeatability in the machine operation.

1.6.1 Proportional -Integral -Derivative (PID) TUNING

The following is a brief explanation of the three control modes and their tuning constants. The three terms are not independent, but mutually interactive, and that both the order and magnitude of adjustments made to the tuning constants can affect the settings of the others.

1.6.2 PROPORTIONAL CONTROL

With this type, of control the magnitude of the control output is proportional to the difference between the actual pressure, in other words the magnitude of the error signal. The proportional band is the range of error above and below setpoint,within which the control output is proportional between zero and 100 percent.

1.6.3 INTEGRAL CONTROL

It is a characteristic of purely proportional control that, in response to changing load conditions, it tends not to stabilize the process at setpoint some distance away from it. Integral or reset control responds to this steady-state error, or proportional droop by shifting the proportional band up or down the pressure scale so as to stabilize the process at setpoint. The amount of reset action to use, expressed in repeats per minute, is the second tuning constant.

1.6.4 DERIVATIVE CONTROL

This type of control acting responds to changes in error or the rate at which the actual pressure approaches the setpoint. The faster the change in the magnitude of the error the greater the rate control signal and vice versa. It serves to intensify the effect of the proportional corrective action, causing the process to stabilize faster. Rate controls main effect is to prevent the undershoot/overshoot oscillation that may never be completely eliminated with proportional plus reset control alone. The amount of rate action expressed in percent is the third tuning constant usually the last to be set.

Bauer[1] has reported experimental results on the filling of a rectangular, thin mold with low density polyethylene. He also showed that the melt progresses in a circular pattern which becomes distorted as the melt contacts the walls.

Harry and Parrott [2] employed the numerical simulation to analyze the filling of a rectangular cavity with a gate which occupied the whole cross section of the cavity. They assumed a linear pressure drop and constant polymer properties.

Very little work is reported in the literature regarding the analysis of the packing stage. The main contribution is an attempt by Spencer and Gilmore [3] to calculate the maximum pressure in the mold by means of an equation of state and an empirical relation for filling time. The bulk of the other work deals with the thermodynamics of the packing stage, especially it relates to shrinkage [4].

Literally no work is reported in the literature regarding the analysis of the flow in gates and runners or the effect of wear and tear of gates and runners on the molded products. My work is conducted to study and analyze the effect of wear and tear of gates and runners of multi-cavity injection mold by naturally imbalance the flow. For this work a mold of two cavities with the volume in ratio of 2:1 is used. The gates and runners in one flow of the mold are varied at a time and analyzed the flow pattern in the mold for each change in gate and runner dimension. Flows in runners and gates of circular and rectangular geometries are analyzed because these are the most widely used geometries that are being used in real life.

1.7 OUTLINE

The rest of the thesis is organized as follows: Chapter 2 highlights the injection molding process, various injection molds, different kinds af gates and runners presently being in use. Chapter 3 The moldflow package that is being used in working, Chapter 4 the test case for each polymer, Chapter 5 the significant results, Chapter 6 the discussions on the the results that are observed, Chapter 7 and 8 the conclusions and the further Work that can be done in this area.

CHAPTER 2

INJECTION MOLDS

2.1 TYPES OF MOLDS

The function of a mold is twofold: imparting the desired shape to the plasticized polymer and cooling the injection molded part. It is basically made of two sets of components: (1) the cavities and cores and (2) the base in which the cavities and cores are mounted. The separation between the two mold halves is called the parting line.

There are basically six injection molds in use today, constituting about a two billion dollar market in the United States alone. These types are: (1) the cold-runner two-plate mold; (2) the cold-runner three plate mold; (3) the hot-runner mold; (4) the insulated hot-runner mold; (5) the hot manifold mold; and (6) the stacked mold. All these molds are illustrated in Fig.2.1and Fig.2.2

2.1.1 COLD RUNNER TWO PLATE MOLD

A two-plated mold consists of two plates with the cavity and cores mounted in either plate as shown in Fig. 2.1. The plates are fastened to the press platens, and the moving half of the mold usually contains the ejector mechanism and the runner system. All basic designs for injection molds have this design concept. A two-plate mold is the most logical type of tool to use for parts requirelarge gates. This cold-runner system results in the sprue, runners, and gates solidifying the cavity plastic material.

2.1.2 COLD RUNNER THREE PLATE MOLD

The three-plate is made up of three parts: (1) the stationary or runner plate, which is attached to the stationary platen and usually contains the sprue and half of the runner; (2) the middle or cavity plate, which contains half of the runner and gate and is allowed to float when the mold is open and (3) the movable or force plate, which contains the molded part and the ejector system for the removal of the molded part is shown in Fig.2.1

When the press starts to open, the middle plate and the movable plate move together, thus releasing the sprue and the runner system and degating the molded part. This type of cold-runner mold design makes it possible to segregate the runner system and the part when the mold opens. In the hot runner, the runners are kept hot in order to keep the molten plastic in a fluid state at all times. In effect this is a runnerless molding process. In runnerless molds, the runner is contained in a plate of its own.

2.1.3 HOT-RUNNER MOLD

Hot-runner molds are similar to three-plate injection molds, except that the runner section of the mold is not opened during the molding cycle(see fig. 2.1). The heated runner [late is insulated from the rest of the cooled mold. Other than the heated plate for the runner the remainder of the mold is a standard two plate die.

The runnerless molding has several advantages over conventional cold runner type molding. There are no molded site products to be disposed of or reused, and there is no separating of the gate from the part. The cycle time is only as long as required for the molded part to be cooled and ejected from the mold.

In the system, a uniform melt temperature can be attained from the injection cylinder to the mold cavities. Shot size capacity and the clamp tonnage required in the injection molding machine are decreased by the size of the sprue and runners.

2.1.4 INSULATED HOT RUNNER MOLD

The insulated hot-runner is a variation of the hot-runner mold. In this type of molding the molding the outer surface of the material in the runner acts like an insulator for the molten material to pass through as shown in fig. 2.2. In the insulated mold, the molding material remains molten by retaining its own heat. Sometimes a torpedo and a hot probe are added for more flexibility.

This type of mold is ideal for multicavity center-gated parts. The size of the runner is almost twice the diameter when compared to the cold-runner system.

2.1.5 HOT MANIFOLD MOLD

The hot-manifold is a variation of the hot-runner mold. In the hot-manifold die, the runner, and not the runner plate, is heated. This is done by using electric-cartridge-insert probes in sprue, runners and gates.

2.1.6 STACKED MOLD

Basically a stacked mold is a multiple two plate mold with the molds placed one on top of the other as shown in fig. 2.2. This construction can also be used with three plate, hot runner and insulated hot runner molds. A stacked two-mold construction doubles the output from a single press and only requires the same clamping force on the mold if a duplicate set of cavities is used or the maximum clamping crossing-section area is not exceeded. The machine will require additional shot capacity. Stacked molds are also being used with more than two plates.

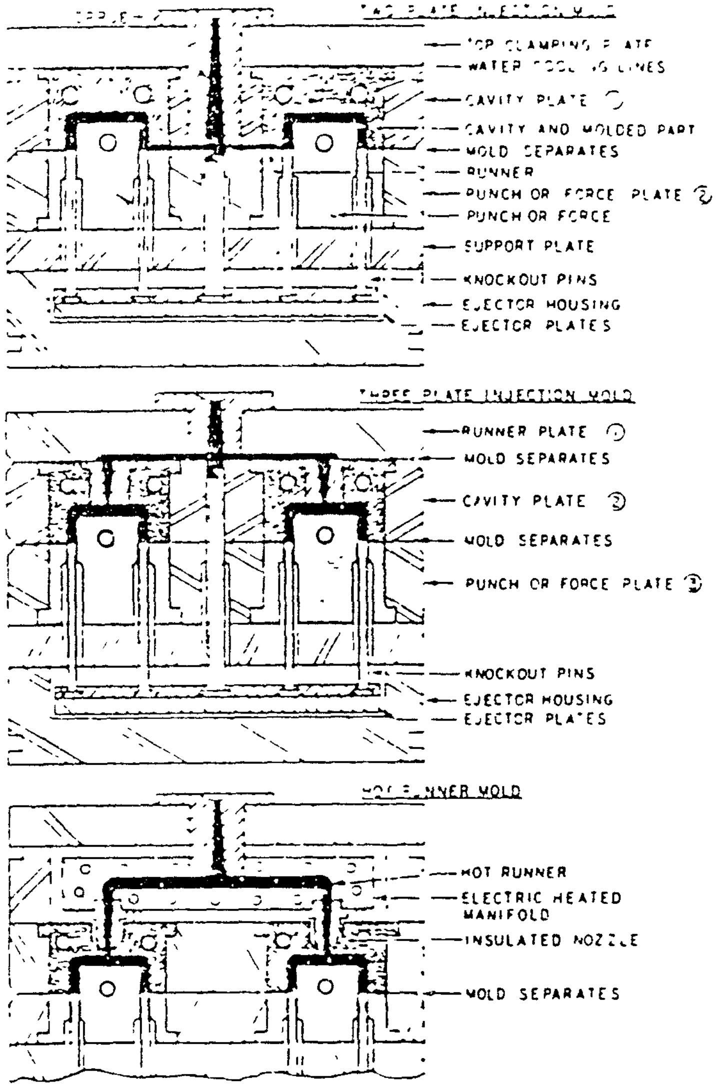


Fig. 2.1 Types of Injection Molds (From: ref.[7])

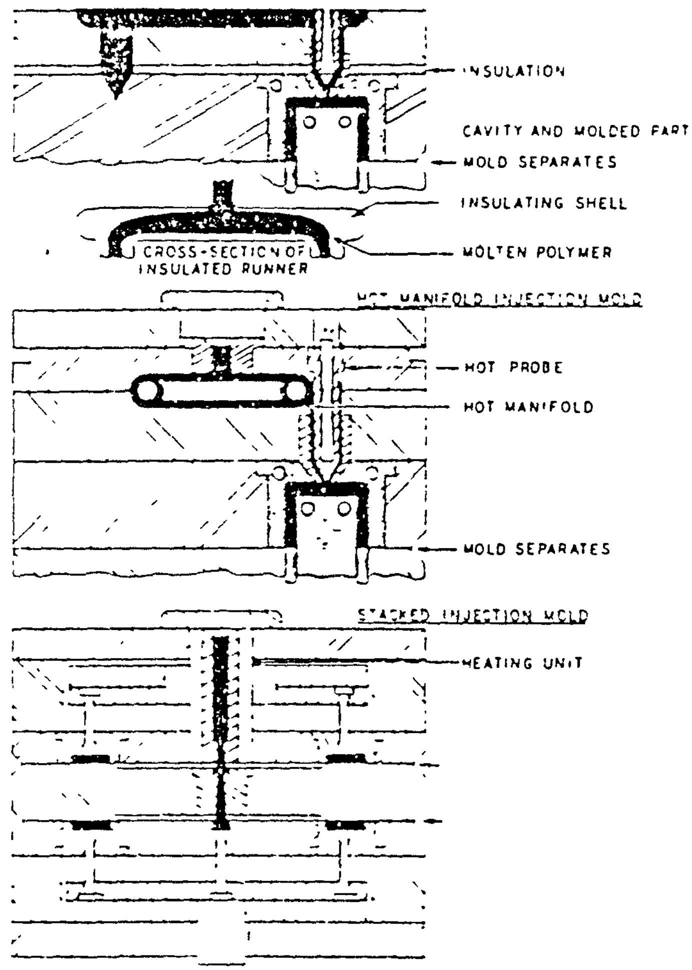


Fig. 2.2 Types of Injection Molds (From: ref.[7])

2.2 TYPES OF GATES

The gate is given a smaller cross section than the runner so that the molding can be easily separated from the runners. The location of the gate must be such that weld lines are avoided. Weld lines reduces strength and spoil the appearance of the molding particularly in the case of glass fibre reinforced plastics. The gates must be so located that the air present in the mold cavity can escape during injection .

The following gate types which are shown in Fig.2.3 are usually employed, and each has its own advantage for application.

2.2.1 DIRECT GATE

For single cavity mold where the sprue feeds material directly into the cavity a direct gate is applied.

2.2.2 PINPOINT GATE

Generally used in three plate and hot runner mold construction, it provides rapid freeze off and easy separation of the runner from the part. Advantage of the pinpoint gate is that it can easily provide multiple gating to a cavity.

2.2.3 SUBMARINE GATE

Used in multicavity molds, it degates automatically, so it is particularly suitable for automatic operation. For multiple cavities in angular gate entrance requires special care in machining during mold making.

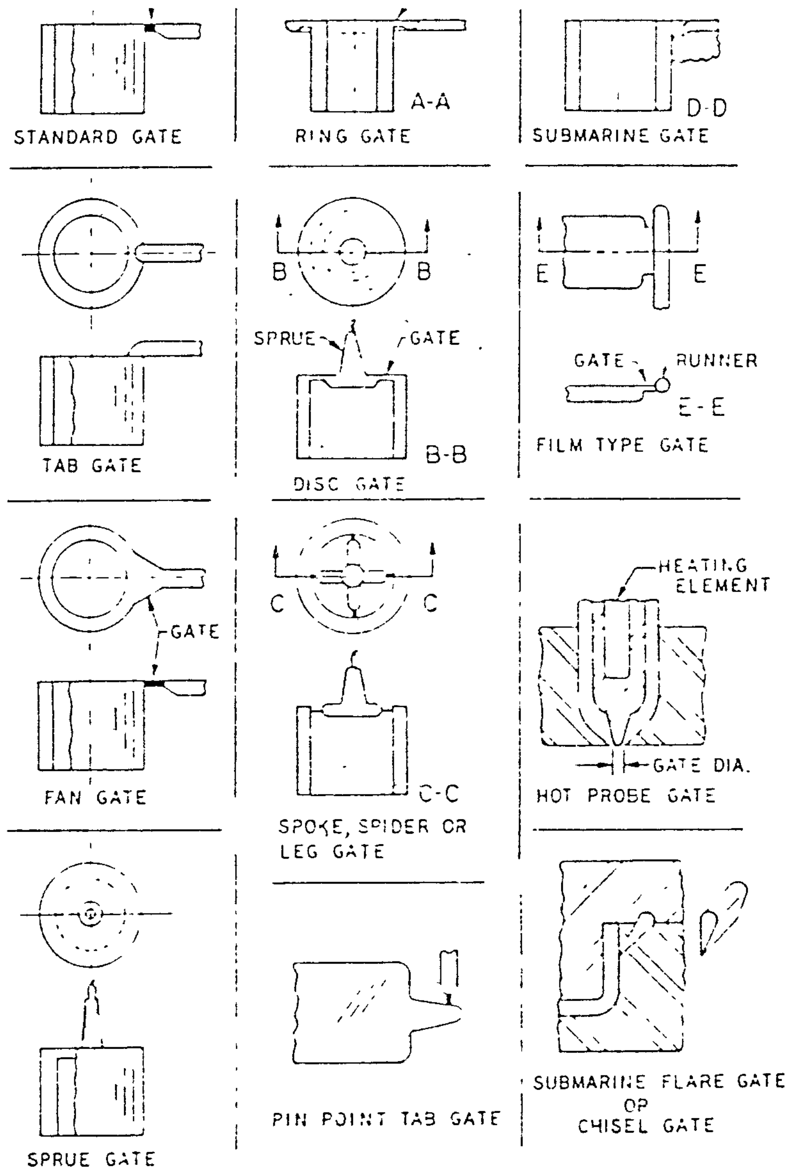


Fig. 2.3 Types of Gates (From: ref.[8])

2.2.4 TAB GATE

This gate is used in cases where it is desirable to transfer the stress generated in the gate to an auxiliary tab, which is removed in a post molding operation. Flat and thin parts require this type of gate.

2.2.5 EDGE GATING

Edge gating is carried out at the side or by overlapping the part. It is commonly employed for parts that are machine-attended by an operator. When degating is performed with the aid of the auxiliary equipment it becomes necessary to construct holding devices.

2.2.6 PIN OR FLASH GATE

This gate is used when the danger of the part warpage and dimensional change exist. It is especially suitable for flat parts of considerable area.

2.2.7 DIAPHRAGM AND RING GATE

This gate is used mainly for cylindrical and round parts on which concentricity is an important dimensional requirement and a weld line presence is objectionable.

2.2.8 INTERNAL RING GATE

This gate is suitable for tube shaped articles in single cavity molds.

2.2.9 FOUR PIN GATE

This is also used for tube shaped articles and offers easy debating. Disadvantages are possible weediness and the fact that perfect roundness is unlikely.

2.2.10 HOT PROBE GATE

This may also be called an insulated runner gate, and is used in runnerless molding. In this type of molding the molten plastic material is delivered to the mold through the heated runners thus minimizing the finishing and scrap costs.

Where cavities are of different shot weights, the gate size of one cavity may be established arbitrarily as follows:

1.38 For round gates:

$$d2 = d1(w2/w1)1/4$$

1.39 For rectangular gates (assuming gate width constant):

$$t2 = t1(w2/w1)1/3$$

where $d1$ = gate diameter of the first cavity

$d2$ = gate diameter of the second cavity

$t1$ = depth of gate in first cavity

$t2$ = depth of gate in second cavity

$w1$ = weight of first cavity component

$w2$ = weight of second cavity component

2.3 RUNNER SYSTEMS

The function of the runner system is to transmit the hot melt to the cavities with the minimum material and pressure drop waste.

The conduit length must be kept to a minimum level and cross section should be optimally set for low pressure drop relatively slow cooling, avoiding premature solidification and short shots.

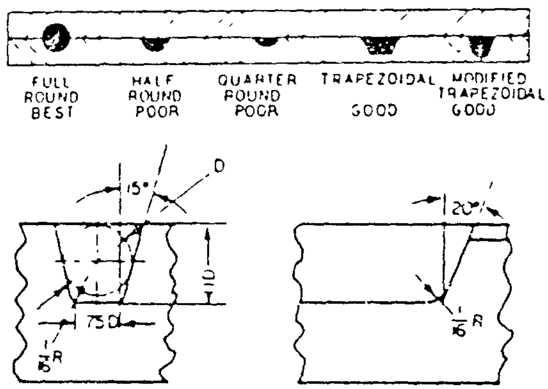
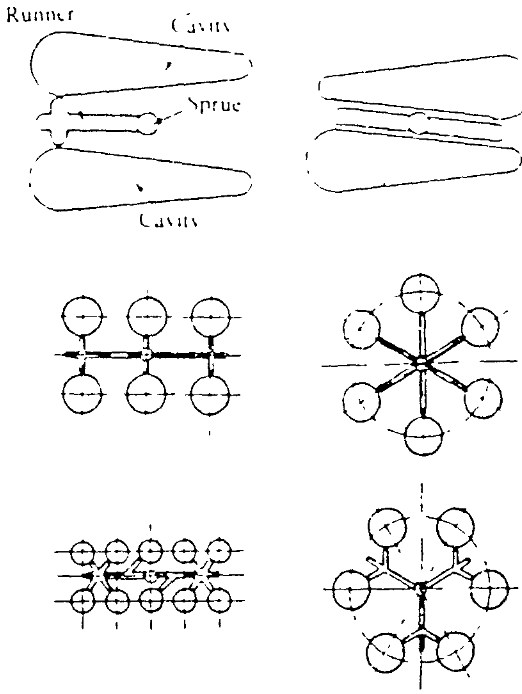


Fig. 2.4 Different Shapes of Runners (From: ref.[8])



Examples of cavity layout in multicavity molds Right views show balanced systems, and left views are unbalanced systems except for top left that is balanced.

Fig. 2.5 Layout in multicavity molds (From: ref.[7])

Cavities should be placed so that (1) the runner is short and, if possible, free of bends, and (2) the supply of material to each cavity is balanced.

A balanced supply ensures that any change made in any one of the molding parameters will affect all cavities in the same direction. The surface finish of the runner system should be as good as that in the cavity.

The runners in multi cavity molds must be large enough to convey the plastic melt rapidly to the gates without excessive chilling by the relatively cool mold. Runner cross sections that are too small require higher injection pressure and more time to fill the cavities.

Large runners produce a better finish on the molded parts, and minimize weld lines, flow lines, sink marks, and internal stresses.

Various shapes of runners used in common are shown in Fig. 2.4. A full round runner is always preferred over any other cross-sectional shape, as it provides the minimum contact surface of the hot plastic with the cool mold.

The layer of plastic in contact with the metal mold chills rapidly, so that only the material in the central core continues to flow rapidly. A full round runner requires machining both halves of the mold, so the two semi circular portions are aligned when the mold is closed.

There are, however, many mold designs that make it desirable to incorporate the runner in one plate only. In that case, a trapezoidal cross section is used, of a sizethat will surround a corresponding round diameter. If the trapezoid can be cut so that it would exactly accommodate fully round runner of the desired diameter with the sides of the runner tapered at 5 to 15 degrees from vertical above the halfway line, this is almost as good as the round runner.

2.3.1 DESIGN OF RUNNER SYSTEM

Generally the runner is 1.5 times the characteristic thickness of the molded part. There are techniques for computing the minimum runner size required to convey melt at the proper rate and pressure loss to achieve optimum molded part quality. Examples of cavity layout in multi cavity molds for balanced and unbalanced systems are shown in Fig. 2.5.

The computations are based on a key rheological property of the material to be molded. This property of the material's shear rate as its melt viscosity at several commonly encountered melt temperatures for the material.

Engineering a runner system requires an understanding of the pressure drop of the plastic melt as it passes through a channel. This pressure drop is controlled primarily by the volumetric flow rate or injection speed, the melt viscosity, and the channel dimensions. Runner engineering should start by assuming an "ideal" melt temperature. This temperature can be found in the resin supplier's molding manual.

2.4 COOLING CHANNELS

2.4.1 MOLD VENTING

Every mold contains air that must be removed or displaced as the mold is being filled with a plastic material. The air present in the mold cavity must be allowed to escape freely during injection. Venting is done by small gaps or vents provided in the mold parting lines or by other small channels in the mold. Vents must be provided at the end of the flow paths.

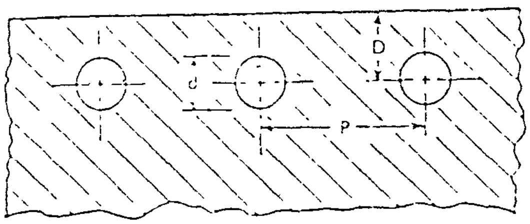
Vacuum venting of molds has not yet found widespread acceptance in injection molding of thermoplastics. However, in view of the present trend toward higher injection speeds it is most probable that in the future vacuum molds will be generally used to pre vent venting problems. In venting parts, the most minute flash may be objectionable.

Venting are most important in thermosetting than in thermoplastics. First of all runners should be vented poor to approaching the gates.

2.4.2 MOLD COOLING

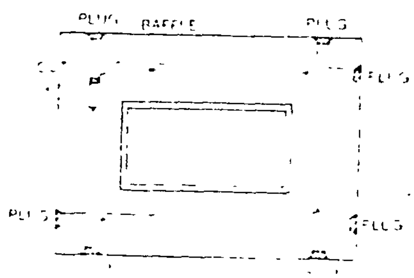
One of the most important aspects of mold design is the provision of suitable cooling arrangements. The cooling system is an essential mold feature, requiring special attention in the mold design. It should ensure rapid and uniform cooling of the molding.

Rapid cooling improves process economics, while uniform cooling improves product quality by preventing differential shrinkage, internal stresses and mold release problems. Uniform cooling ensures a shorter molding cycle. Rapid and uniform cooling is achieved by a sufficient number of properly located cooling channels. The location of this channels should be consistent with the shape of the molding., and should be as close to the cavity as allowed by the strength and rigidity of the mold.



Recommended depth and pitch
d = Diameter of Water Line = 7/16 to 9/16 inch
D = Depth of Water Line = d to 2d
P = Pitch = 3d to 5d

Recommended depth and pitch of mold cooling channels (consider depth of 1 diameter for steel, 1½ diameters for beryllium copper, and 2 for aluminum)



Examples of cavity cooling systems

Fig. 2.6 Cavity Cooling Systems (From: ref.[8])

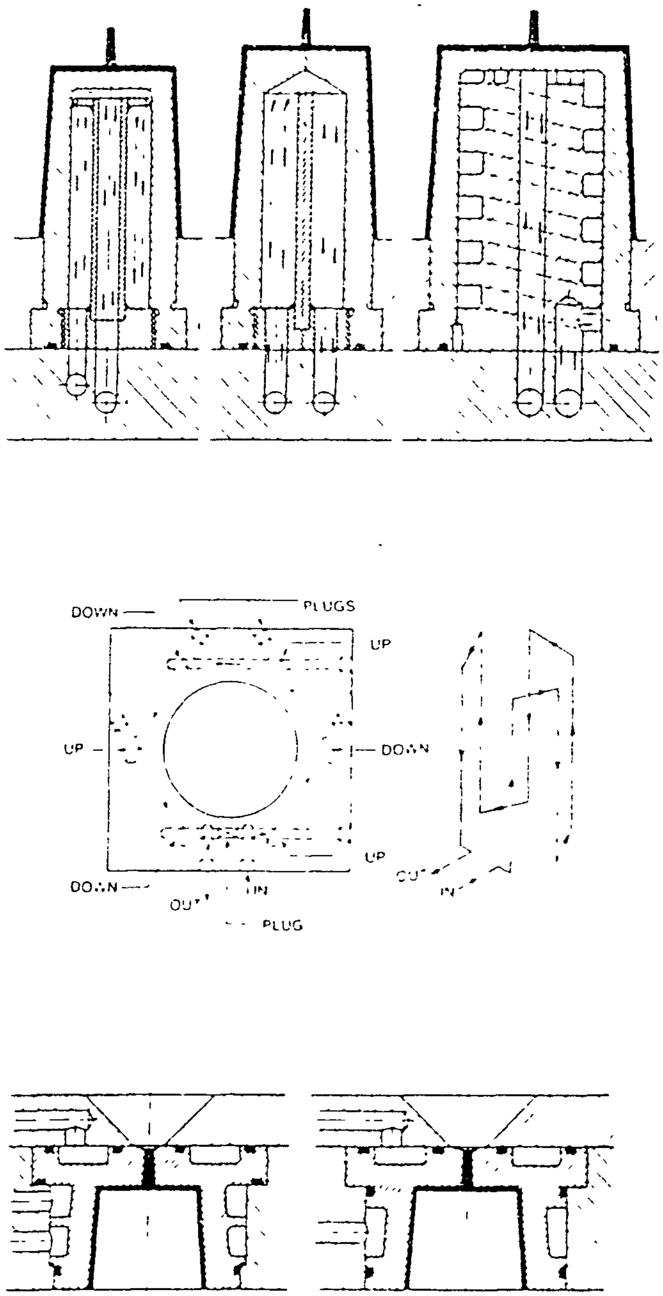


Fig. 2.7 Cavity Cooling Systems (From: ref.[8])

Increasing the depth of the cooling lines from the molding surface reduces the heat transfer efficiency, and too wide a pitch gives a nonuniform mold surface temperature as shown in the Fig.2.6. Examples of the layouts usually employed for cooling systems are shown in Fig.2.7.

The desired location of thc heating cooling passages is in the mold inserts themselves, they should be located close to where most of the heat has to be dissipated.

Fluid passages for effective mold and part cooling should be placed to cover the most of the molding surface and to be close to the mold face. The distance between mold face and the fluid passage opening has to be large enough to resist distortion or flexing of the metal under injection pressures. The dimensions of the fluid passages should be such as to create a turbulent flow, since turbulent flow will dissipate about three times as many as laminar flow.

2.5 PRINCIPLES OF MACHINE OPERATIONS

During the process of converting a plastic raw material into a finished molded product, three basic elements in modelling - time, temperature and pressure - must be correlated in a way that will produce a part with anticipated properties. Changes in any of these individually or in combination spell problems in product properties and performance characteristic.

2.5.1 TIMES

Involves these elements. Time beginning with material entering the heating cylinder until injected into the mold, time of injection into the mold, time of maintaining pressure in the mold cavity, time of solidification, press opening time, press closing time, time of ejections related to mold opening time.

2.5.2 TEMPERATURES

Temperature is affected by temperature of material entering the hopper, throat temperature, heat distributed by the screw compression and speed of rotation, heat obsorbed from the cylinder, mold temperature readings, flow control of coolant in mold passages for desired temperatures, temperature of environment.

2.5.3 PRESSURES

Pressures that require consideration are injection high pressure the pressure needed to fill cavities to proper part density, hold pressure are the pressure maintained on the material during solidification and prevents backflow into the nozzle area, back pressure which influences mixing and feeding of material into the measuring chamber, clamp pressure which indicates effective mold closing.

2.6 MOLD GEOMETRY

As shown in the fig. 2.8, the mold consists of two rectangular cavities of (5 mm x 100 mm) and (5 mm x 50 mm) uniform thickness, which are preceded by small gates and that by long runners and a sprue. Different cases are analyzed by varying the dimensions of gates and runners with rectangular and circular geometries.

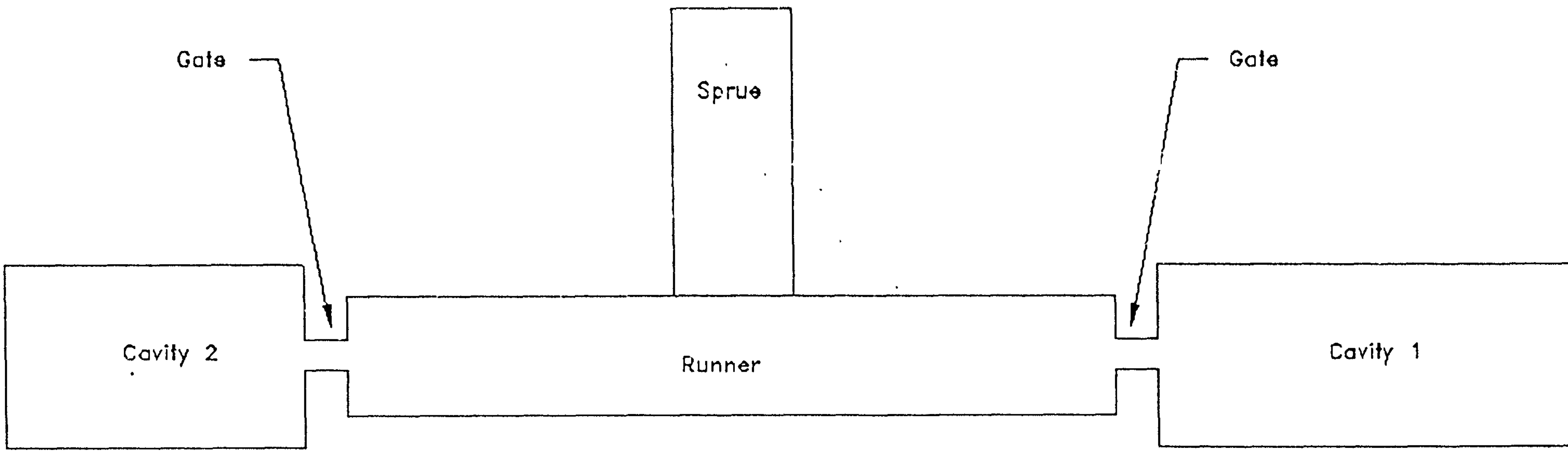


Fig. 2.8 Initial Cavity Layout

The volume of cavity in flow 1 is twice the volume of cavity in flow 2. First the flows in the two cavities are balanced for the assumed pressure by the flow balance option in the MOLDFLOW package.

CHAPTER 3

MOLDFLOW FOR BALANCING GATES AND RUNNERS

3.1 ADVANTAGES OF FLOW ANALYSIS

Recently there is a tremendous growth in the number of software products available to serve the needs of plastic industry. The computer aided Engineering technique can be applied in Injection molding to (1) maximize the probability of first time plastic part or mold functionality (2) To solve process problems such as warping, dimensional inconstancy, and long cycle times (3) to reduce molding costs such as: mold start up costs, mold rework costs, and scrap and regrind costs.

Flow analysis can provided rational solutions to many of the hard to understand problems in the Injection molding process. Computerized flow analysis has emerged as a powerful tool to aid in the implementation of applying Injection molding as the production process of choice to a widening spectrum of products. The flow analysis tool i.e., MOLDFLOW can be successfully applied and utilized by three different groups in product development: the product designer, the mold designer, and finally the injection molder.

The MOLDFLOW can help the product designer in selecting the material for the product, the minimum practical wall thickness for the part, and the location of the gate. For the mold designer it helps in analyzing the good filling pattern, optimal gate locations and the number of gates and in successful design of variety of runner systems in balancing the multi cavities. And finally the Injection molders can anticipate the benefit the flow analysis of the quality, cost, and processability of the products they produce. By reducing stress and part warpage, material saving, less overpacking, and minimizing the runner size and regrinding costs.

3.2 BASIC MOLDFLOW TECHNOLOGY

The Moldflow programs were developed in Australia, by Colin Austin over ten years ago. Moldflow is a registered trademark of Moldflow Australia. Using a number of different methods, we can describe the part's geometry to the computer. Then by selecting, from a data bank of tested material, we will have the information to run with the part description, through several subroutines within the program.

Within the main program for Moldflow, there is a simple procedure that gives a selection of 13 choices:

3.2.1 TO PRINT MOLD FILE

The computer works in meters, which is not the most readable system; so option 1 lets us print the dimensions of the mold file in meters, millimeters, or the inches.

3.2.2 TO GO TO REDIMENSION SUBROUTINE

As an analysis develops, some dimensions will need to be changed within the mold file. This option allows us to manually change any section.

3.2.3 TO CHANGE MATERIAL FILE

Often a molder will be looking at two or more materials. At this time there are more than 500 materials on file in the databank. Because there are over ten times that number of materials, many suppliers are beginning to test their material to the Moldflow standards. This will help sell and support material choices.

3.2.4 TO CHANGE MOLD FILE

Because each part must be looked at by itself, a provision has been made to bring into the program any one of number of different mold files. Also different runner systems can be viewed under the same conditions.

3.2.5 TO ANALYZE SINGLE FLOW

Within a single part, many different directions are taken by the plastic as it fills the cavity. This option will allow the study of these flows, one at a time.

3.2.6 TO ANALYZE ALL FLOWS

There is also the provision to look at the complete system, to see what happens to every flow within an analysis.

3.2.7 TO SCAN INJECTION TIME

As the designer is first developing his analysis, an average mold and melt temperature is first established. Using this hit and trial setting, the correct fill time may be brought about.

3.2.8 TO FLOW BALANCE

Once everything is known about the flow of the material through the system, speedy balancing of each flow is done with this option. Certain sections are set as being changeable by the computer to arrive at a total pressure for all of the flows.

3.2.9 TO MAKE EQUIVALENT RECTANGLE

In order to make it easier to balance a runner system, the part can be turned into an equivalent section that has the same pressure. This way very long mold files are eliminated.

3.2.10 TO STORE RESULTS

As analysis is progressing, some printouts are discarded as being too high or too low, too hot or too cold. Only the results that are of value to the analysis are saved and put into a store file, waiting to be printed out for the final report.

3.2.11 TO SPECIFY FLOW RATE

Once the optimum condition s have been established for the part, the flow rate is known. This then can be used to set the fill time for the runner file.

3.2.12 TO COPY CURRENT MOLD FILE

As the computer or the operator changes sections, by wall thickness or diameter or flow lengths, these descriptions can be saved under their own file name for later use.

3.2.13 TO END

Using a few subroutines, the designer has been able to do what has only been, up to this time, possible by trial and error. It was often at great expense, with many delays and sometimes with disastrous.

CHAPTER 4

THE ROLE OF RHEOLOGY IN MOLD FILLING

The rheological properties of a melt govern the way it deforms and flows in response to applied forces as well as the decay of stresses when the flow halted. In mold filling, it is viscosity, along with the thermal properties, that governs the ability of the melt to fill the mold, that is, the pressure required to force the melt through the runner and gate and into the cavity. Viscosity plays an important role in mold filling process.

4.1 MELT FLOW

The objective of injection molding process is to produce a product that is free of voids and sink marks, is not subjected to warpage, and has sufficient strength and stiffness for its end use. This requires that the melt flow freely into the mold cavity and that the final part be reasonably free of residual stresses.

To see more clearly the role of rheology in mold filling, it will be useful to examine the various stages of the process with special attention to shear rates and stresses. Runners are normally designed to allow the melt to reach the cavity while contributing as little as possible to overall pressure drop between the cylinder and the end of the cavity. A round runner gives the lowest pressure drop for a given flow rate.

The pressure drop in the runner can be important in the case of a multi-cavity mold because it is highly desirable to have equal flow rates to all cavities. In designing an artificially balanced runner system, one wants to adjust the flow to each cavity so that all cavities fill at about the same time. Flow rate is a function of pressure drop. For the quantitative design of runner system the temperature dependence of the viscosity and the heat transfer must also be taken into account .

The shear rate experienced by the melt in flowing from the injector system to the gate is usually around 1000 sec-1, that in the gate is much higher. The shear rate in the gate is higher in turn which will reduce the viscosity. Once the viscosity is reduced by shear gate high rates, the melt will continue to flow with this reduced viscosity for a time as it enters the cavity, even though the shear rate in the cavity is much higher. The melt experiences high shear rate in the gate for only a brief period of time. Therefore it is not clear how much reduction in viscosity actually occurs in the gate, or how much this influences the cavity flow near the gate.

4.2 CAVITY FILLING

The objective in filling the cavity is to achieve complete filling without short shots while avoiding sink marks, warpage, sticking in the mold, flash, and poor mechanical properties. Some of the factors that favor complete filling, however, also promote over pressurization and residual stresses, so care must be taken in selection operating conditions for a given mold and resin.

The melt in the center has a lower viscosity due to its higher temperature, and as a result, the maximum shear rate occurs nat at the surface of the frozen layer but closer to the center. The shear rate in the cavity is generally in the range of 8000 to 15000 sec-1.

The melt does not reach the wall or the surface of the frozen wall layer by simple forward advance but rather tends to flow down the center of the cavity to the melt front and then flow out toward the wall. This can have an important effect on the direction of the flow induced orientation of the polymer molecule.

In the packing stage, flow in the delivery system falls almost to zero, and the pressure at the gate rises to approach the injection pressure. This maintains a small flow into the cavity to compensate for thermal contraction resulting from cooling and freezing. Residual stresses and orientation are present in molded parts as a result of the rapid cooling that takes place in the mold. These effects can cause warpage, delamination and poor mechanical properties, particularly low impact strength.

The shear stresses that occur in the cavity during filling provide a rough guide to the level of orientation that has been generated. Thus, a high viscosity or a high injection pressure will usually mean high orientation.

It is generally accepted that viscosity is the key rheological property in mold filling.

4.3 FILLING AND COOLING TIMES

The principal components of the cycle time are the filling and the cooling time. The relative importance of the two and thus the role played by rheology as a factor in the cycle time, depends on the shape of the cavity. For a thin cavity, the fill time will be long compared to the cooling time. This is due to slow filling as a result if the large resistance to the flow in the cavity and the rapid cooling associated with the thin section. In slow filling much of the cooling will take place during the filling stage, and this makes it particularly difficult to avoid a short shot. Rapid cooling will result in high residual stresses, and thus in a low heat distortion temperature.

In thick mold, on the other hand, the filling process makes a minor contribution to the cycle time. Little cooling occurs during filling and even complete filling and avoidance of over pressurization can accomplished entirely by means of viscosity control. When the wall is thin and the flow length is long, it is particularly desirable to use a resin with a low viscosity at high shear rates.

4.4 TEMPERATURE AND PRESSURE

Once a mold and a resin have been selected, the molder still has some flexibility in the selection of operating conditions that can help him process, the key variables being temperature and pressure. The mold temperature must be lower than the softening point of the resin, but if it is too low, high thermal stresses can cause poor part appearance and performance.

The melt temperature is more important, as it has a strong effect on both the rheological properties of the and thermal phenomena. The higher temperature leads to faster relaxation of orientation and a longer time available for relaxation. An increase in melt temperature lengthens the cycle time, increases energy costs and can lead to sticking in the mold.

Increasing the pressure is another way to achieve faster flow into the mold. As in the case of temperature increases, there are limitations on injection pressure. Increasing the pressure means a higher clamp force and higher energy consumption. It can also cause sticking, flash, and high residual stresses especially near the gate.

CHAPTER 5

RESULTS

5.1 TEST CASE FOR THE MATERIALS

A mold of geometry given in the previous chapter 2 is taken as a reference model. The material is selected from the appendix 13. The optimal operating conditions such as: mold temperature, melt temperature and the fill time are selected from the Material Database module in the MOLDFLOW package. Initially the flow in the multi cavity is balanced by assuming the pressure for the selected operating conditions, by the flow balance option in the MOLDFLOW.

Once the flow is balanced the dimensions of the gates and runners of circular and rectangular geometries are increased one at a time by an incremental steps of 0.05mm. The variations in the operating conditions as an effect of change in the dimensions are noted for each increment. It is observed that, when the dimension of gate or runner is increased in flow path 1 the pressure required to fill the cavity 1 is decreased while the flow rate remaining constant. The fill time is decreased till the pressure required to fill the cavity 1 is reached to the original assumed balanced pressure. As the fill time is deceases the flow rate increases. The flow rate at the balanced pressure is noted.

The dimensions of gate and runner of circular and rectangular geometries are varied, and each time the variation in the fill time and the flow rate are noted and the percentage change in the fill time and the flow rate are calculated. The graphs of dimension change verses the fill time, the flow rate, the percentage change of the fill time and the flow rate are plotted, for the four different materials ABS, PC, PA, and PA6 of grade, trade name, and code given in appendix 13 in the appendices. All the variations in the graphs are discussed in detail in the next chapter.

The increase and decrease of the pressure required to fill the cavities due to the wear and tear of gates and runners, causes the problems in the cavities like short shot, overpack, warpage, and flash etc., which are the reasons for bad quality end products.

5.2 Effects of Wear in Gates and Runners for Material ABS

In fig. 5.1 the effect of the axial wear of a circular gate with the original dimensions (0.8mm x 1.3mm) on the percentage change of the fill time and the flow rate for the material ABS is presented. This curve indicates that the axial wear causes an increase in the percentage change of fill time and flow rate. The percentage change of flow rate is higher than the percentage change of fill time.

In fig. 5.2 the effect of axial wear of rectangular gate with the original dimensions (0.8mm X 0.7mm X 1.3mm) on the percentage change of the fill time and the flow rate for the material ABS is presented. This curve indicates that the variations in percentage change of the fill time and flow rate are very high for the first increase in the length and, becomes linear thereafter.

In the figs. 5.3 and 5.4 the effect of the circular wear of circular gate with original diameter (0.8mm) and circular runner with original diameter (3mm) on percentage change of the fill time and flow rate for the material ABS is presented. Both the curves behaves in the same way for the increase in the diameter of gate and runner.

In fig. 5.5 the effect of the rectangular wear in width of rectangular gate on the percentage change of the fill time and the flow rate is shown for the material ABS. It indicates that the variation is slow until some extent and rises at a point and, becomes horizontal after that rise.

In the figs.5.6 and 5.8 the effect of rectangular wear of gate and runner of rectangular geometries on the percentage change of the fill time and flow rate are presented, for the material ABS. It is indicated that the variation is very higher for the wear in rectangular runner than in rectangular gate.

In figs. 5.9 and 5.10 the effect of axial wear in circular gate and rectangular gate on the fill time is presented, for the material ABS. It indicates that the fill time decreases as the length of the gate decreases. For the rectangular gate when the length of the gate decreased the change in fill time is very high for first decrease, after that it is very slow.

In the figs. 5.11 and 5.12 the effect of circular wear of circular gate and circular runner on the fill time is presented, for the material ABS. This curves indicates that the fill time decreases as the diameter of the gate and runner is increased.

In the fig. 5.13 the effect of the rectangular wear in width of rectangular gate on the fill time is shown for the material ABS. The curve indicates that as the width increases the fill time decreases. At one point the fill time decreases drastically and again becomes stable.

In the figs. 5.14 and 5.16 the effect of the rectangular wear of rectangular gate and rectangular runner on fill time is presented, for the material ABS. It indicates that the fill time decreases as the thickness of gate and runner increases.

In the figs. 5.17 and 5.18 the effect of the axial wear of circular gate and rectangular gate on the flow rate is shown for the material ABS. The curves indicate that the axial wear causes increase in the flow rate.

In the figs. 5.19 and 5.20 the effect of the circular wear of circular gate and circular runner on the flow rate is presented for the material ABS. This curves indicates that as the circular wear increases the flow rate increases.

In the figs. 5.21 and 5.22 the effect of the rectangular wear in gate on the flow rate for ABS material is presented. This curves shows that the wear in thickness of the gate increases the flow rate as expected, but the effect of the wear in width on the flow rate is unprotected.

In the figs. 5.23 and 5.24 the effect of rectangular wear in rectangular runner on the flow rate for the material ABS is presented. The curves indicate that when the thickness of the runner increases the flow rate also increases, where as when the width of runner is increased the flow rate does not increase as expected.

5.3 Effects of Wear in Gates and Runners for Material PC

In the figs. 5.25 and 5.26 the effect of axial wear on the percentage change of the fill time and the flow rate for the material PC is presented. This curve shows that the axial wear causes an increase in the percentage change in the fill time and the flow rate. And also the percentage change of flow rate is more than the percentage change of fill time.

In the figs. 5.27 and 5.28., the effect of circular wear of circular gate and circular runner on the percentage change of the fill time and the flow rate is represented for the material PC. It indicates that the axial wear causes an increase in the percentage change of fill time and the flow rate.

The effect of the rectangular wear of rectangular gate and rectangular runner on the percentage change of fill time and flow rate is presented in fig. 5.29, 5.30, 5.31 and, 5.32., for the material PC. This curves indicates that the percentage change increases as the dimension of the gate or runner increases. Only when the width of runner is increased the variation in percentage change is unpredictable as shown by the curves in fig. 5.31.

The effect of the axial wear of a circular gate and a rectangular gate on the fill time is shown in the Figs. 5.33 and 5.34., for the material PC. This curves shows that the axial wear in gate of circular and rectangular geometries causes decrease in the fill time.

The effect of the circular wear of a circular gate and runner on the fill time is presented in the figs. 5.35 and 5.36., for the material PC. This curves reveals that the circular wear causes decrease in the fill time.

The effect of rectangular wear of rectangular gate and runner on the fill time is presented in the figs. 5.37, 5.38, 5.39, and 5.40., for the material PC. Each curve shows that the rectangular wear causes decrease in the fill time.

The effect of axial wear of rectangular gate and circular gate on the flow rate is presented in the figs. 5.41 and 5.42., for the material PC. The curves shows that the flow rate increases as the length of the gate decreases, both for circular and rectangular gate geometries.

The effect of circular wear of circular gate and runner on the flow rate is presented in the figs. 5.43 and 5.44., for the material PC. The curves indicates that the flow rate increases as the diameter of gate or runner increases.

The effect of rectangular wear of rectangular gate and runner on the flow rate is presented in the figs. 5.45, 5.46, 5.47, and 5.48., for the material PC. All the curves indicates that the flow rate increases as the rectangular dimension increases. For the increase of the width in rectangular runner the flow rate increase is very low compared to the other curves, and it increases in step wise.

5.4 Effects of Wear in Gates and Runners for Material PA

In the figs. 5.49 and 5.50 the effect of axial wear on the percentage change of the fill time and the flow rate for the material PA is presented. This curve indicates that the axial wear causes an increase in the percentage change in the fill time and the flow rate. And also shows that the percentage change of flow rate is more than the percentage change of fill time.

In the figs. 5.51 and 5.52., the effect of circular wear of circular gate and circular runner on the percentage change of the fill time and the flow rate is represented for the material PA. It indicates that the axial wear causes an increase in the percentage change of fill time and the flow rate.

The effect of the rectangular weaı of rectangular gate and rectangular runner on the percentage change of fill time and flow rate is presented in fig. 5.53, 5.54, 5.55 and, 5.56., for the material PA. This curves indicates that the percentage change increases as the dimension of the gate or runner increases. Only when the width of runner is increased the variation in percentage change is unpredictable as shown by the curves in fig. 5.55.

The effect of the axial wear of a circular gate and a rectangular gate on the fill time is shown in the Figs. 5.57 and 5.58., for the material PA. This curves shows that the axial wear in gate of circular and rectangular geometries causes decrease in the fill time.

The effect of the circular wear of a circular gate and runner on the fill time is presented in the figs. 5.59 and 5.60., for the material PA. This curves reveals that the circular wear causes decrease in the fill time.

The effect of rectangular wear of rectangular gate and runner on the fill time is presented in the figs. 5.61, 5.62, 5.63, and 5.64., for material PA. Each curve shows that the rectangular wear causes decrease in the fill time.

The effect of axial wear of rectangular gate and circular gate on the flow rate is presented in the figs. 5.65 and 5.66., for the material PA. The curves shows that the flow rate increases as the length of the gate decreases, both for circular and rectangular gate geometries.

The effect of circular wear of circular gate and runner on the flow rate is presented in the figs. 5.67 and 5.68., for the material PA. The curves indicates that the flow rate increases as the diameter of gate or runner increases.

The effect of rectangular wear of rectangular gate and runner on the flow rate is presented in the figs. 5.69, 5.70, 5.71, and 5.72., for the material PA. All the curves indicates that the flow rate increases as the rectangular dimension increases. For the increase of the width in rectangular runner the flow rate increase is very low compared to the other curves, and it increases in step wise.

5.5 Effects of Wear in Gates and Runners for Material PA6

In the figs. 5.73 and 5.74 the effect of axial wear on the percentage change of the fill time and the flow rate for the material PA6 is presented. This curve shows that the axial wear causes an increase in the percentage change in the fill time and the flow rate. And also the percentage change of flow rate is more than the percentage change of fill time.

In the figs. 5.75 and 5.76., the effect of circular wear of circular gate and circular runner on the percentage change of the fill time and the flow rate is represented for the material PA6. It indicates that the axial wear causes an increase in the percentage change of fill time and the flow rate.

The effect of the rectangular wear of rectangular gate and rectangular runner on the percentage change of fill time and flow rate is presented in fig. 5.77, 5.78, 5.79 and, 5.80., for the material PA6. This curves indicates that the percentage change increases as the dimension of the gate or runner increases. Only when the width of runner is increased the variation in percentage change is unpredictable as shown by the curves in fig. 5.79.

The effect of the axial wear of a circular gate and a rectangular gate on the fill time is shown in the Figs. 5.81 and 5.82., for the material PA6. This curves shows that the axial wear in gate of circular and rectangular geometries causes decrease in the fill time.

The effect of the circular wear of a circular gate and runner on the fill time is presented in the figs. 5.83 and 5.84., for the material PA6. This curves reveals that the circular wear causes decrease in the fill time.

The effect of rectangular wear of rectangular gate and runner on the fill time is presented in the figs. 5.85, 5.86, 5.87, and 5.88., for material PA6. Each curve shows that the rectangular wear causes decrease in the fill time.

The effect of axial wear of rectangular gate and circular gate on the flow rate is presented in the figs. 5.89 and 5.90., for the material PA6. The curves shows that the flow rate increases as the length of the gate decreases, both for circular and rectangular gate geometries.

The effect of circular wear of circular gate and runner on the flow rate is presented in the figs. 5.91 and 5.92., for the material PA6. The curves indicates that the flow rate increases as the diameter of gate or runner increases.

The effect of rectangular wear of rectangular gate and runner on the flow rate is presented in the figs. 5.93, 5.94, 5.95, and 5.96., for the material PA6. All the curves indicates that the flow rate increases as the rectangular dimension increases. For the increase of the width in rectangular runner the flow rate increase is very low compared to the other curves, and it increases in step wise like a staircase.

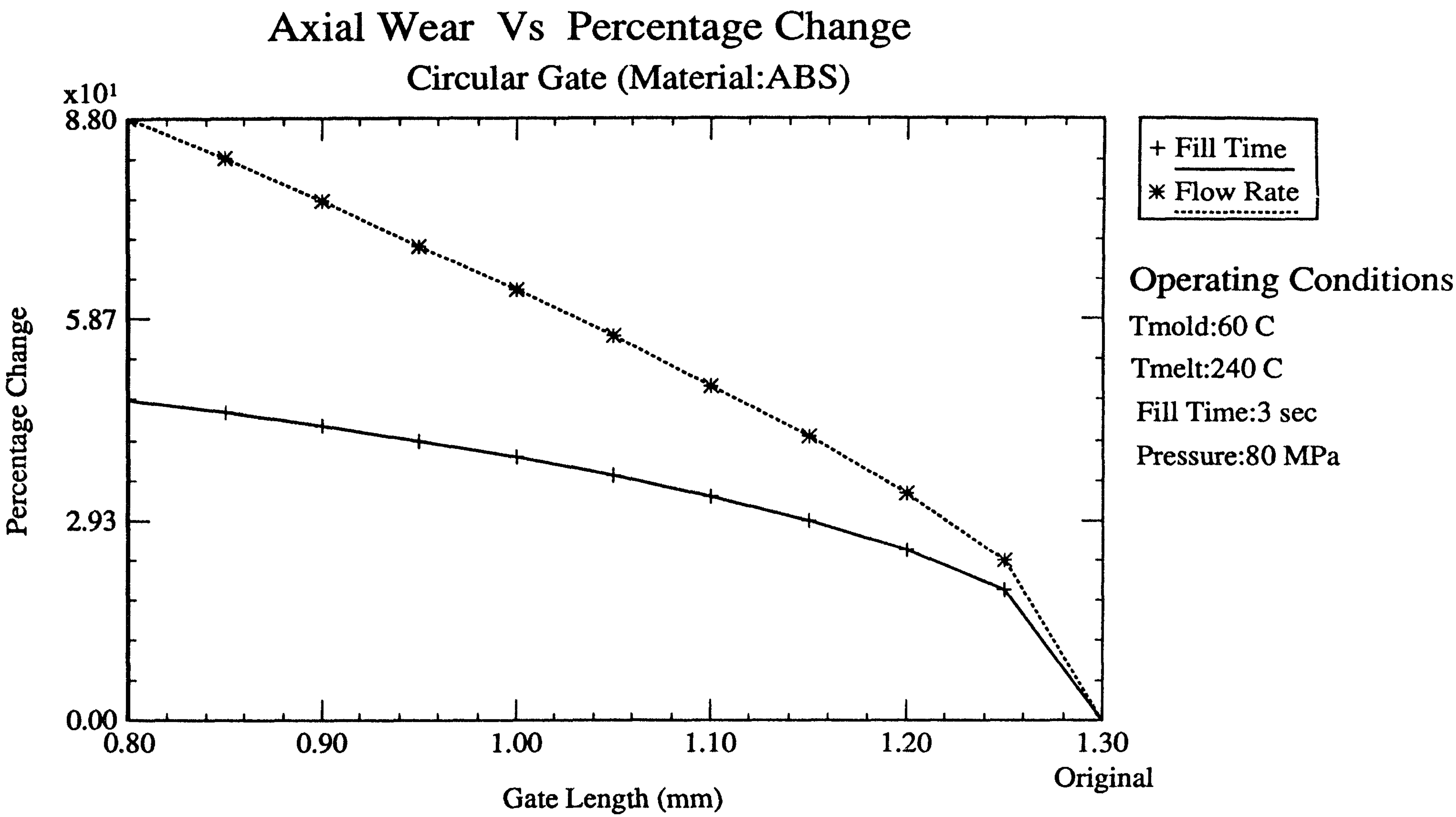


Fig. 5.1

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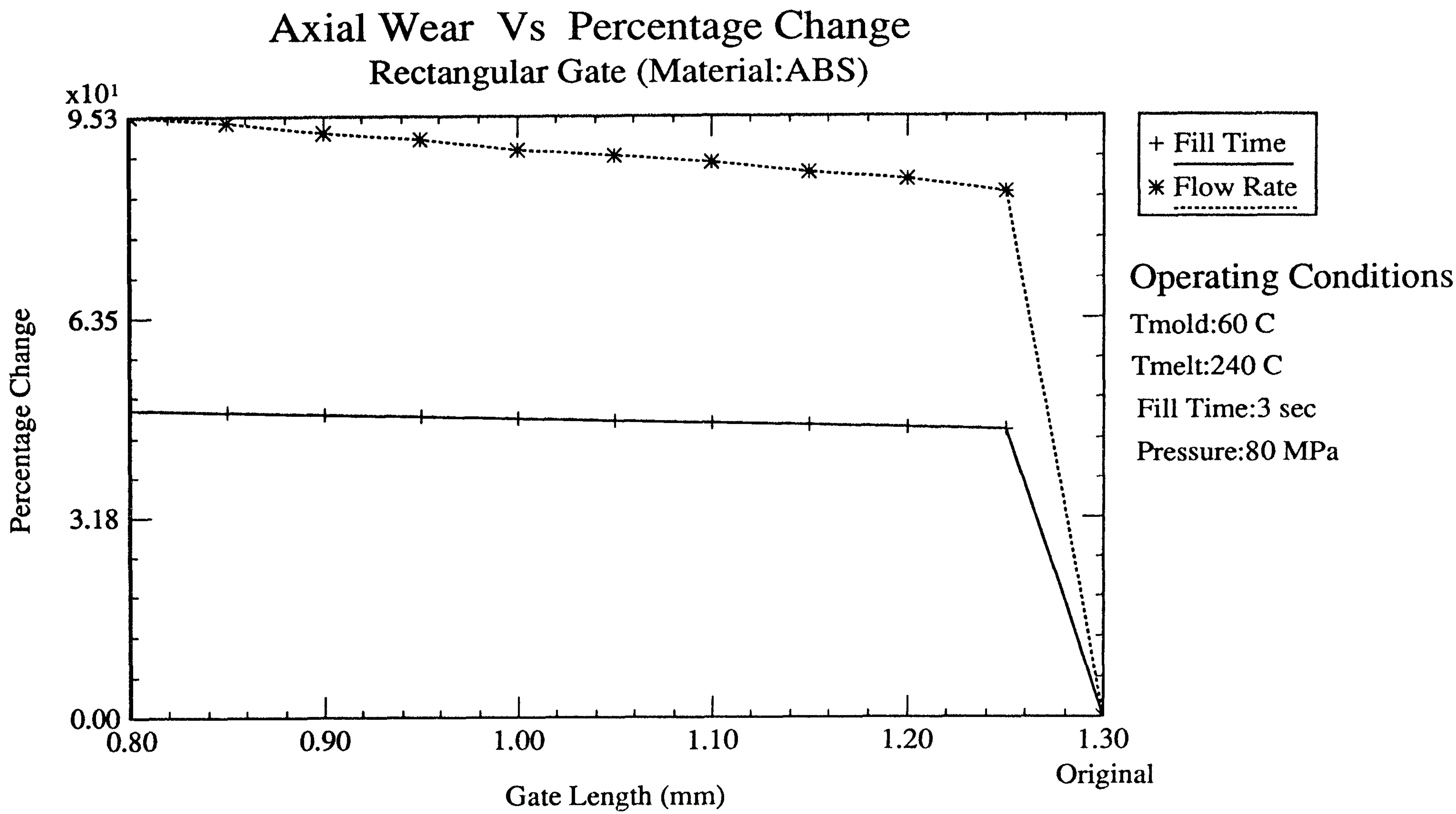

Fig. 5.2

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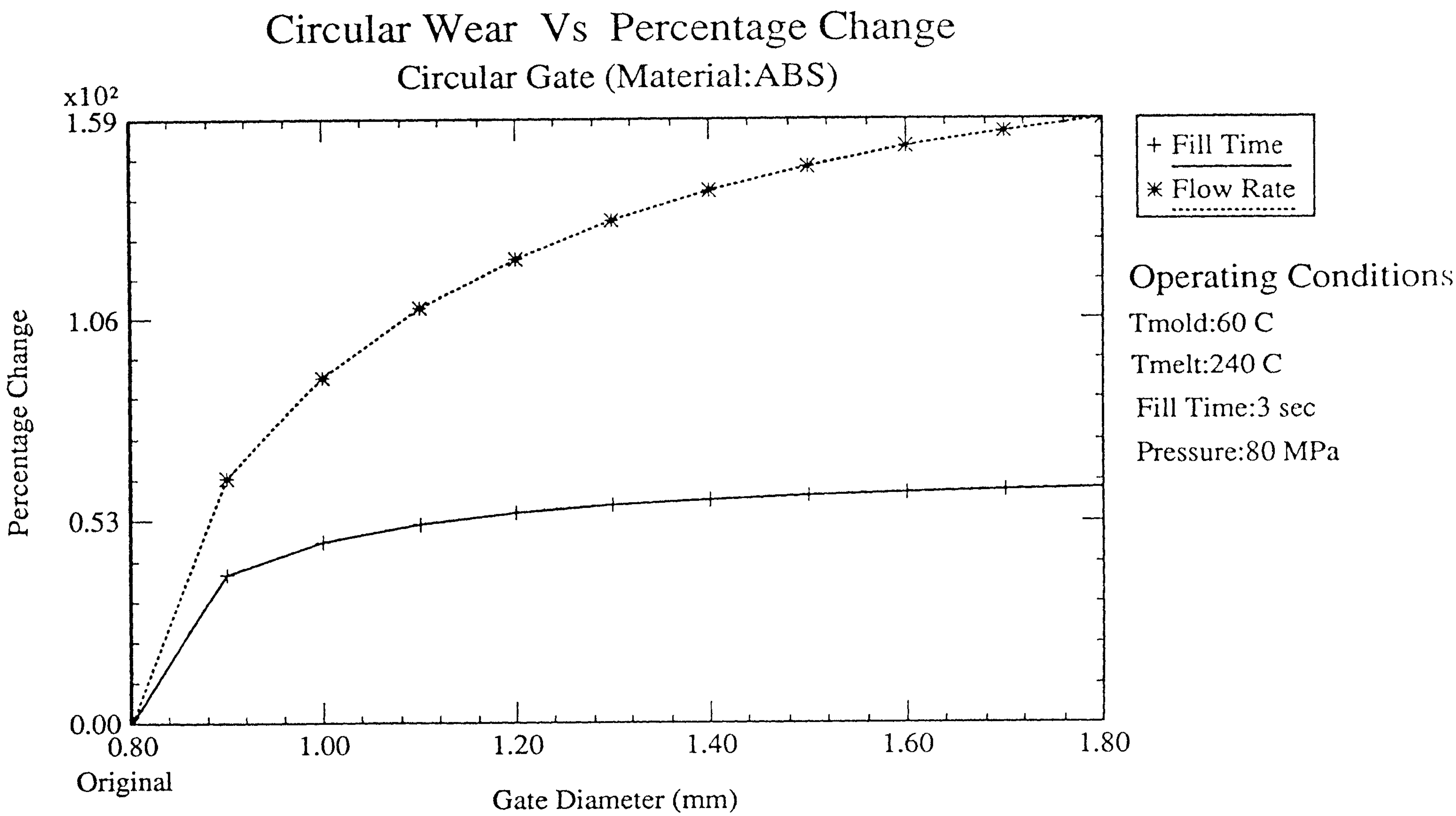

Fig. 5.3

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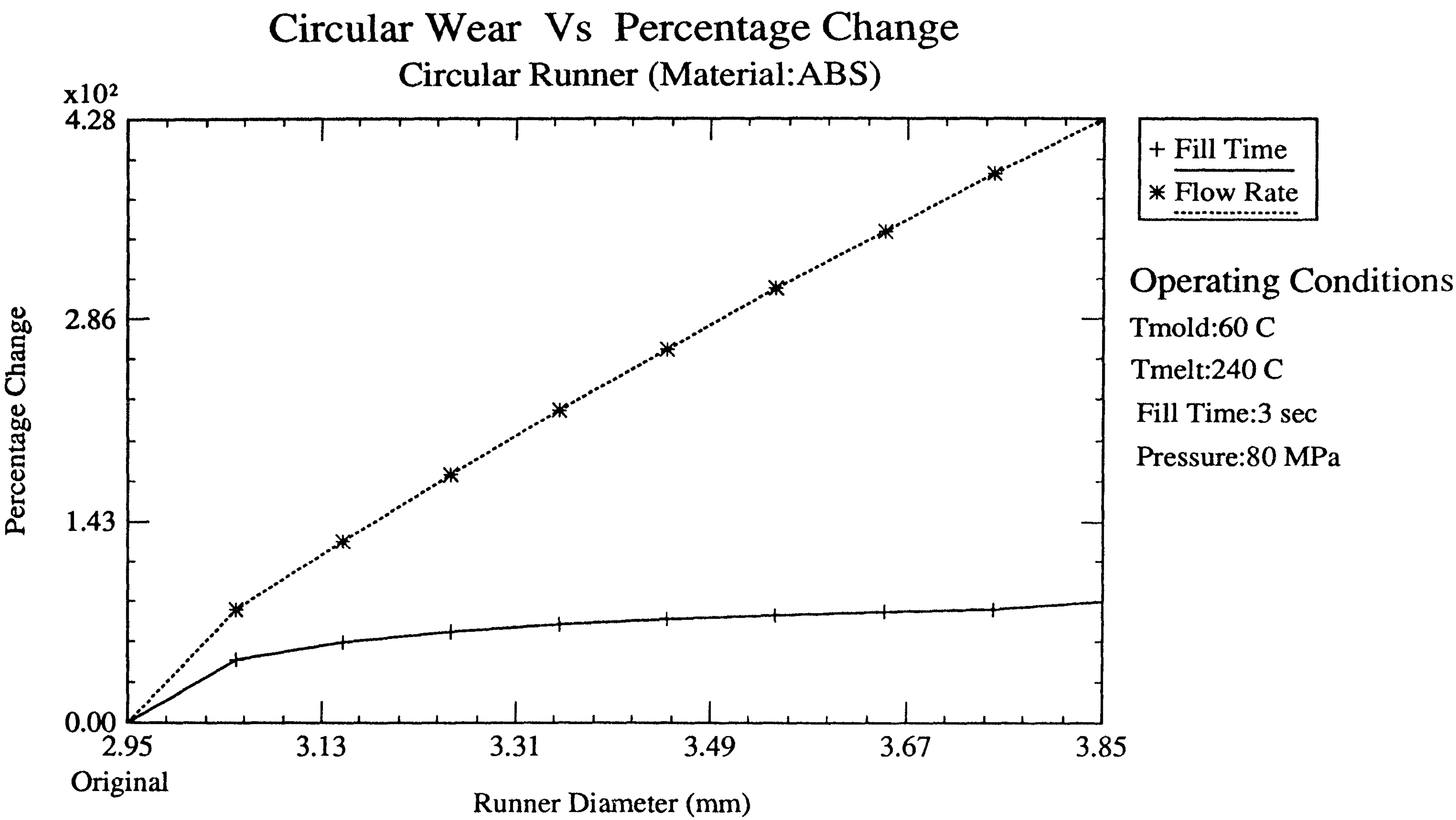

Fig. 5.4

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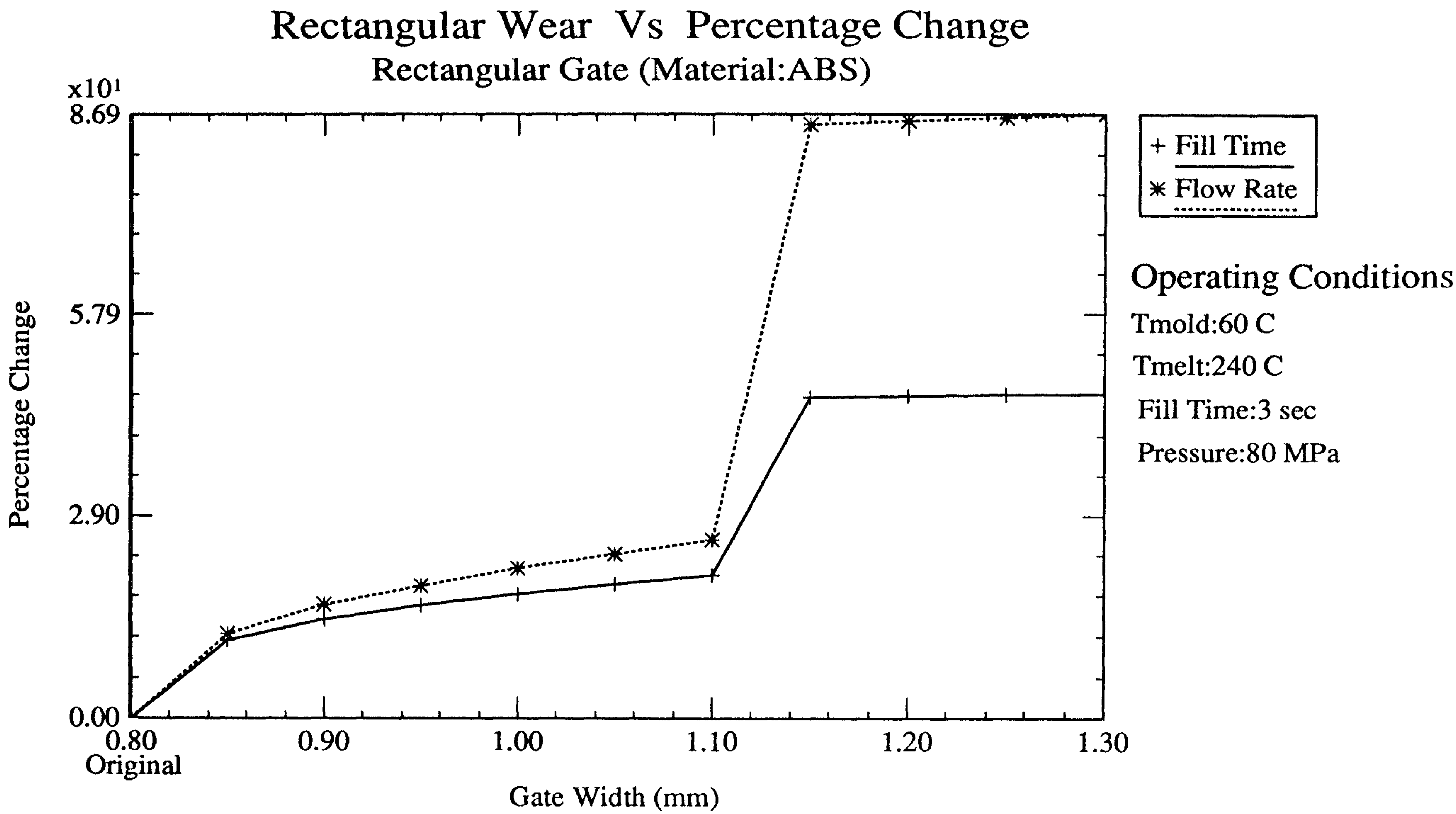

Fig. 5.5

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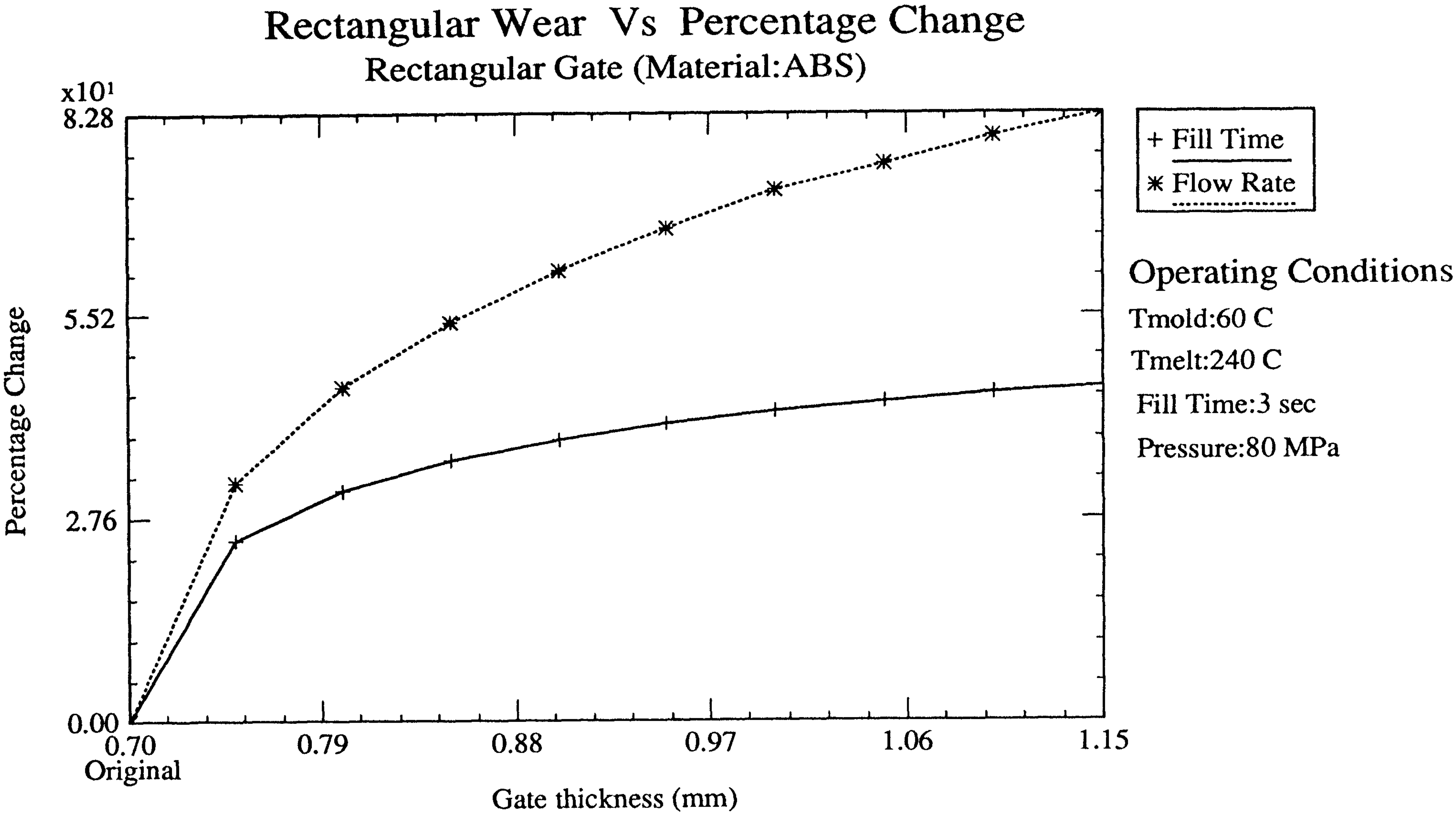

Fig. 5.6

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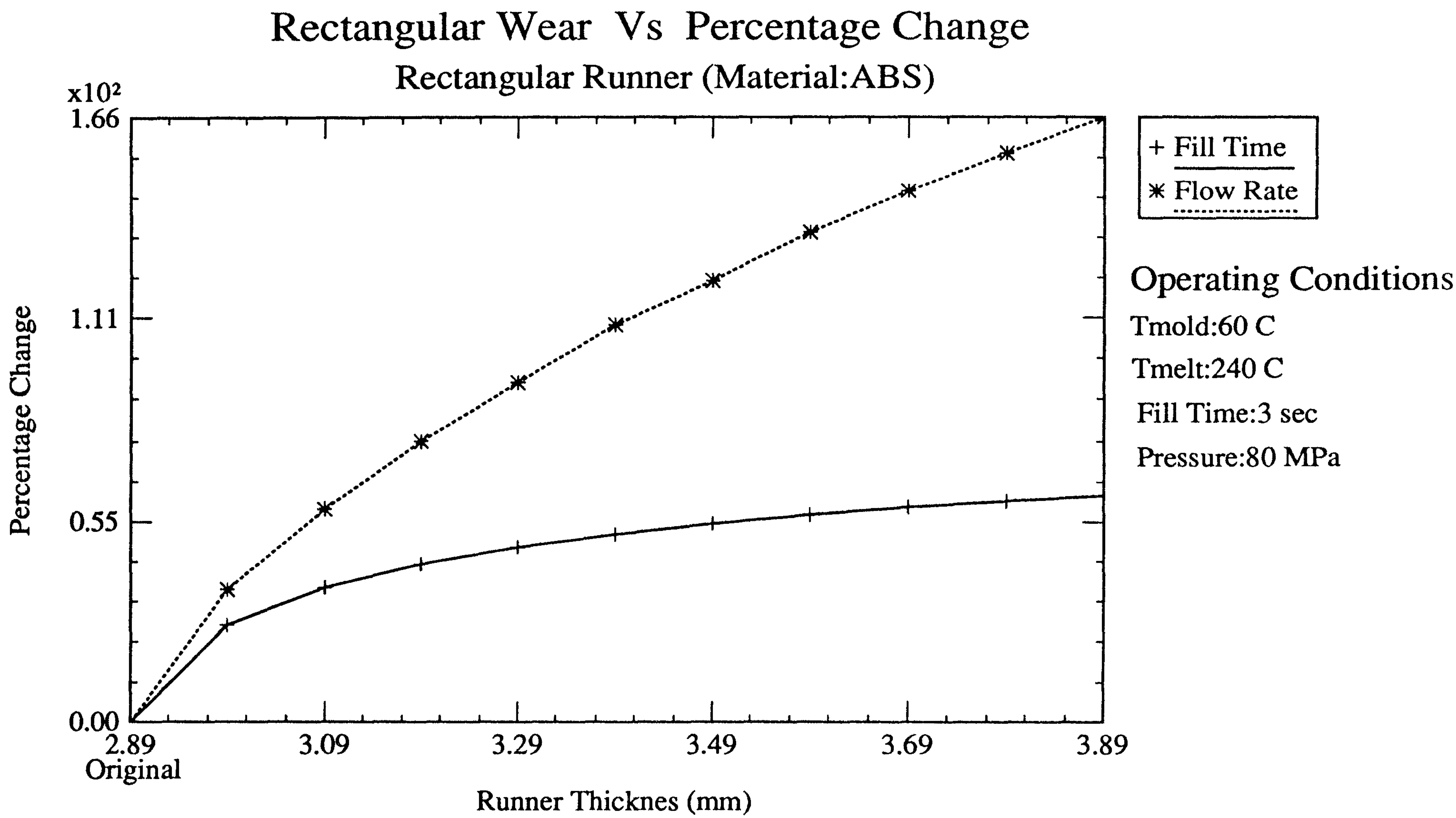

Fig. 5.8

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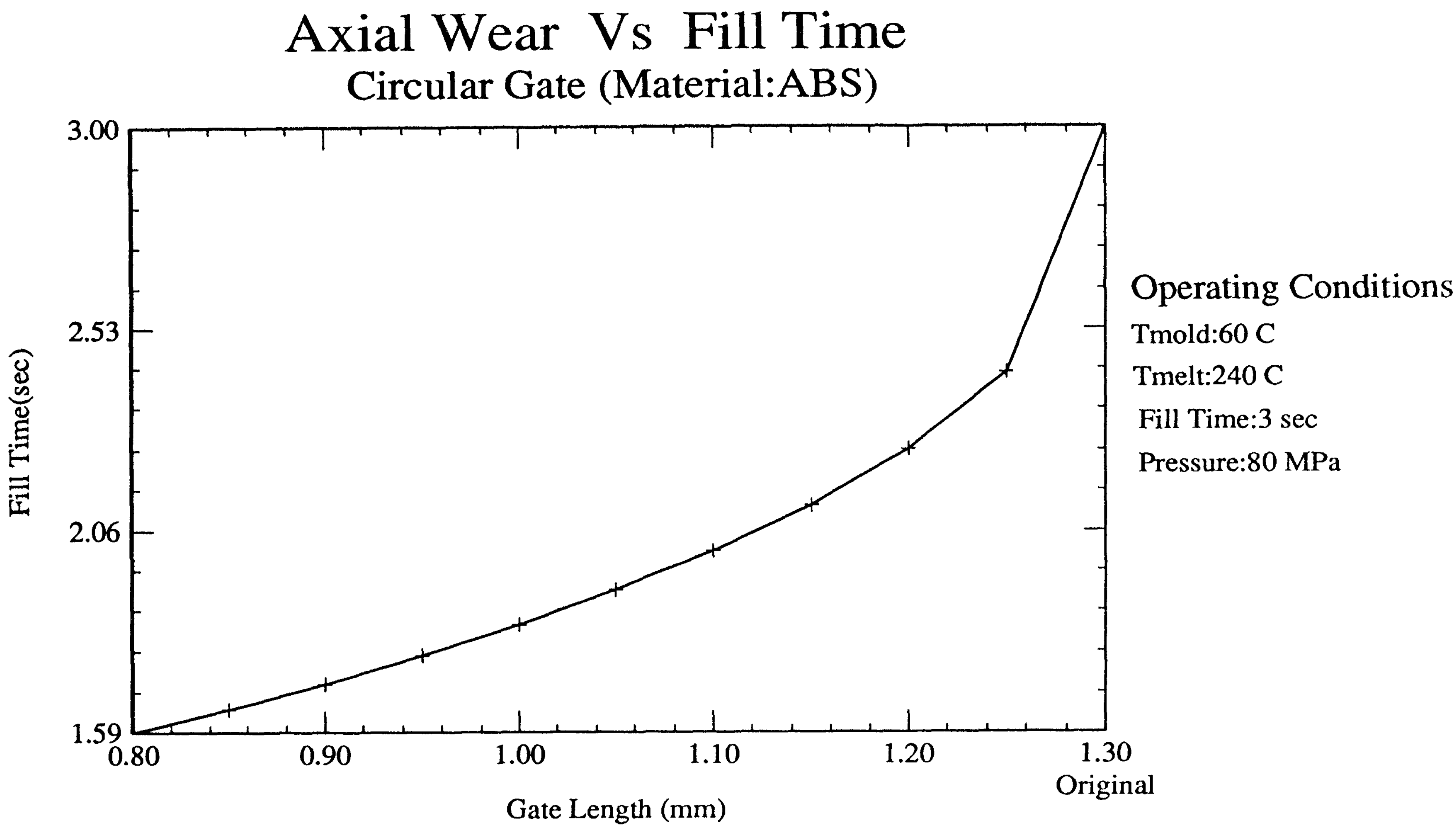

Fig. 5.9

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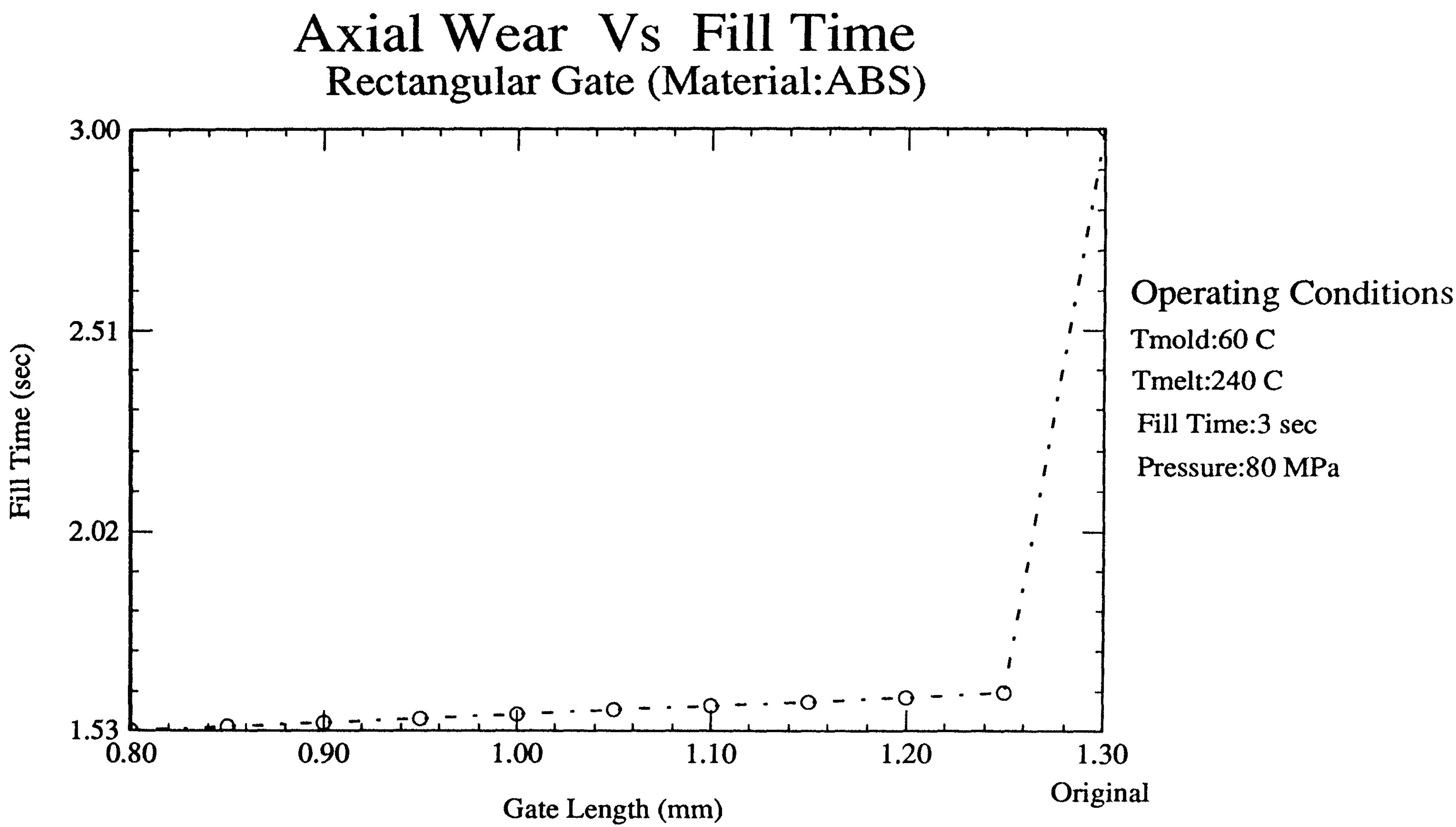

Fig. 5.10

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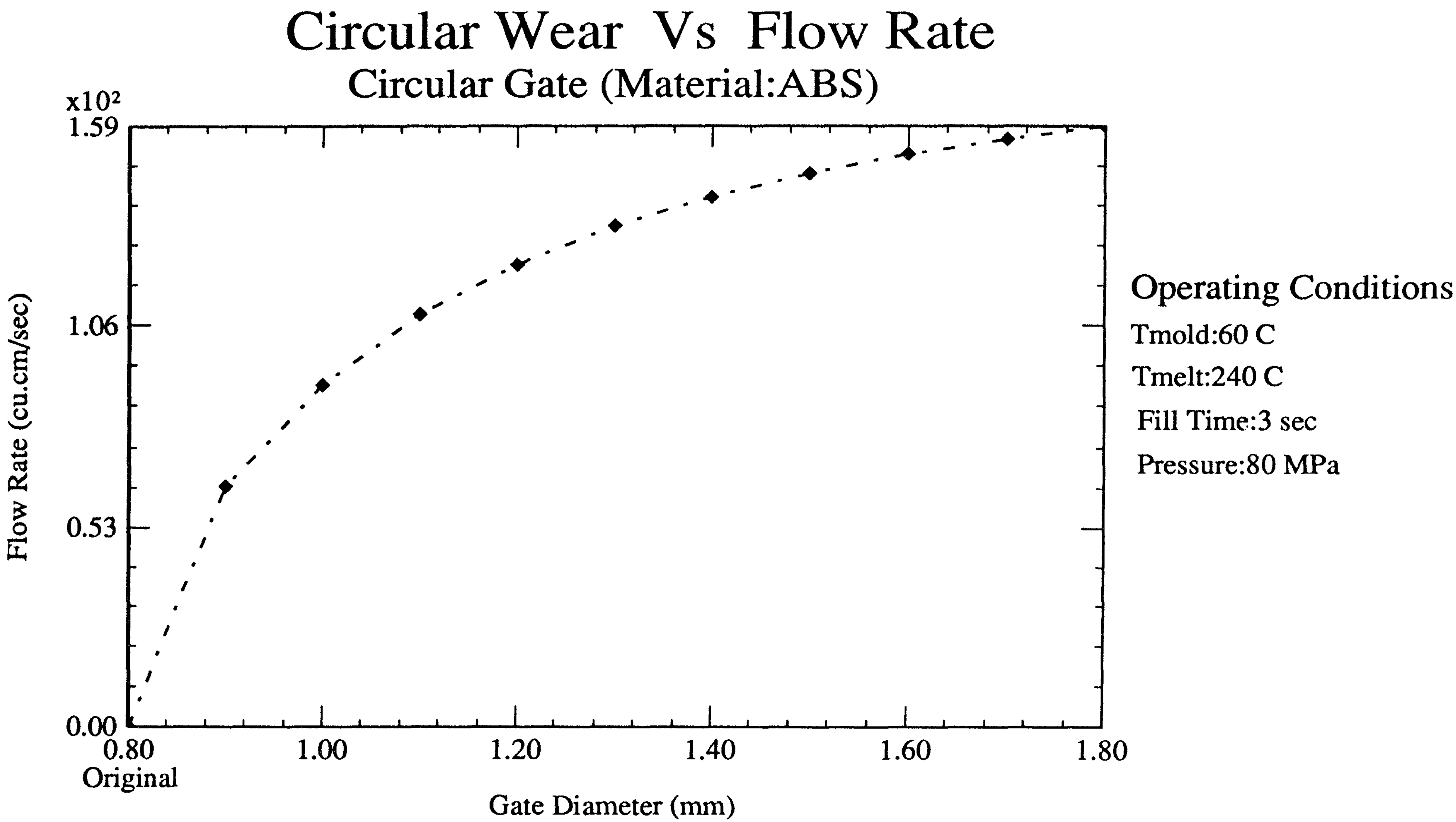

Fig. 5.11

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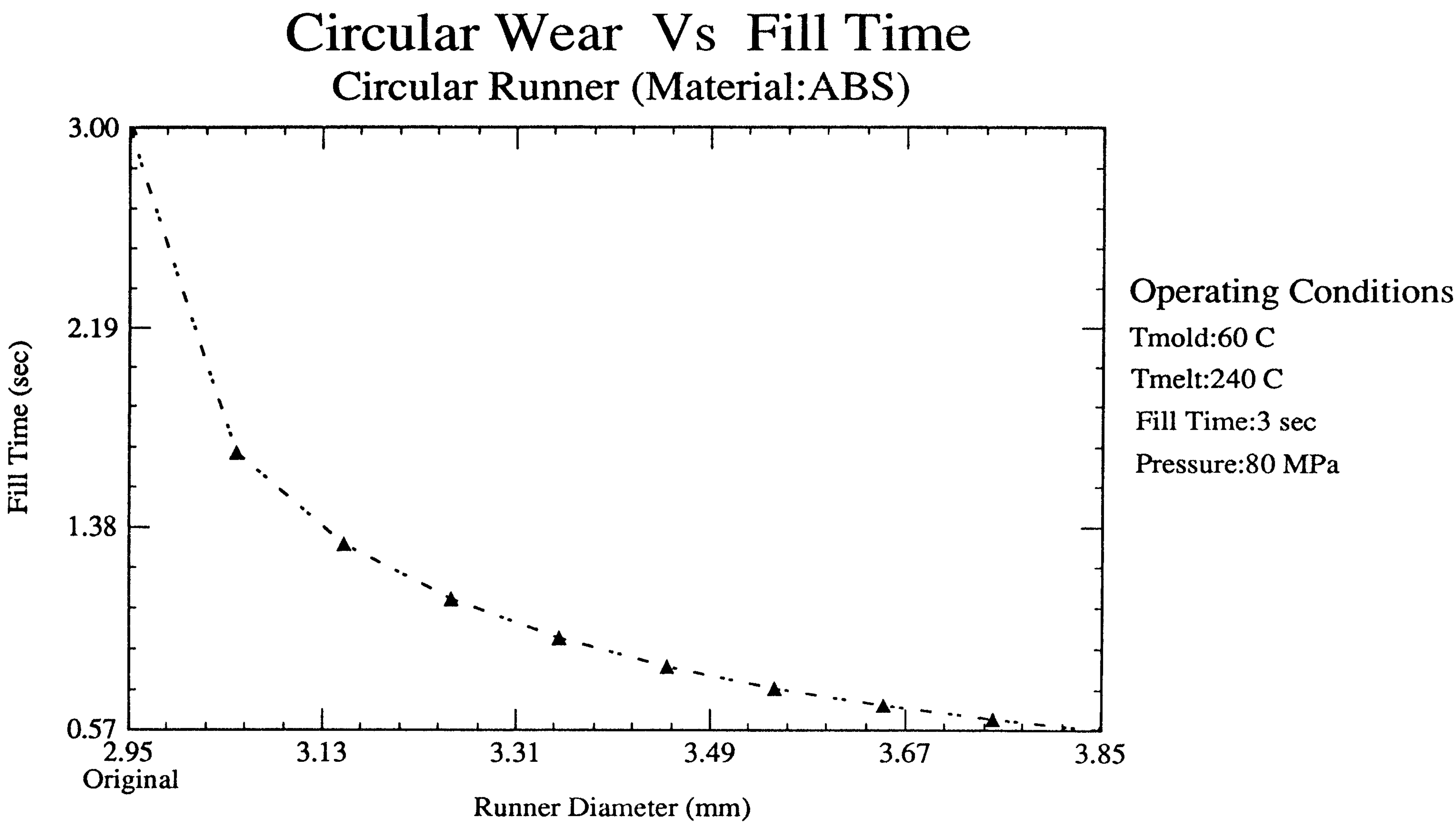

Fig. 5.12

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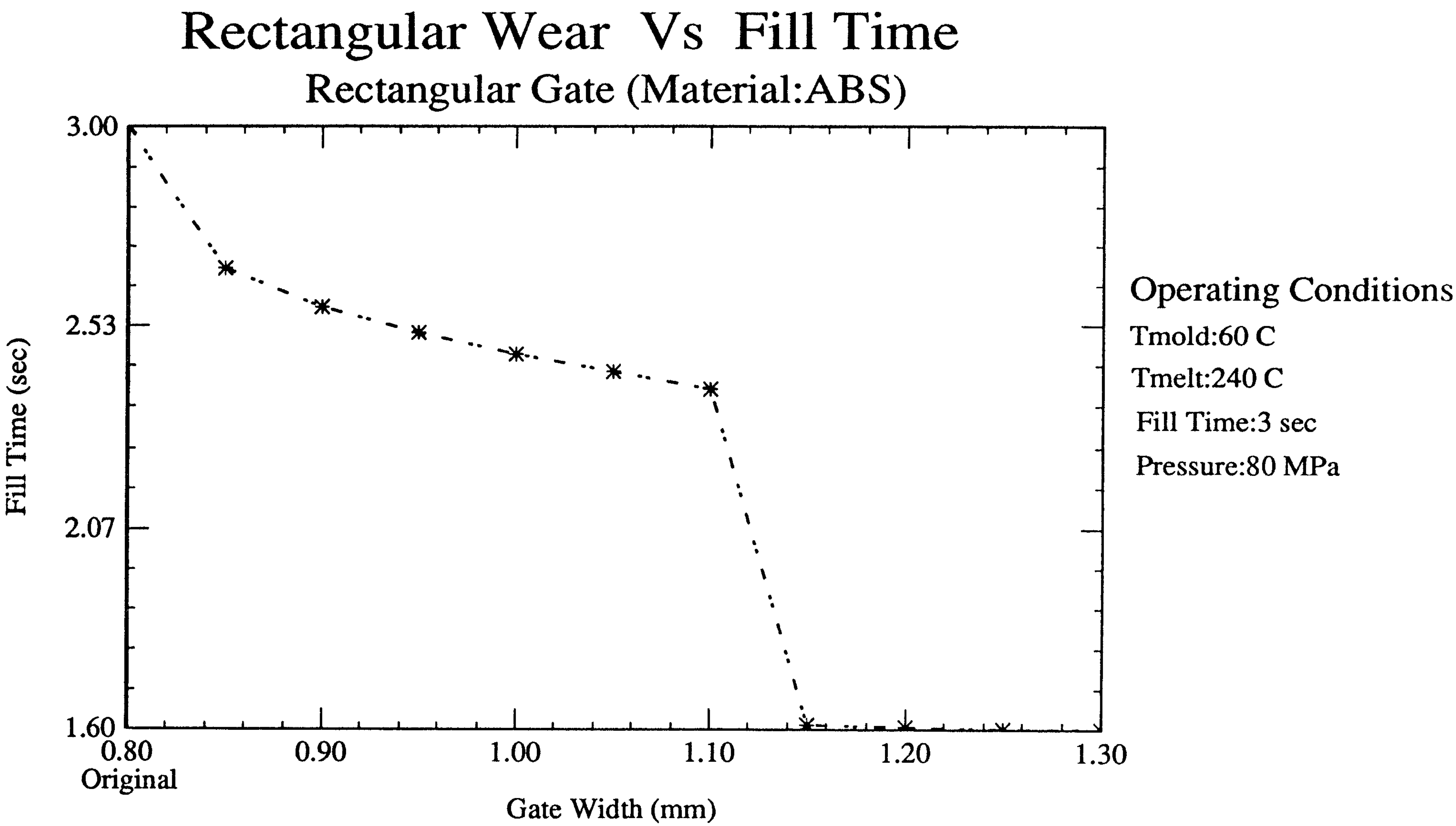

Fig. 5.13

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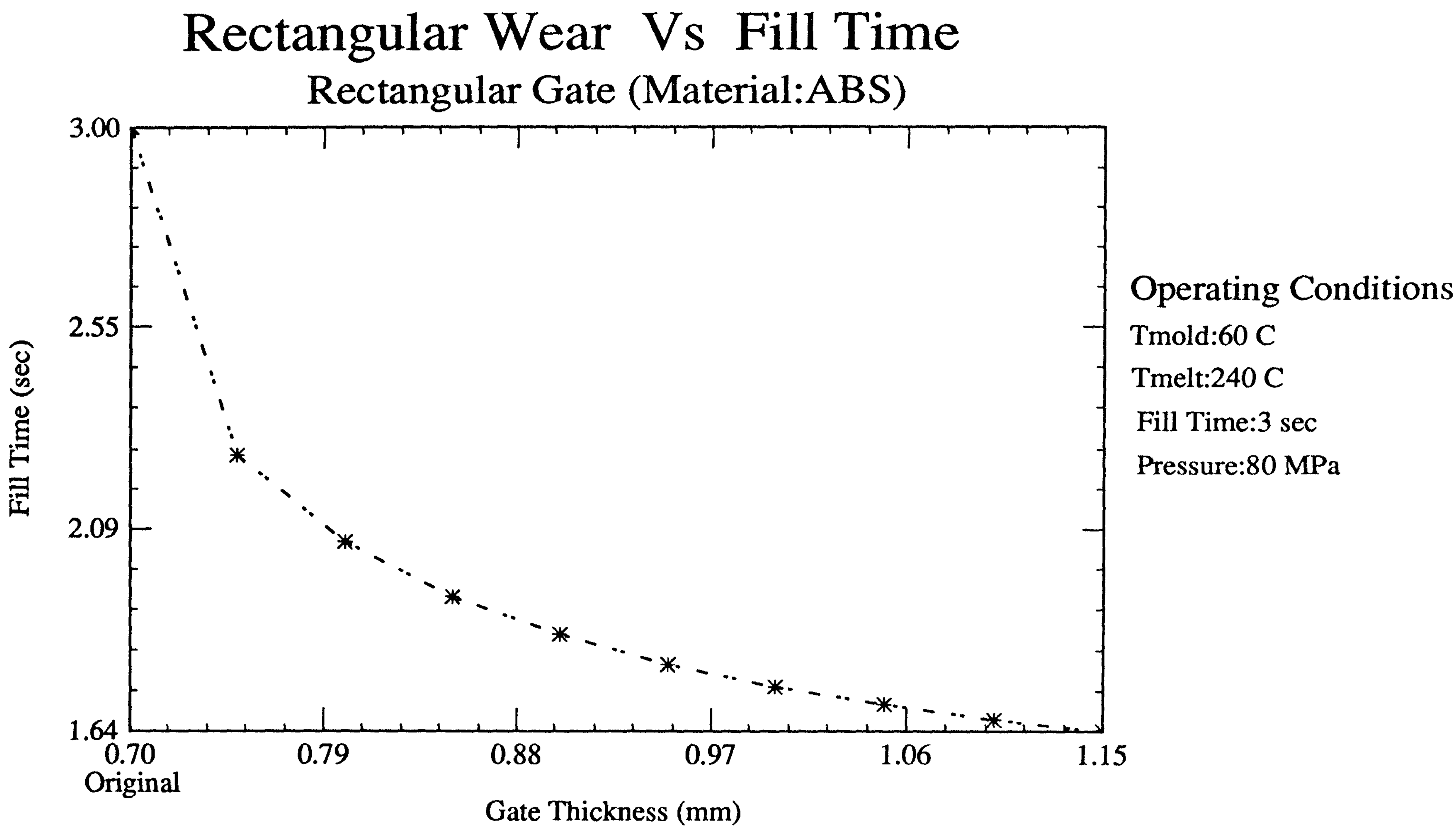

Fig. 5.14

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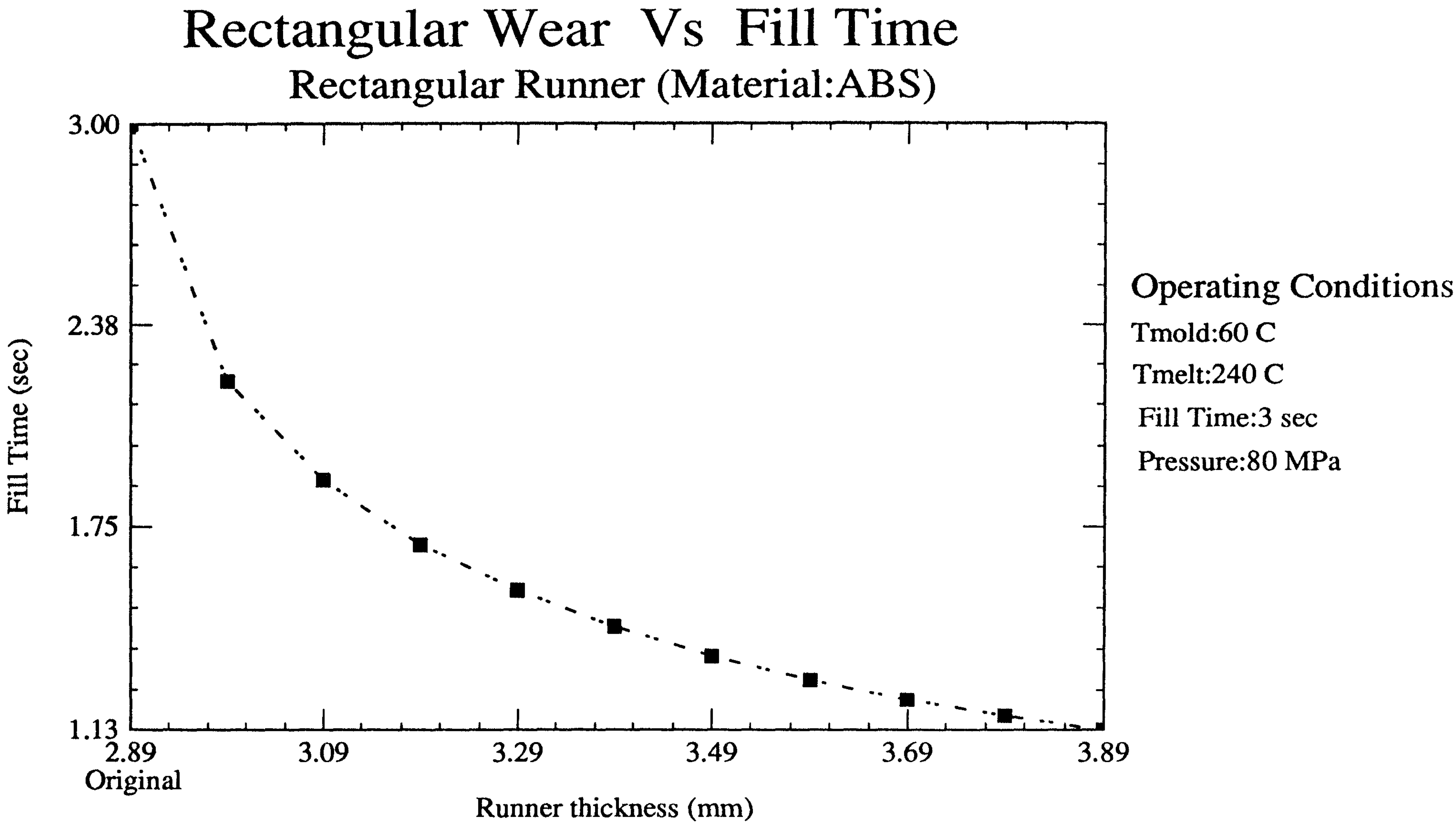

Fig. 5.16

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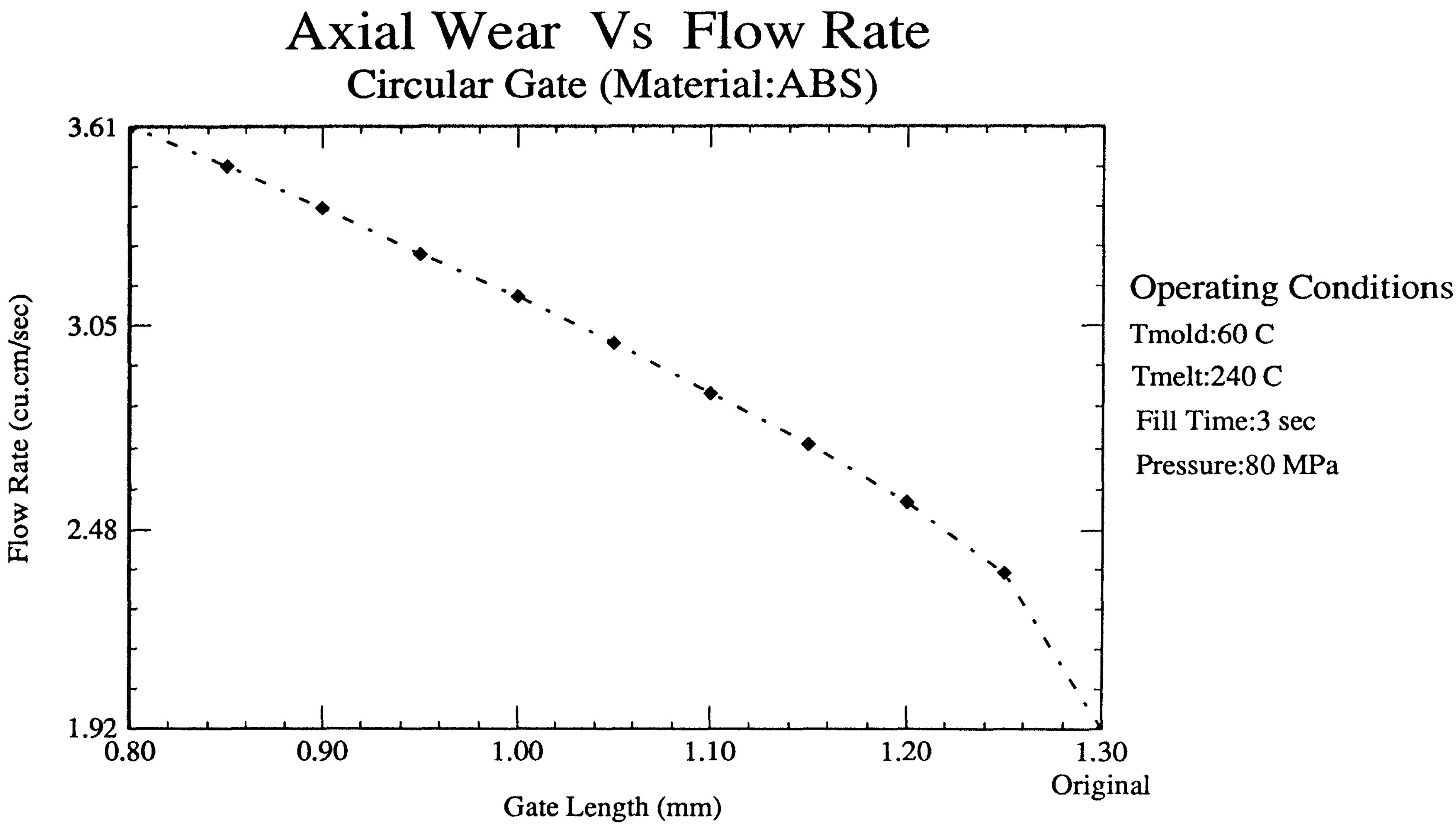

Fig. 5.17

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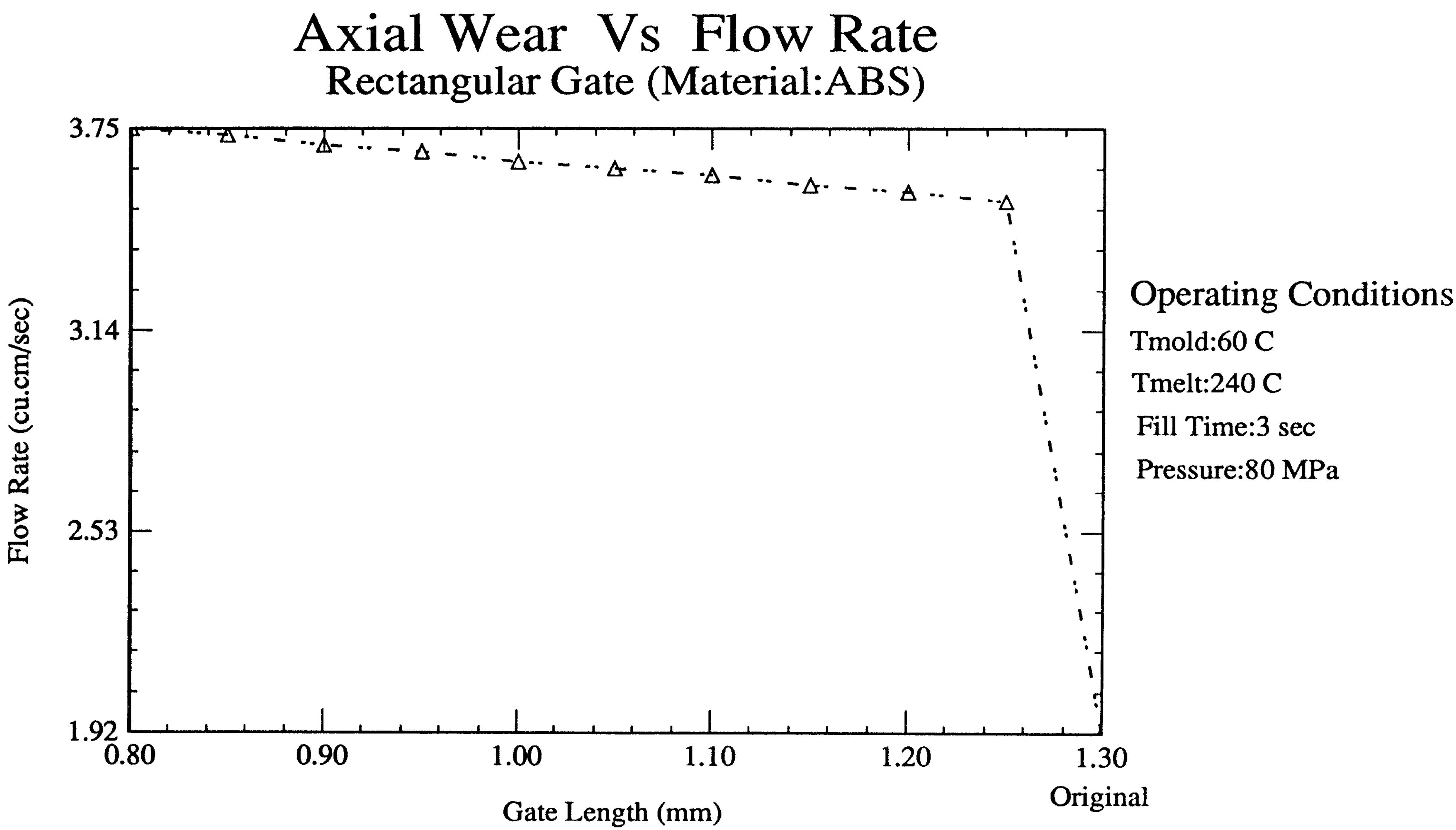

Fig. 5.18

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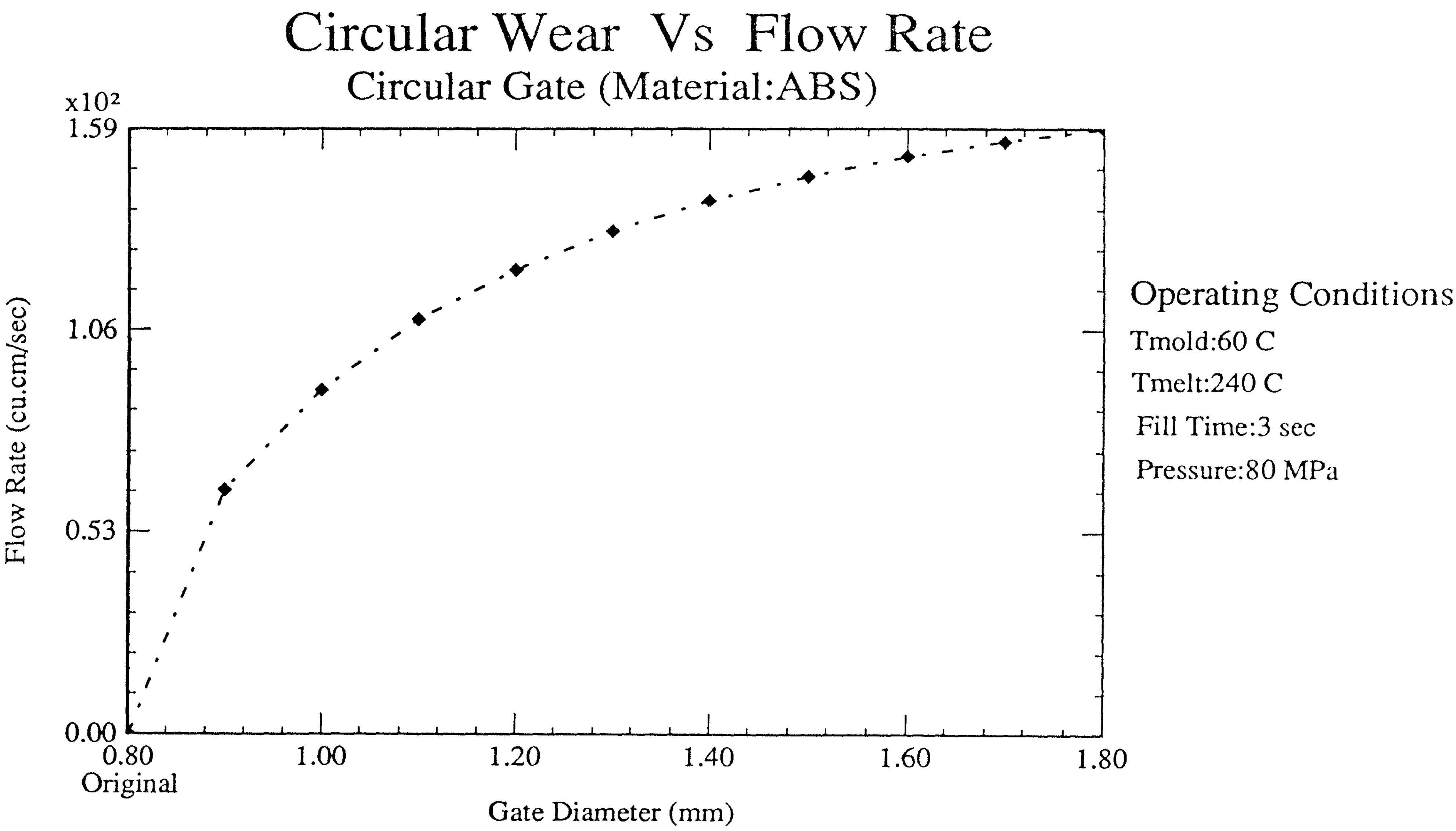

Fig. 5.19

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Circular Wear Vs Flow Rate

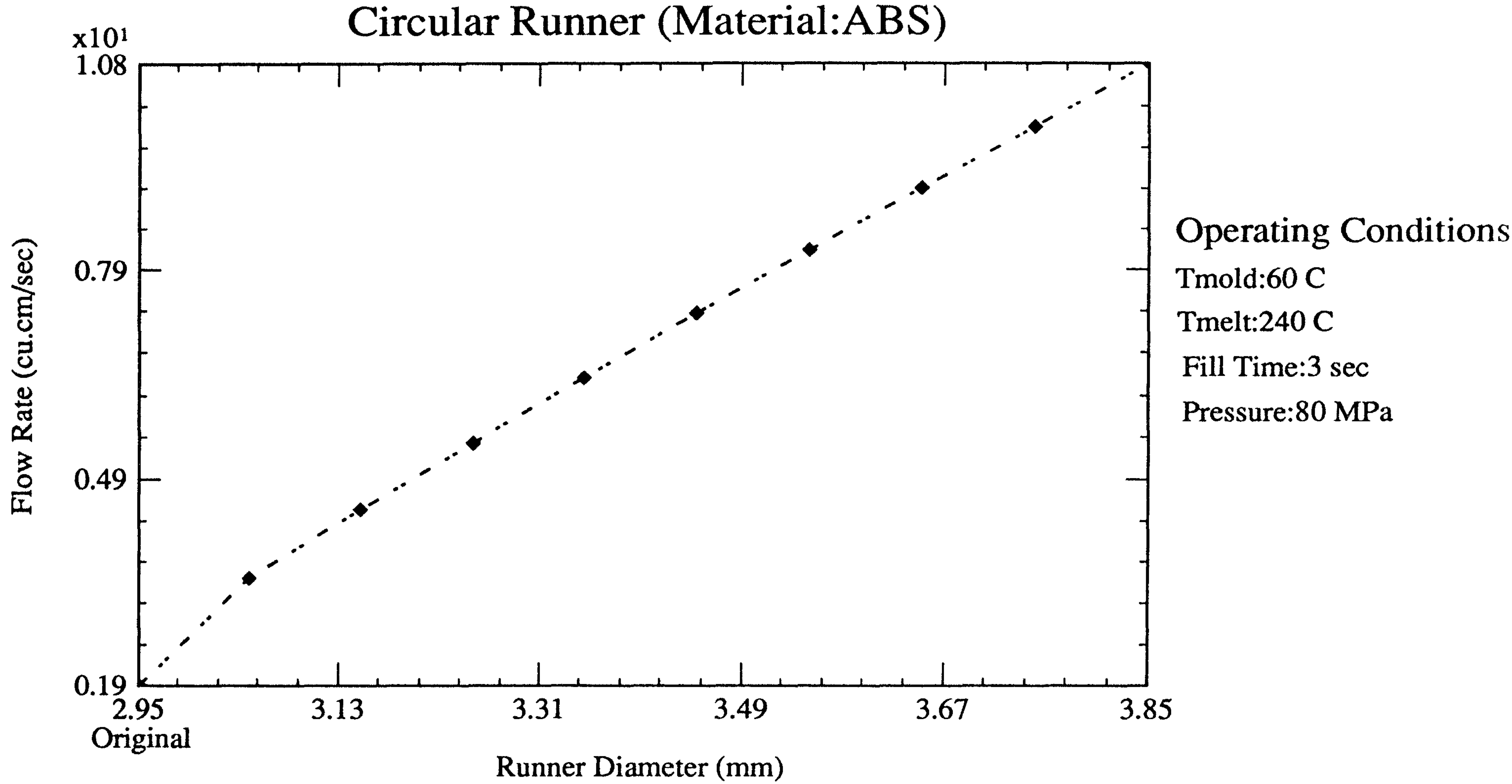

Fig. 5.20

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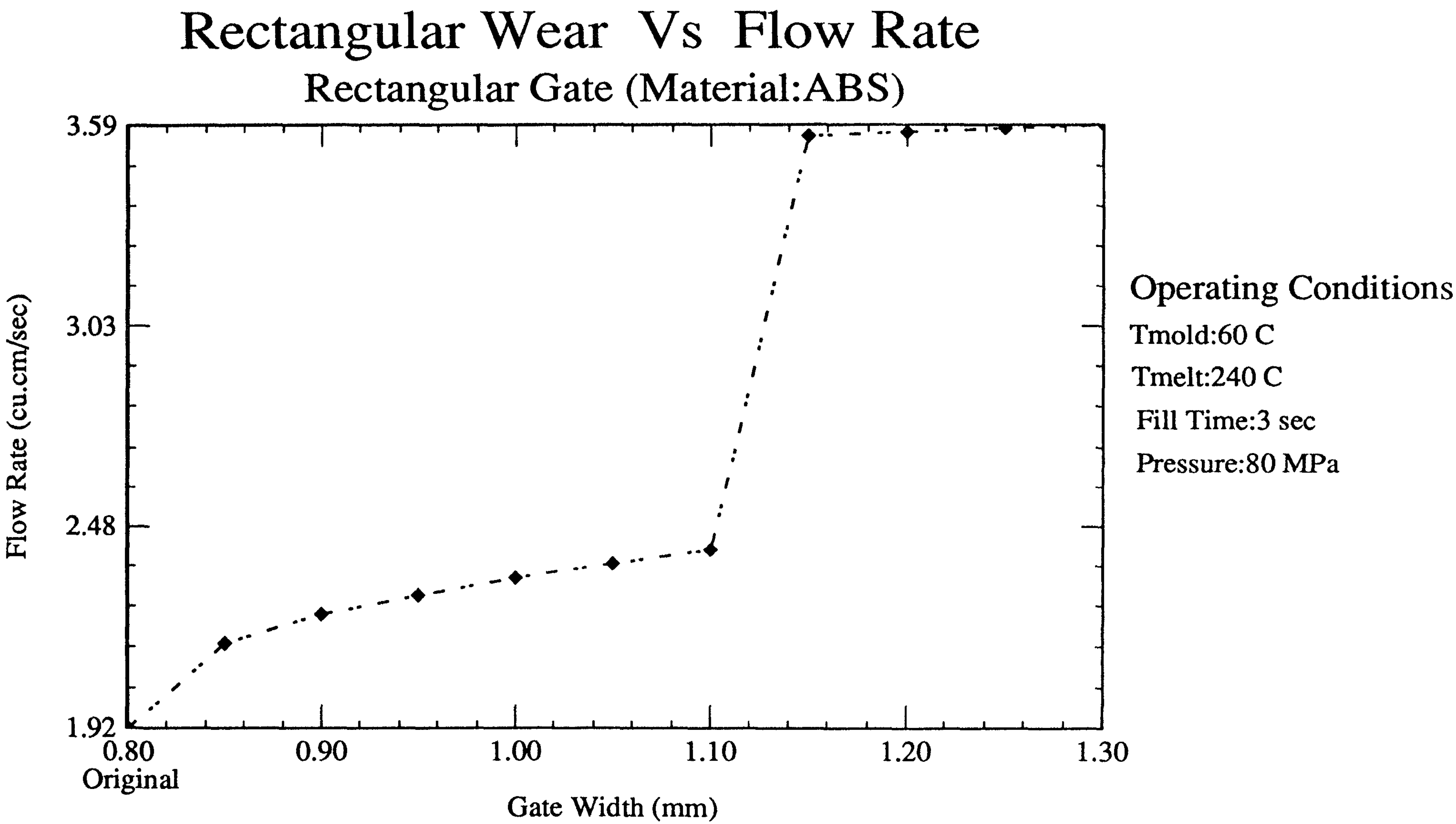


Fig. 5.21

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw54 - Fri Apr 19 19:25:08 1991 (data file was nabsrecgatw.data)

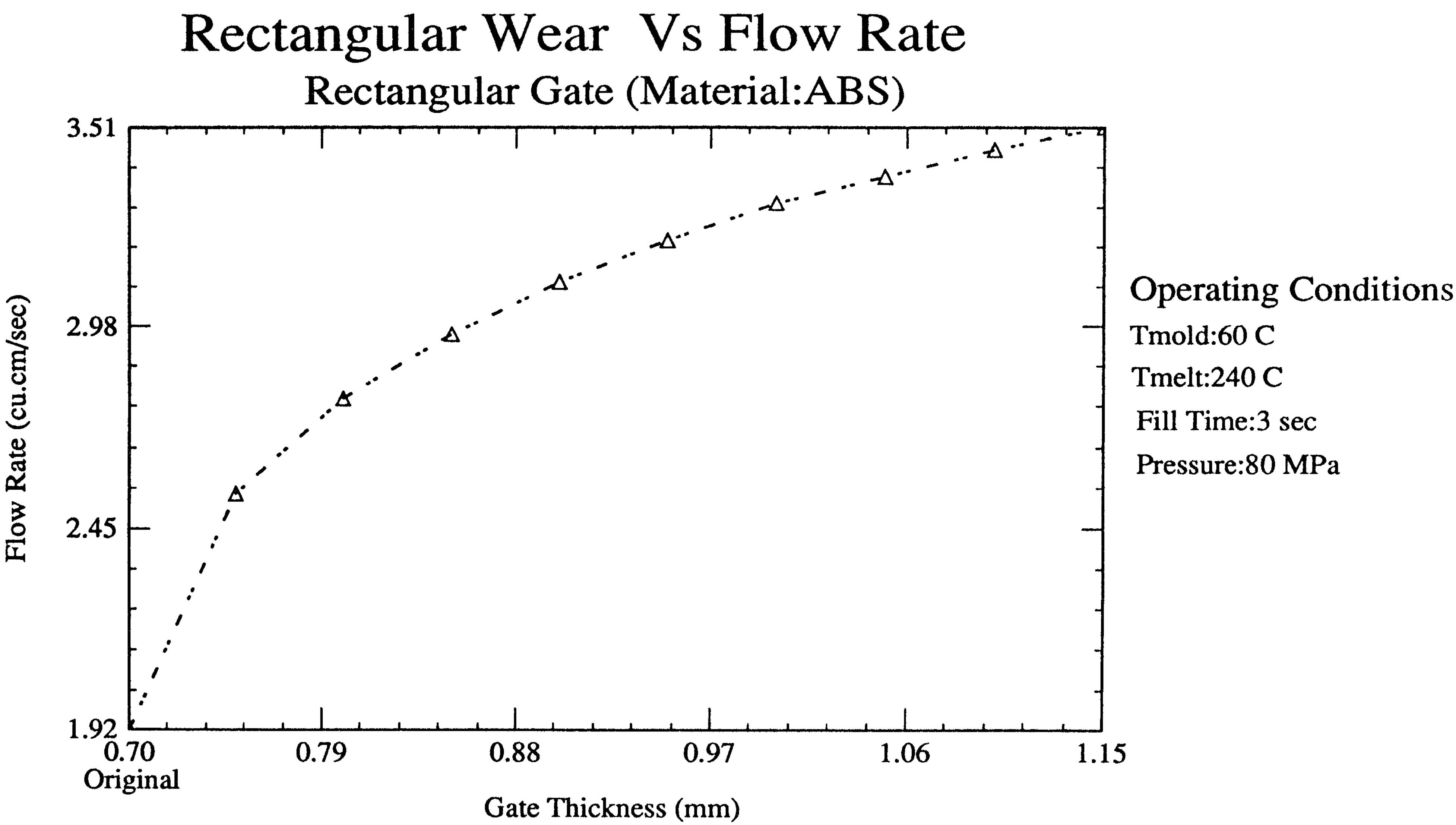


Fig. 5.22

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw54 - Fri Apr 19 19:39:55 1991 (data file was nabsrecgatt.data)

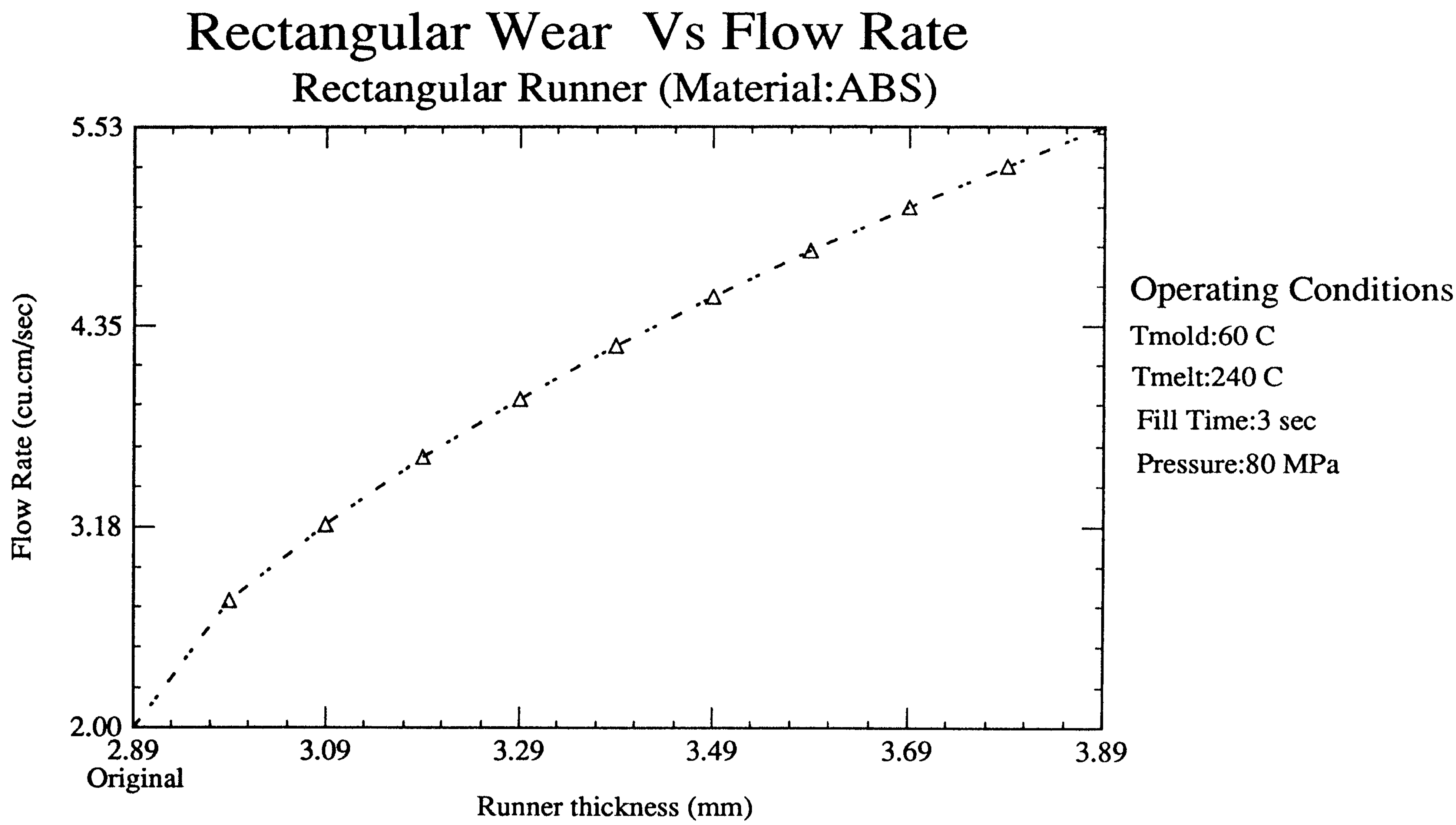


Fig. 5.24

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw54 - Fri Apr 19 19:45:06 1991 (data file was nabsrecrunt.data)

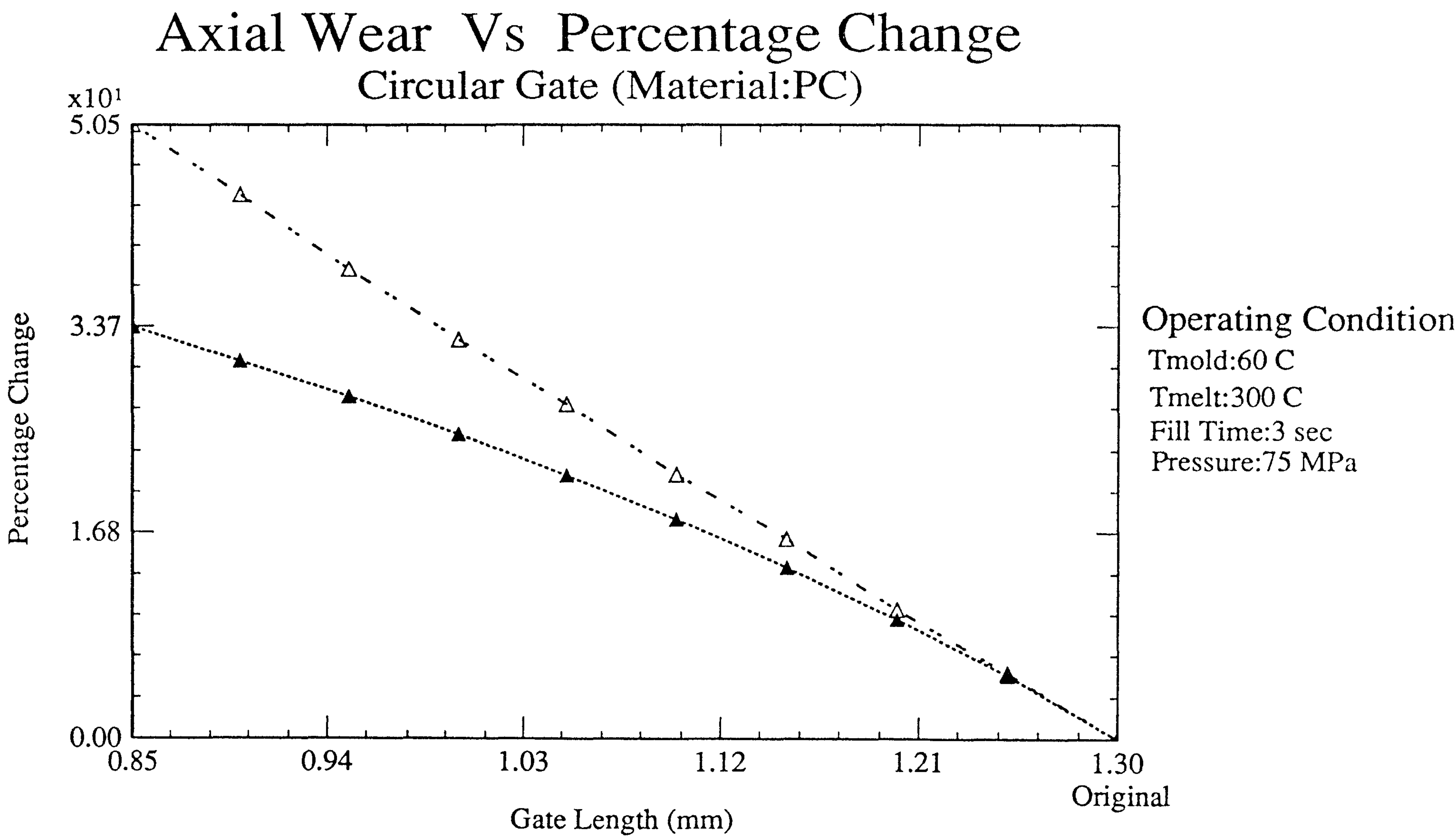


Fig. 5.25

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw54 - Fri Apr 19 21:41:20 1991 (data file was 521.data)

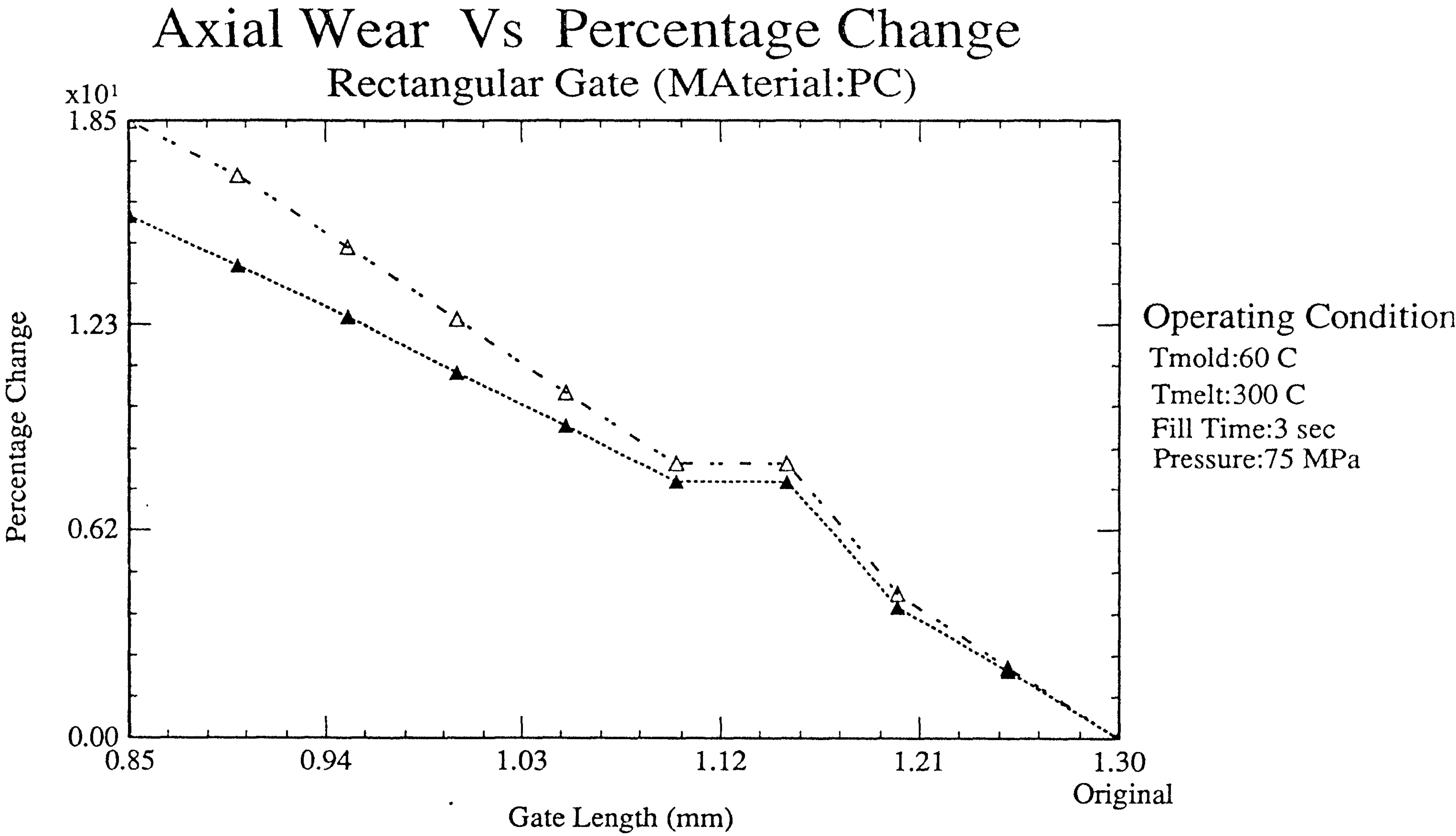


Fig. 5.26

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw54 - Fri Apr 19 21:37:39 1991 (data file was npcrgatl%.data)

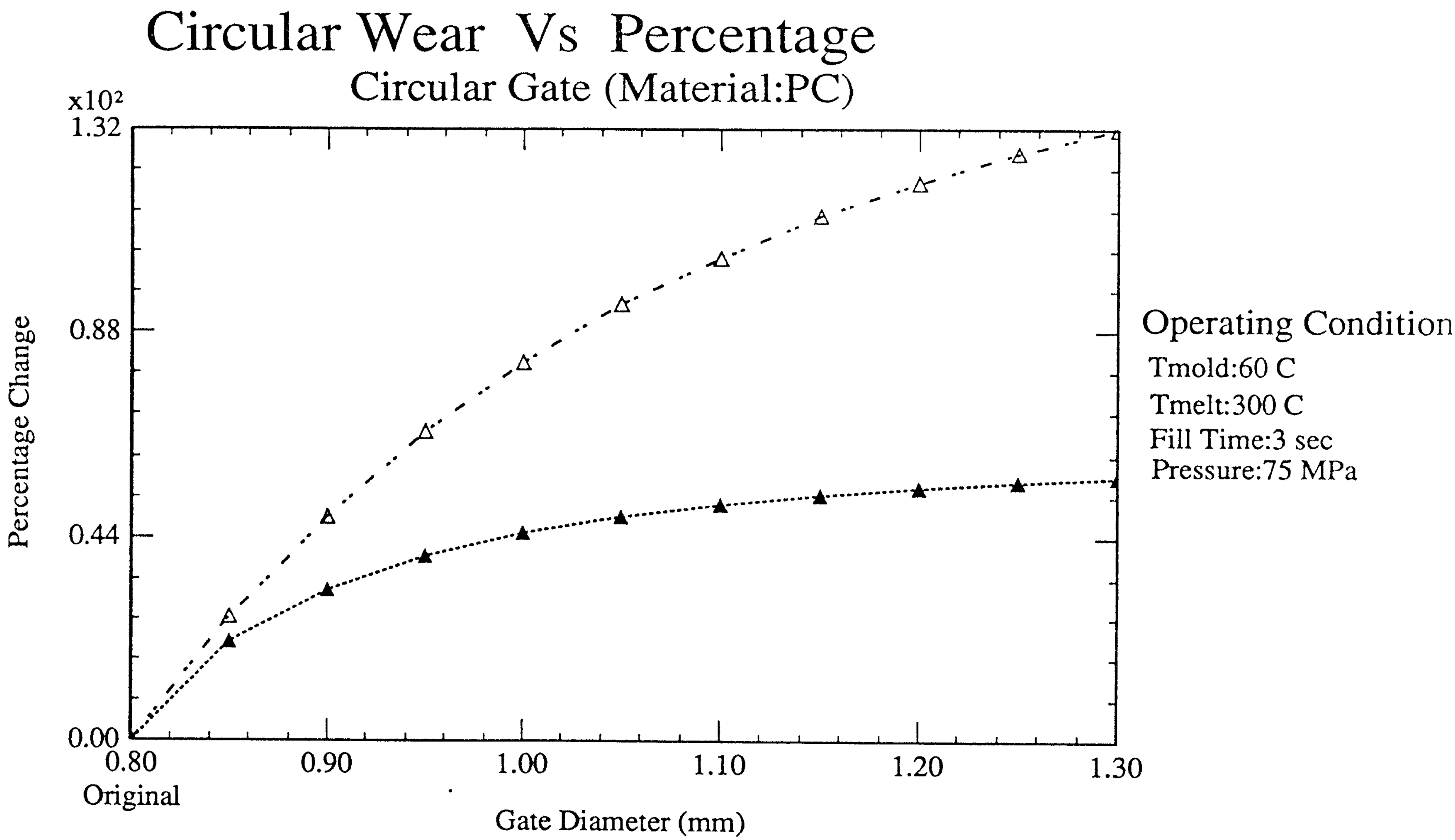


Fig. 5.27

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw54 - Fri Apr 19 20:56:10 1991 (data file was npccgat% data)

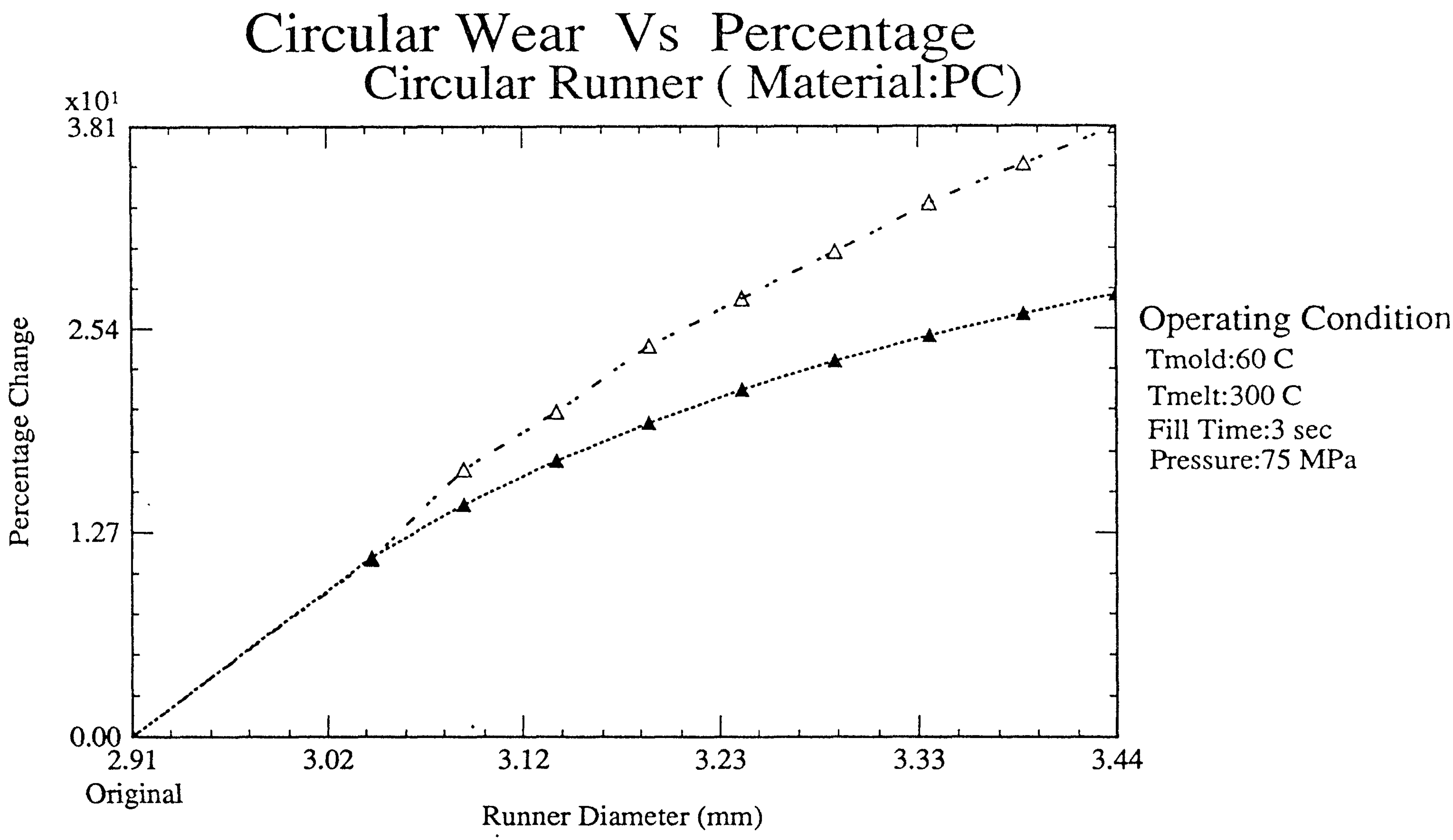


Fig. 5.28

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw54 - Fri Apr 19 21:18:19 1991 (data file was npccrun%.data)

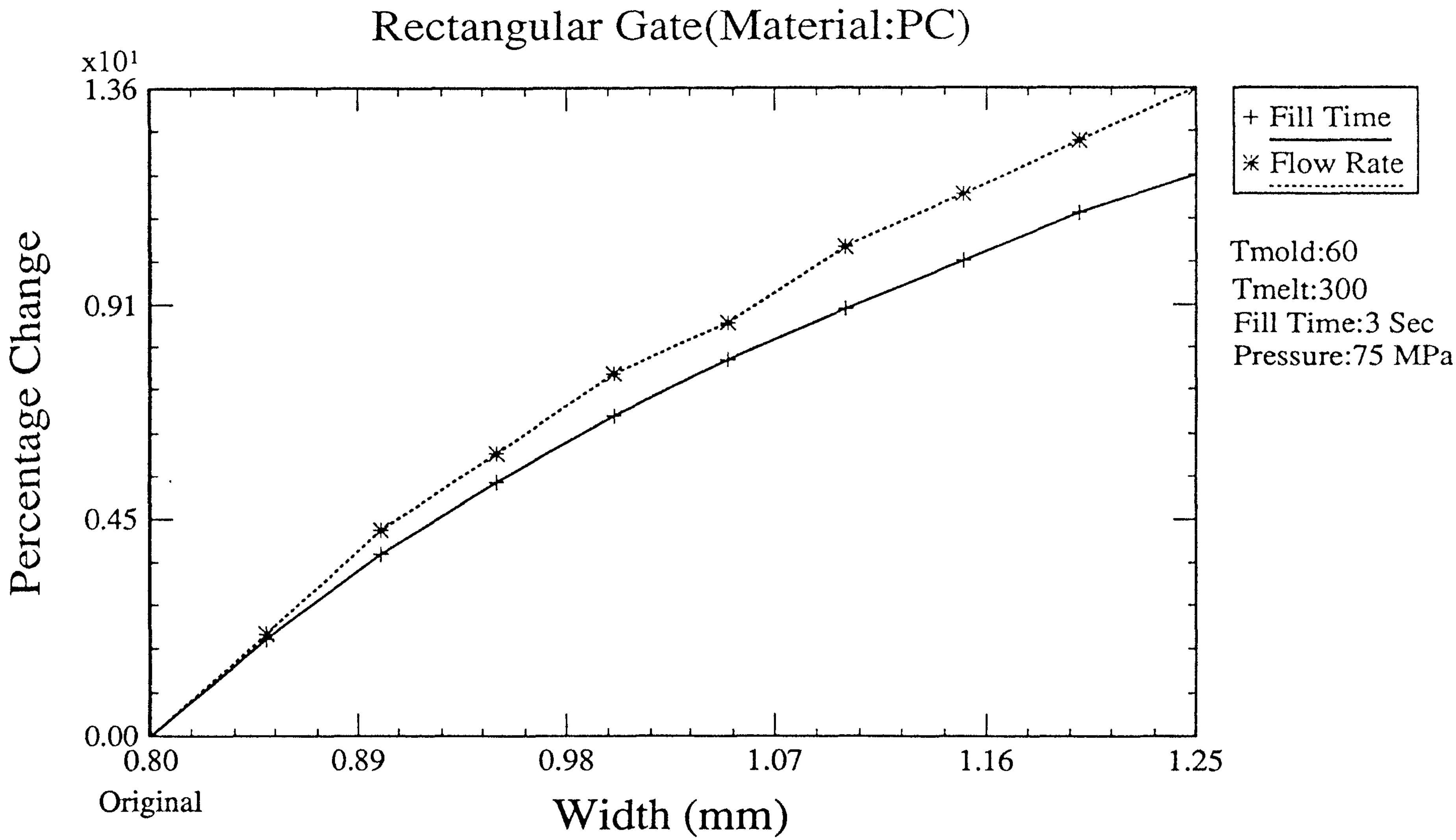


Fig. 5.29

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw55 - Wed Apr 10 17:13:25 1991 (data file was /usr/tmp/TG.AAAa02920)

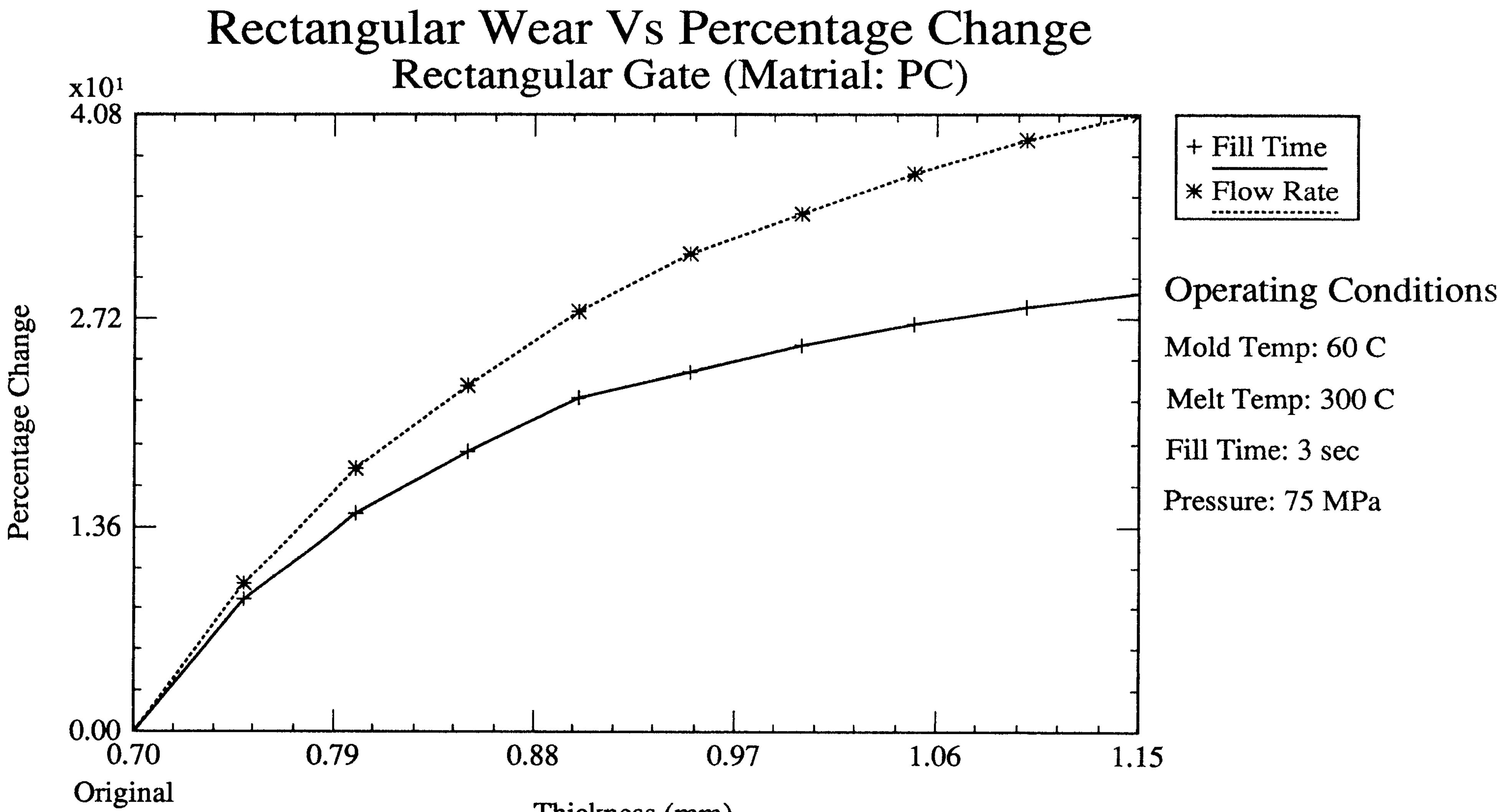


Fig. 5.30

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw53 - Sun Apr 28 23:08:27 1991 (data file was 530.data)

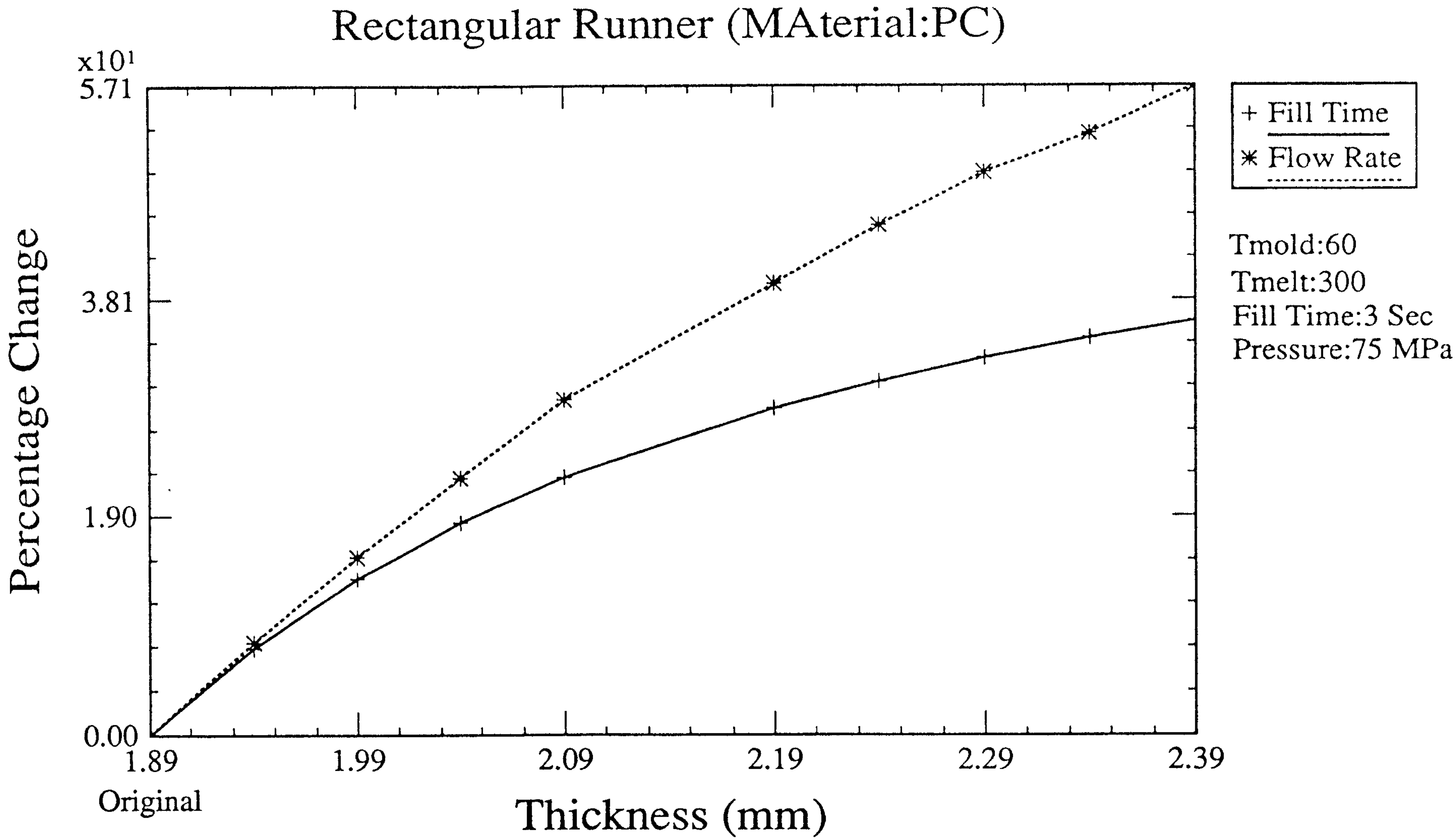


Fig. 5.32

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw55 - Wed Apr 10 17:32:23 1991 (data file was /usr/tmp/TG.AAAa02920)

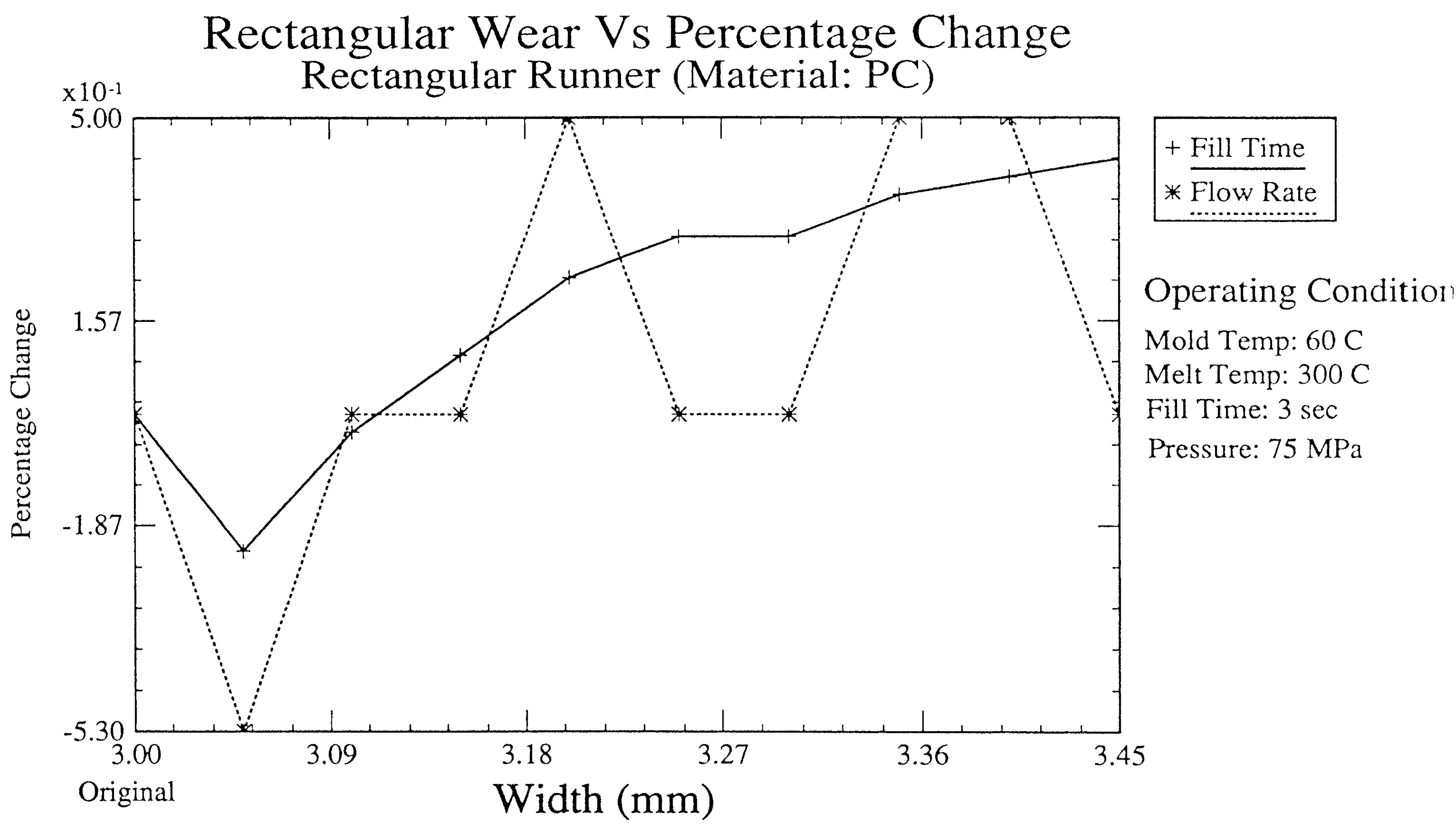


Fig. 5.31

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw53 - Sun Apr 28 23:11:09 1991 (data file was 531.data)

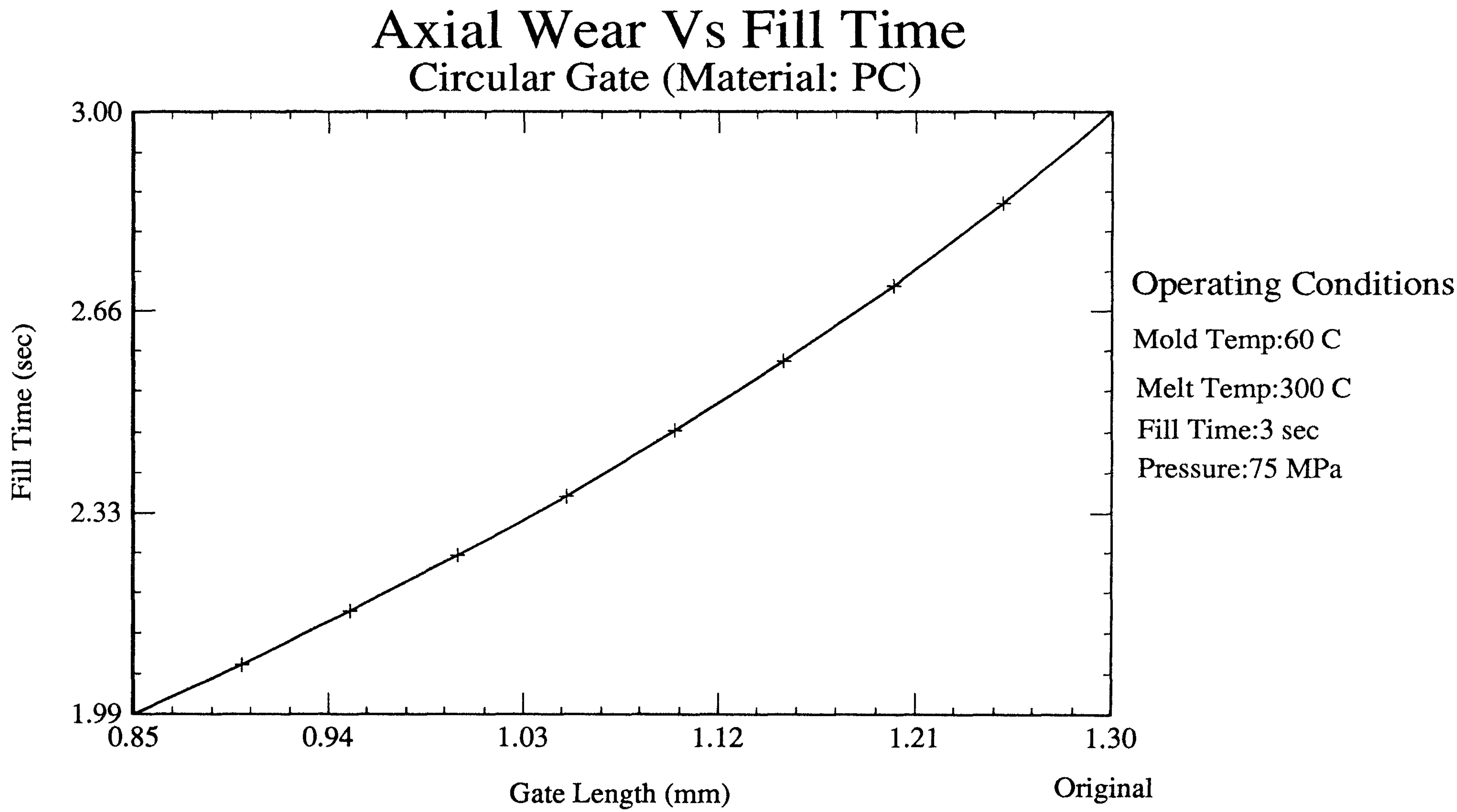


Fig. 5.33

TempleGraph 2 3, Origin: /usr/mesunb/users/ksv2028@mesunw57 - Tue Apr 30 17:50:05 1991 (data file was npccgatl.data)

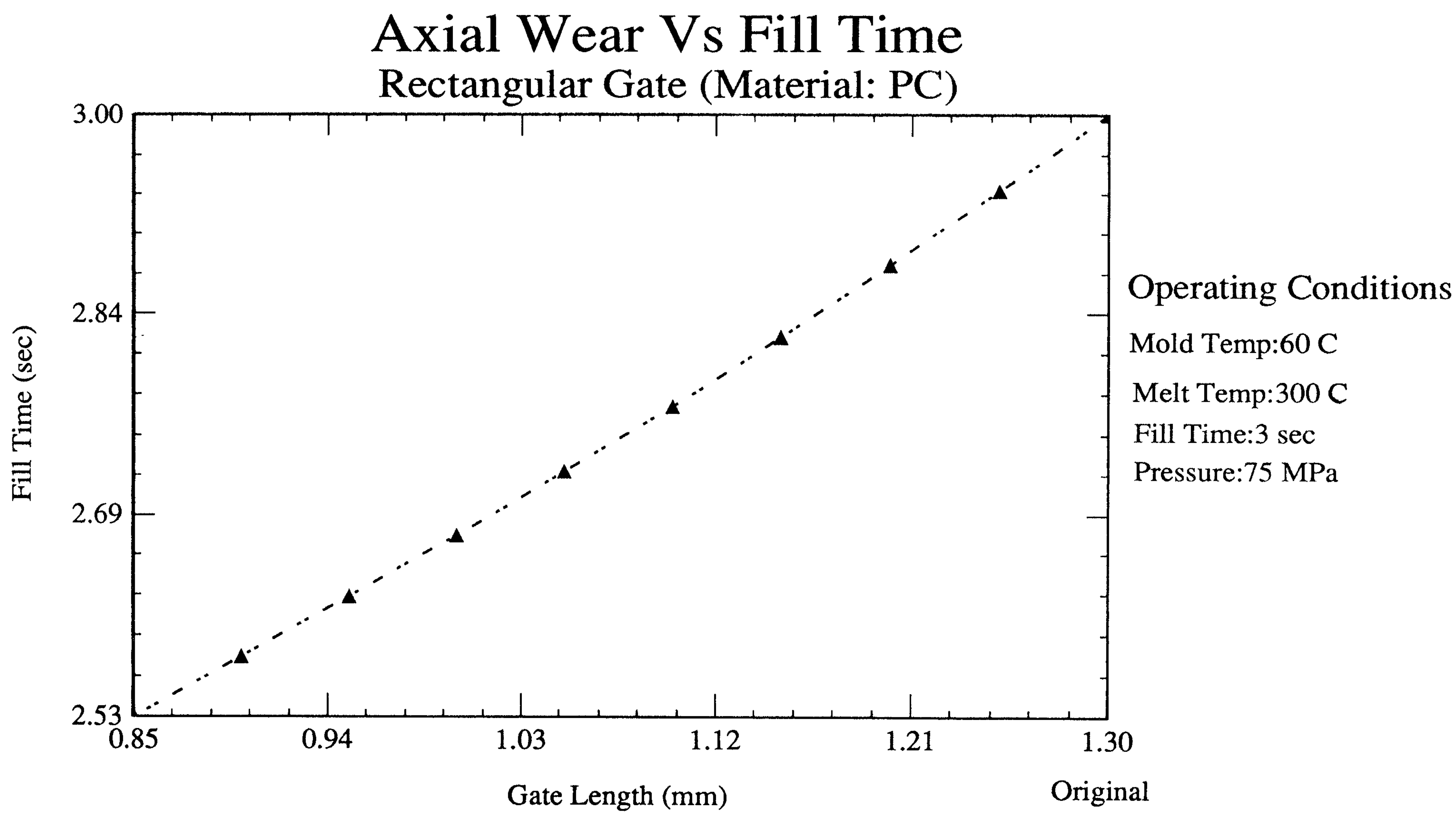


Fig. 5.34

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw57 - Tue Apr 30 18:01:11 1991 (data file was npcrgatl data)

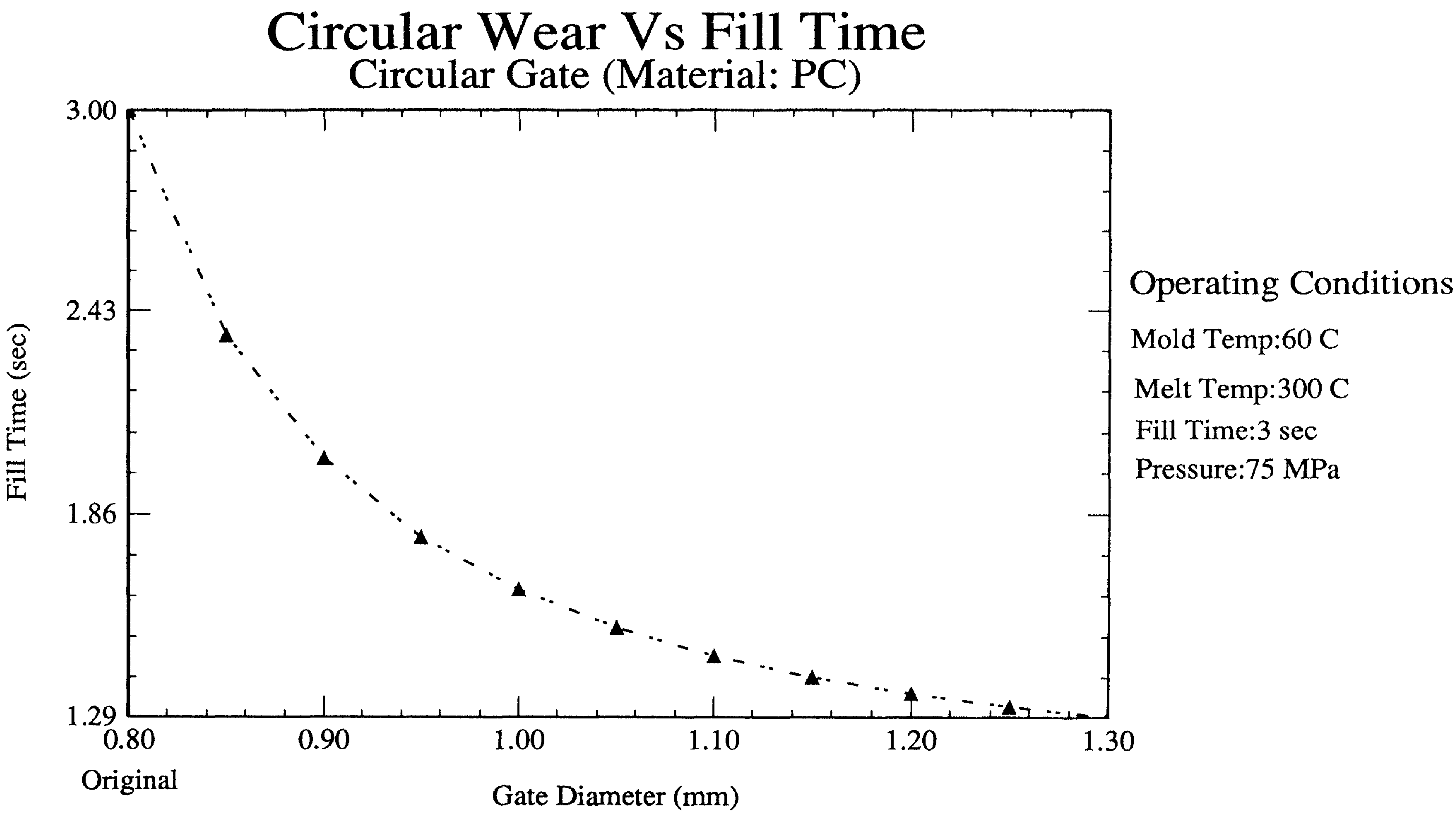


Fig. 5.35

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw57 - Tue Apr 30 18:13:46 1991 (data file was npccgat.data)

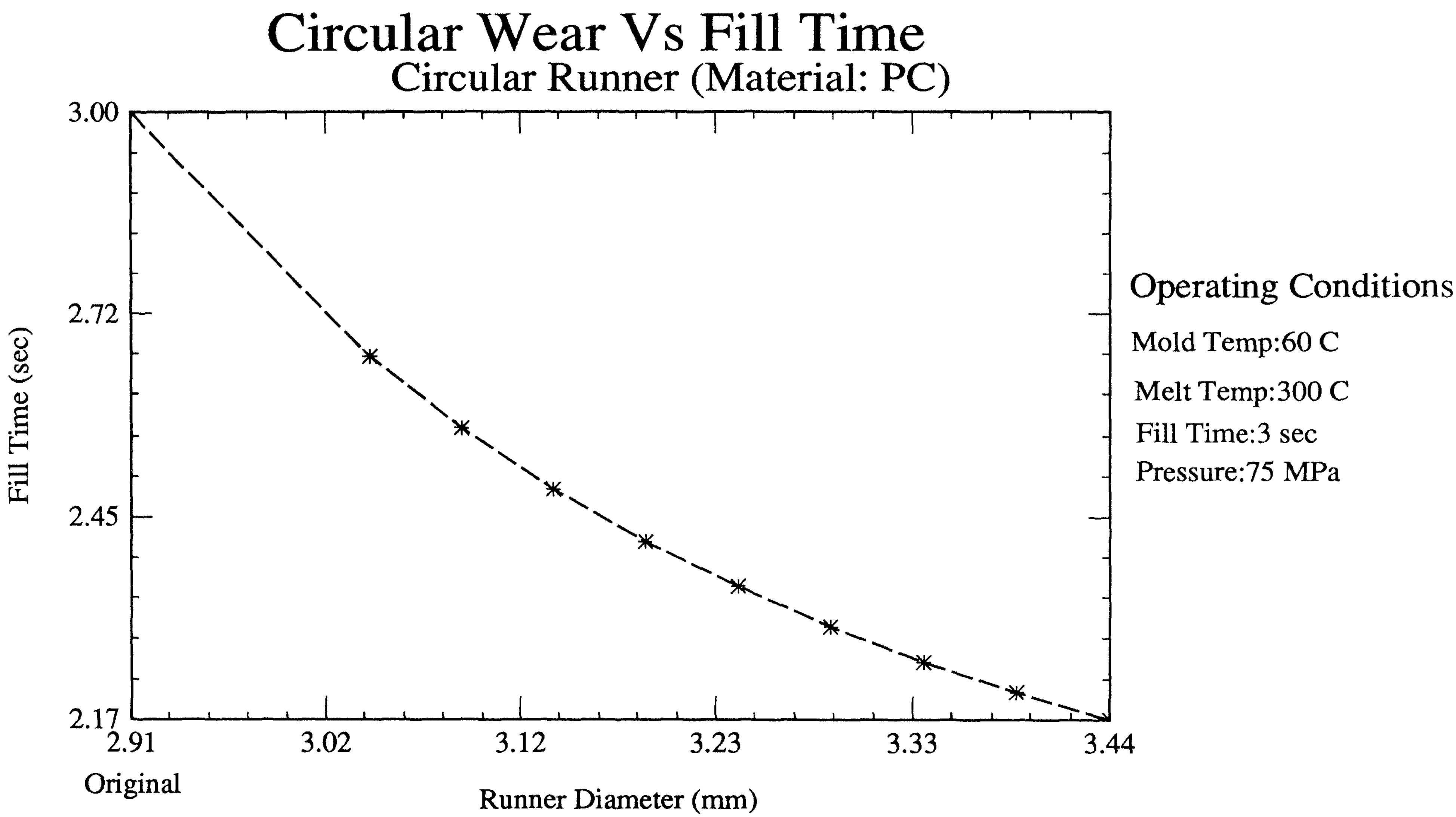


Fig. 5.36

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw57 - Tue Apr 30 18:23:37 1991 (data file was npccrun.data)

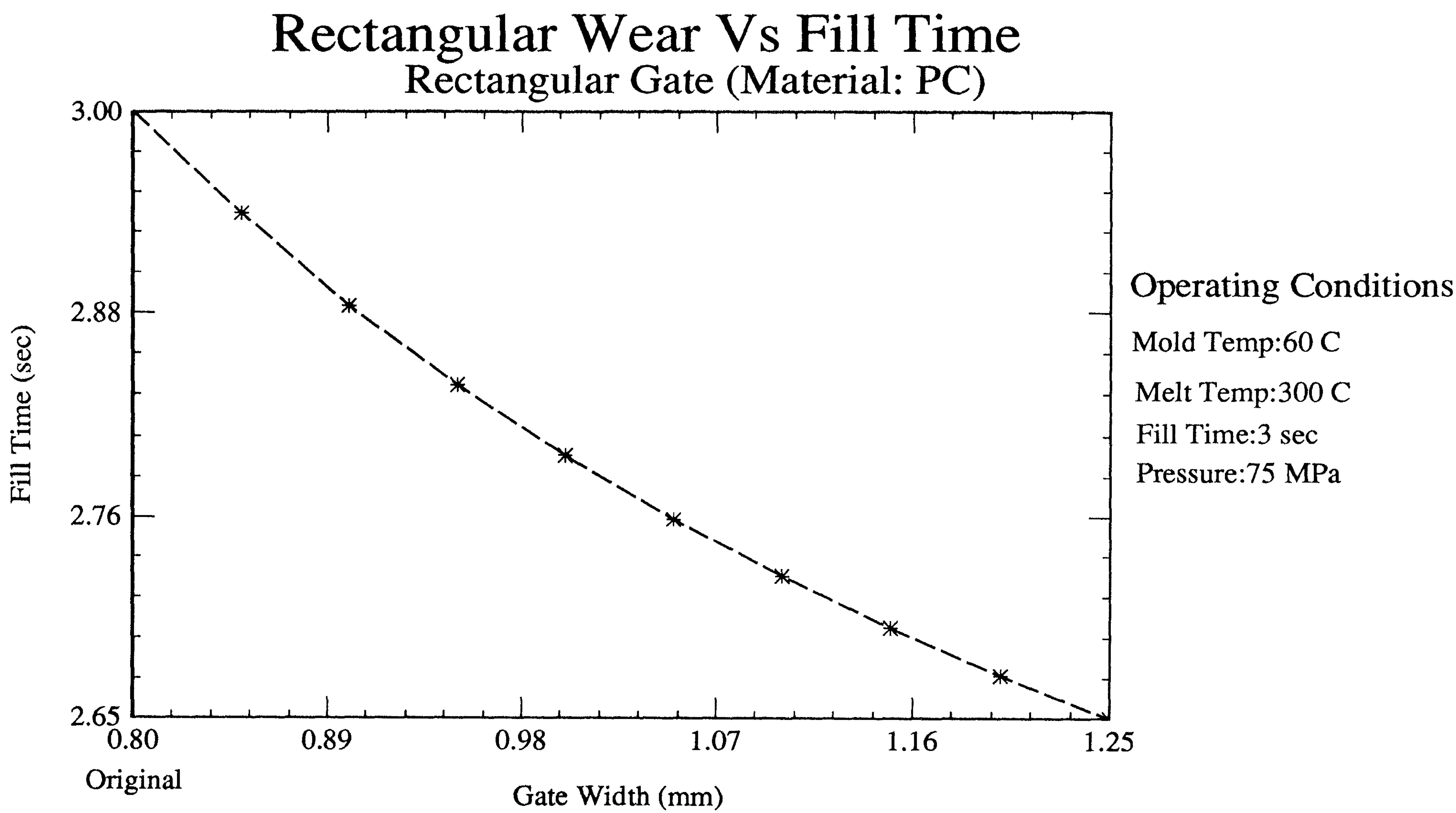


Fig. 5.37

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw57 - Tue Apr 30 18:35:49 1991 (data file was npcrgatw.data)

Rectangular Gate Vs Fill Time

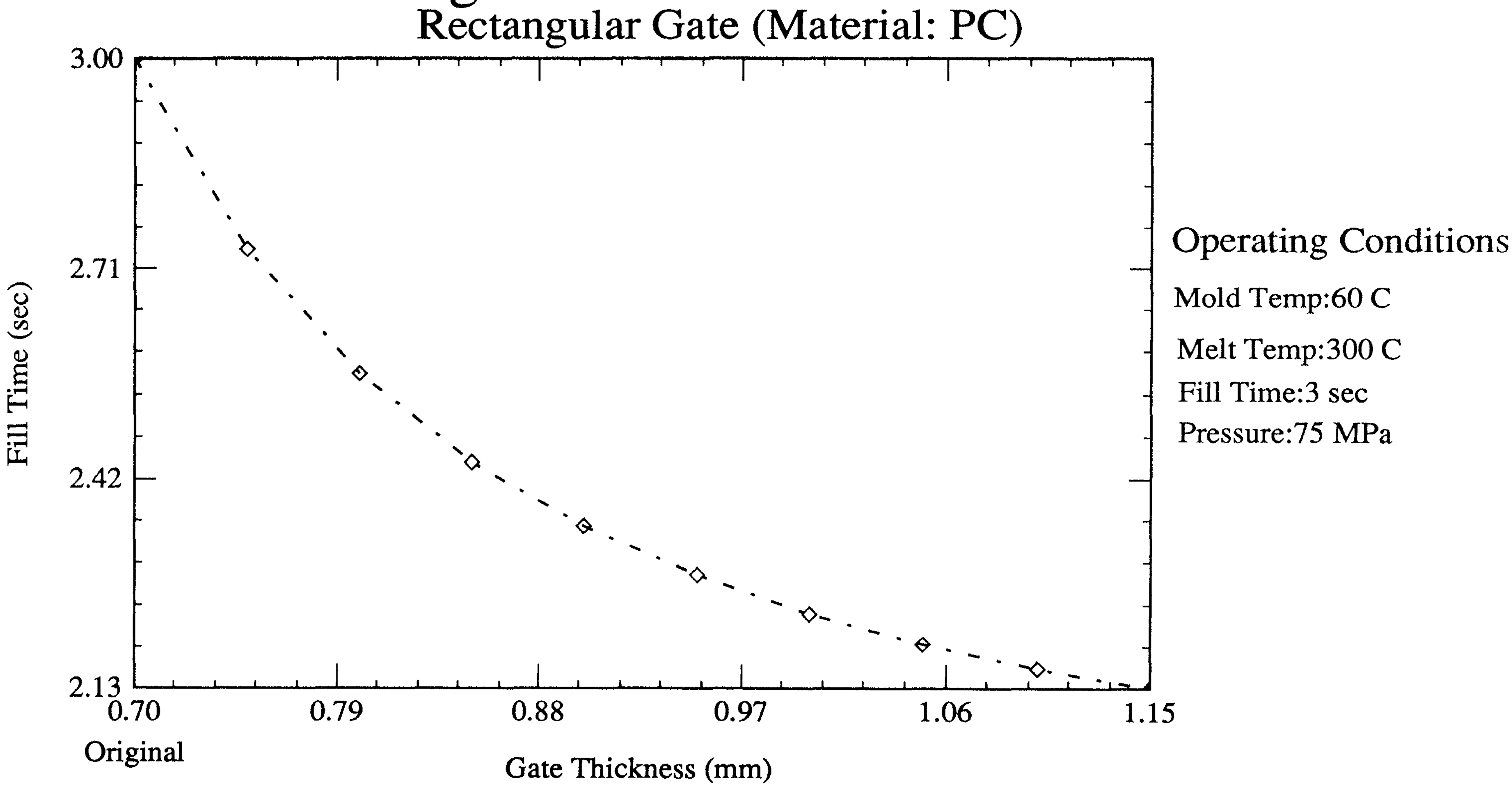


Fig. 5.38

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw57 - Tue Apr 30 18:44:15 1991 (data file was npcrgatt.data)

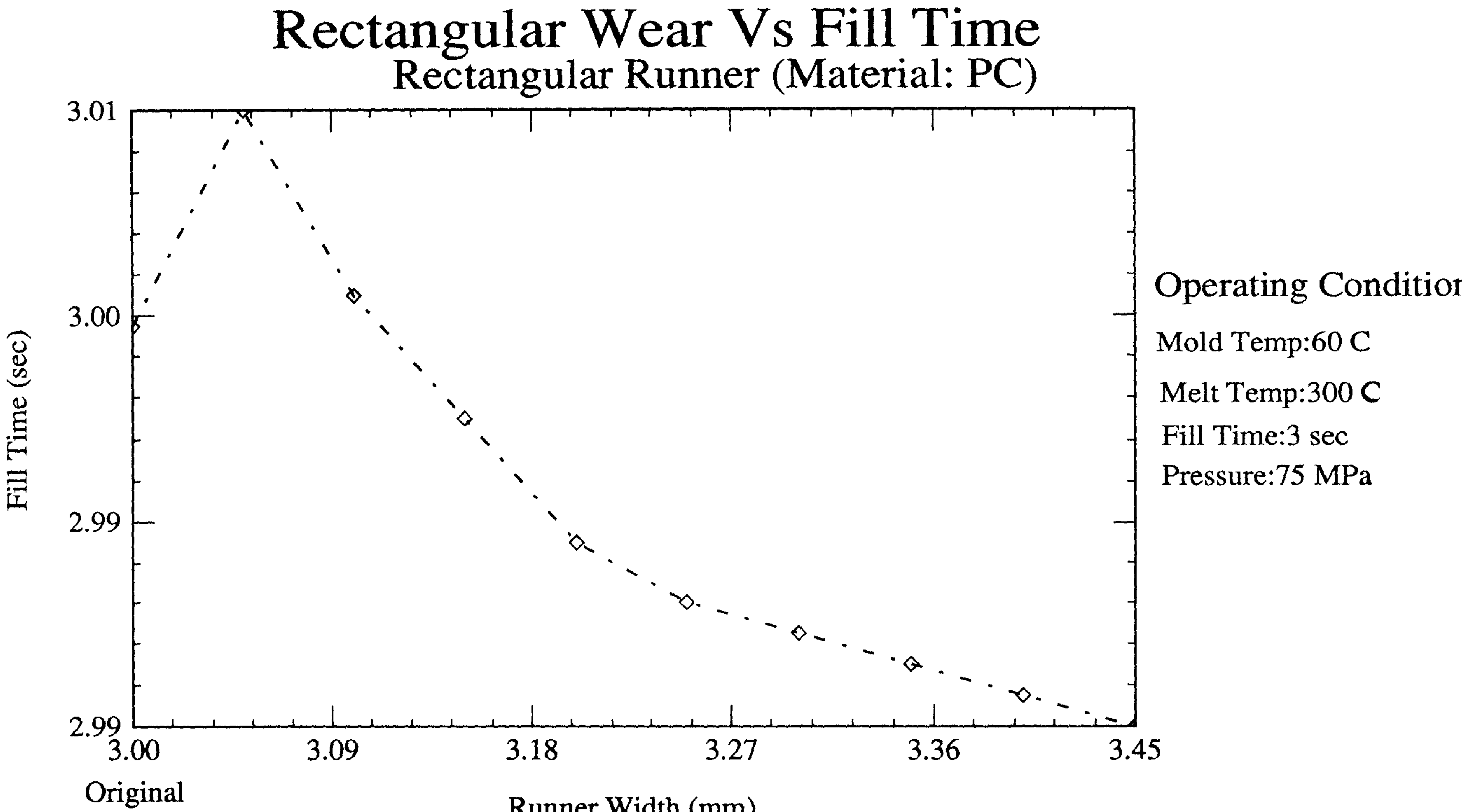


Fig. 5.39

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw57 - Tue Apr 30 18:49:13 1991 (data file was npcrecrunw.data)

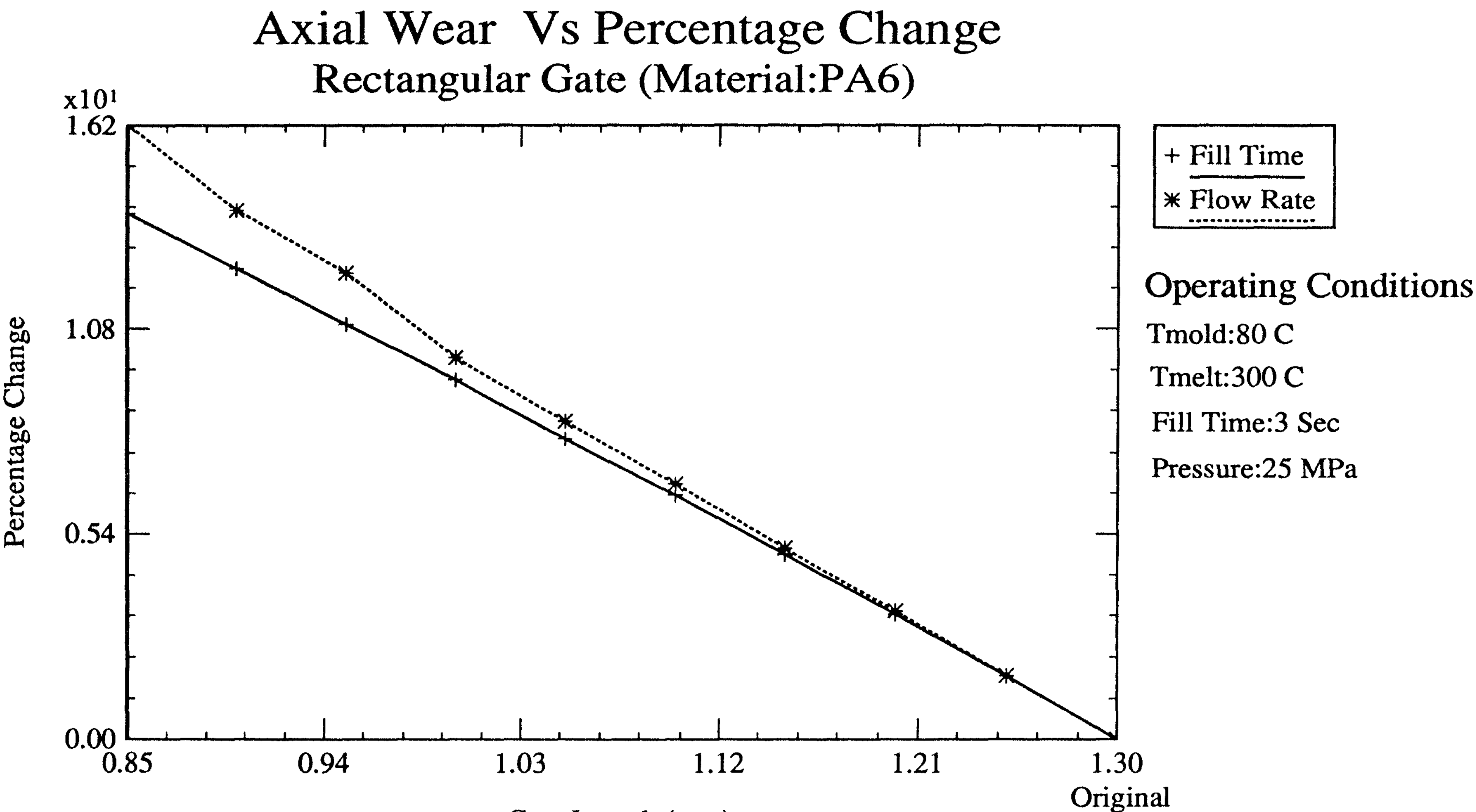


Fig. 5.74

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw54 - Thu Apr 18 21:08:57 1991 (data file was /usr/tmp/TG.AAAa12006)

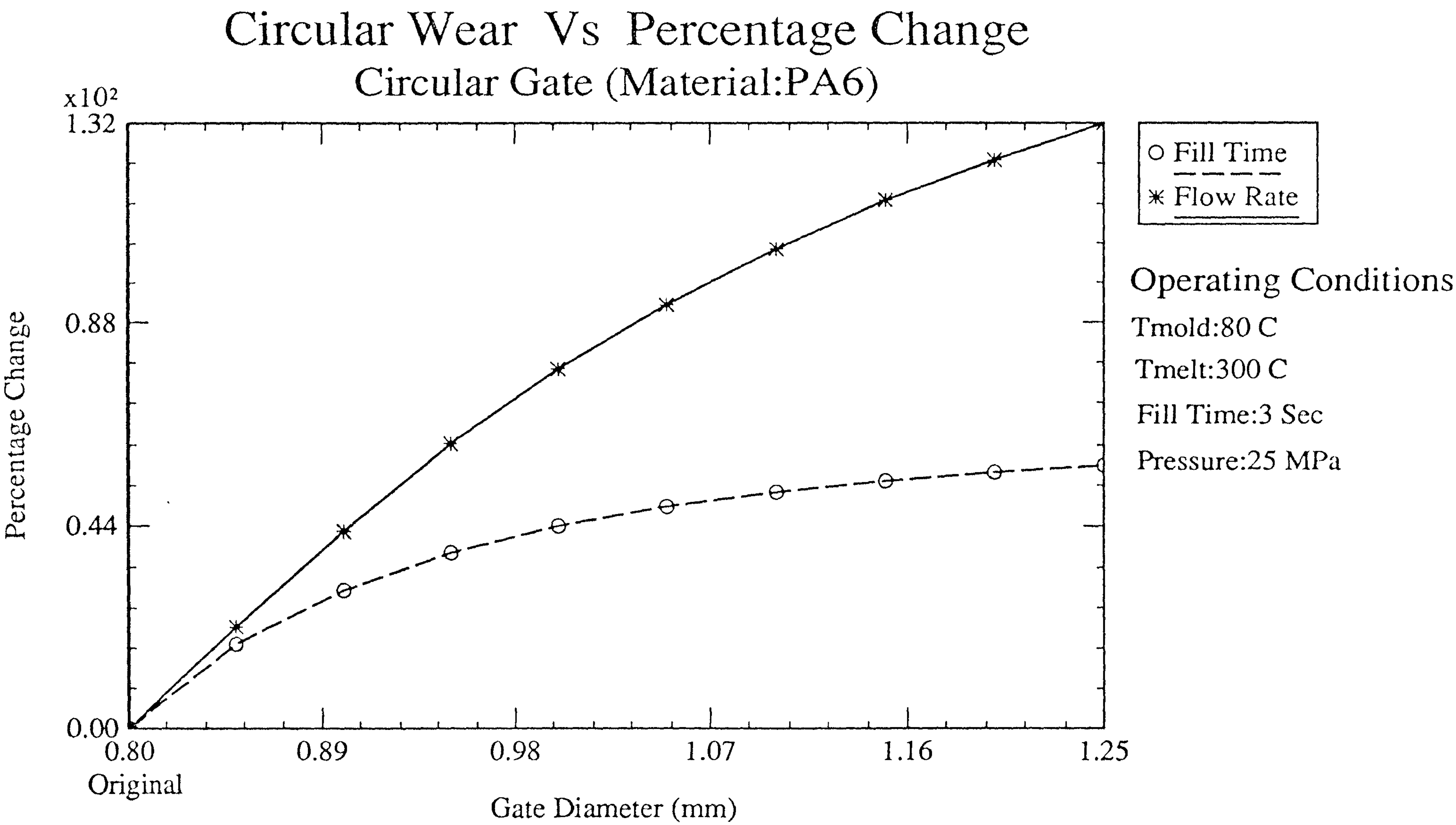


Fig. 5.75

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw54 - Thu Apr 18 22:49:56 1991 (data file was npa6%.data)

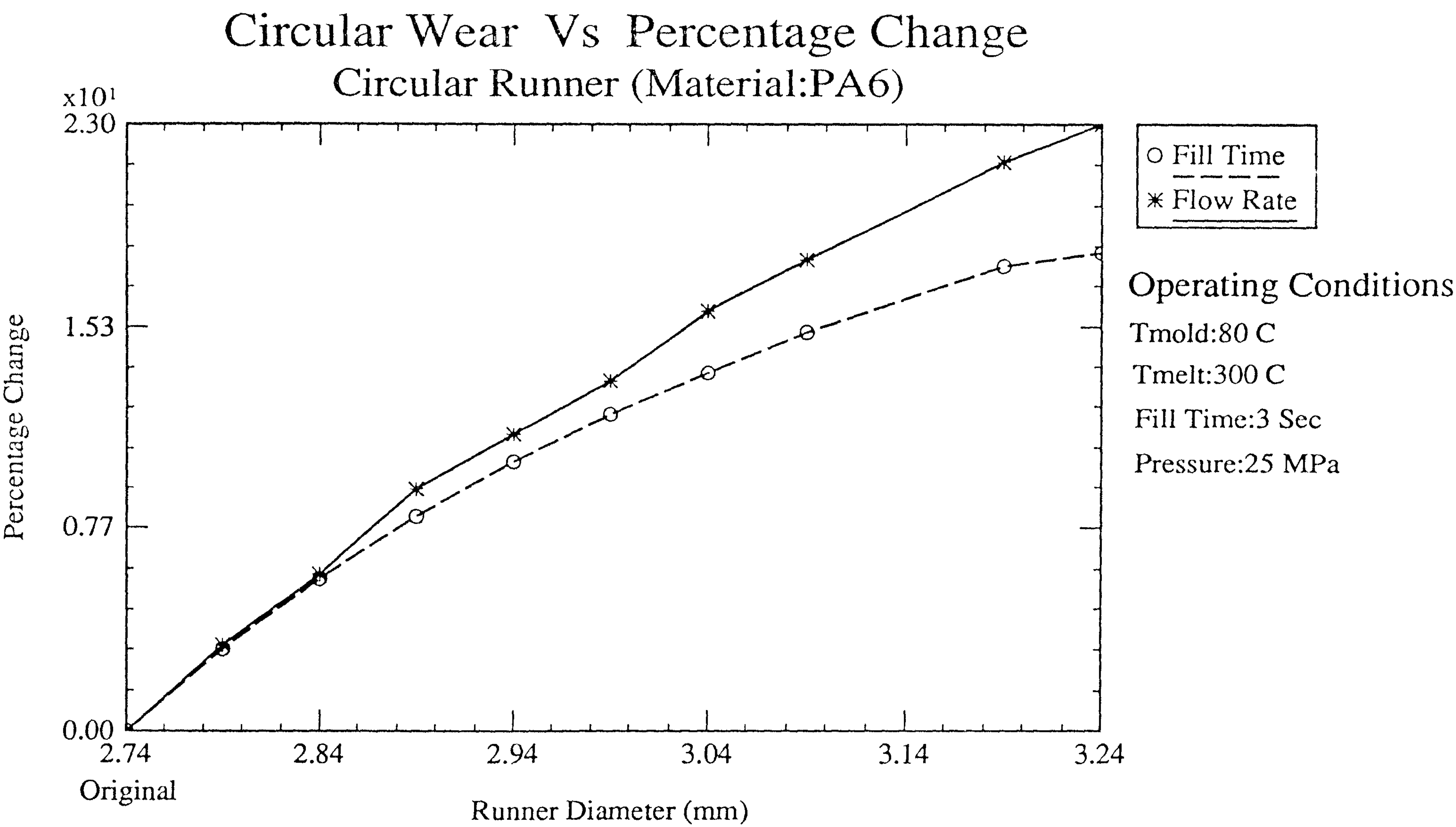
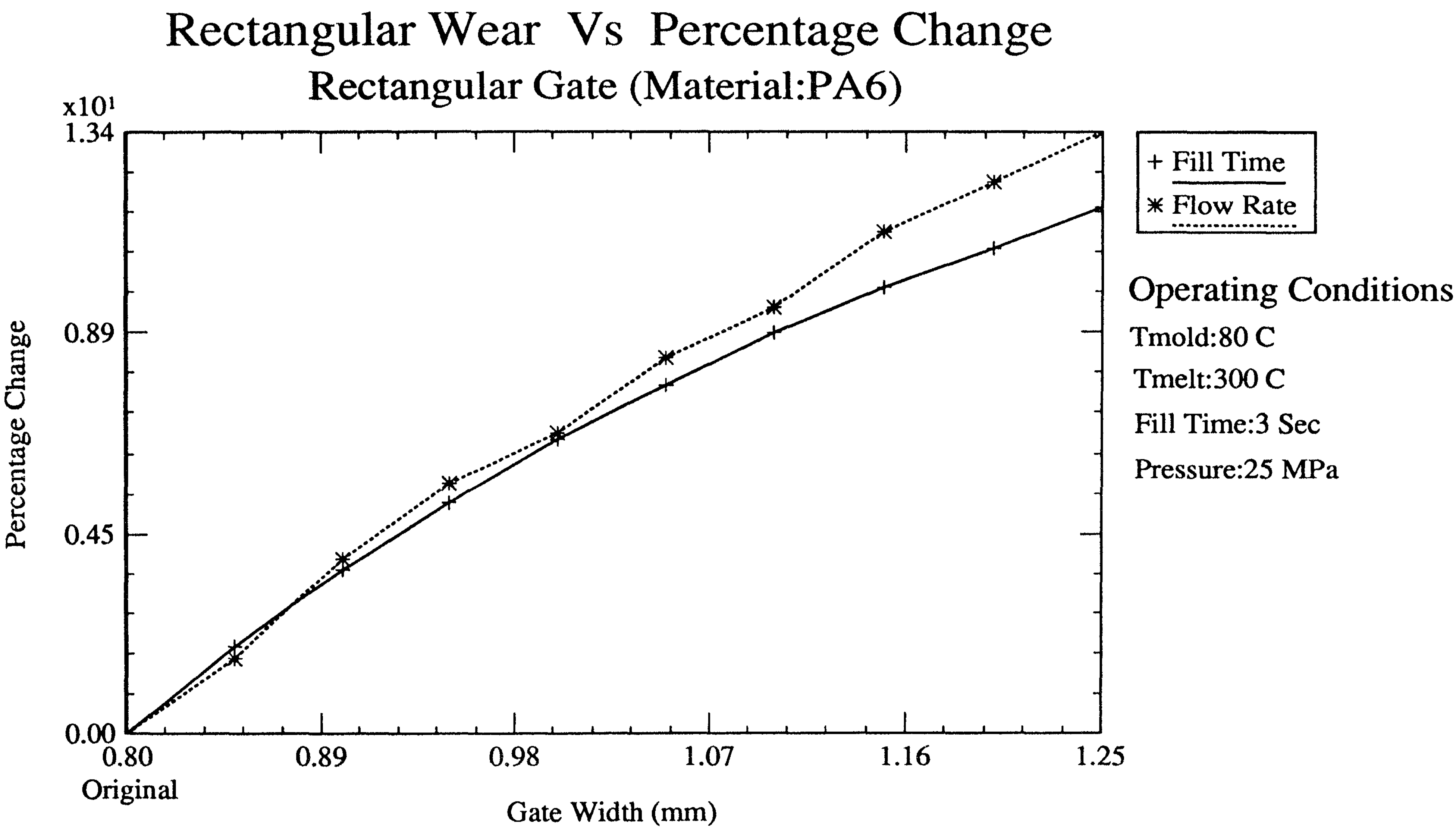


Fig. 5.76

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw54 - Thu Apr 18 22:56:10 1991 (data file was npa6crun%.data)



Rectangular Wear Vs Percentage Change
Rectangular Gate (Material:PA6)
x10¹
1.34
0.89
0.45
0.00
Percentage Change
0.80
Original
0.89
0.98
1.07
1.16
1.25
Gate Width (mm)
+ Fill Time
✳ Flow Rate
Operating Conditions
Tmold:80 C
Tmelt:300 C
Fill Time:3 Sec
Pressure:25 MPa

Fig. 5.77

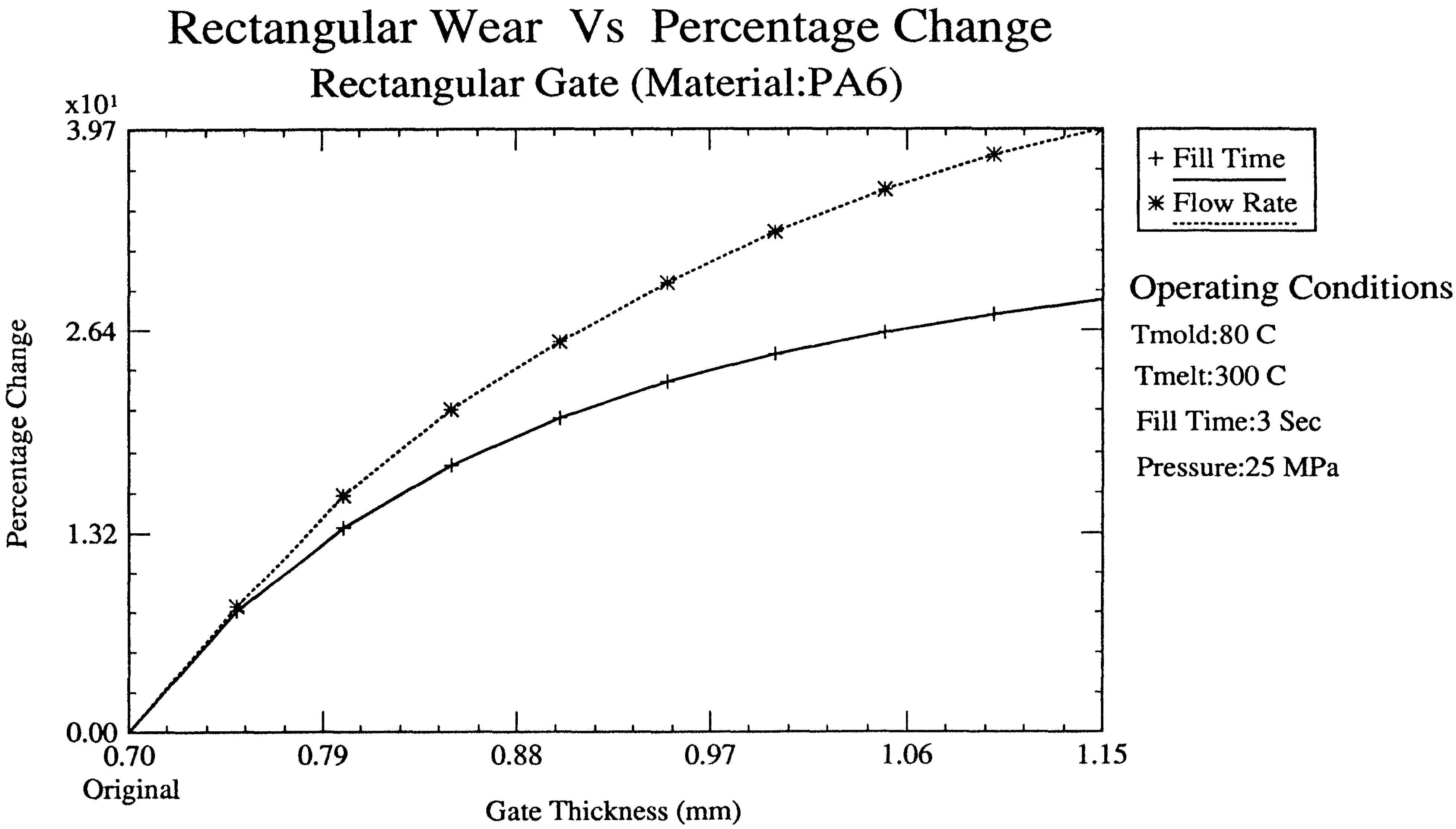


Fig. 5.78

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw54 - Thu Apr 18 20:59:06 1991 (data file was /usr/tmp/TG.AAAa12006)

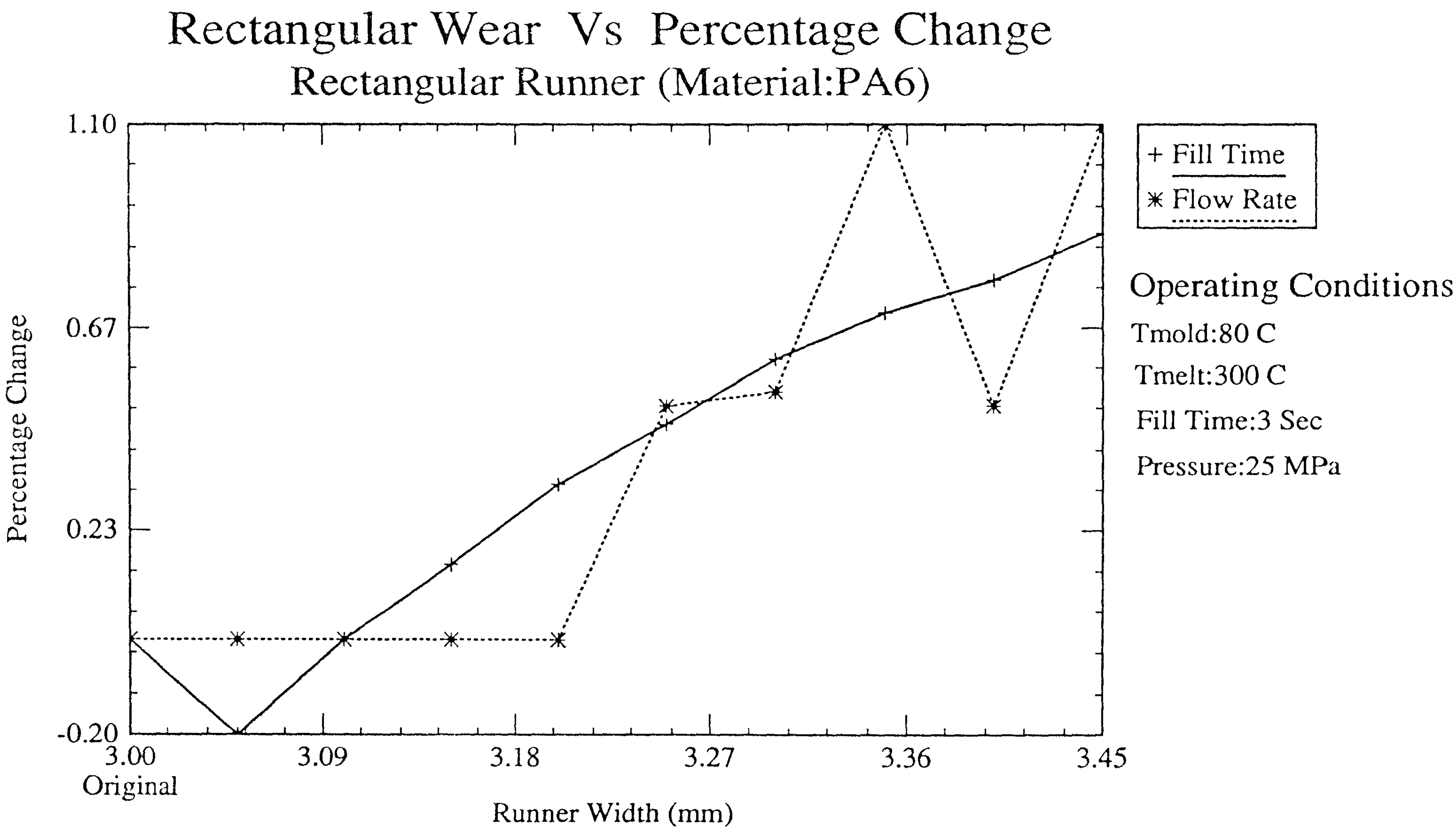


Fig. 5.79

TempleGraph 2.3, Origin /usr/mesunb/users/ksv2028@mesunw54 - Thu Apr 18 21:24:35 1991 (data file was /usr/tmp/TG.AAAa12006)

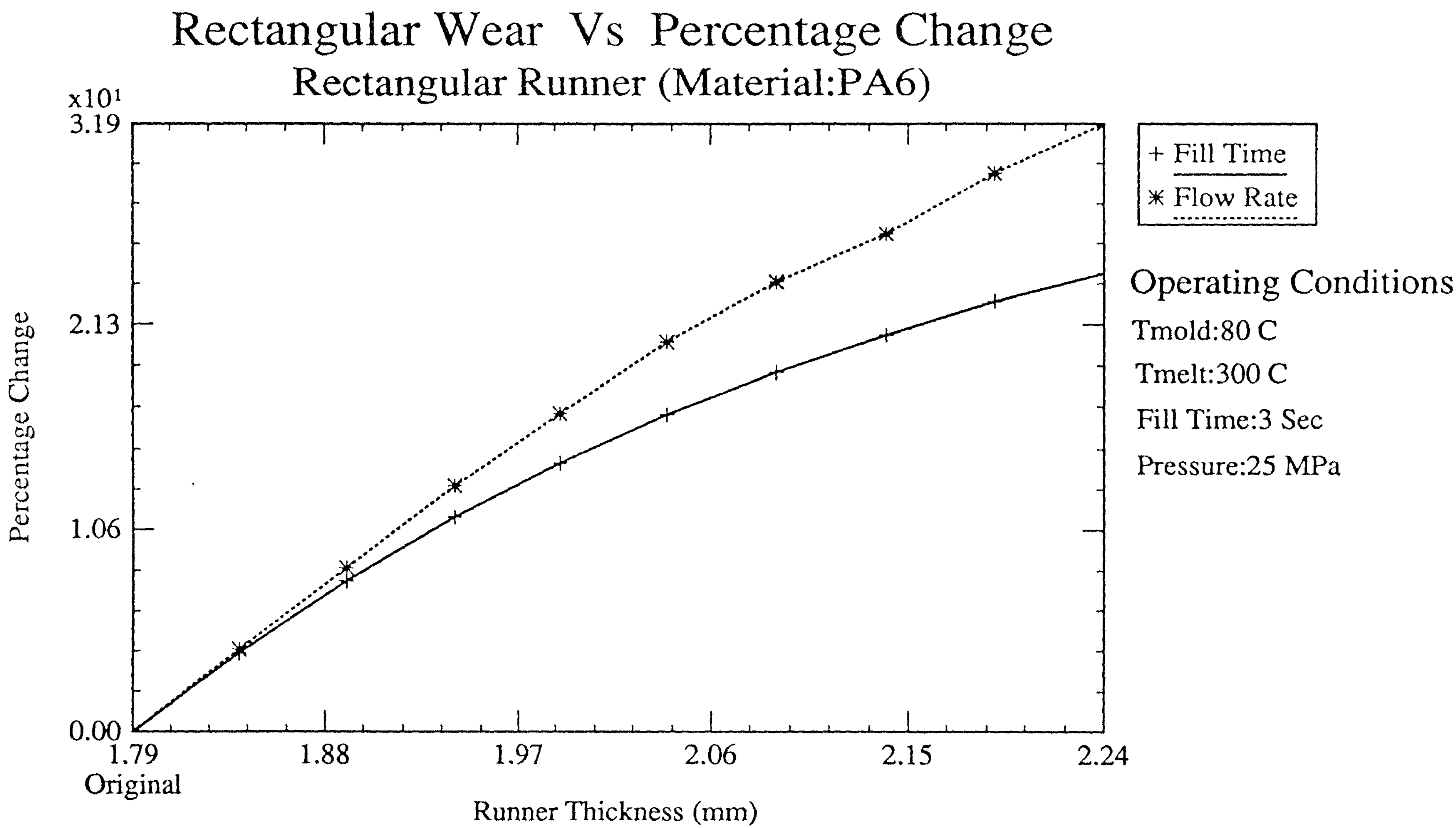

Rectangular Wear Vs Percentage Change
Rectangular Runner (Material:PA6)
x10¹
3.19
2.13
1.06
0.00
Percentage Change
1.79
Original
1.88
1.97
2.06
2.15
2.24
Runner Thickness (mm)
+ Fill Time
* Flow Rate
Operating Conditions
Tmold:80 C
Tmelt:300 C
Fill Time:3 Sec
Pressure:25 MPa

Fig. 5.80

Rectangular Wear Vs Fill Time
Rectangular Runner (Material: PC)

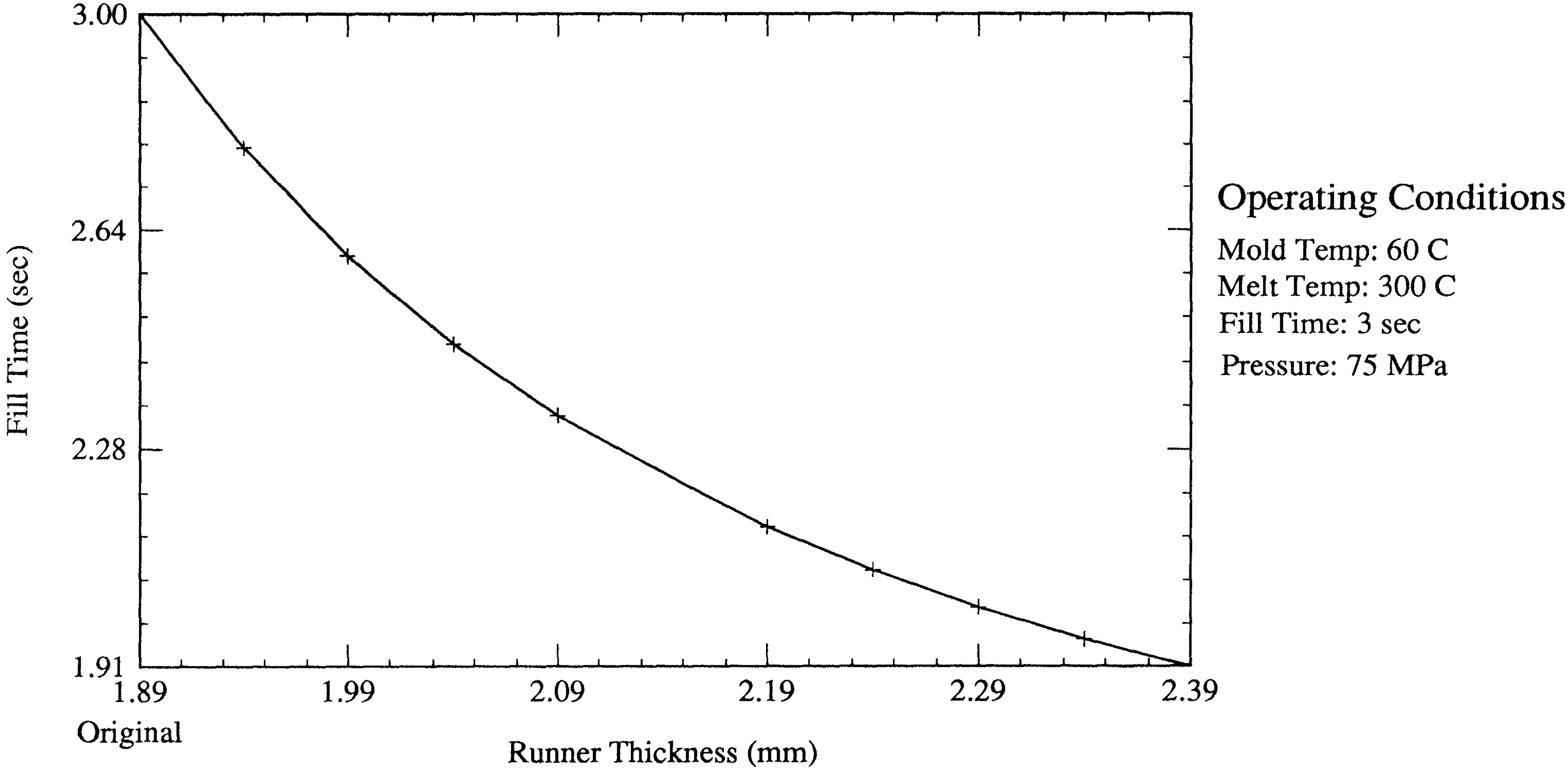


Fig. 5.40

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw57 - Tue Apr 30 19:28:11 1991 (data file was npcrecrunt.data)

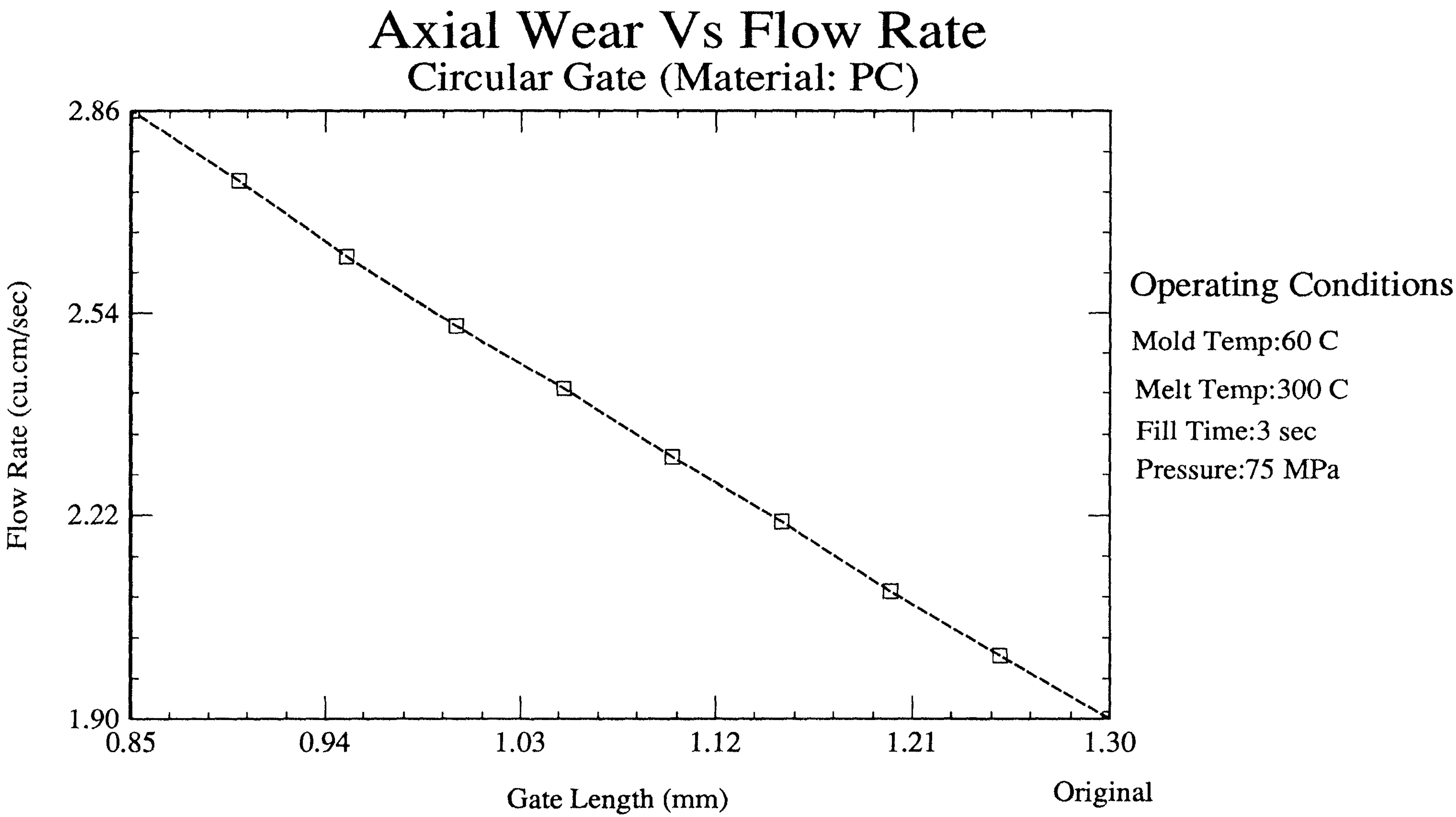


Fig. 5.41

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw57 - Tue Apr 30 17:52:53 1991 (data file was npccgatl.data)

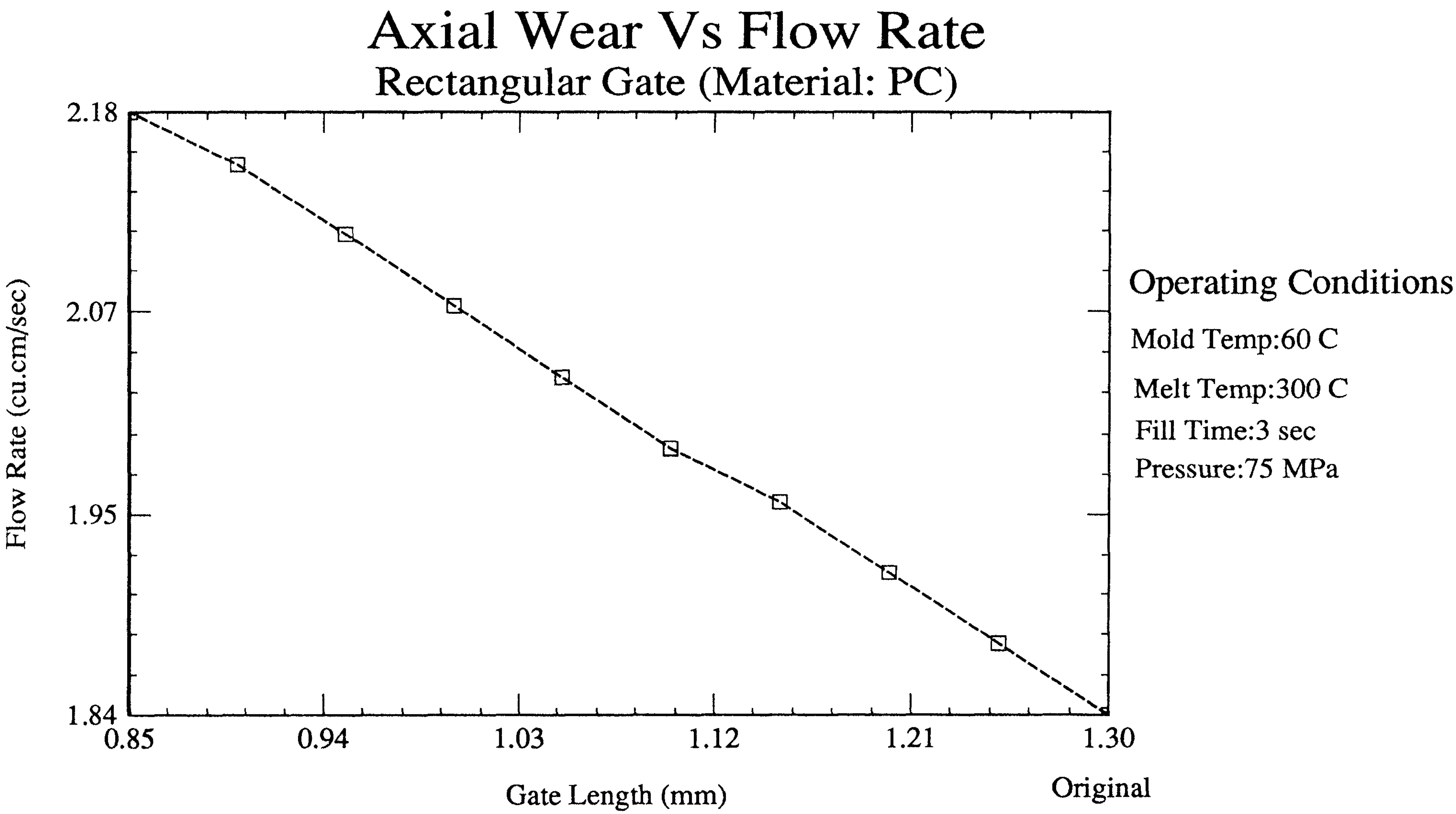


Fig. 5.42

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw57 - Tue Apr 30 17:58:28 1991 (data file was npcrgatl.data)

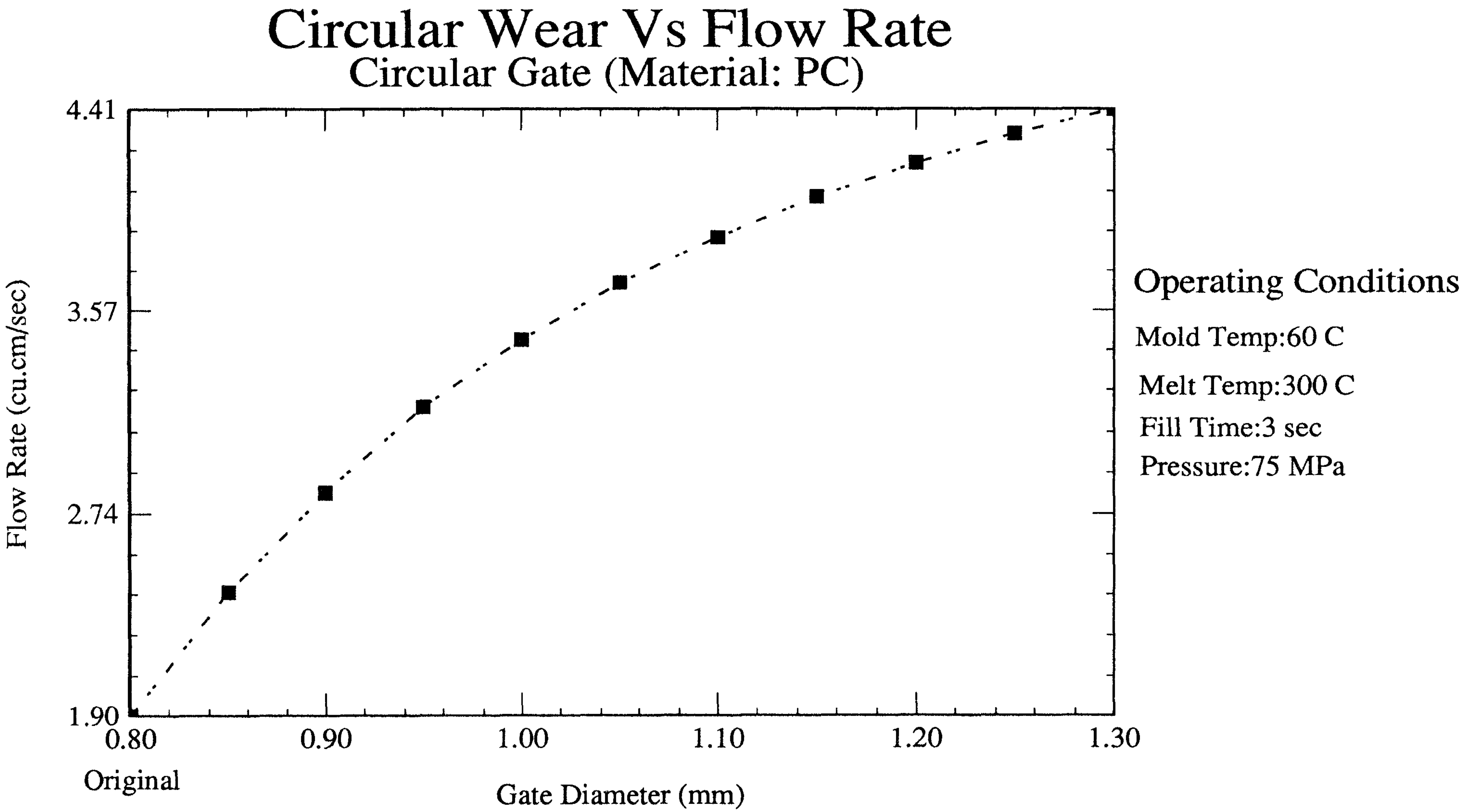


Fig. 5.43

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw57 - Tue Apr 30 18:17:16 1991 (data file was npccgat.data)

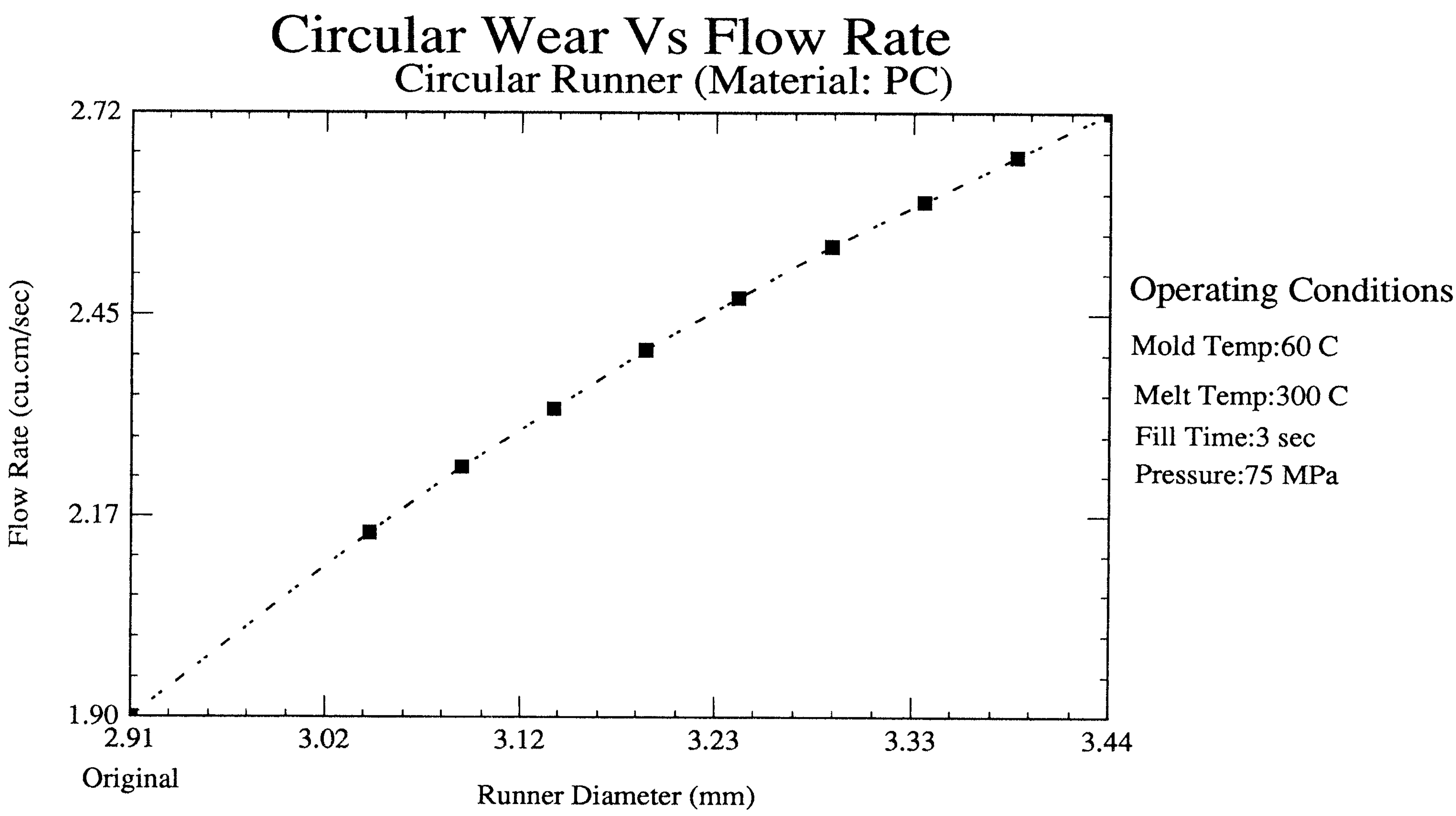


Fig. 5.44

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw57 - Tue Apr 30 18:21:01 1991 (data file was npccrun.data)

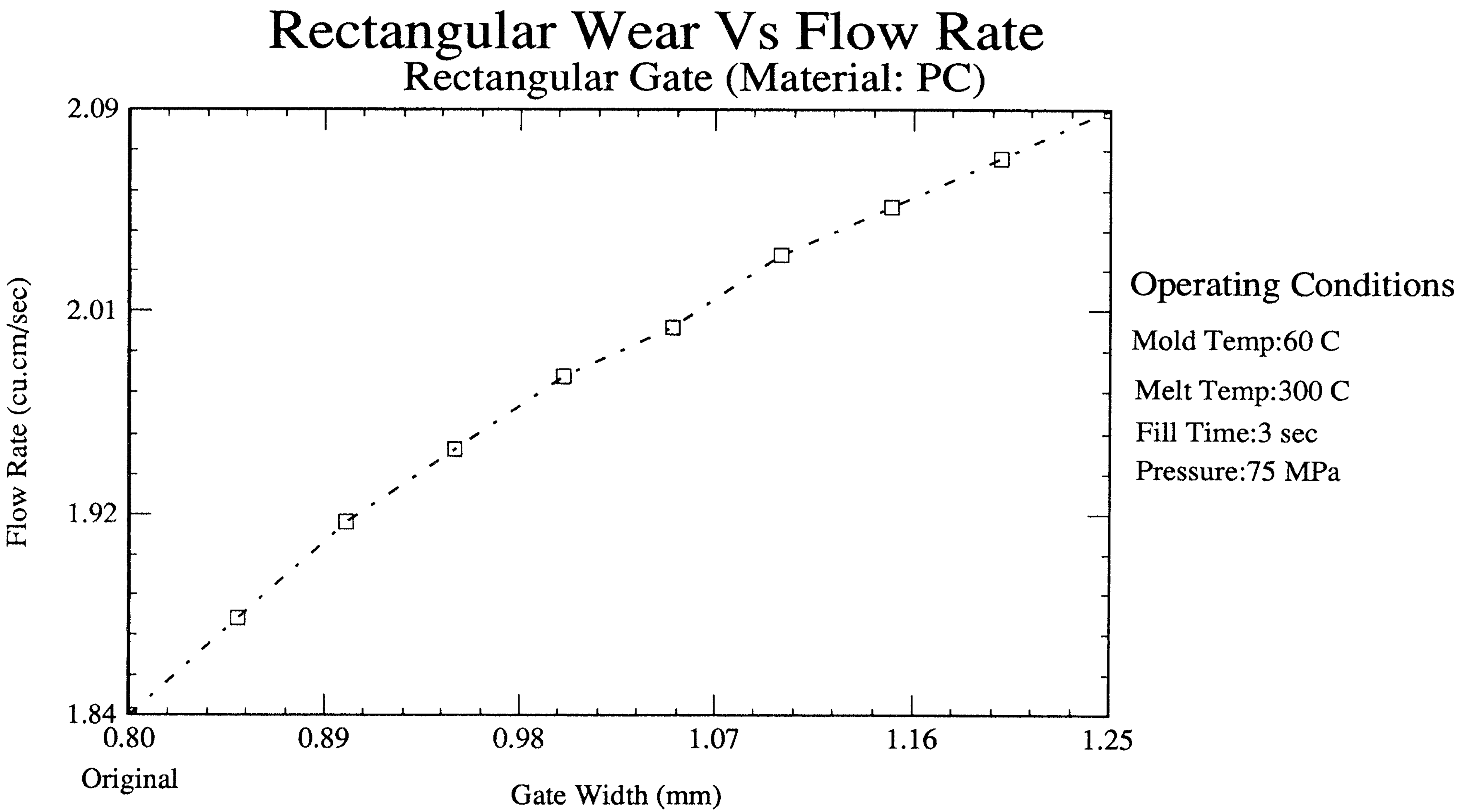


Fig. 5.45

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw57 - Tue Apr 30 18:38:11 1991 (data file was npcrgatw.data)

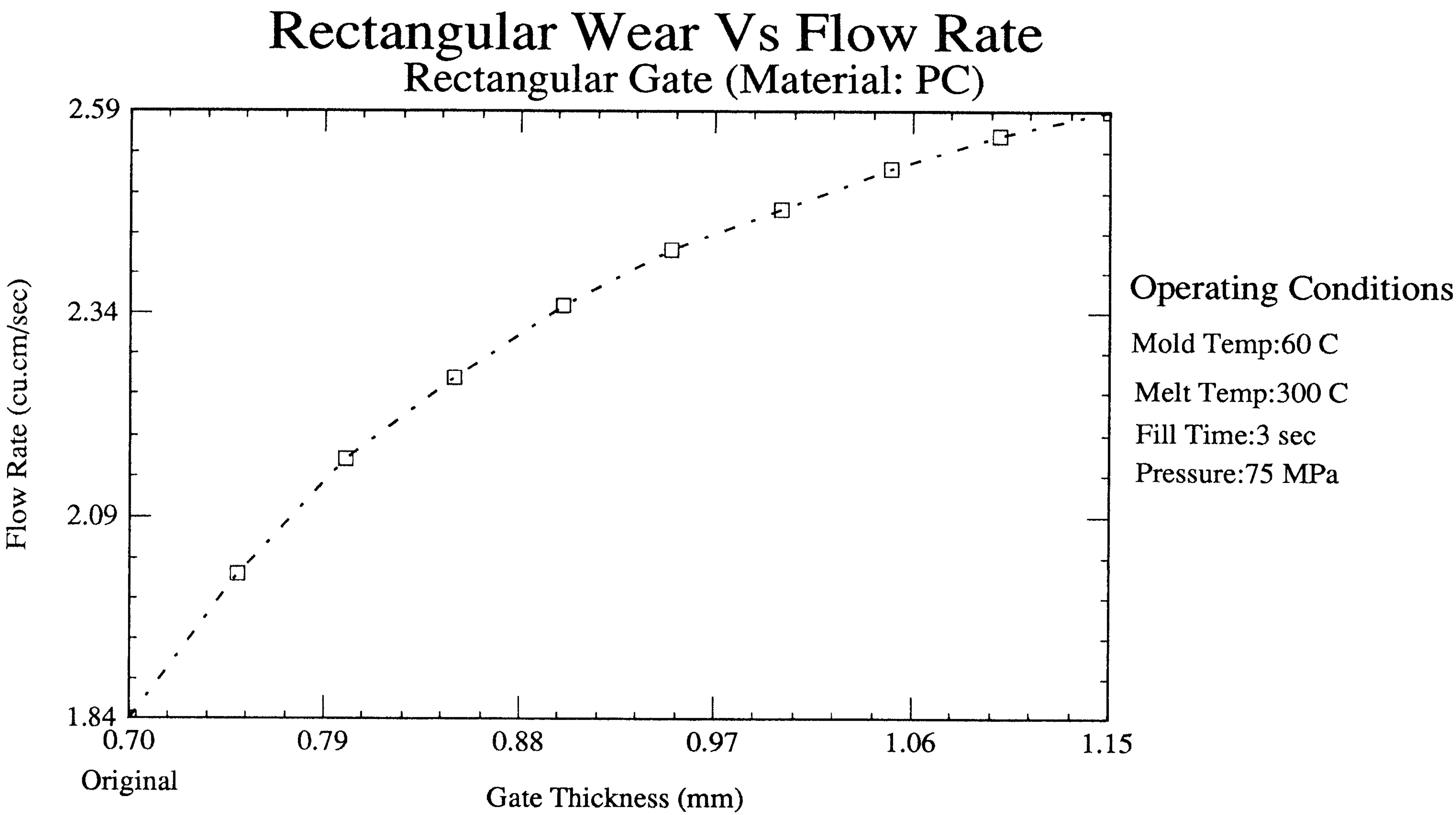


Fig. 5.46

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw57 - Tue Apr 30 18:41:46 1991 (data file was npcrgatt.data)

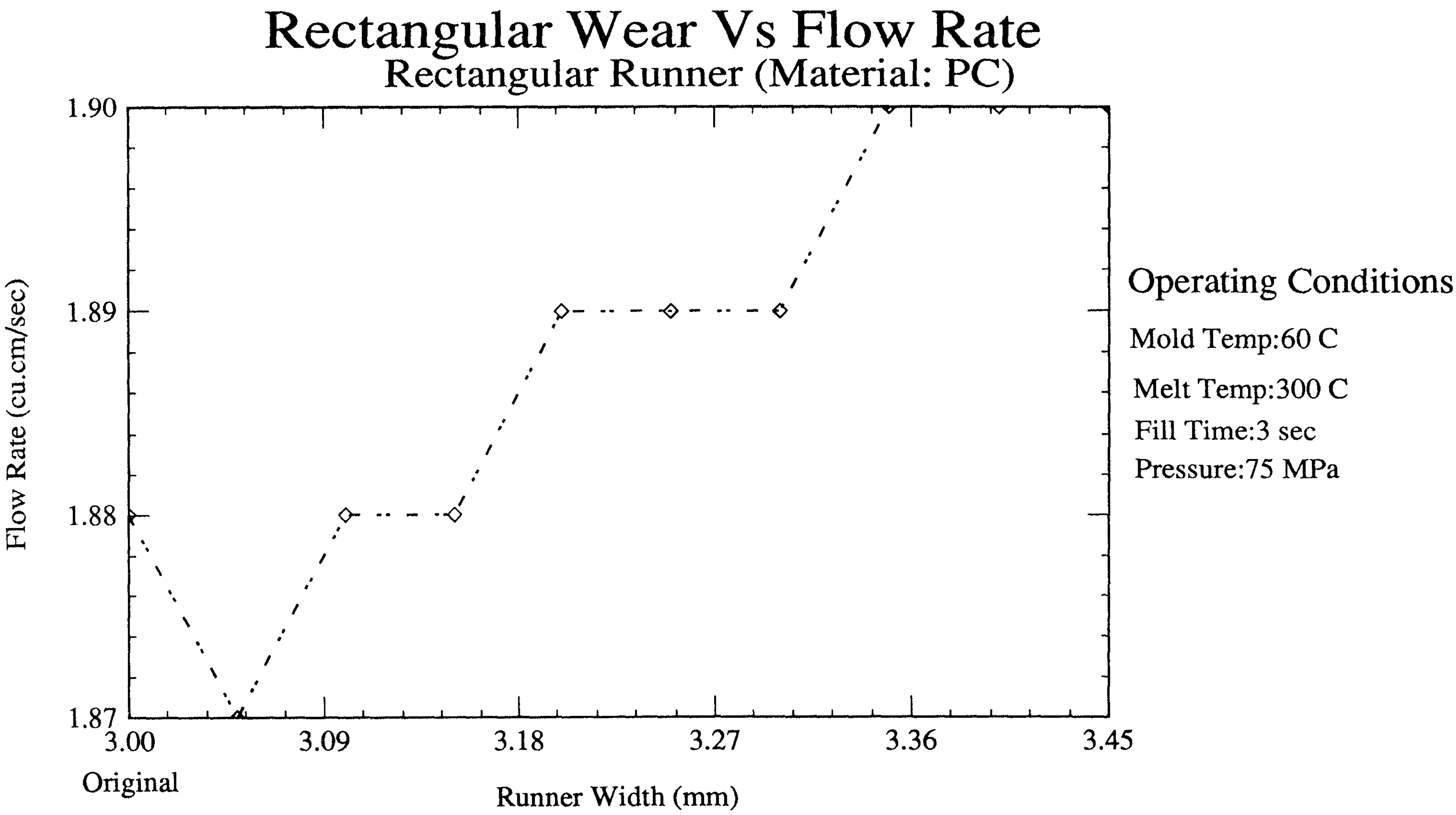


Fig. 5.47

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw57 - Tue Apr 30 18:57:36 1991 (data file was npcrecrunw.data)

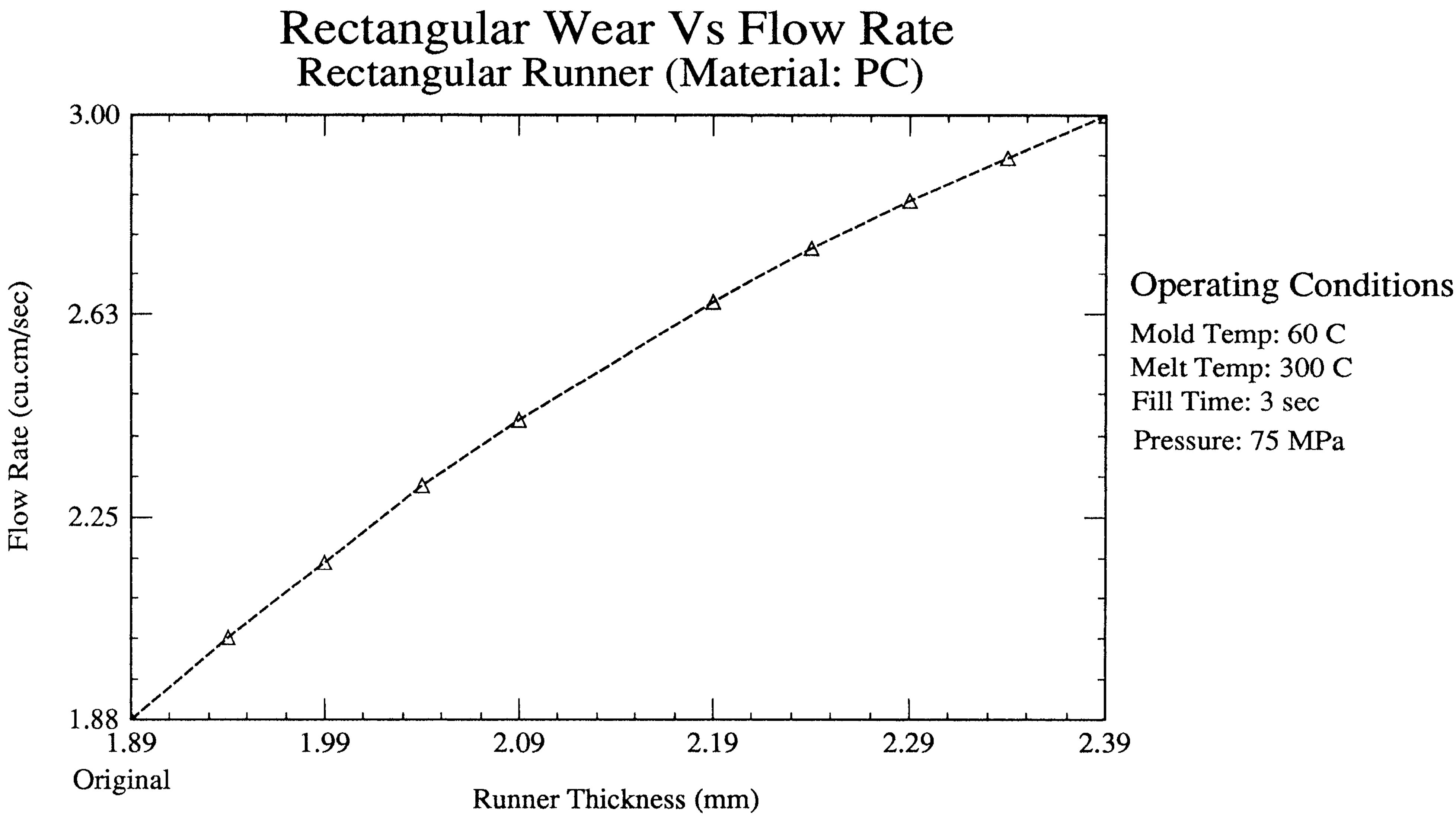


Fig. 5.48

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw57 - Tue Apr 30 19:33:24 1991 (data file was npcrecrunt.data)

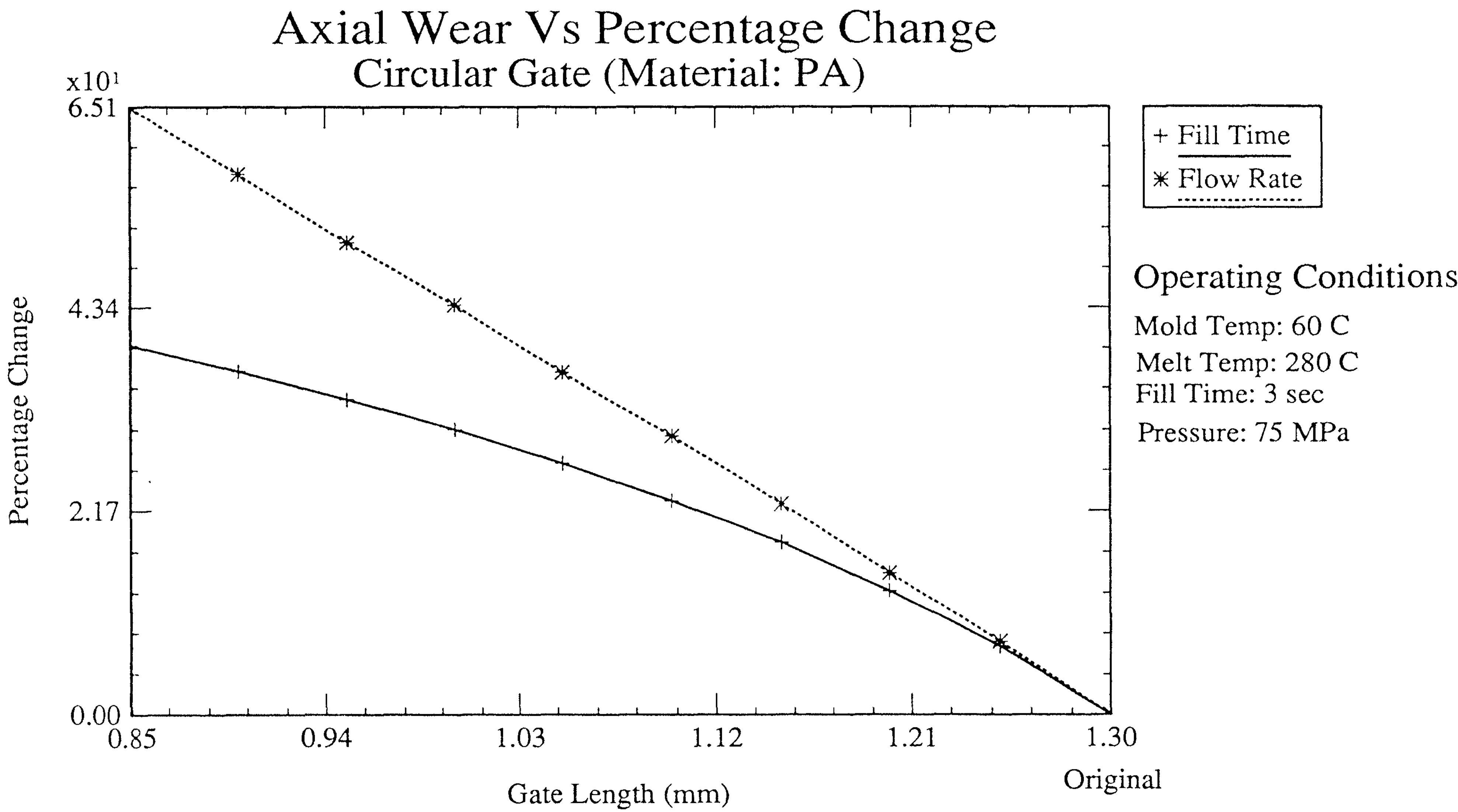


Fig. 5.49

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw53 - Sun Apr 28 23:12:52 1991 (data file was 549.data)

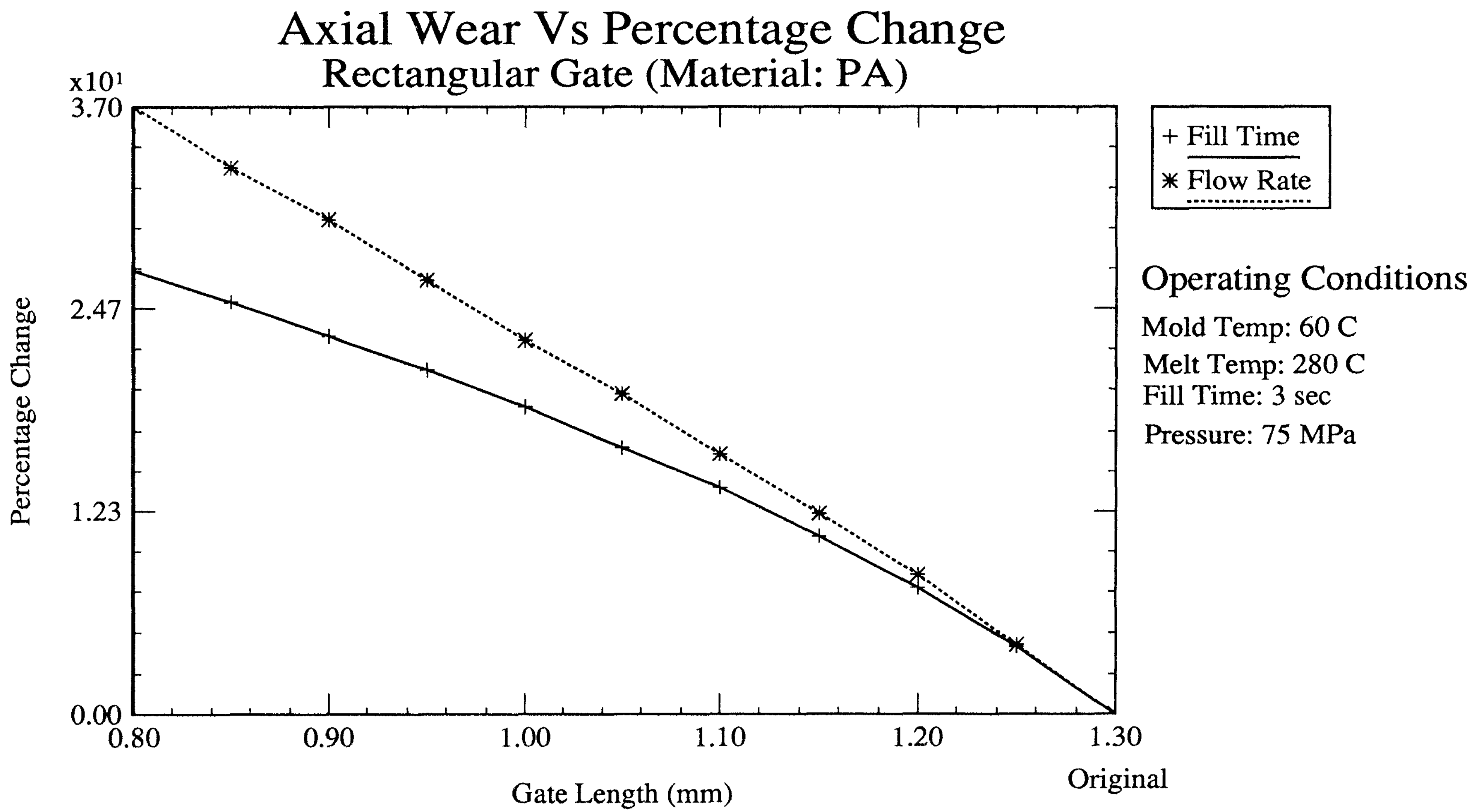


Fig. 5.50

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw53 - Sun Apr 28 23:14:20 1991 (data file was 550.data)

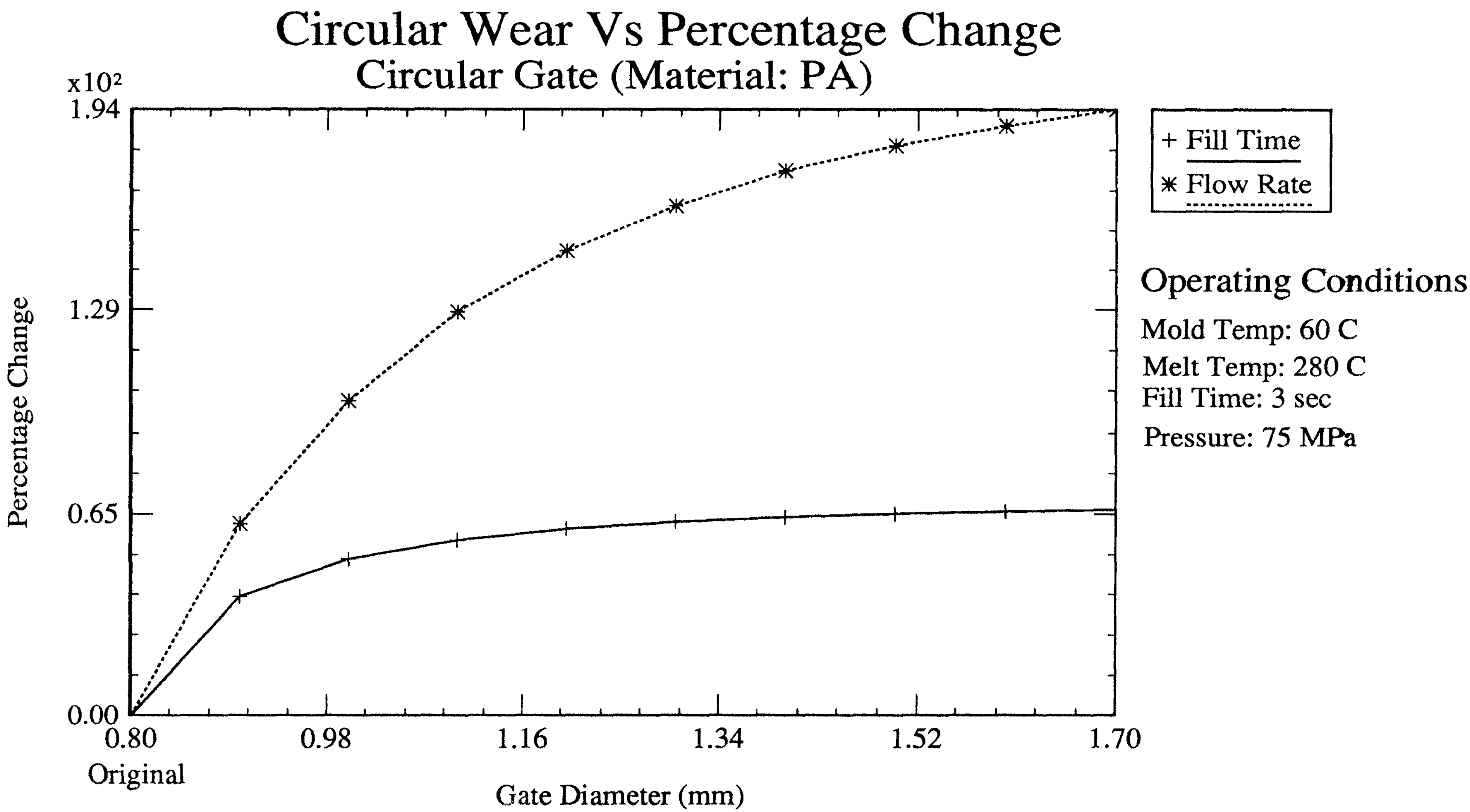


Fig. 5.51

TempleGraph 2 3, Origin: /usr/mesunb/users/ksv2028@mesunw57 - Tue Apr 30 19:45:24 1991 (data file was npacirgat%.data)

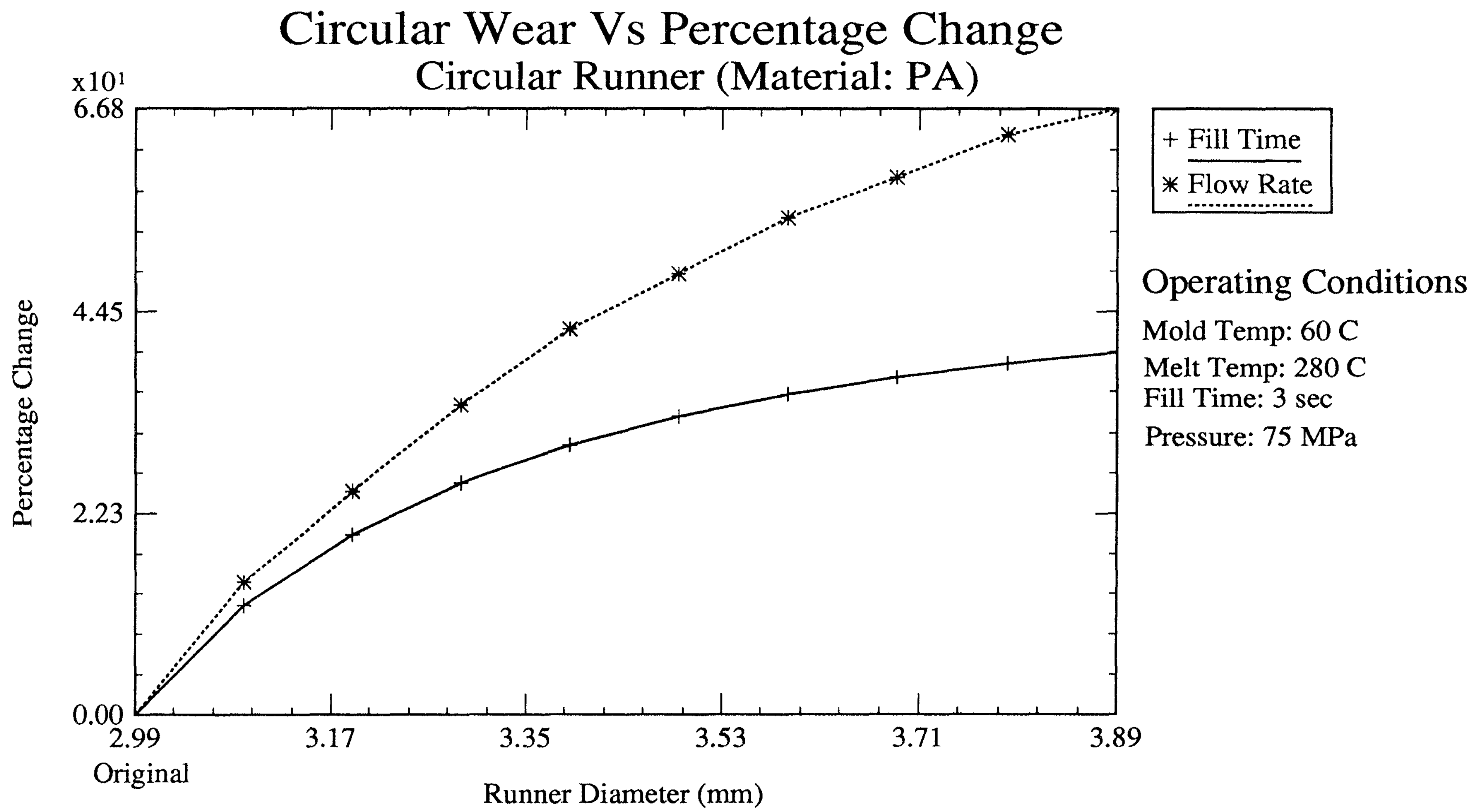
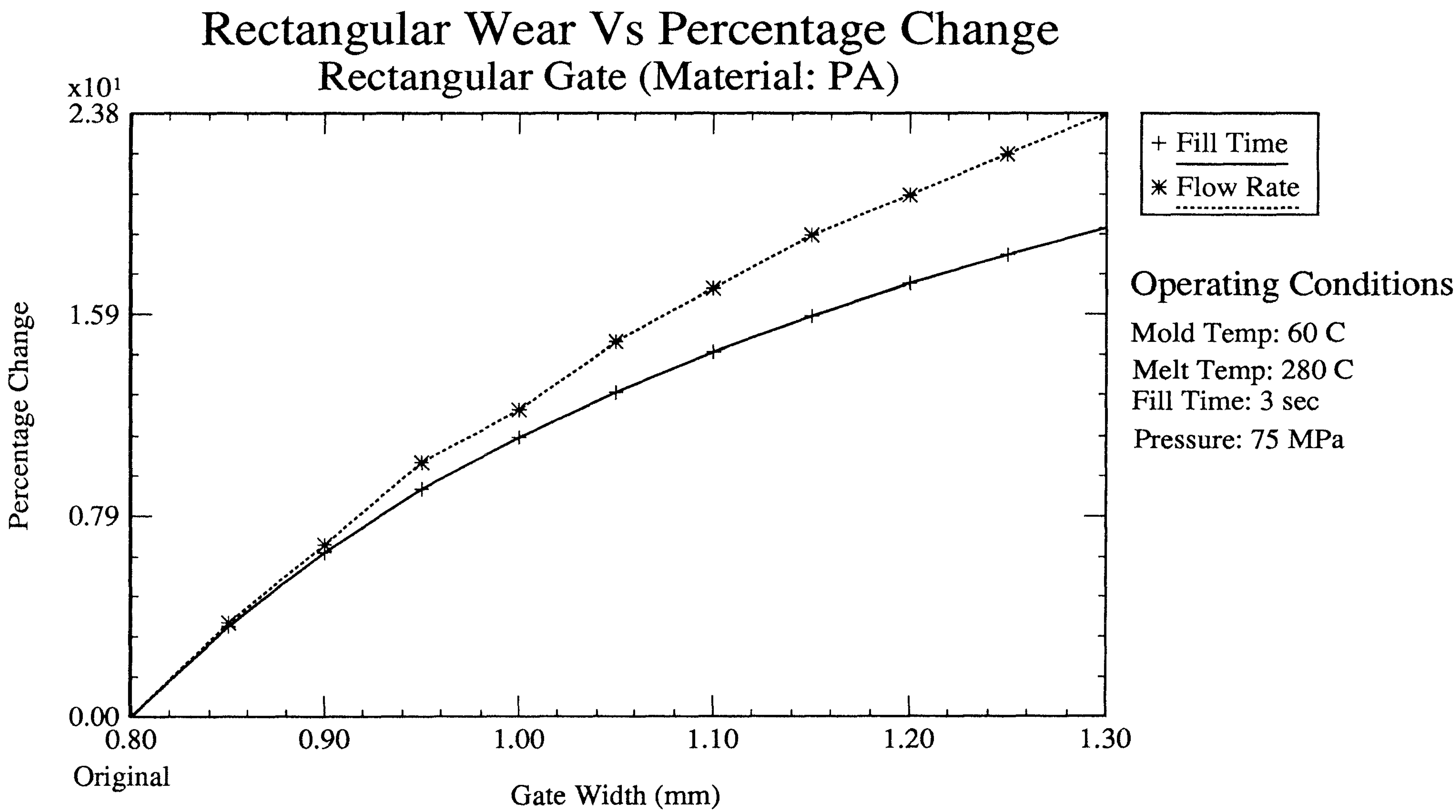


Fig. 5.52

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw57 - Tue Apr 30 19:49:20 1991 (data file was npacirrun%.data)



Rectangular Wear Vs Percentage Change
Rectangular Gate (Material: PA)
x10¹
2.38
1.59
0.79
0.00
Percentage Change
0.80
0.90
1.00
1.10
1.20
1.30
Original
Gate Width (mm)
+ Fill Time
✳ Flow Rate
Operating Conditions
Mold Temp: 60 C
Melt Temp: 280 C
Fill Time: 3 sec
Pressure: 75 MPa

Fig. 5.53

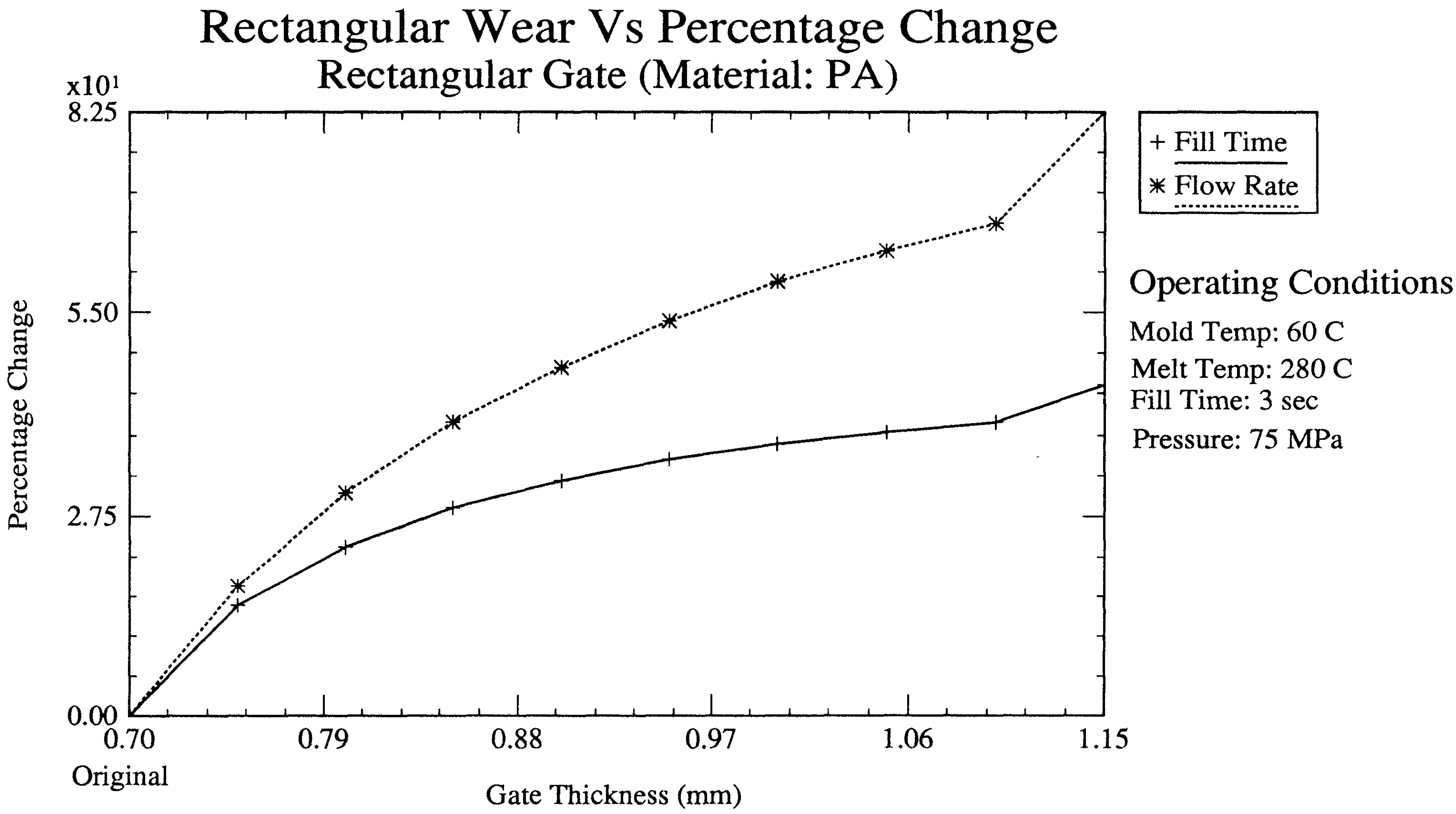


Fig. 5.54

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw53 - Sun Apr 28 23:16:50 1991 (data file was 554.data)

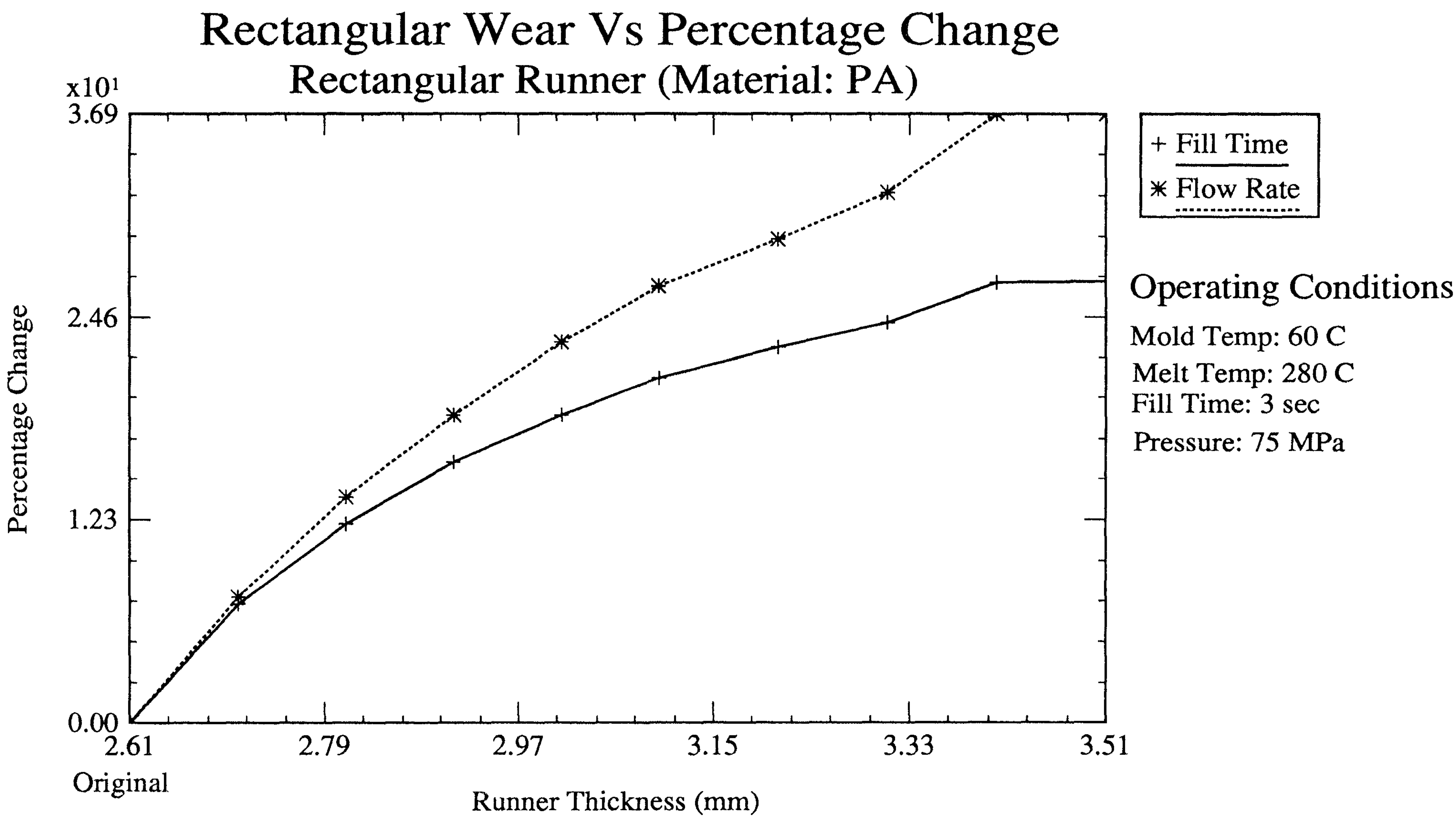


Fig. 5.56

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw53 - Sun Apr 28 23:17:44 1991 (data file was 556.data)

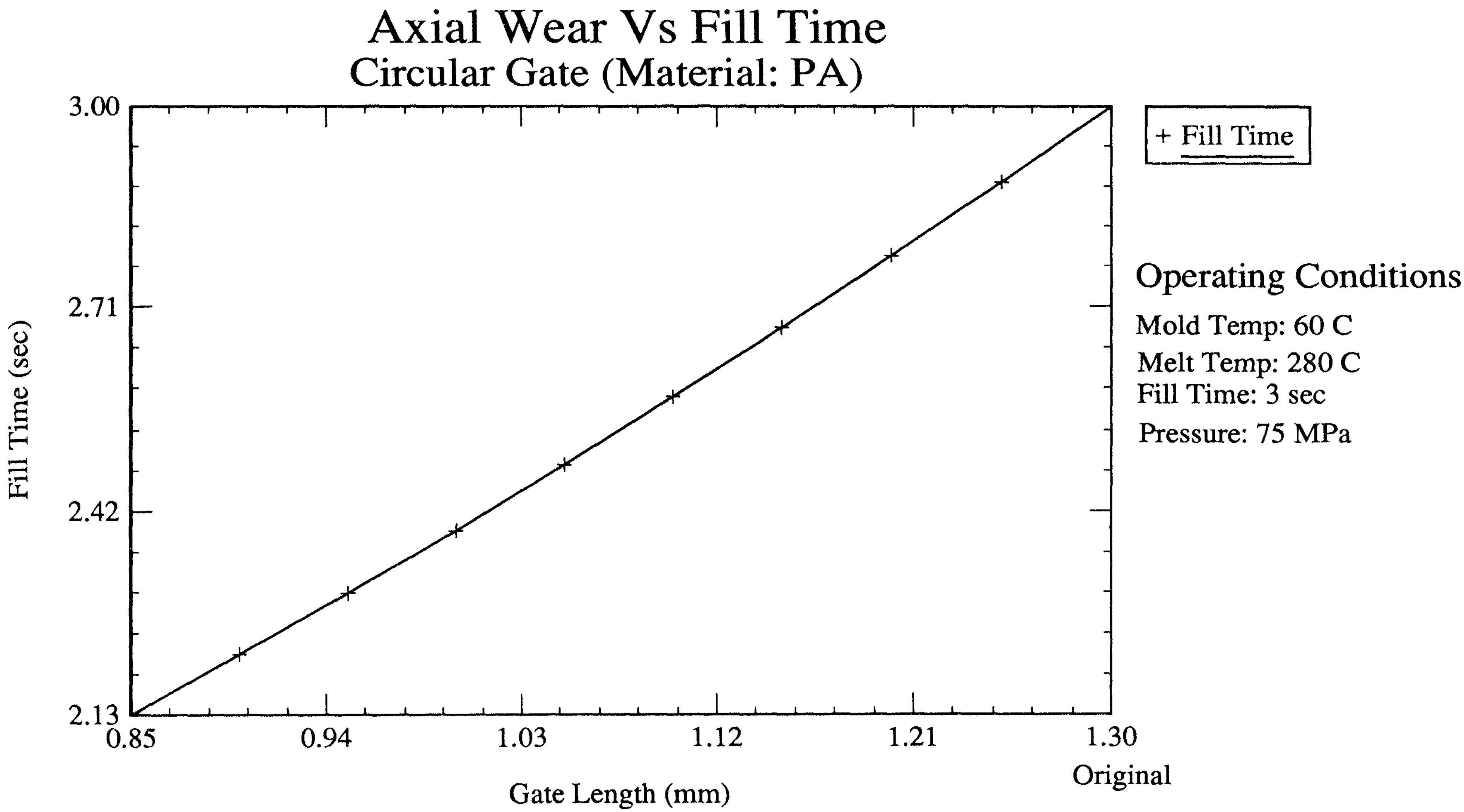


Fig. 5.57

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw57 - Tue Apr 30 19:56:47 1991 (data file was npacgatl.data)

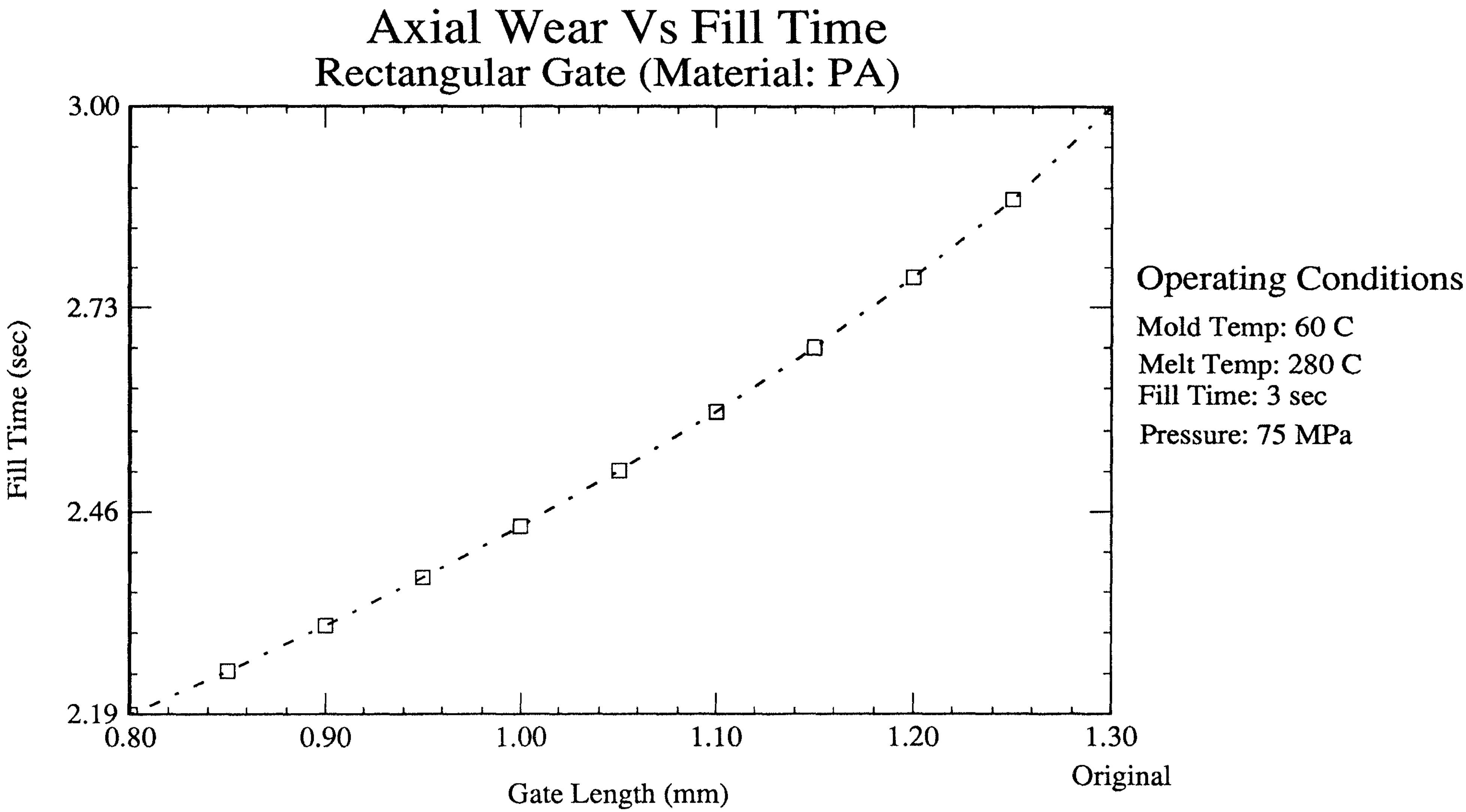


Fig. 5.58

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw57 - Tue Apr 30 20:05:34 1991 (data file was nparecgatl.data)

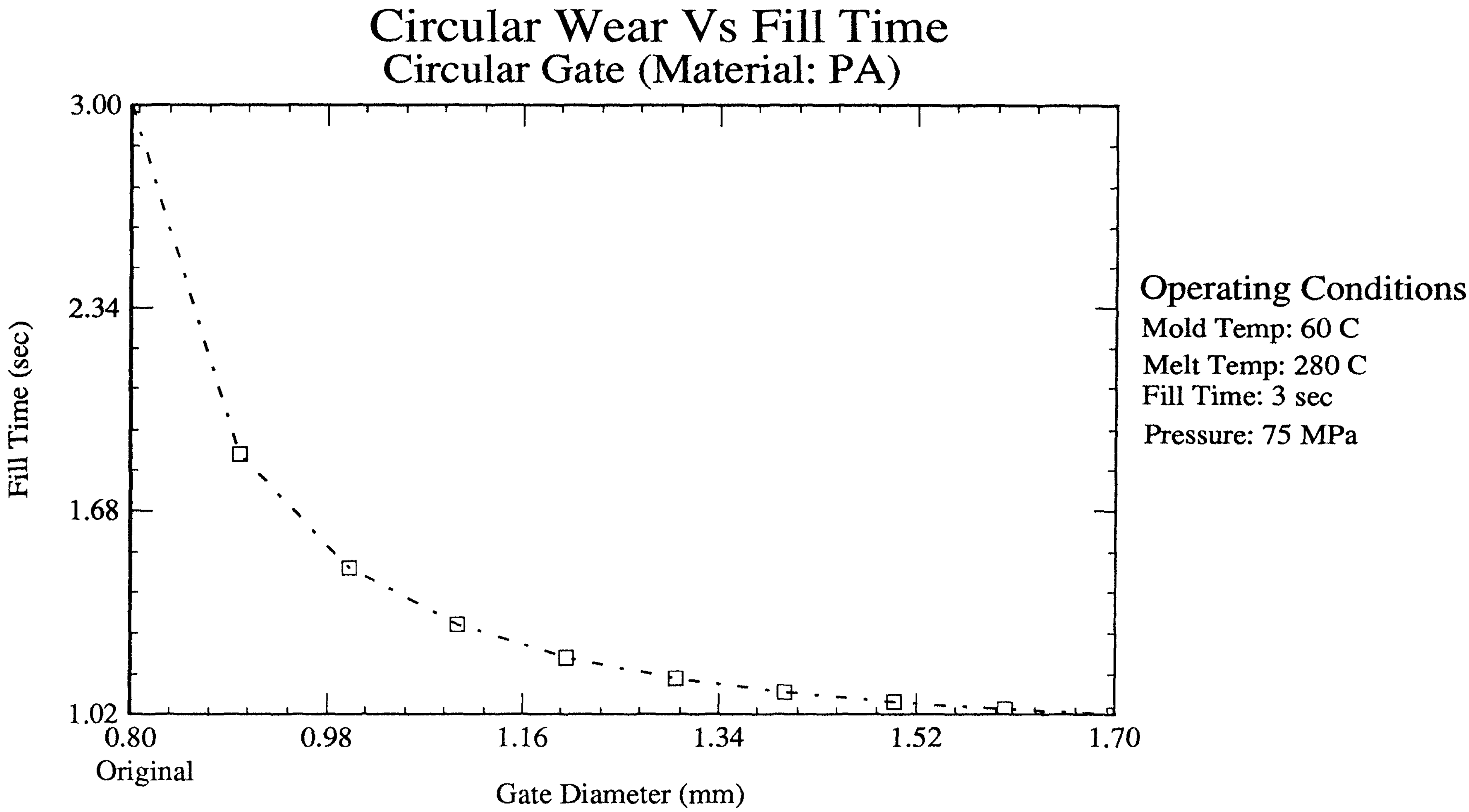


Fig. 5.59

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw57 - Tue Apr 30 20:11:03 1991 (data file was npacgat.data)

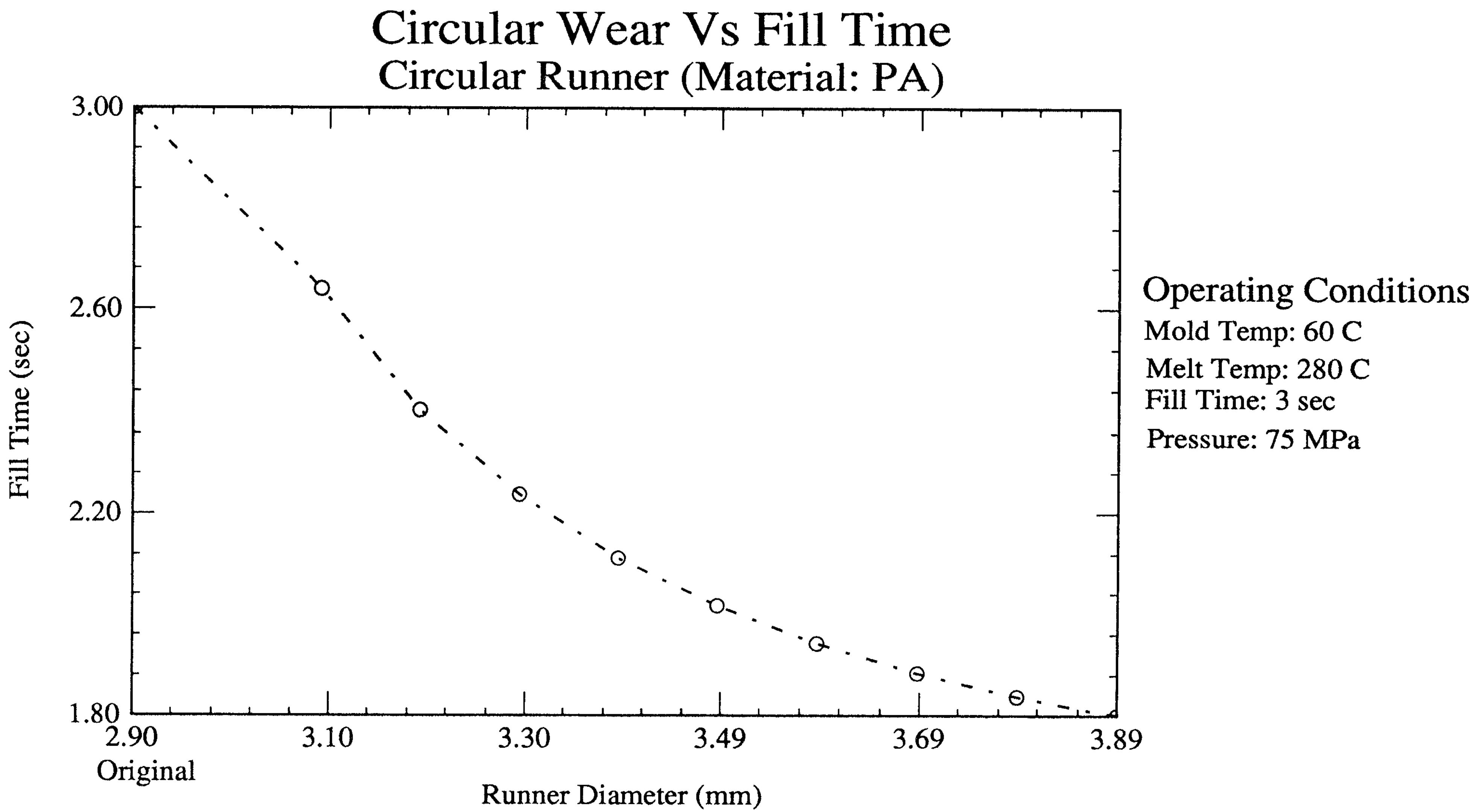


Fig. 5.60

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw57 - Tue Apr 30 20:19:59 1991 (data file was npacrun.data)

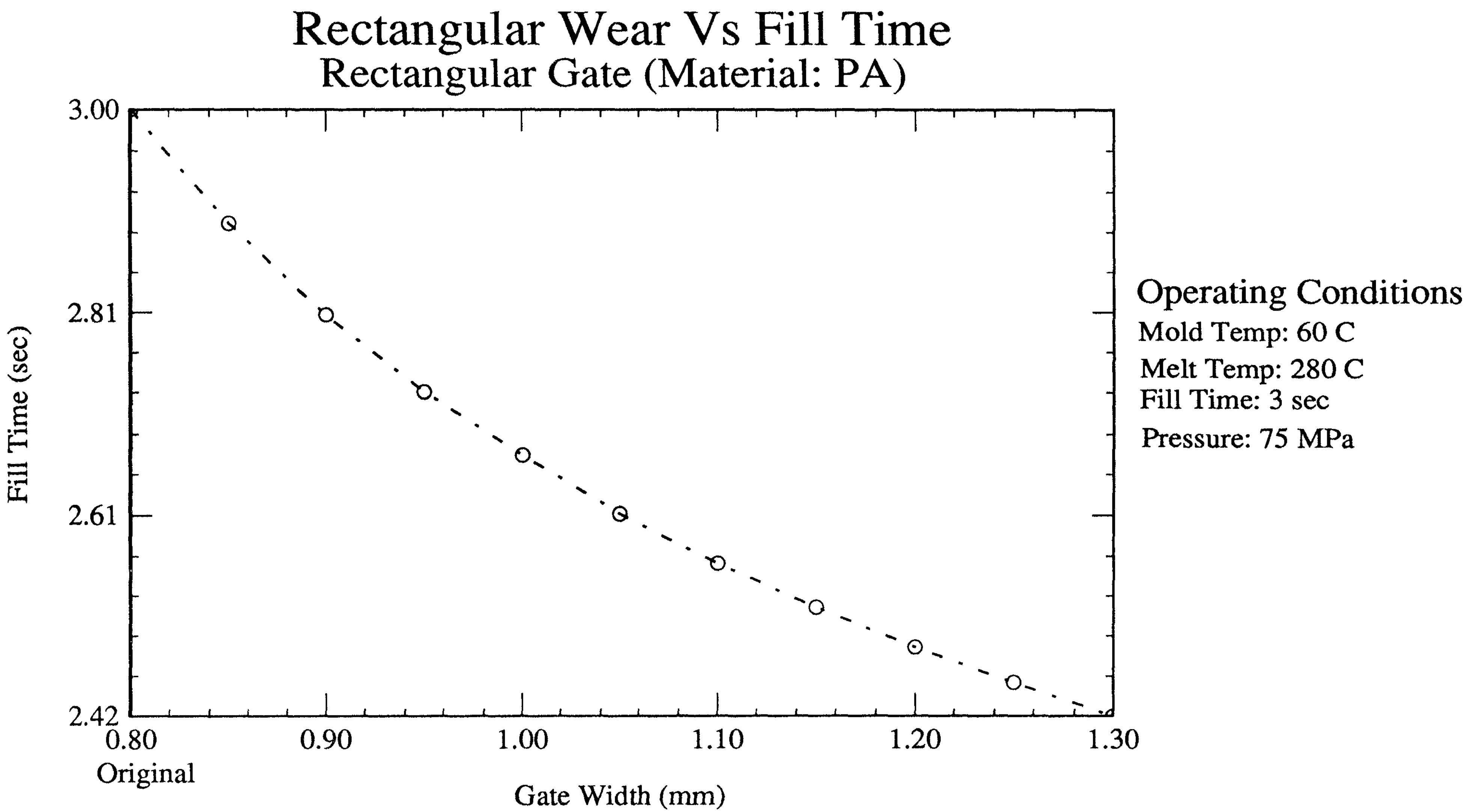


Fig. 5.61

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw57 - Tue Apr 30 20:25:17 1991 (data file was nparecgatw.data)

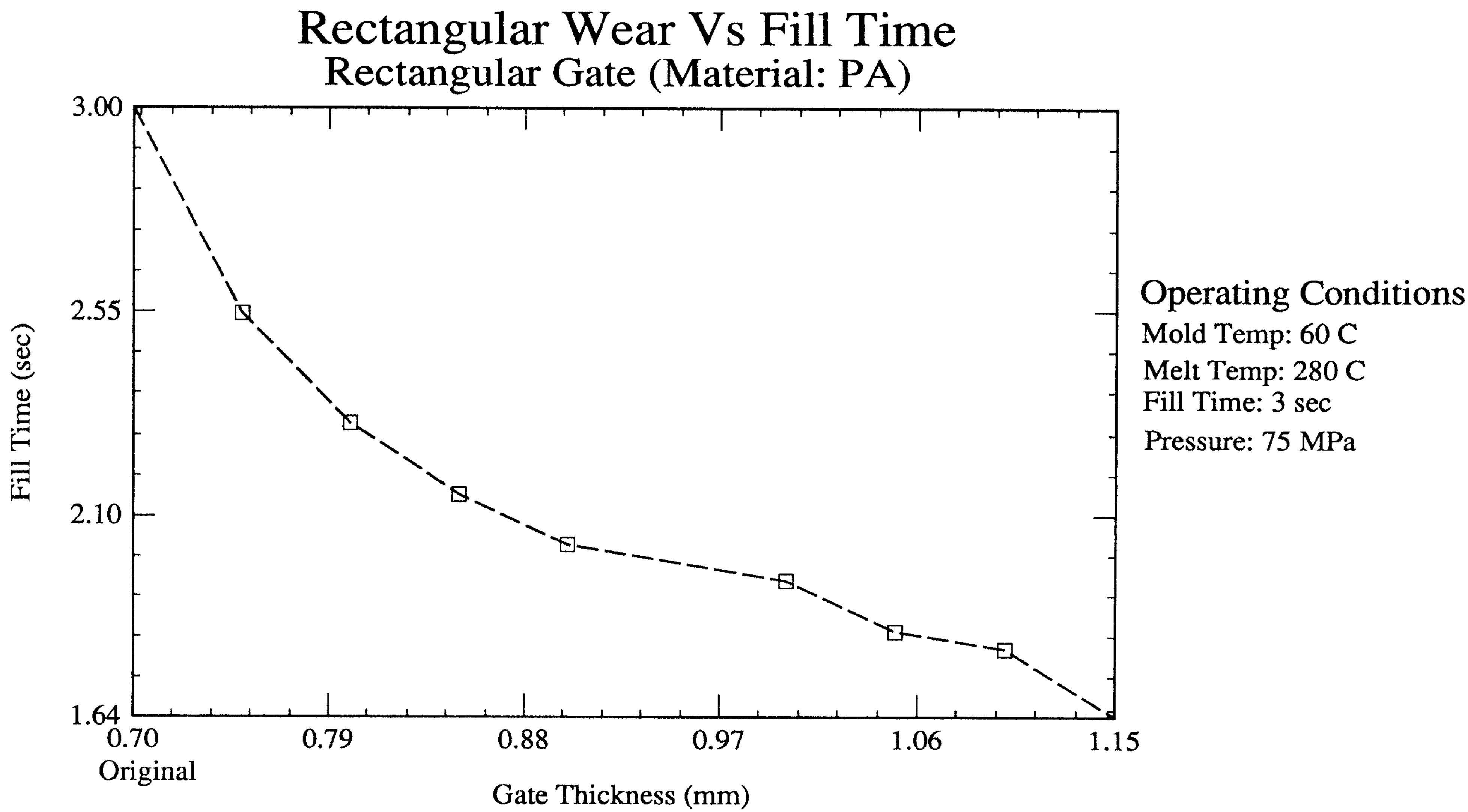


Fig. 5.62

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw57 - Tue Apr 30 20:32:06 1991 (data file was nparecgatt.data)

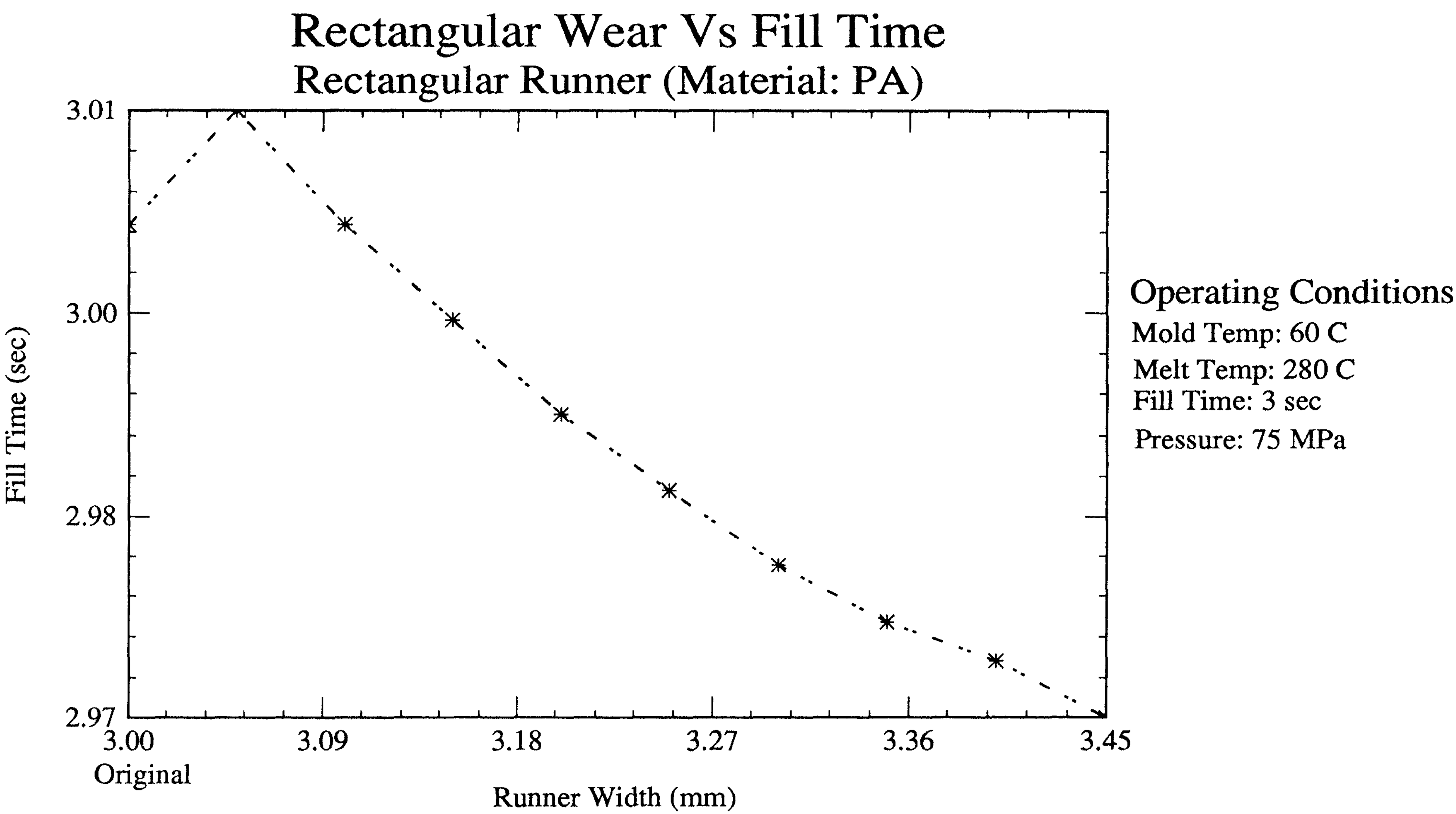


Fig. 5.63

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw57 - Tue Apr 30 20:46:00 1991 (data file was nparrunw.data)

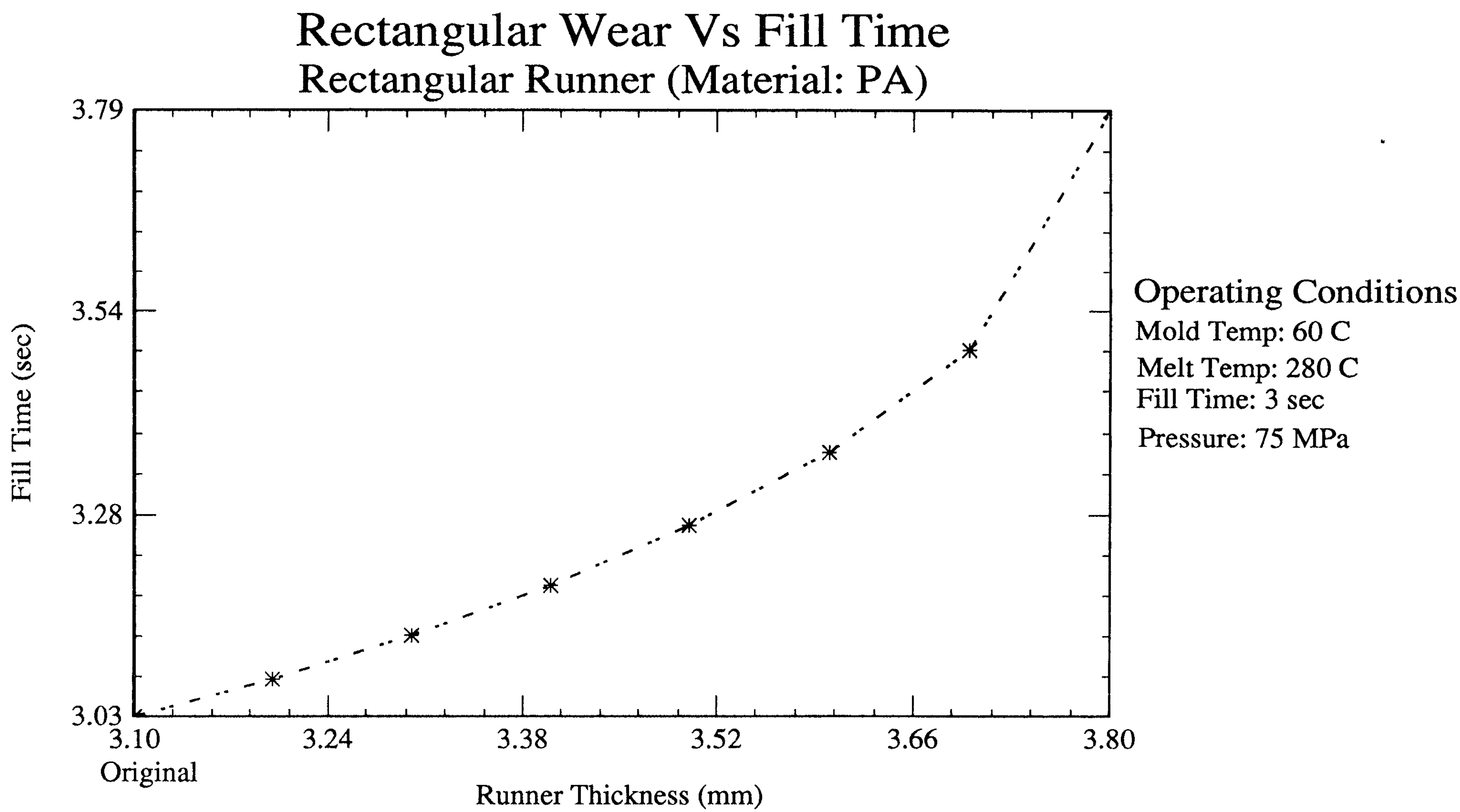


Fig. 5.64

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw57 - Tue Apr 30 20:47:56 1991 (data file was nparecrunw.data)

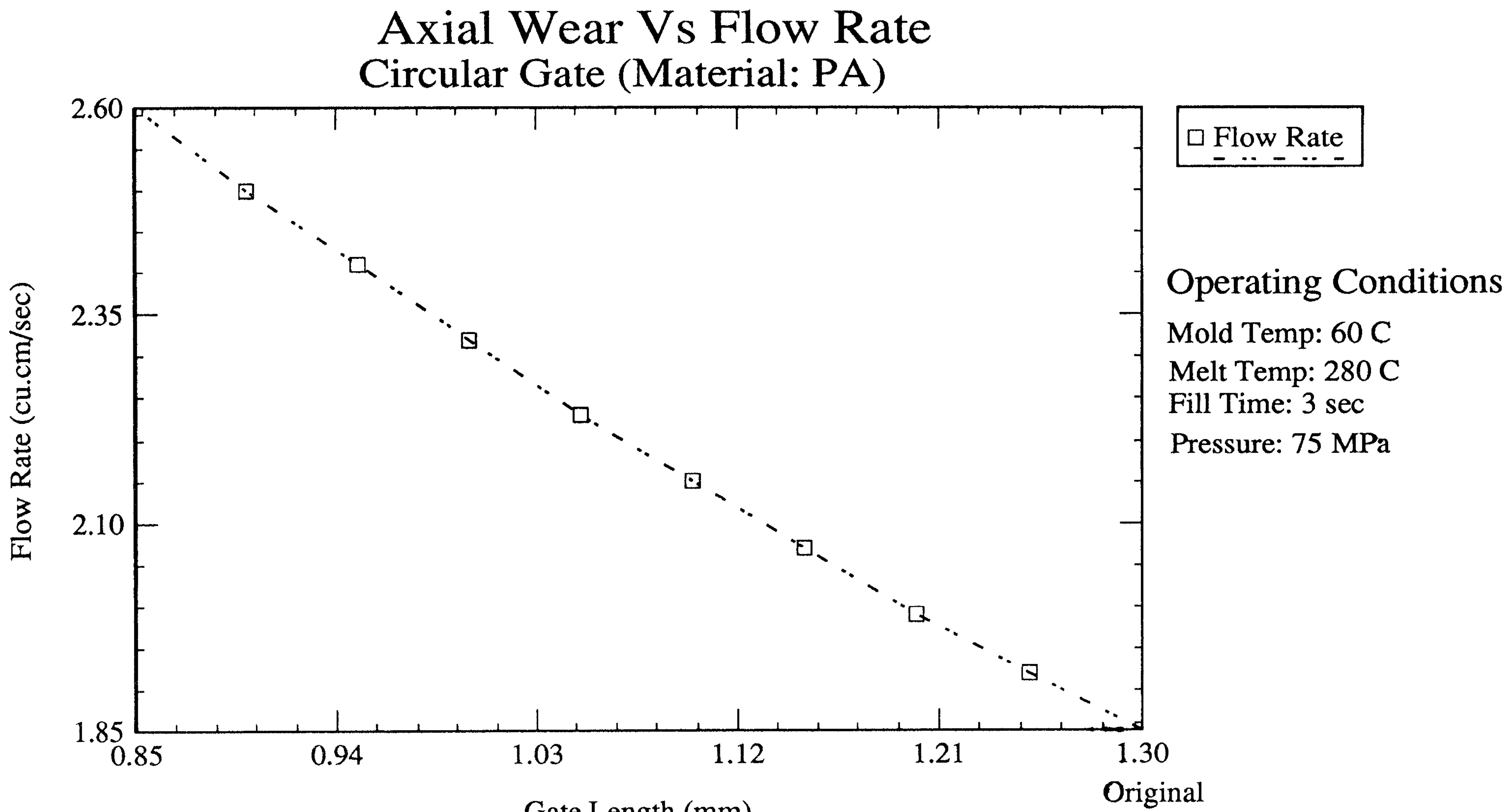


Fig. 5.65

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw57 - Tue Apr 30 19:59:04 1991 (data file was npacgatl.data)

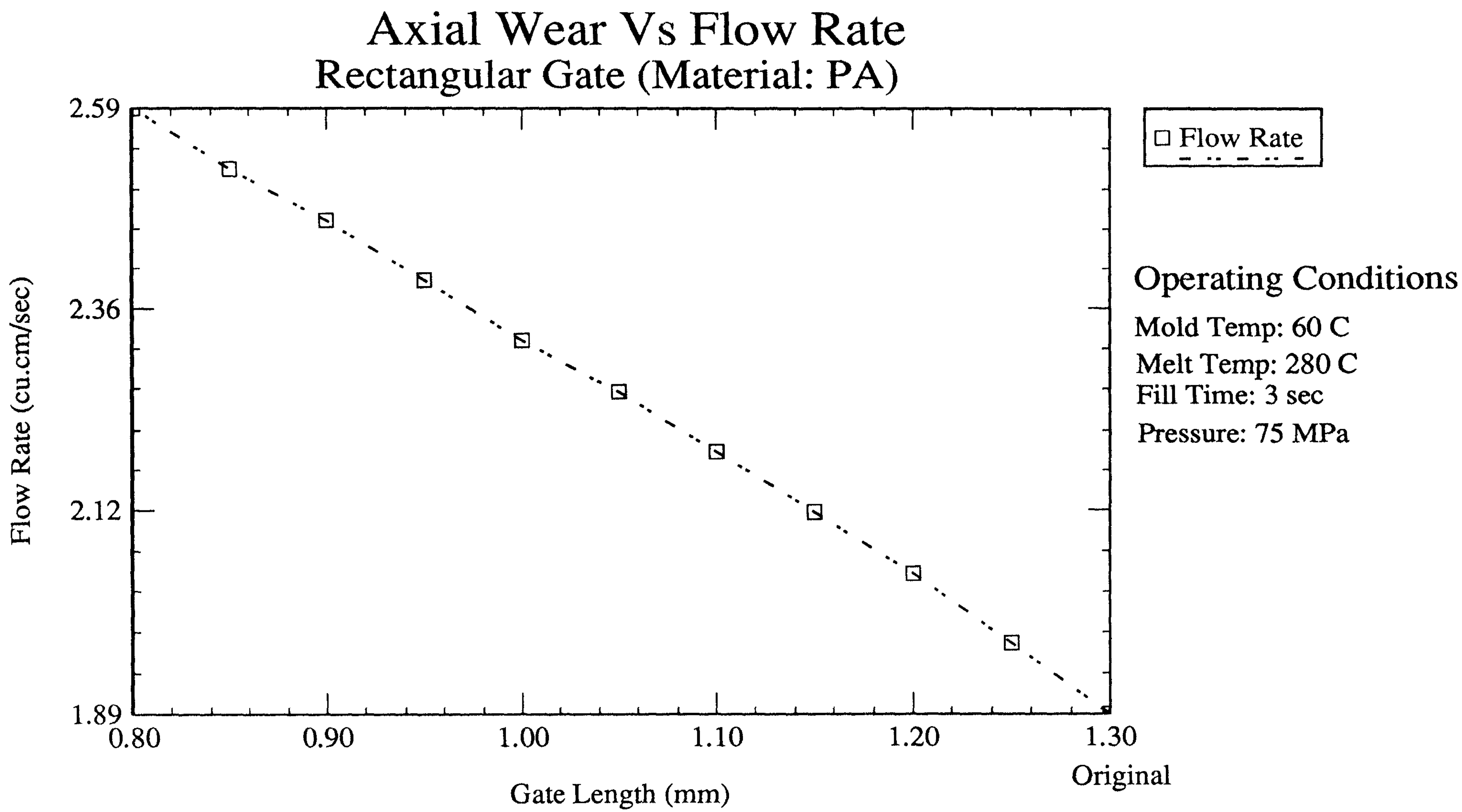


Fig. 5.66

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw57 - Tue Apr 30 20:03:07 1991 (data file was nparecgatl.data)

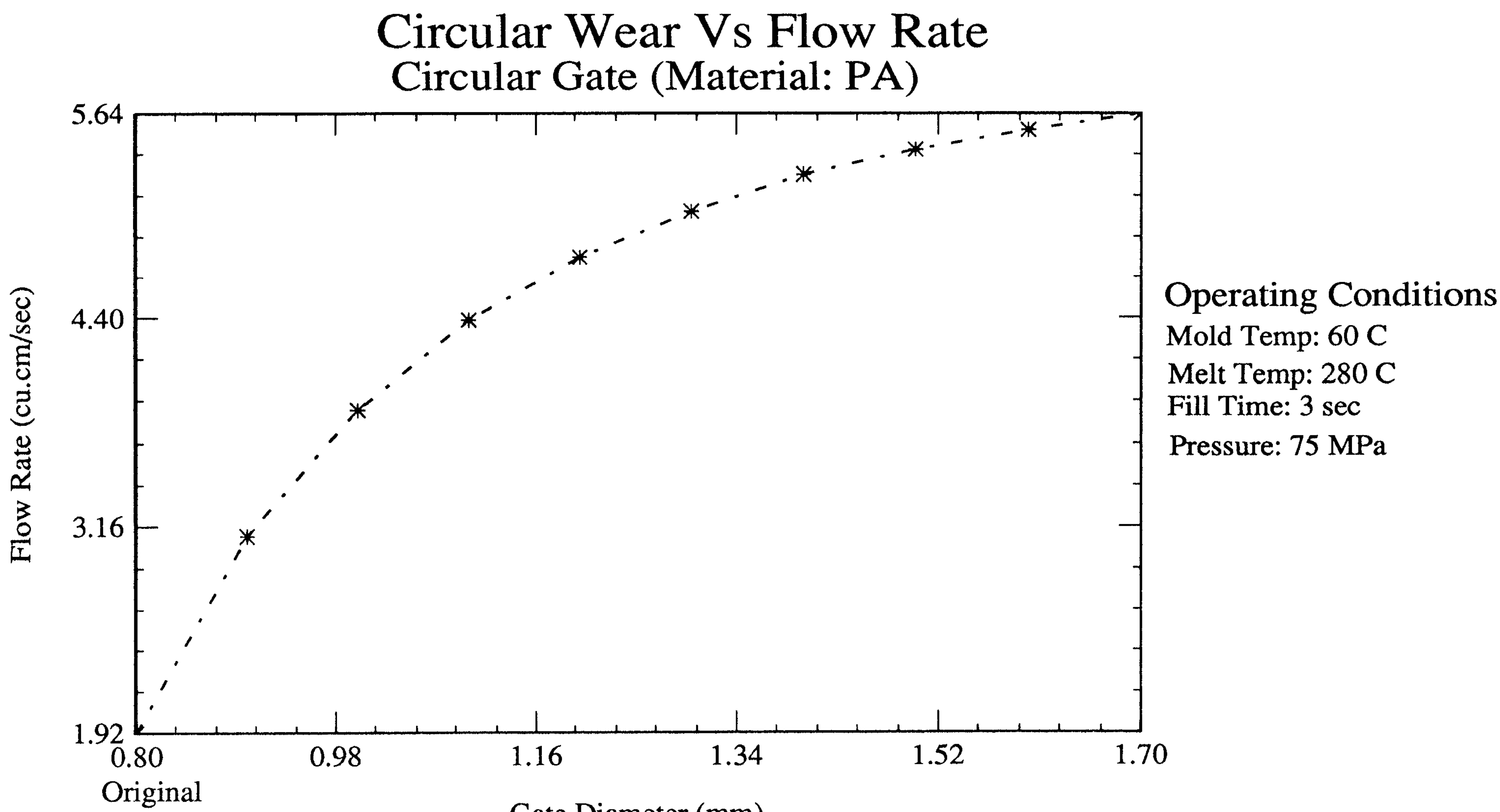


Fig. 5.67

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw57 - Tue Apr 30 20:14:03 1991 (data file was npacgat.data)

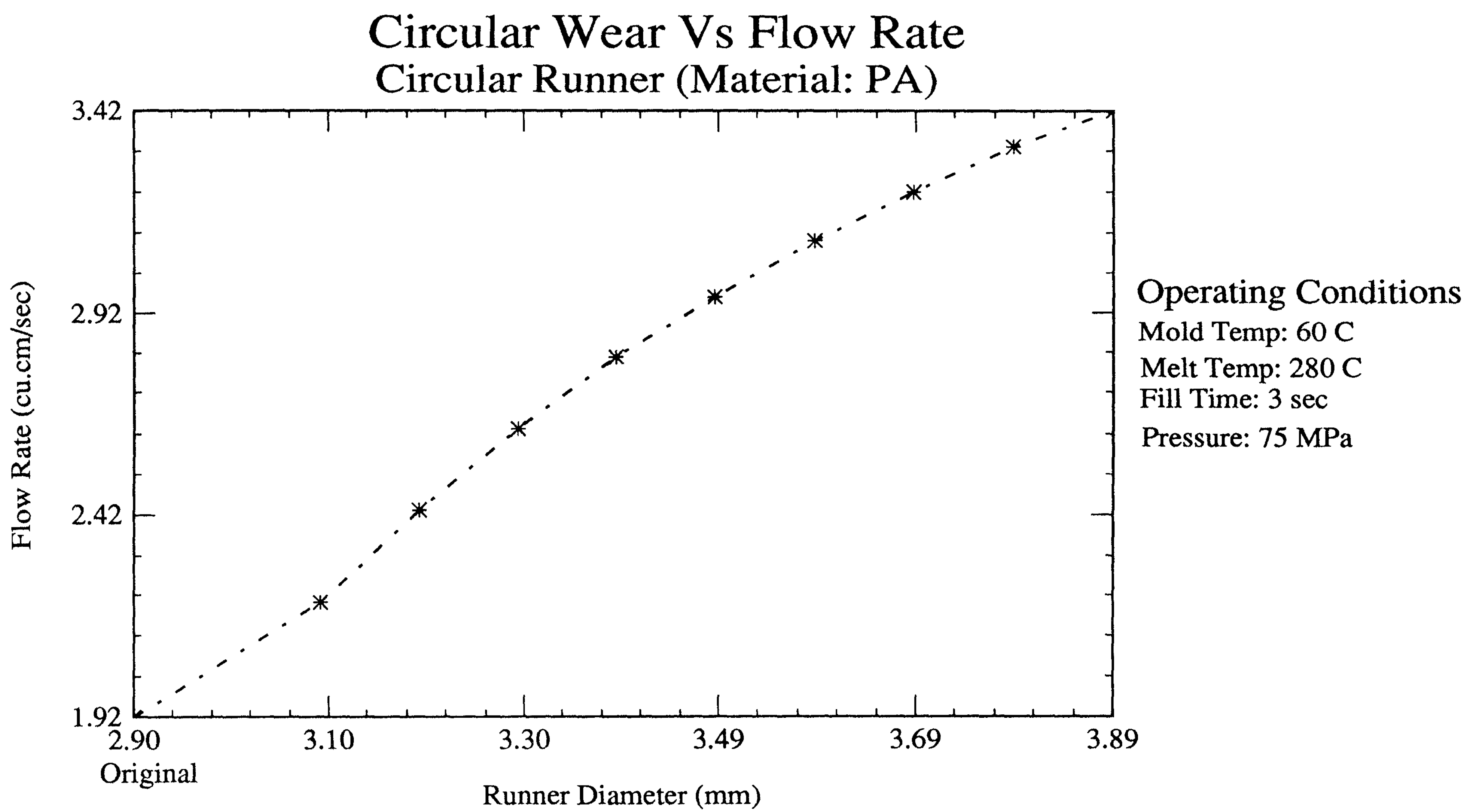


Fig. 5.68

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw57 - Tue Apr 30 20:17:08 1991 (data file was npacrun.data)

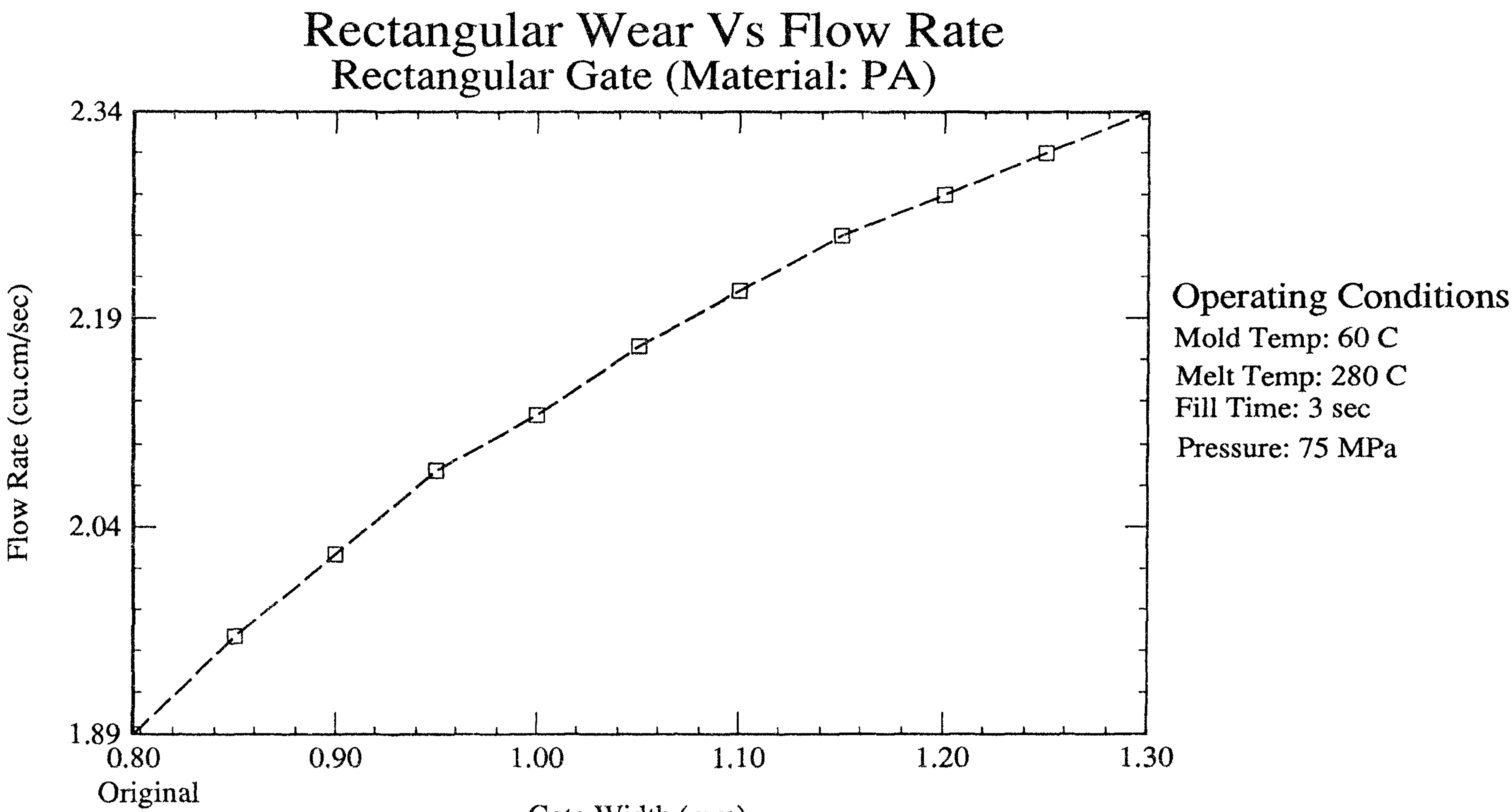


Fig. 5.69

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw57 - Tue Apr 30 20:27:26 1991 (data file was nparecgatw.data)

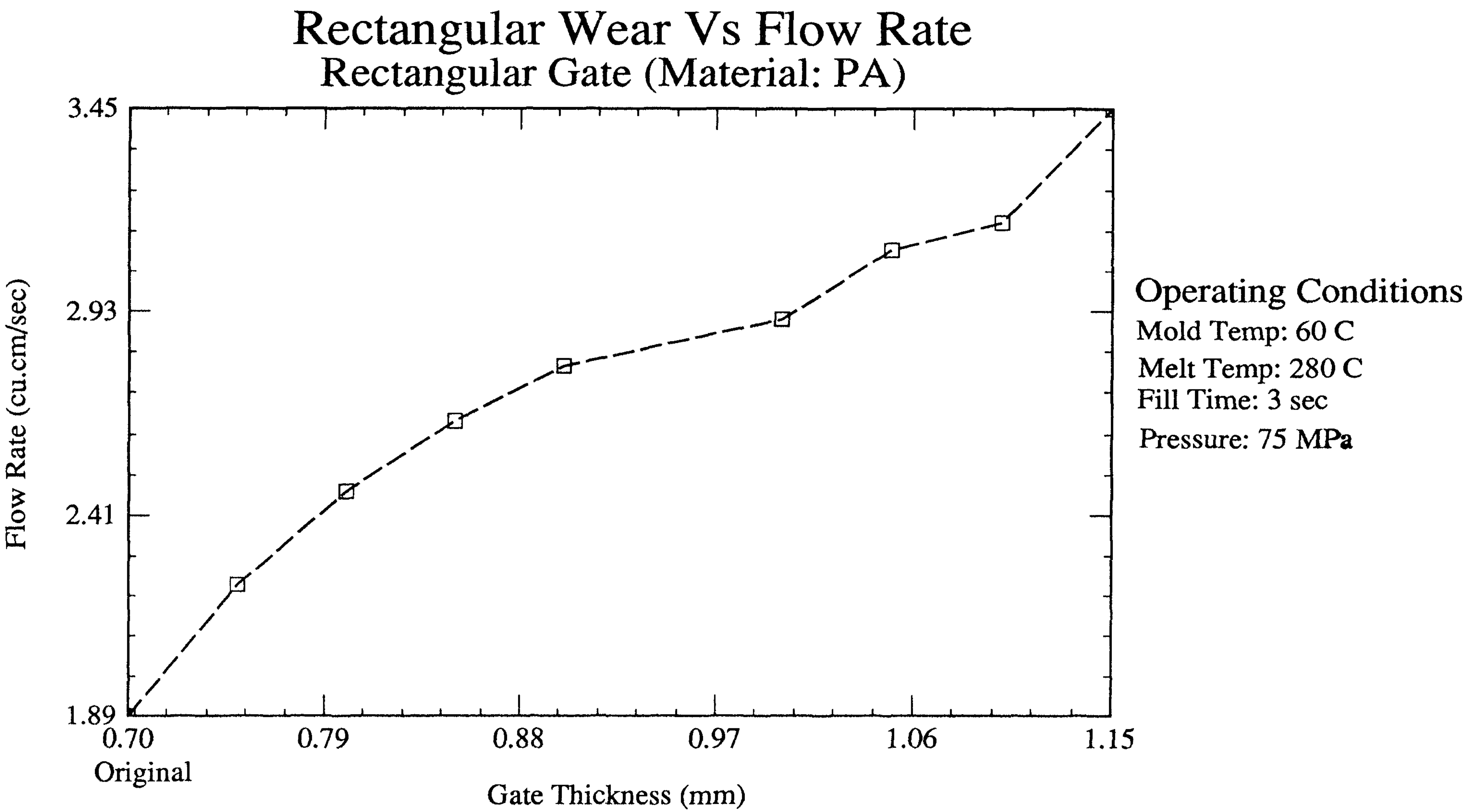


Fig. 5.70

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw57 - Tue Apr 30 20:29:41 1991 (data file was nparecgatt.data)

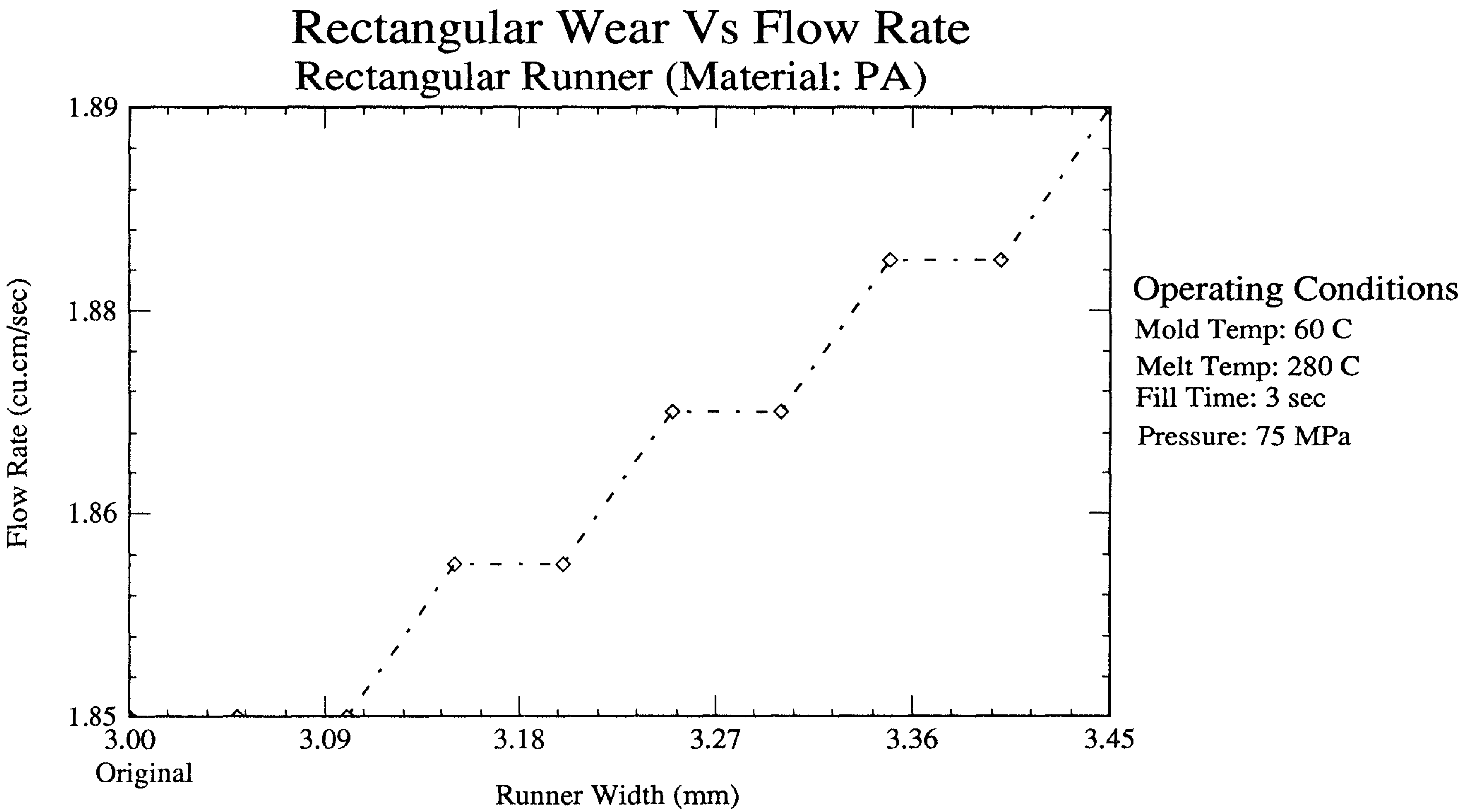
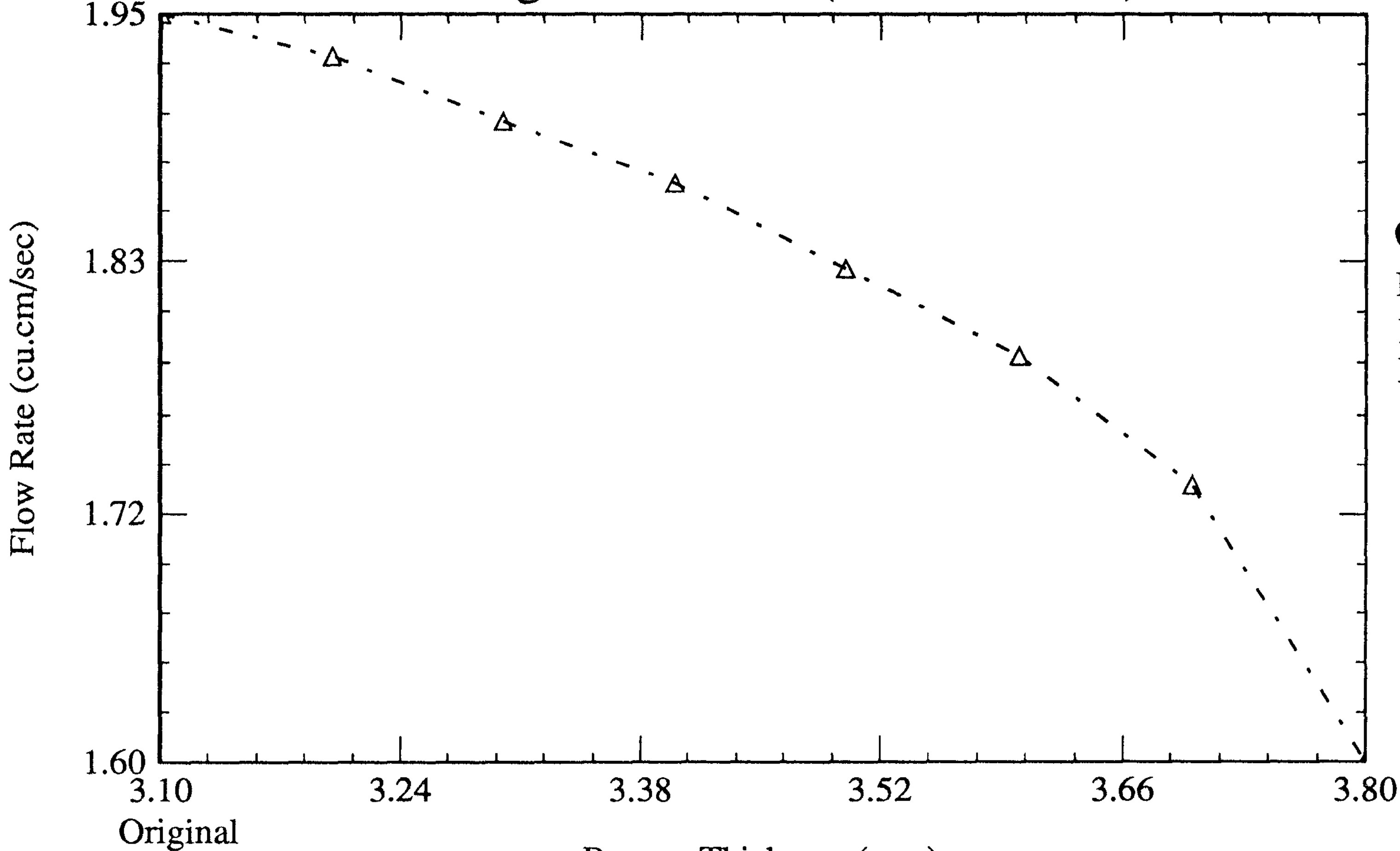


Fig. 5.71

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw57 - Tue Apr 30 20:43:37 1991 (data file was nparrunw.data)

Rectangular Wear Vs Flow Rate

Rectangular Runner (Material: PA)



Operating Conditions
Mold Temp: 60 C
Melt Temp: 280 C
Fill Time: 3 sec
Pressure: 75 MPa

Fig. 5.72

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw57 - Tue Apr 30 20:50:22 1991 (data file was nparecrunw.data)

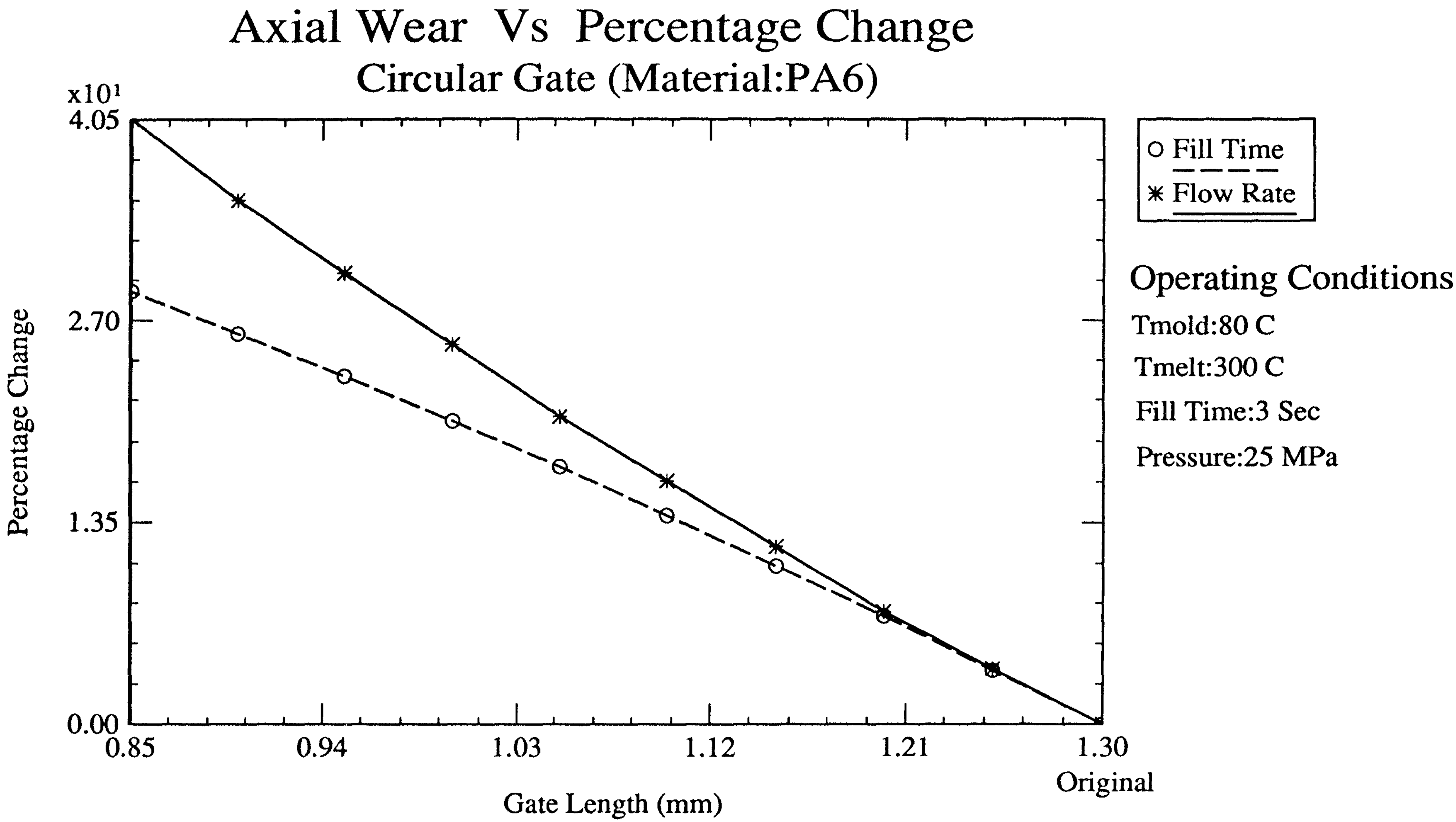

Axial Wear Vs Percentage Change
Circular Gate (Material:PA6)
x10¹
4.05
2.70
1.35
0.00
0.85
0.94
1.03
1.12
1.21
1.30
Original
Percentage Change
Gate Length (mm)
Fill Time
Flow Rate
Operating Conditions
Tmold:80 C
Tmelt:300 C
Fill Time:3 Sec
Pressure:25 MPa

Fig. 5.73

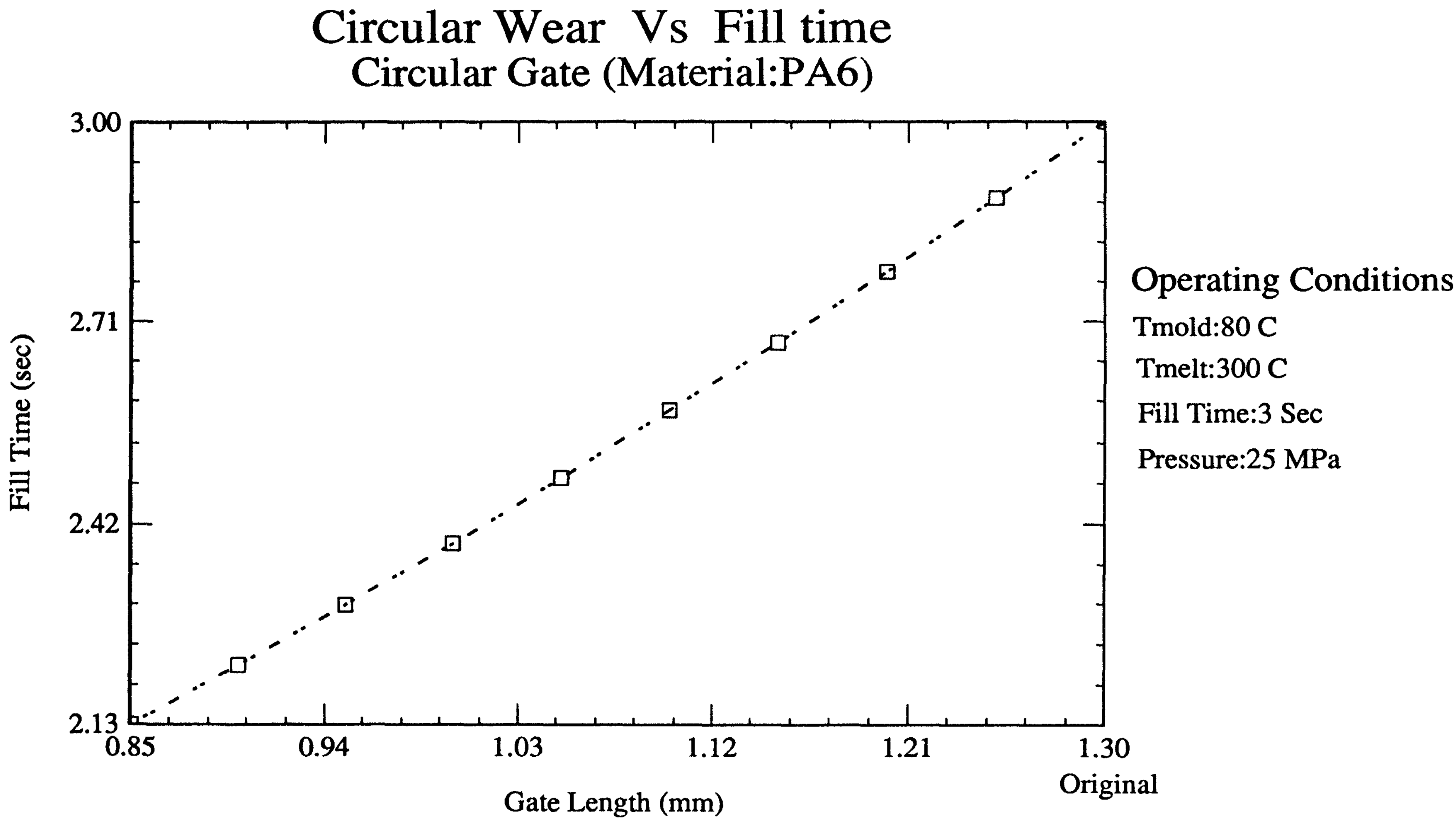


Fig. 5.81

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw54 - Thu Apr 18 21:48:34 1991 (data file was /usr/tmp/TG.AAAa12006)

Axial Wear Vs Fill Time

Rectangular Gate (Material:PA6)

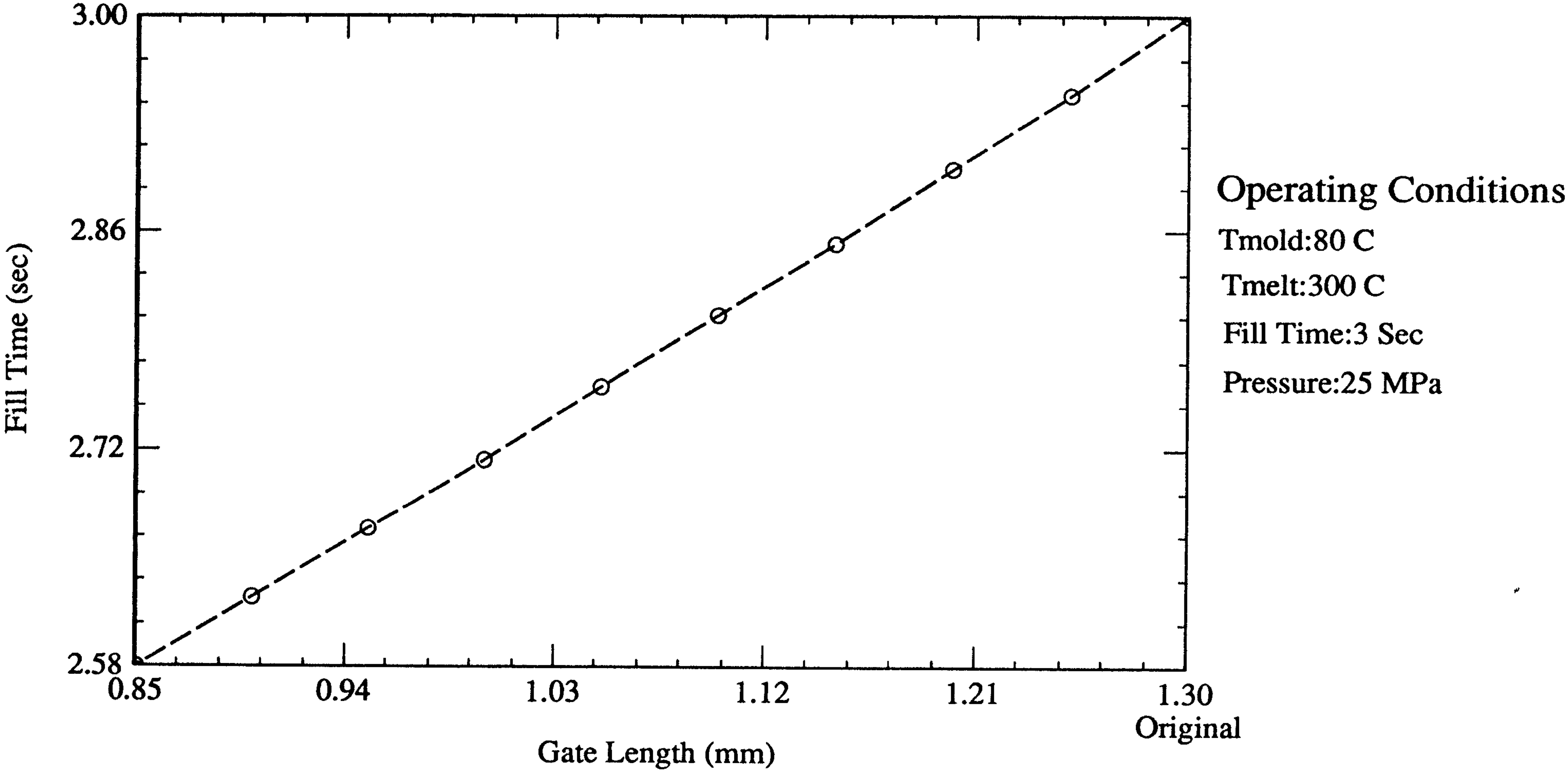


Fig. 5.82

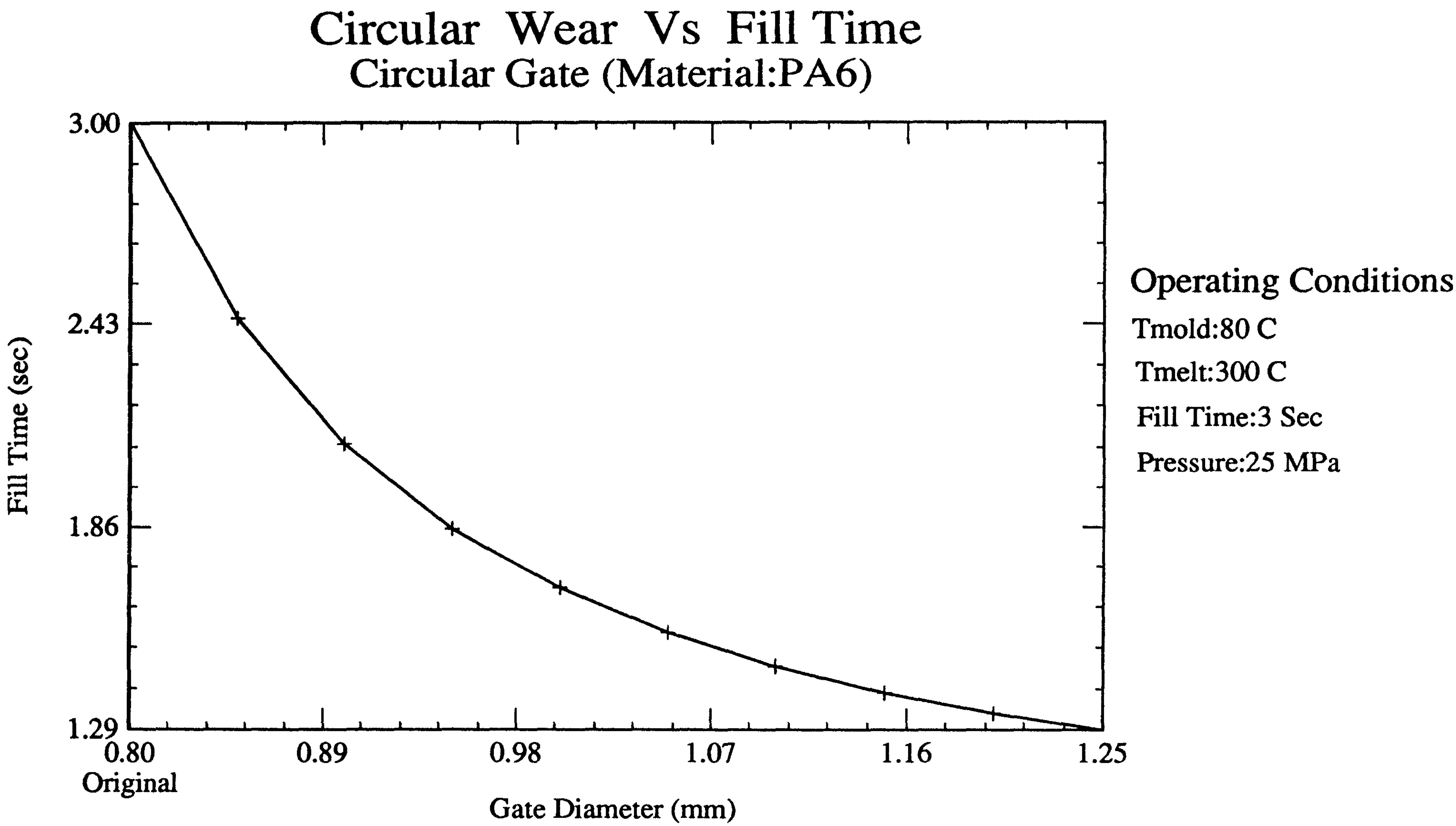


Fig. 5.83

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw54 - Thu Apr 18 21:39:38 1991 (data file was /usr/tmp/TG.AAAa12006)

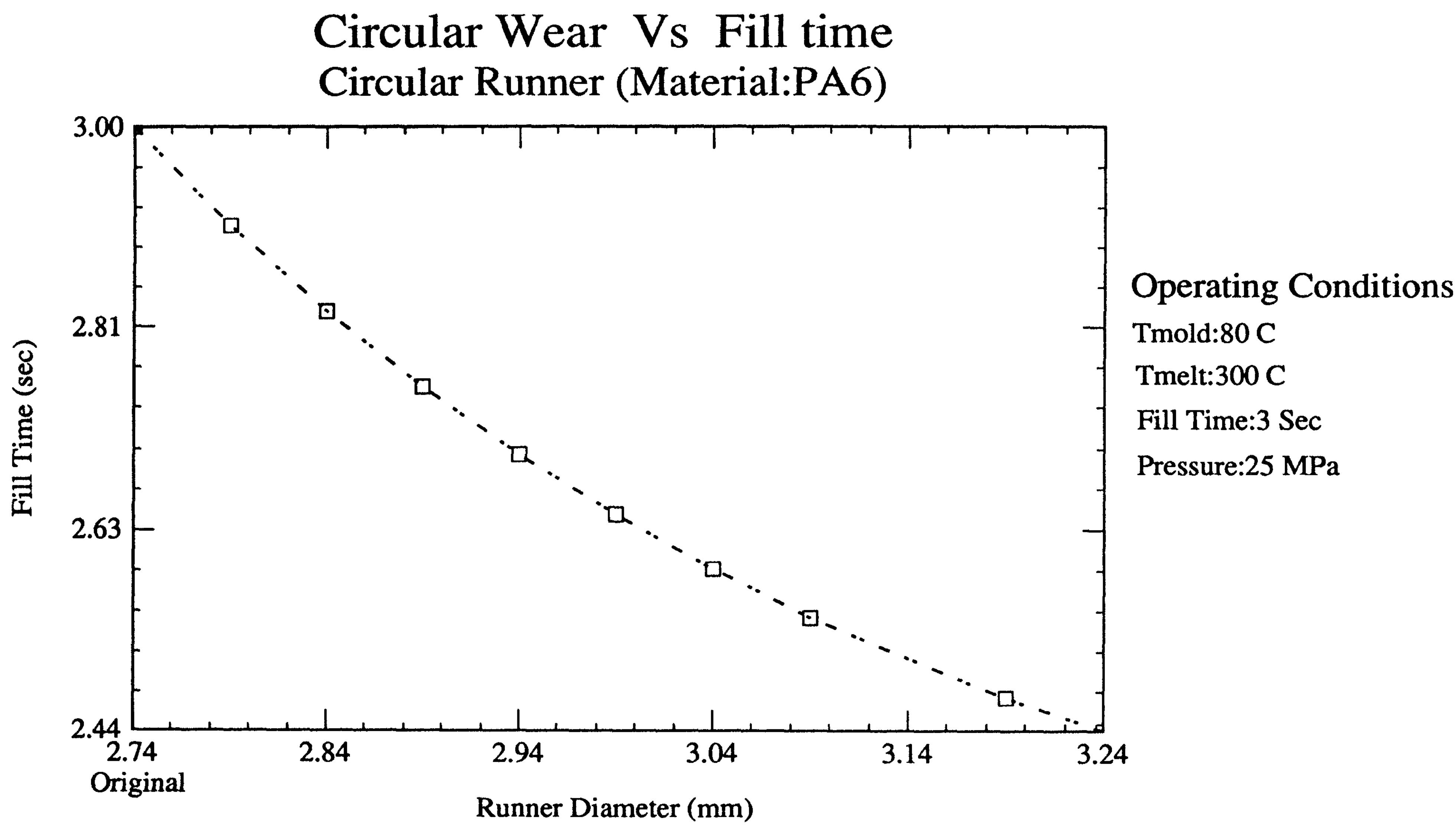


Fig. 5.84

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw54 - Thu Apr 18 21:55:50 1991 (data file was /usr/tmp/TG.AAAa12006)

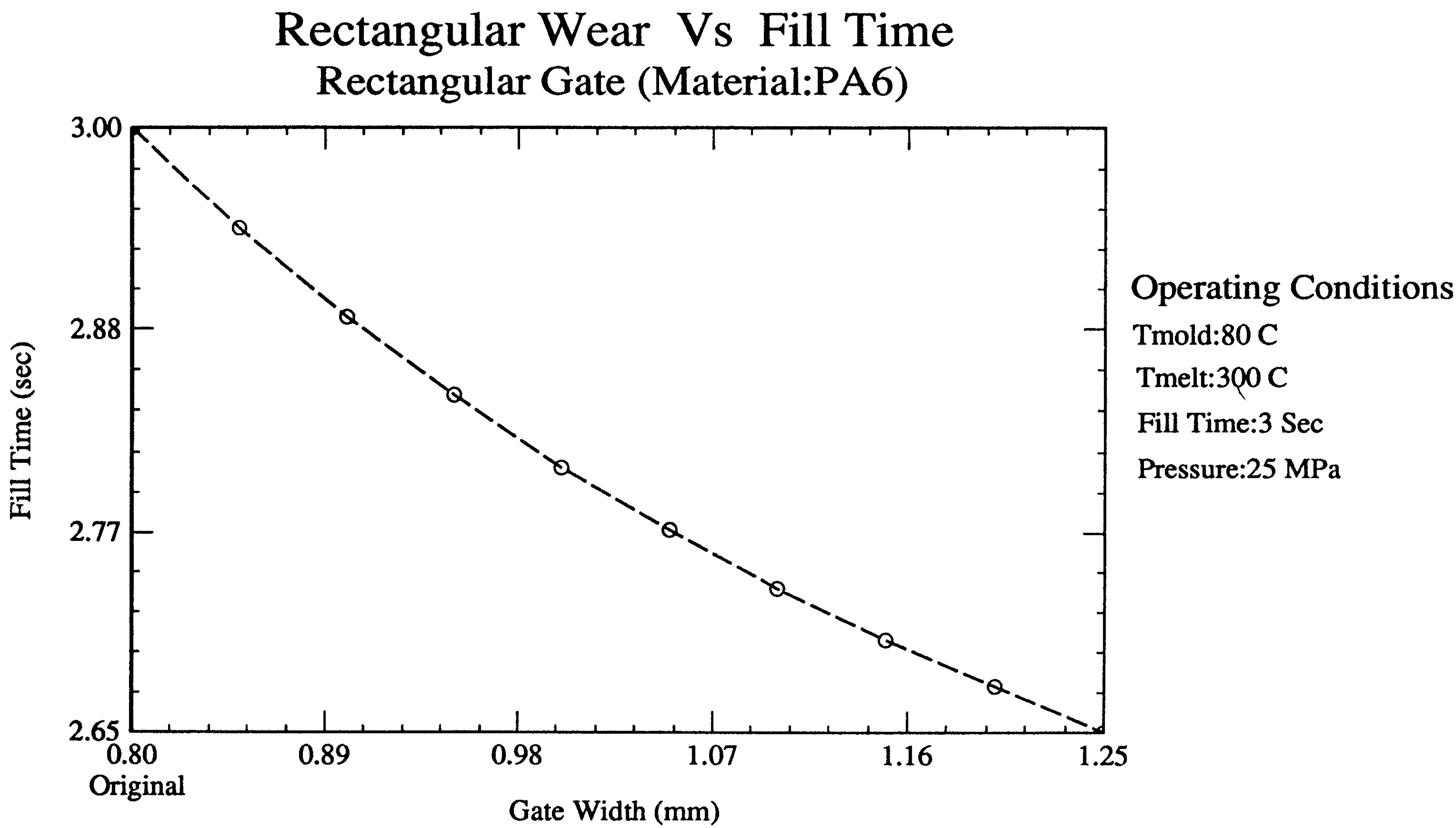


Fig. 5.85

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw54 - Thu Apr 18 22:09:35 1991 (data file was /usr/tmp/TG.AAAa12006)

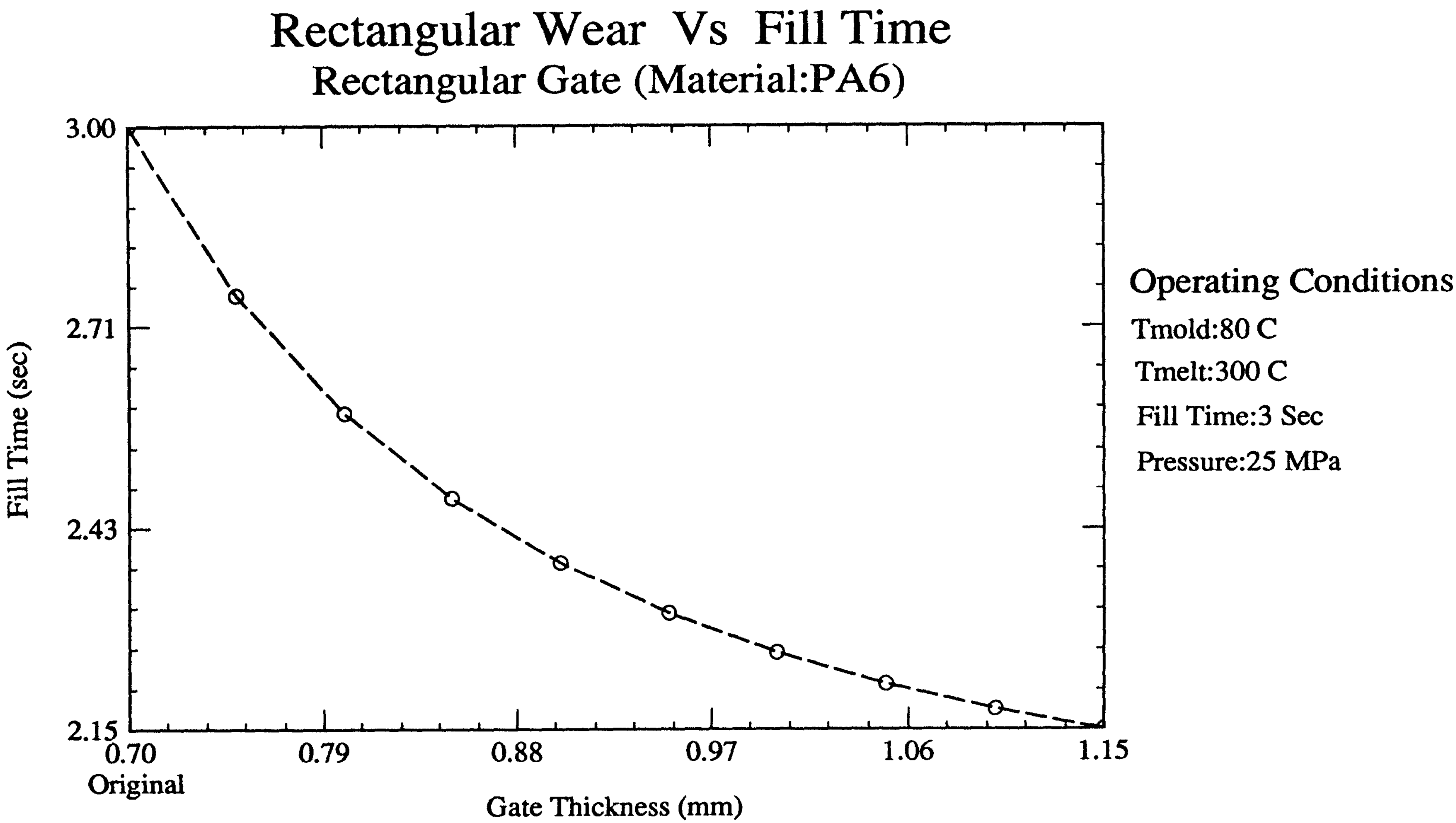


Fig. 5.86

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw54 - Thu Apr 18 22:05:03 1991 (data file was /usr/tmp/TG.AAAa12006)

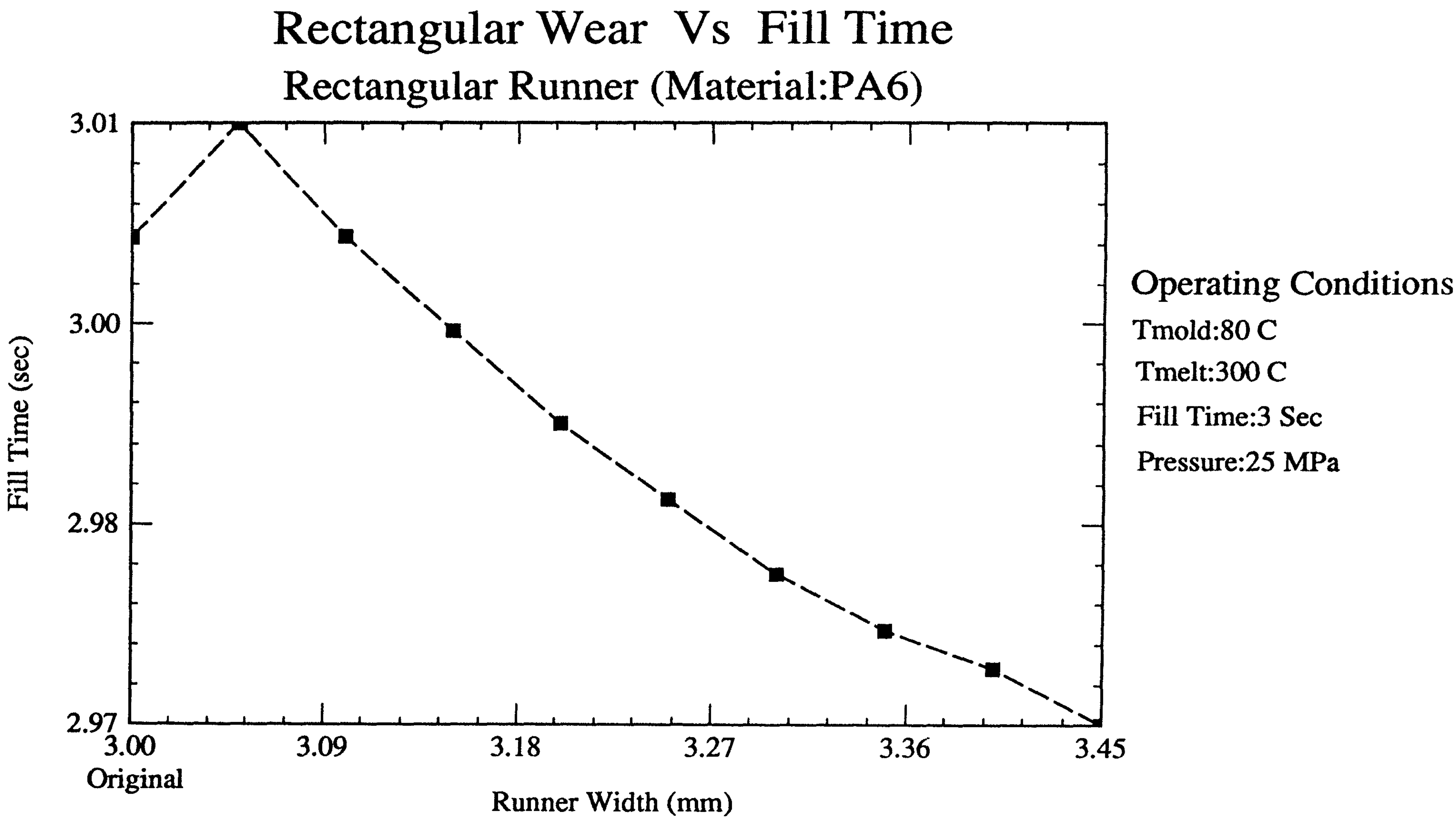
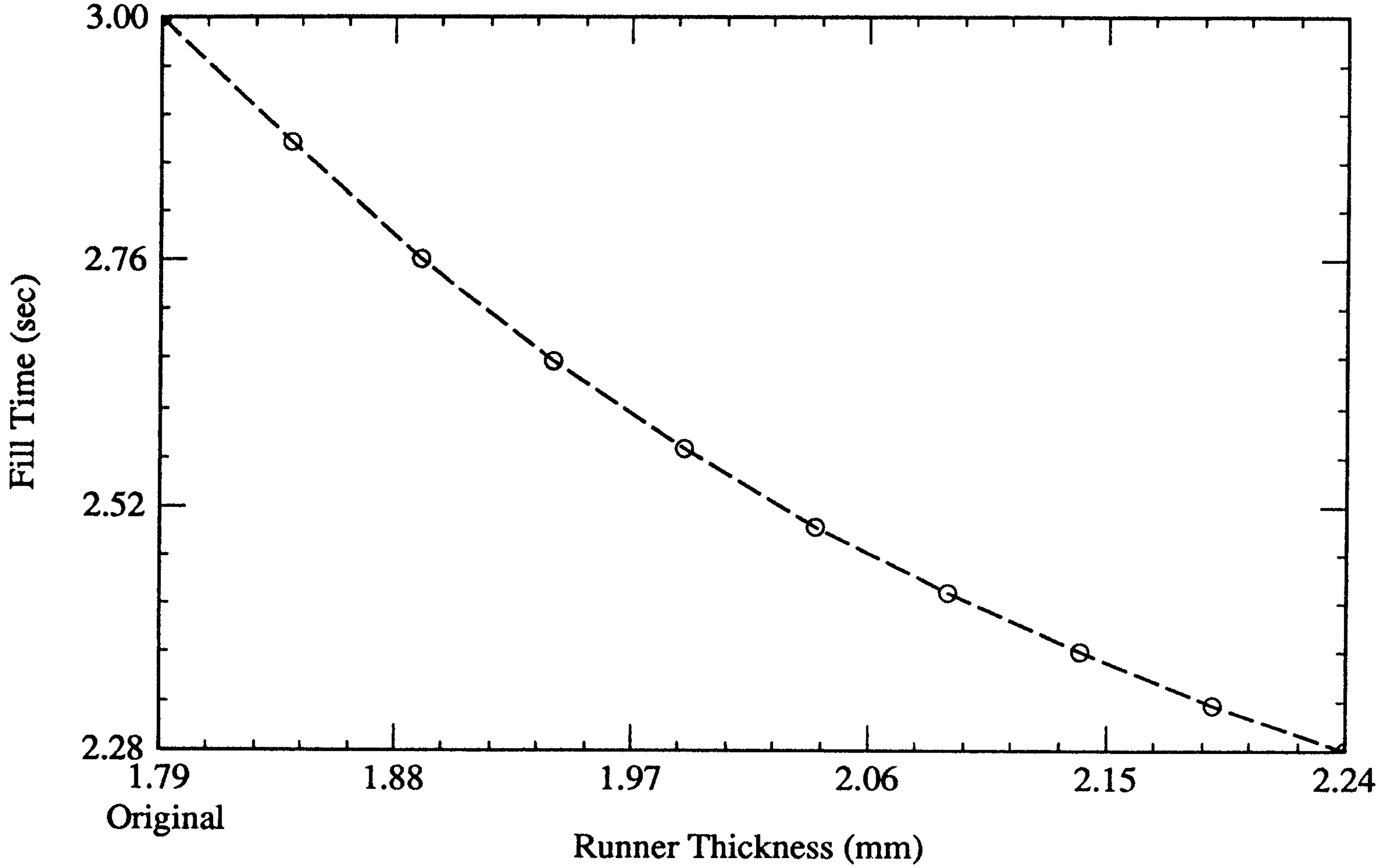


Fig. 5.87

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw54 - Thu Apr 18 22:35:04 1991 (data file was /usr/tmp/TG.AAAa12006)

Rectangular Wear Vs Fill Time

Rectangular Runner (Material:PA6)



Operating Conditions

Tmold:80 C

Tmelt:300 C

Fill Time:3 Sec

Pressure:25 MPa

Fig. 5.88

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw54 - Thu Apr 18 22:26:04 1991 (data file was /usr/tmp/TG.AAAa12006)

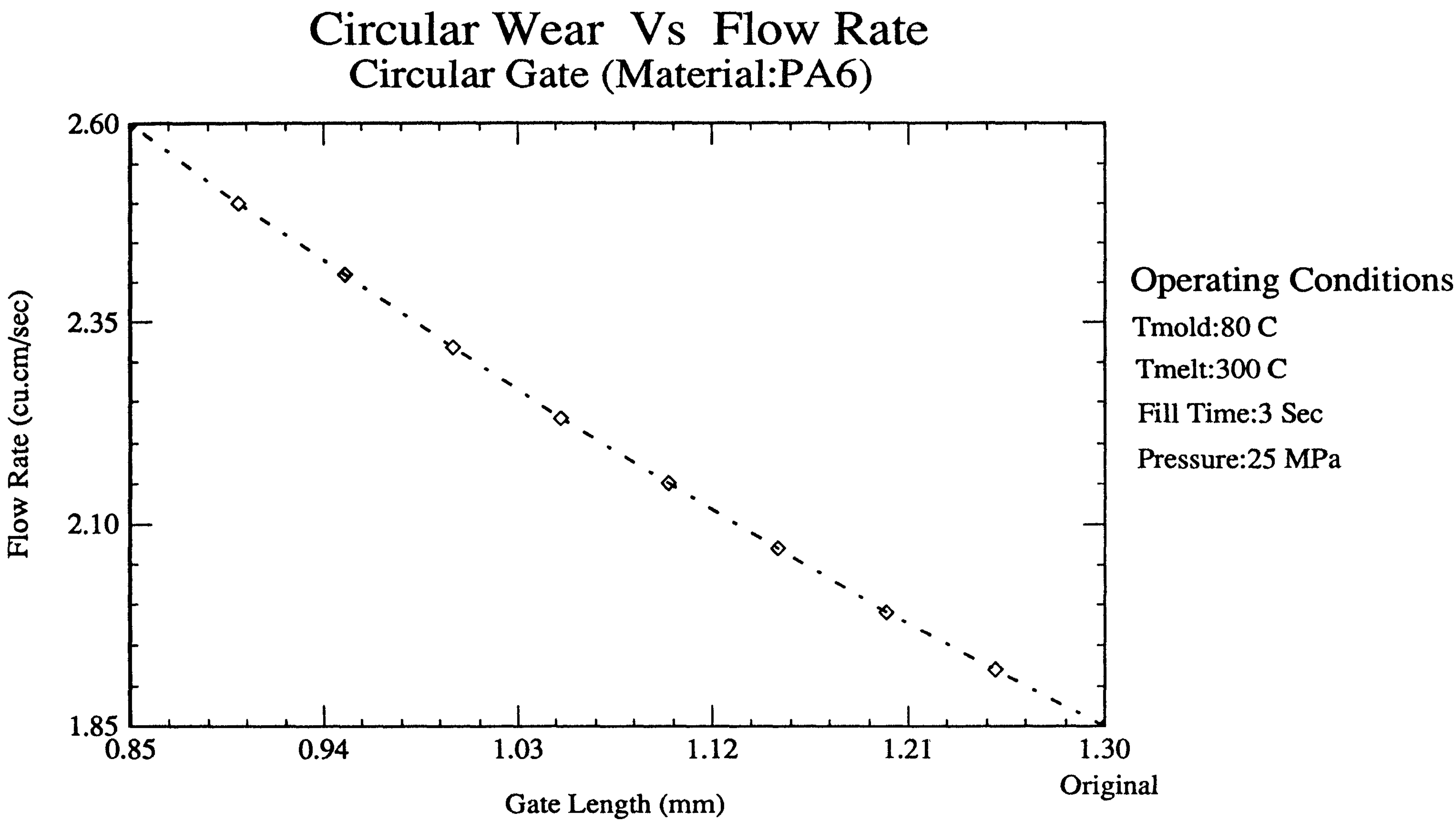


Fig. 5.89

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw54 - Thu Apr 18 21:45:17 1991 (data file was /usr/tmp/TG.AAAa12006)

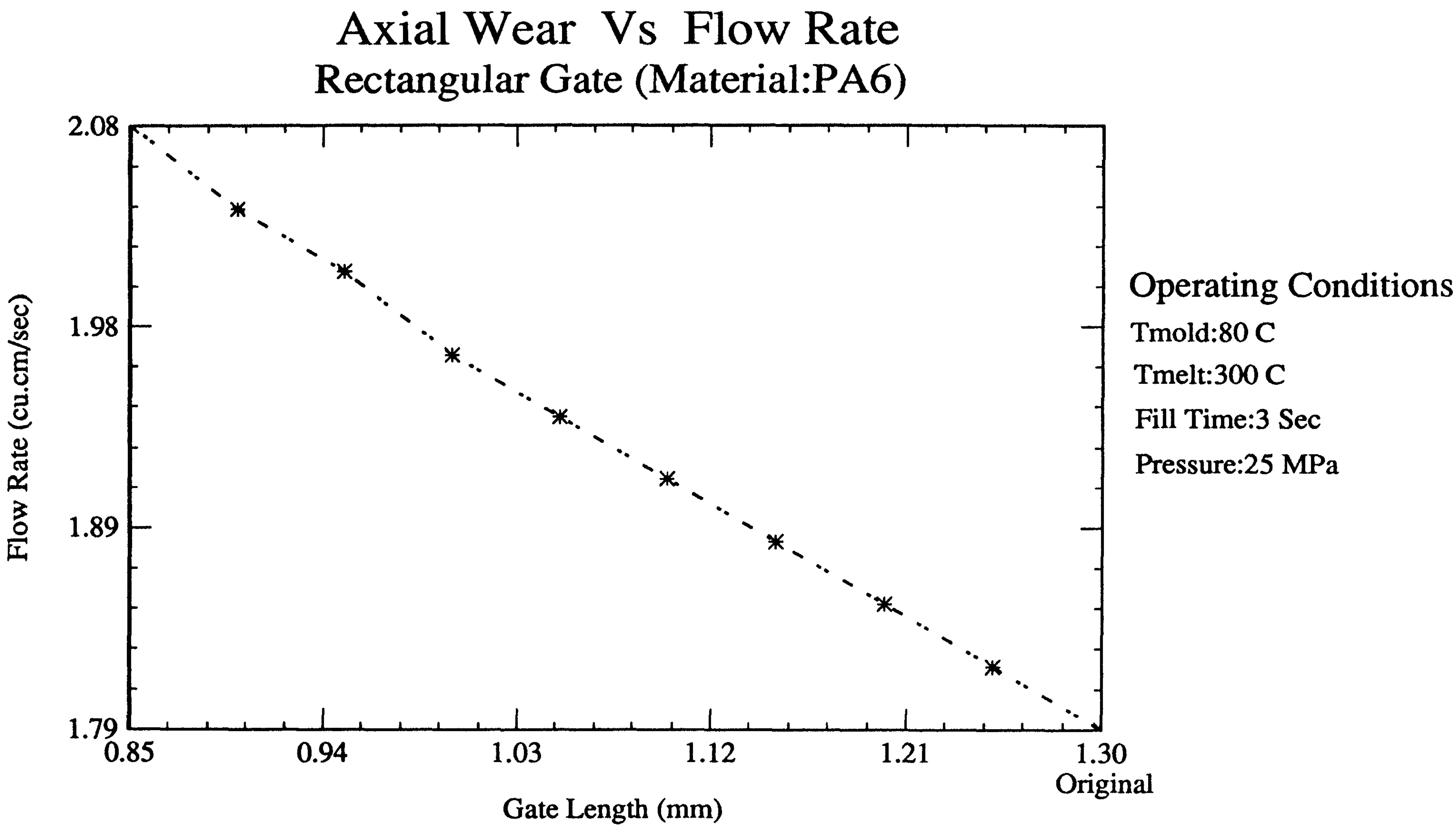


Fig. 5.90

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw54 - Thu Apr 18 22:17:55 1991 (data file was /usr/tmp/TG.AAAa12006)

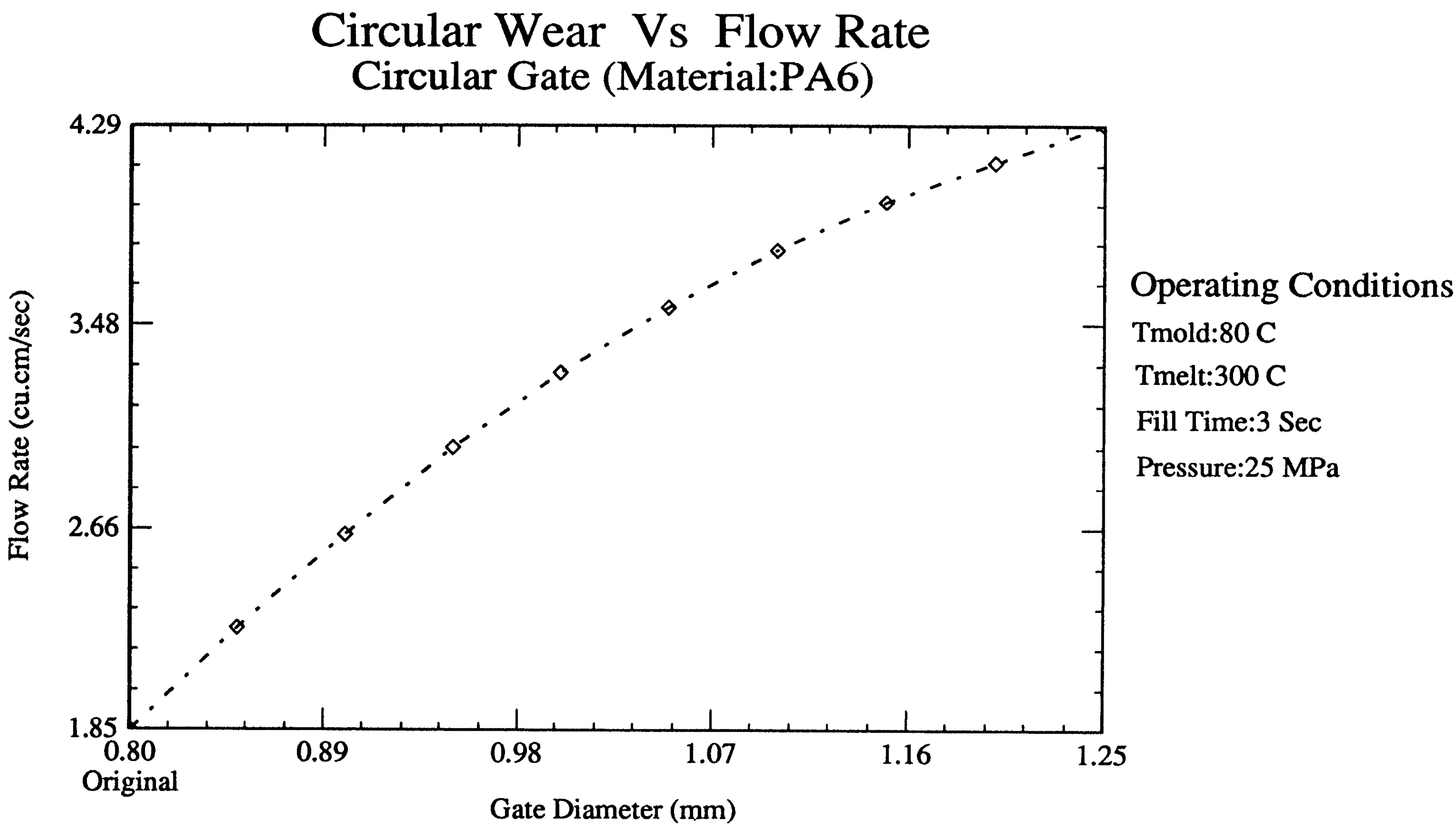
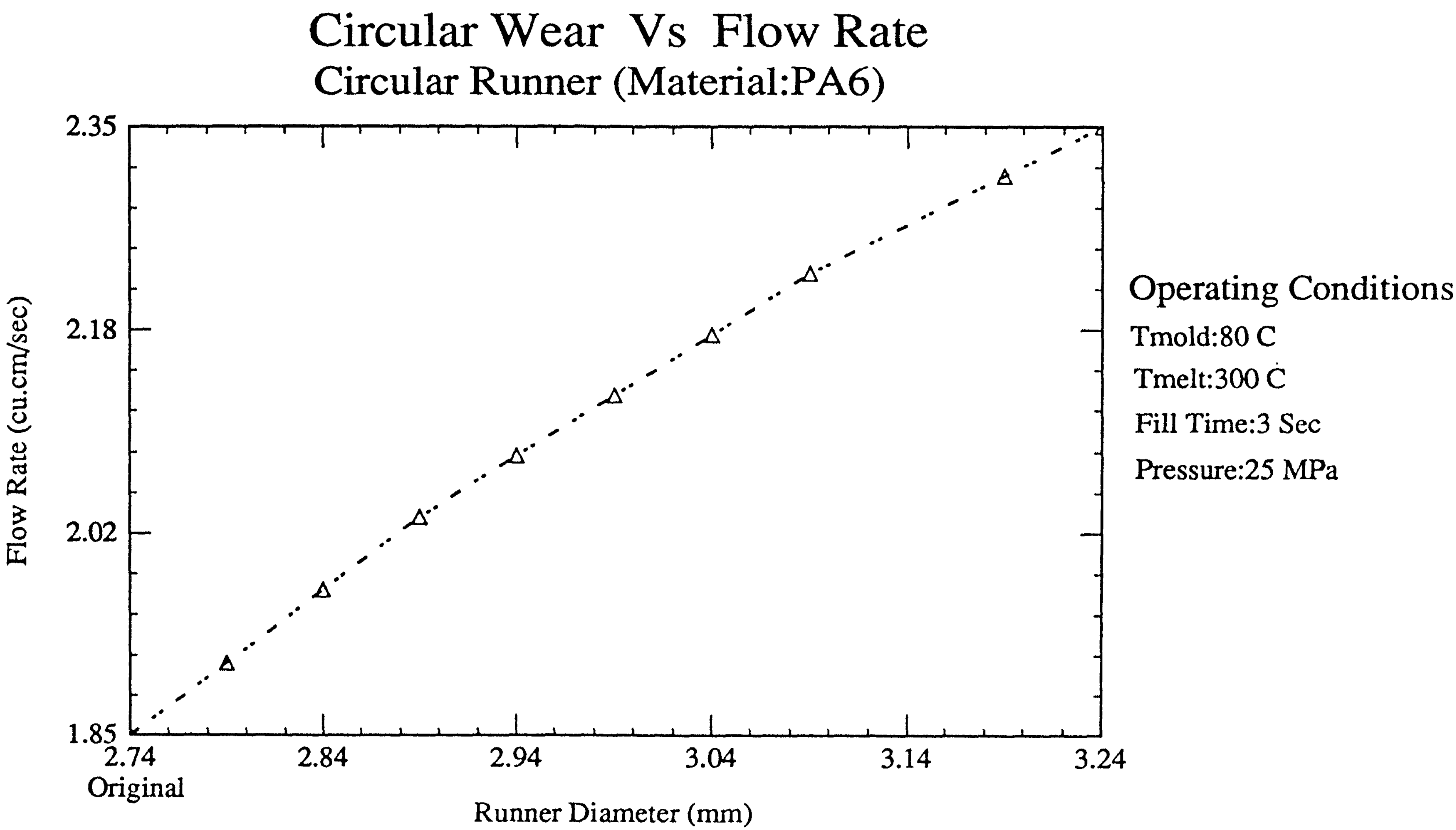


Fig. 5.91

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw54 - Thu Apr 18 21:41:35 1991 (data file was /usr/tmp/TG.AAAa12006)



Circular Wear Vs Flow Rate
Circular Runner (Material:PA6)
Flow Rate (cu.cm/sec)
2.35
2.18
2.02
1.85
2.74
Original
2.84
2.94
3.04
3.14
3.24
Runner Diameter (mm)
Operating Conditions
Tmold:80 C
Tmelt:300 C
Fill Time:3 Sec
Pressure:25 MPa

Fig. 5.92

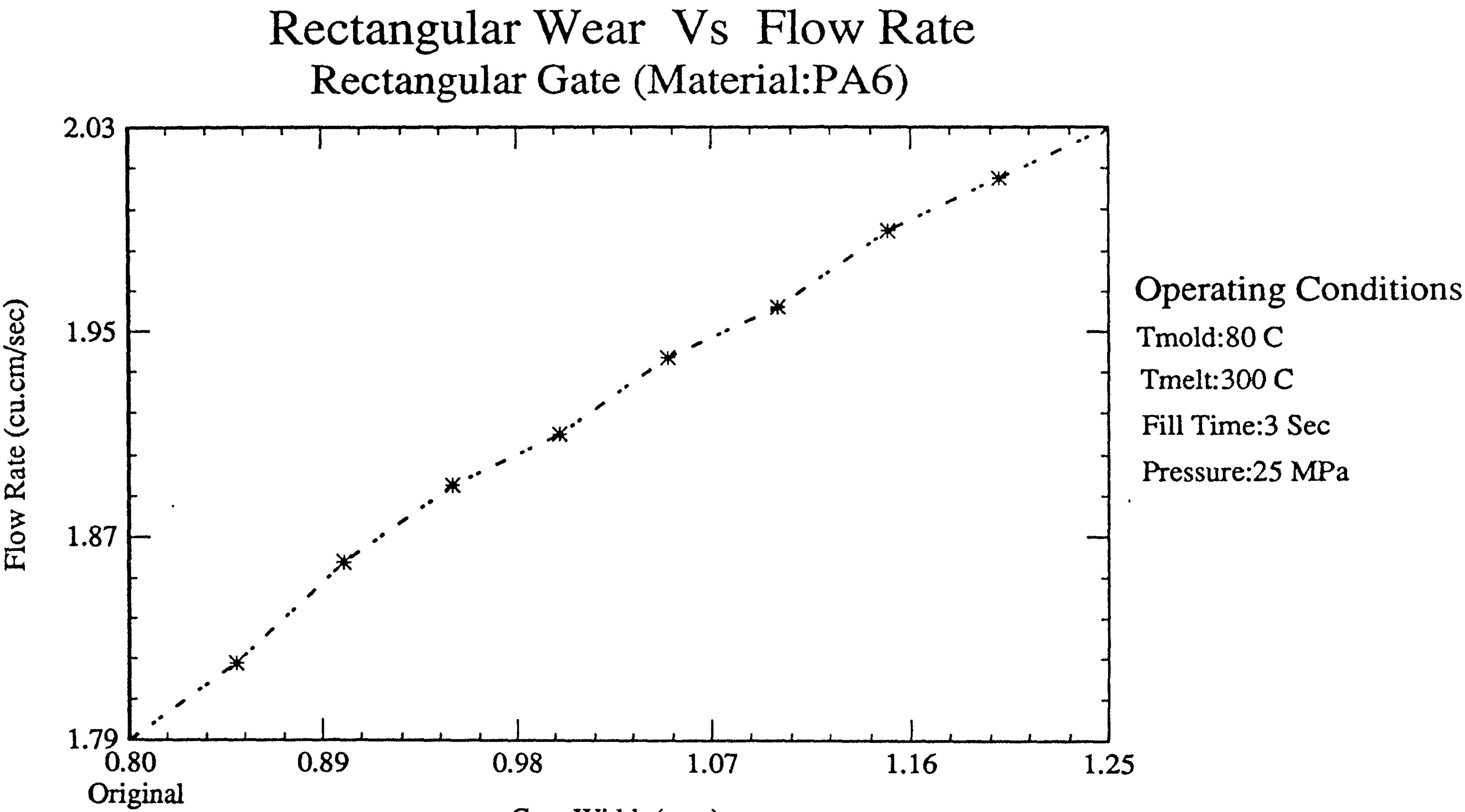


Fig. 5.93

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw54 - Thu Apr 18 22:11:41 1991 (data file was /usr/tmp/TG.AAAa12006)

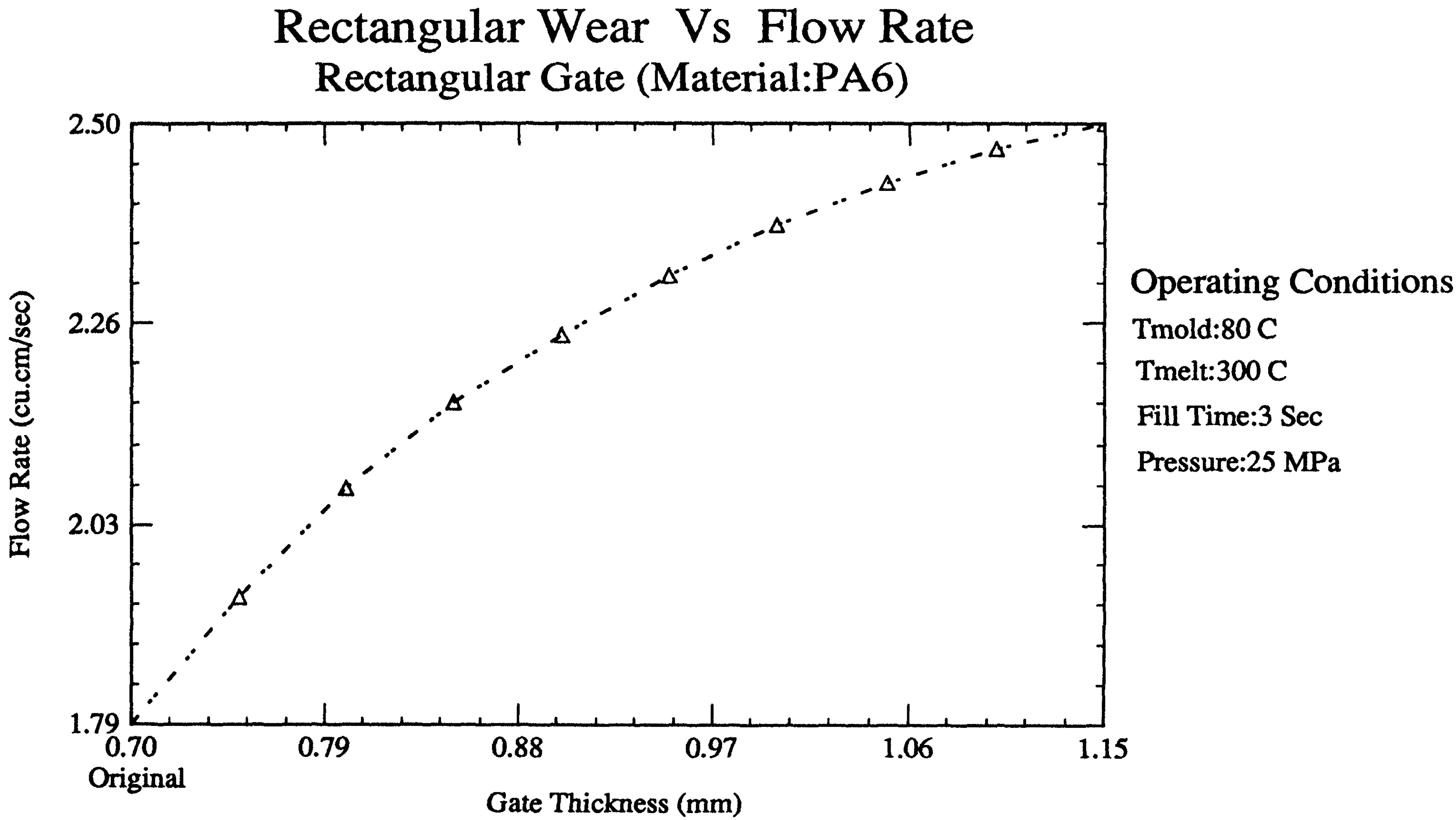


Fig. 5.94

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw54 - Thu Apr 18 22:03:18 1991 (data file was /usr/tmp/TG.AAAa12006)

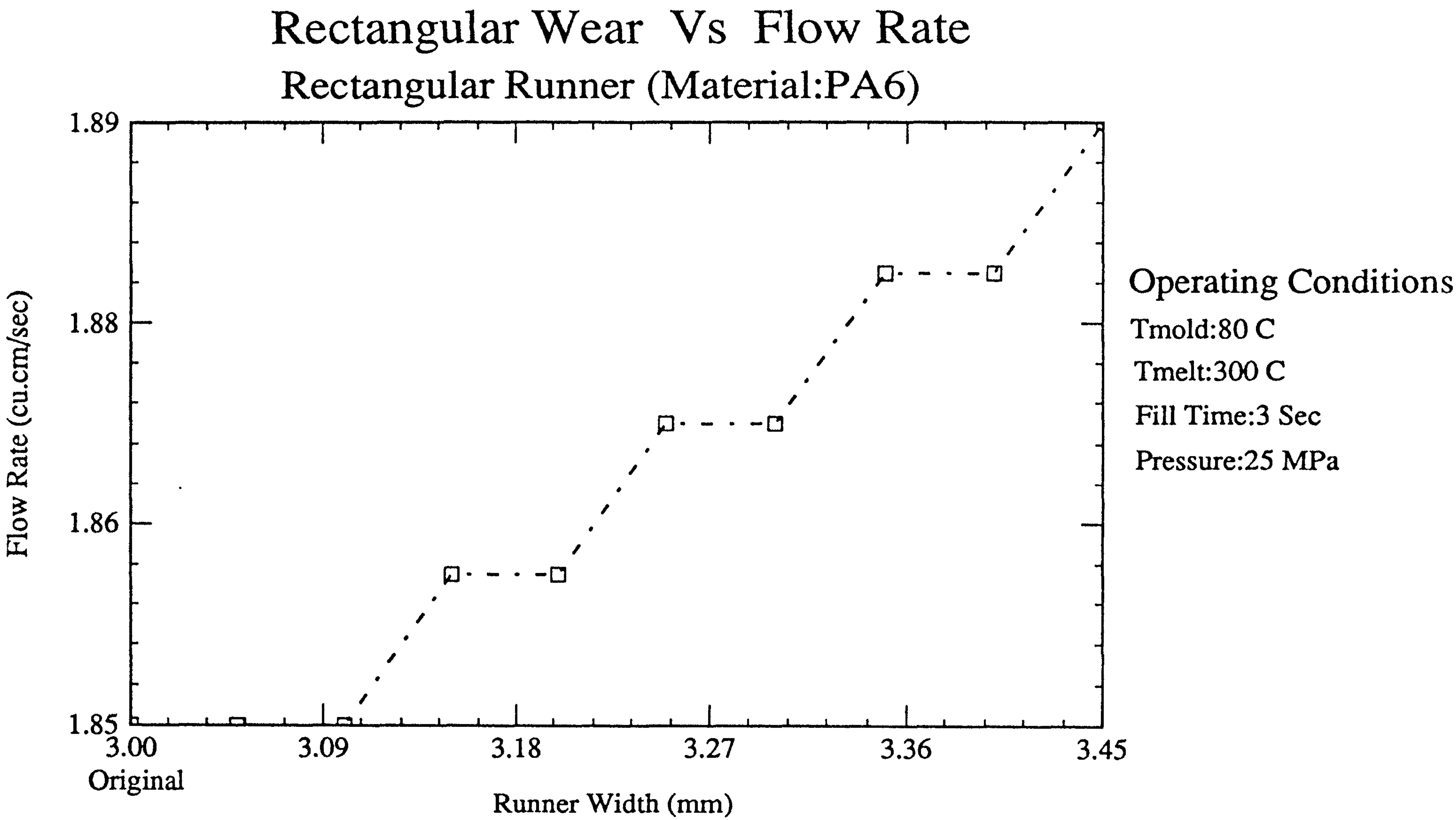


Fig. 5.95

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw54 - Thu Apr 18 22:32:59 1991 (data file was /usr/tmp/TG.AAAa12006)

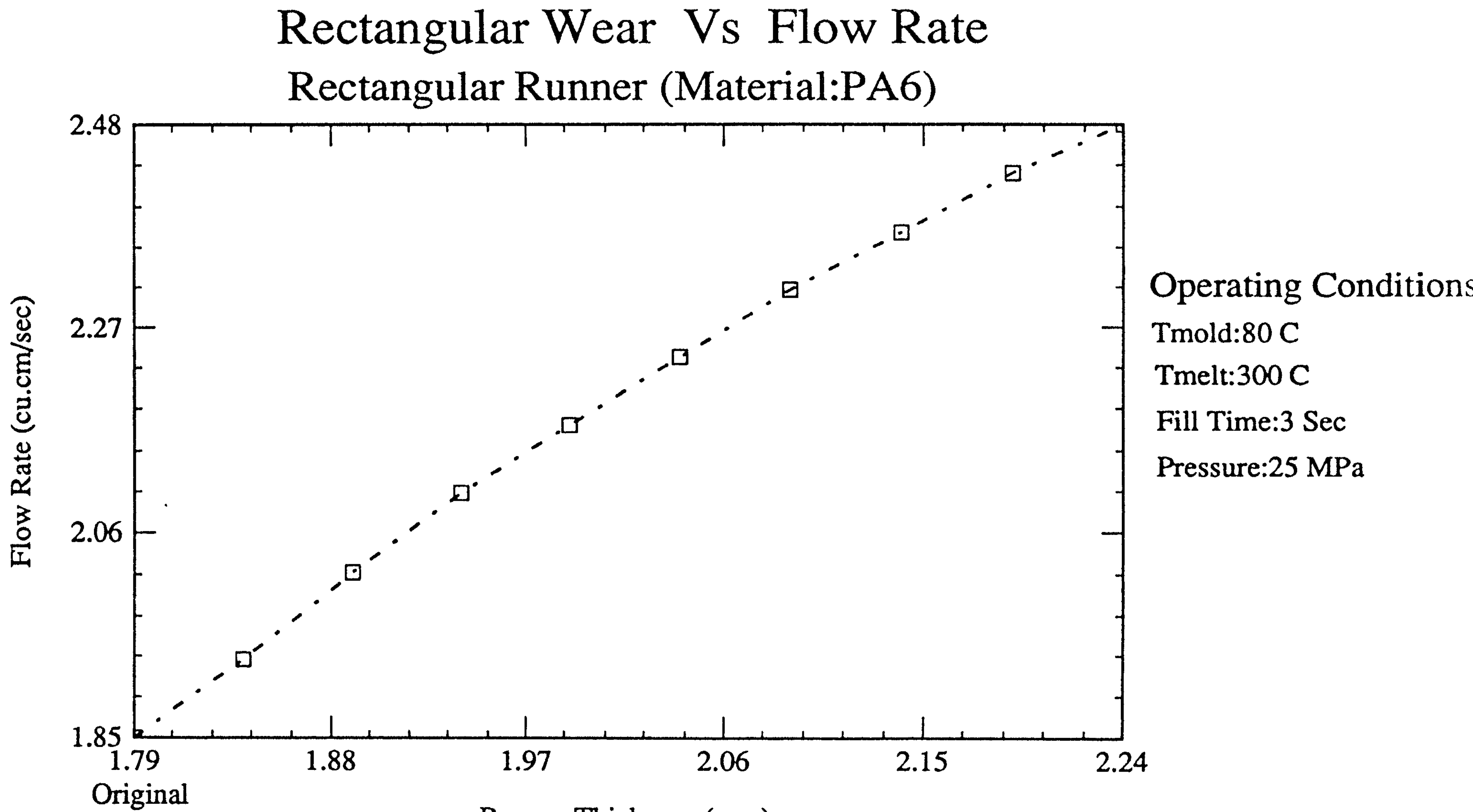


Fig. 5.96

TempleGraph 2.3, Origin: /usr/mesunb/users/ksv2028@mesunw54 - Thu Apr 18 22:29:29 1991 (data file was /usr/tmp/TG.AAAa12006)

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CHAPTER 6

DISCUSSION

6.1 MATERIAL ABS

When the dimension of the gate or runner is increased, the pressure required to fill the cavity is decreased. To balance that pressure, the fill time is reduced until the pressure to fill it reaches the original balanced pressure. While the fill time is reduced, the flow rate is increased and the pressure required to fill the cavity 2 is increased.

All the above observations are noted for each variation in gate and runner dimensions. For each variation, the fill time, flow rate and the percentage change in fill time and flow rate are plotted against the changes in gate and runner dimensions

As the gate diameter is increased from 0.8mm to 1.8mm in incremental steps of 0.1mm, the change in fill time, flow rate, and percentage change of both the fill time and flow rate are very high for the first variation in dimensions as shown in the Fig: 5.3, 5.11 and 5.19. Ensuing that initial high change, the variations in the variables are relatively slow thereafter.

Similarly when the length of the gate is reduced from 1.3mm to 0.8mm the variations in fill time, flow rate, and percentage change are very slow compared to the change in diameter of the gate as seen in Fig: 5.1, i.e., the variables are not so sensitive to the change in length as to the change in diameter.

For a rectangular gate when the thickness of the gate is varied, the fill time, flow rate and percentage change are very sensitive to the first change in thickness. Following that initial change the variables tend to be more linear to any further changes in dimensions as seen in the Figs: 5.6, 5.14 and 5.22. The thickness is varied from 0.7mm to 1.15mm in steps of 0.05mm.

When the width of the gate is varied, the fill time, flow rate, and percentage change are linear up to a certain point, following which there is a drastic rise in all three variables, and from that point on they again follow a linear path. If the Figs: 5.5, 5.13 and 5.21 of this variations are observed, the curves look linear initially, and suddenly the curve rises at a point and again becomes linear. After this stage, variation in flow is very slow for any further increases in dimensions.

By changing the rectangular gate length, only for the first change in dimension the fill time, flow rate and percentage change varies tremendously; after that variations are very slow as shown in the Figs: 5.2, 5.10, and 5.18.

For changes in runner diameter, there is very high variation in fill time, flow rate and percentage change, i.e., the flow is very sensitive to the variation in circular runner as shown in the Figs: 5.4, 5.12, and 5.20.

For the rectangular runner, when the thickness is varied, the fill time, flow rate, and percentage change vary linearly. For the first change in thickness, the variations are high compared to the rest of the changes as shown in the Figs: 5.8, 5.16, and 5.24.

6.2 MATERIAL POLYCARBONATE

As the diameter of the gate is increased from 0.8mm to 1.3mm with an increment of 0.05mm, the pressure required to fill the cavities, fill time, flow rate and the percentage change of fill time and flow rate vary rapidly as shown in Figs: 5.27, 5.35, and 5.43. For the variation in length of the gate there are changes in operating conditions, but these changes are not as high as those observed while varying the diameter of the gate. The response of the variables to the variations in gate diameter is almost the same for polycarbonate and Nylon6.

While varying the thickness of the rectangular gate the variation in pressure, fill time, flow rate and percentage change in fill time and flow rate are high when compared to the variations that accompany changes in dimensions of width and length of the gate as shown in Figs: 5.26, 5.29, and 5.30. The same is observed for the material Nylon6.

While varying the thickness of the rectangular runner the operating conditions vary as expected, but when the width is varied the results are unpredictable. This can be clearly seen in the Figs: 5.31, 5.39, and 5.47.

For a circular runner, when diameter is varied from 2.91mm to 3.44mm in increments of 0.05mm the variation in the variables is higher initially and becomes linear after each incremental rise in runner diameter which can be seen in Figs: 5.28, 5.36, and 5.40.

6.3 MATERIAL POLYACETAL

For polyacetal material, the gate diameter is increased from 0.8mm to 1.7mm in steps of 0.1mm. It is observed that the pressure, filltime, flow rate, and percentage change of fill time and flow rate vary drastically. As shown in the Figs: 5.51, 5.59, and 5.67, the variations are much higher compared to the other materials.

For the variation in circular gate length and circular runner diameter the variations in variables are almost the same, but very slow and small as shown in the Figs: 5.49 5.57, 5.65, 5.52, 5.60, and 5.68,.

We observe that the changes are higher when the thickness of the rectangular gate is varied than when the width and length are varied as shown in Figs: 5.50, 5.54 and 5.54.

When the thickness of the rectangular runner is varied the pressure, fill time, flow rate, and the percentage change of fill time and flow rate are varying as expected. Consequently, when the width of the runner is varied, the fill time required to return to the balanced pressure increases as the dimension is increased, and the flow rate is decreased as shown in Figs: 5.55, 5.63, and 5.71. This same behavior has been observed for all material that are studied.

6.4 MATERIAL NYLON6

Like the other materials, Nylon6 is also very sensitive to the variations in the diameter of the circular gate as shown in the Figs: 5.75, 5.83, and 5.91.

When the length of the circular gate is varied the pressure required to fill the cavity, the fill time, the flow rate and the percentage change of fill time and flow rate changing as usual; but these changes are less compared to the other materials for the same kind of wear, which can be observed in the Fig: 5.73, 5.81, and 5.89.

While varying the thickness of the rectangular gate the variations in the fill time, the flow rate and the percentage change of fill time and flow rate are very high compared to the variations that are observed when the dimensions of width and length of gate are varied as shown in the Figs: 5.74, 5.77, and 5.78. The same variations are observed in the material polycarbonate.

Similarly, when the thickness of the rectangular runner is varied, the fill time, the flow rate and the percentage change of fill time and the flow rate are varying as expected. But when the width of the runner is varied the observations are unpredictable as shown in the Figs: 5.79, 5.87, and 5.95. The same pattern of observations are noted for every material that is studied.

Generalizations can be made in evaluating all the cases we observe that the circular gate wear is more sensitive, i.e., the variations of pressure, fill time, flow rate and percentage change in fill time and flow rate are very high compared to the wears in other geometries of gates or runners. All the materials respond in the same way with a little variations, to the changes in gates and runners dimensions. The little variations are observed because the each material has its own rheological properties. It can be said that to some extent the effect of wear and tear depends on the material properties that have been used.

CHAPTER 7

CONCLUSIONS

The following conclusions have been made from the thorough analysis of the results drawn in previous chapter. They are:

1. Wear of the gates and runners causes an imbalance to the cavity flow paths.

For the same mold geometry and mold wear and for different molding conditions, the pressure required to fill, the fill time, the flow rate and percentage change of fill time and flow rate respond differently for different materials. Therefore, it is concluded that the quality of the end product in multi cavity mold, when it is effected by wear and tear in gate or runner depends on the rheological properties of the material being used. The work done attempts to draw a line as to what extent the wear and tear of gate or runner of different geometry can be tolerated. Suggestions can be made on whether replacing or regrinding the gates and runners is economically feasible by assuming that the variations of flow above 20% cannot be tolerated.

2. Circular gate wear has a severe effect on flow imbalance.

Upon evaluating the wear of gates and runners of different geometries, it is observed that when the diameter of the circular gate is varied, the impact of that variation on the flow imbalance in the multicavity mold is more severe than any other variations in dimension of the gates and runners of different geometries. Thus, it is concluded that the impact of the wear of circular gate is most severe on the final product.

3. The material ABS is very sensitive to wear in circular runner.

The variations of operating conditions from the balanced state are very high when the diameter of runner is varied for ABS material, as we can see from the graphs 5.4, 5.12, and 5.20. It once again confirms that the effect of wear and tear of gates and runners on the end product is governed by the rheological properties of the material.

4. It is not possible to bring the imbalanced flow back to the original balanced condition.

One of the most important observations is that once the gates and runners dimension are changed due to wear and tear, it is not possible to bring the flow back to a balanced state irrespective of the number of adjustments that are subsequently made to the operating conditions. Thus, it can be suggested to the manufacturer that once the gates and runners dimension changes due to wear and tear, it is a waste of resources to try to adjust the operating conditions in order to improve the quality of the end products.

By keenly observing the graphs we can conclude that one can bring the imbalanced flow due to wear and tear of gates and runners back to balanced conditions by varying the operating conditions only to some extent; but after that one has to replace the mold or should regrind the gates and/or runners.

FUTURE WORK

This thesis just touches the tip of the iceberg. There is still an abundance of research that can be done in this area. Gates and/or runners may wear at the same time. Studies on the effect of wear and tear of gates and/or runners at the same time can be made taking into consideration other different combinatorial factors. Accurate prediction of the effect of the wear and tear of gates and runners in the multi cavity mold will be very useful for the sophisticated and intelligent manufacturer.

When the gates and/or runners dimensions are varied the amount of imbalance in the flows is directly proportional to the amount of wear. Attempts can be made to find out to what extent the imbalanced flow can be brought closer to the original balanced flow.

When the width of the runner is varied, the results are unpredictable. Research can be done in analyzing the flow in this kind of wear in detail.

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Appendix 1. Operating Conditions in the Rectangular Gate for ABS Under Balanced Conditions.

FLOW NUMBER 1
TOTAL VOLUME ALL FLOWS 5.752 cu.cm
MOLD TEMP 60. deg C MELT TEMP 240. deg C TIME 3.0 sec
FLOW RATE 1.92 cu.cm/sec

SECT NUMBER	PRESS MPa	PRESS DROP MPa	PRESS GRADIENT MPa/m	STRESS Pa	SHEAR RATE 1/sec	TEMP deg C	COOLING TIME sec
1)	80.00	25.61	640.1	480150.	723.	258.	6.9
2)	54.39	38.45	480.7	352570.	501.	280.	7.4
3)	15.94	3.74	2876.5	1007479.	19003.	283.	1.7
4)	12.20	12.20	122.0	182967.	83.	267.	13.8

FLOW NUMBER 2
TOTAL VOLUME ALL FLOWS 5.752 cu.cm
MOLD TEMP 60. deg C MELT TEMP 240. deg C TIME 3.0 sec
FLOW RATE 1.92 cu.cm/sec

SECT NUMBER	PRESS MPa	PRESS DROP MPa	PRESS GRADIENT MPa/m	STRESS Pa	SHEAR RATE 1/sec	TEMP deg C	COOLING TIME sec
1)	80.00	25.61	640.1	480150.	723.	258.	6.9
2)	54.39	46.23	577.9	376514.	389.	280.	6.1
3)	8.16	3.15	2425.8	849035.	10342.	282.	1.7
4)	5.01	5.01	100.1	150225.	45.	263.	13.5

*MAX PRESSURE 80.00 MPa
*MIN PRESSURE 80.00 MPa
*PROJECTED AREA 0.0019 sq.m
*ESTIMATED CLAMP TONNAGE 4. TONNES

Appendix 2. Operating Conditions in the Circular Gate and Circular Runner for ABS Under Balanced Conditions.

FLOW NUMBER 1
TOTAL VOLUME ALL FLOWS 5.761 cu.cm
MOLD TEMP 60. deg C MELT TEMP 240. deg C TIME [illegible]
FLOW RATE 1.92 cu.cm/sec

SECT NUMBER	PRESS MPa	PRESS DROP MPa	PRESS GRADIENT MPa/m	STRESS Pa	SHEAR RATE 1/sec	TEMP deg C
1)	82.00	25.62	[illegible]	480346.	[illegible]	255.
2)	56.38	37.92	[illegible]	[illegible]	[illegible]	[illegible]
3)	18.47	6.61	[illegible]	1027144.	[illegible]	[illegible]
4)	11.86	11.26	[illegible]	177825.	83.	[illegible]

FLOW NUMBER 2
TOTAL VOLUME ALL FLOWS [illegible] cu.cm
MOLD TEMP 60. deg C MELT TEMP [illegible] TIME [illegible]
FLOW RATE 1.92 cu.cm/sec

SECT NUMBER	PRESS MPa	PRESS DROP MPa	PRESS GRADIENT MPa/m	STRESS Pa	SHEAR RATE 1/sec	TEMP deg C
1)	82.00	25.62	[illegible]	[illegible]	[illegible]	[illegible]
2)	56.38	45.95	[illegible]	[illegible]	[illegible]	[illegible]
3)	10.43	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4)	4.88	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

*MAX PRESSURE 82.00 MPa
*MIN PRESSURE [illegible]
*PROJECTED AREA [illegible]
*ESTIMATED CLAMP TONNAGE [illegible] TONNES

Appendix 3. Operating Conditions in the Rectangular Runner for ABS Under Balanced Conditions.

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FLOW NUMBER      1
TOTAL VOLUME ALL FLOWS      [illegible]
MOLD TEMP    60. deg C    MELT TEMP   [illegible]    TIME   [illegible]
FLOW RATE      2.00 cu.cm/sec
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SECT NUMBER	PRESS MPa	PRESS DROP MPa	[illegible]	STRESS [illegible]	SHEAR RATE 1/sec	TEMP [illegible]
1)	65.00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2)	39.14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3)	22.93	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4)	14.35	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

```
FLOW NUMBER      2
TOTAL VOLUME ALL FLOWS      [illegible]
MOLD TEMP    60. deg [illegible]    [illegible]
FLOW RATE      2.00 [illegible]
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SECT NUMBER	PRESS MPa	PRESS [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1)	65.00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2)	39.14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3)	12.92	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4)	5.85	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

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*MAX PRESSURE                [illegible]
*MIN PRESSURE                [illegible]
*PROJECTED AREA              [illegible]
*ESTIMATED CLAMP [illegible] [illegible]
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Appendix 4. Operating Conditions in the Rectangular Gate for PC Under Balanced Conditions.

FLOW NUMBER 1
TOTAL VOLUME ALL FLOWS [illegible] cu.cm
MOLD TEMP 60. deg C MELT TEMP 300. deg C TIME [illegible] sec
FLOW RATE 1.84 cu.cm/sec

SECT NUMBER	PRESS MPa	PRESS DROP MPa	PRESS GRADIENT MPa/m	STRESS Pa	SHEAR RATE 1/sec	TEMP deg C	TIME
1)	75.00	18.93	[illegible]	[illegible]	695.	[illegible]	[illegible]
2)	56.07	42.51	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3)	13.56	9.26	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4)	4.29	4.29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

FLOW NUMBER 2
TOTAL VOLUME ALL FLOWS [illegible] cu.cm
MOLD TEMP 60. deg C MELT TEMP [illegible] deg C TIME [illegible] sec
FLOW RATE 1.84 cu.cm/sec

SECT NUMBER	PRESS MPa	PRESS DROP MPa	PRESS GRADIENT MPa/m	STRESS Pa	SHEAR RATE 1/sec	TEMP deg C	TIME
1)	75.00	18.93	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2)	56.07	47.95	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3)	8.12	6.60	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4)	1.52	1.52	[illegible]	5556.	[illegible]	[illegible]	[illegible]

*MAX PRESSURE [illegible]
*MIN PRESSURE [illegible]
*PROJECTED AREA [illegible]
*ESTIMATED CLAMP TONNAGE [illegible]

Appendix 5. Operating Conditions in the Circular Gate and Circular Runner for PC Under Balanced Conditions.

FLOW NUMBER 1
TOTAL VOLUME ALL FLOWS [illegible] cu.cm
MOLD TEMP 60. deg C MELT TEMP 300. deg C TIME 3.0 sec
FLOW RATE 1.90 cu.cm/sec

SECT NUMBER	PRESS MPa	PRESS DROP MPa	PRESS GRADIENT MPa/m	STRESS Pa	SHEAR RATE 1/sec	TEMP deg C	COOLING TIME sec
1)	75.00	19.25	481.3	360999.	716.	310.	9.0
2)	55.75	28.92	361.5	263221.	511.	320.	[illegible]
3)	26.83	22.53	17324.3	3466003.	24659.	334.	[illegible]
4)	4.31	4.31	43.1	64585.	83.	313.	[illegible]

FLOW NUMBER 2
TOTAL VOLUME ALL FLOWS [illegible] cu.cm
MOLD TEMP 60. deg C MELT TEMP 300. deg C TIME 3.0 sec
FLOW RATE 1.90 cu.cm/sec

SECT NUMBER	PRESS MPa	PRESS DROP MPa	PRESS GRADIENT MPa/m	STRESS Pa	SHEAR RATE 1/sec	TEMP deg C	COOLING TIME sec
1)	75.00	19.25	481.3	360799.	716.	310.	[illegible]
2)	55.75	37.55	494.4	301208.	463.	320.	6.7
3)	16.20	14.68	11283.5	7257915.	13075.	329.	[illegible]
4)	1.52	1.52	30.4	45651.	44.	308.	[illegible]

*MAX PRESSURE 75.00 MPa
*MIN PRESSURE 75.00 MPa
*PROJECTED AREA 0.0019 sq.m
*ESTIMATED CLAMP TONNAGE 3. TONNES

Appendix 6. Operating Conditions in the Rectangular Runner for PC Under Balanced Conditions.

FLOW NUMBER 1
TOTAL VOLUME ALL FLOWS 5.610 cu.cm
MOLD TEMP 60. deg C MELT TEMP 300. deg C TIME 3.0 sec
FLOW RATE 1.87 cu.cm/sec

SECT NUMBER	PRESS MPa	PRESS DROP MPa	PRESS GRADIENT MPa/m	STRESS Pa	SHEAR RATE 1/sec	TEMP deg C	COOLING TIME sec
1)	75.00	19.11	477.7	358395.	707.	309.	9.0
2)	55.89	30.06	377.8	355537.	677.	321.	[illegible]
3)	25.83	21.58	16404.1	2779796.	24125.	334.	[illegible]
4)	4.25	4.25	42.5	53673.	81.	313.	[illegible]

FLOW NUMBER 2
TOTAL VOLUME ALL FLOWS 5.518 cu.cm
MOLD TEMP 60. deg C MELT TEMP 300. deg C TIME 3.0 sec
FLOW RATE 1.87 cu.cm/sec

SECT NUMBER	PRESS MPa	PRESS DROP MPa	PRESS GRADIENT MPa/m	STRESS Pa	SHEAR RATE 1/sec	TEMP deg C	COOLING TIME sec
1)	75.00	19.11	477.7	358305.	707.	309.	[illegible]
2)	55.89	39.18	439.8	387793.	526.	319.	[illegible]
3)	16.71	15.16	11660.9	7322407.	13137.	327.	[illegible]
4)	1.55	1.55	31.1	46537.	44.	308.	[illegible]

*MAX PRESSURE 75.00 MPa
*MIN PRESSURE 75.00 MPa
*PROJECTED AREA 0.0020 sq.m
*ESTIMATED CLAMP TONNAGE 3. TONNES

Appendix 7. Operating Conditions in the Rectangular Gate for PA Under Balanced Conditions.

FLOW NUMBER 1
TOTAL VOLUME ALL FLOWS 5.671 cu.cm
MOLD TEMP 60. deg C MELT TEMP 280. deg C TIME 3.0 sec
FLOW RATE 1.89 cu.cm/sec

SECT NUMBER	PRESS MPa	PRESS DROP MPa	PRESS GRADIENT MPa/m	STRESS Pa	SHEAR RATE 1/sec	TEMP deg C	COOLING TIME sec
1)	70.00	17.69	442.2	331714.	713.	285.	5.7
2)	52.31	34.23	427.9	298856.	572.	292.	5.3
3)	18.08	11.36	8737.5	3058119.	18746.	296.	1.4
4)	6.72	6.72	67.2	100759.	82.	279.	10.3

FLOW NUMBER 2
TOTAL VOLUME ALL FLOWS 5.671 cu.cm
MOLD TEMP 60. deg C MELT TEMP 280. deg C TIME 3.0 sec
FLOW RATE 1.89 cu.cm/sec

SECT NUMBER	PRESS MPa	PRESS DROP MPa	PRESS GRADIENT MPa/m	STRESS Pa	SHEAR RATE 1/sec	TEMP deg C	COOLING TIME sec
1)	70.00	17.69	442.2	331714.	713.	285.	5.7
2)	52.31	41.10	513.7	322829.	427.	289.	4.4
3)	11.21	8.69	6684.3	2339516.	10190.	293.	1.4
4)	2.52	2.52	50.5	75707.	44.	276.	10.0

*MAX PRESSURE 70.00 MPa
*MIN PRESSURE 70.00 MPa
*PROJECTED AREA 0.0019 sq.m
*ESTIMATED CLAMP TONNAGE 3. TONNES

Appendix 8. Operating Conditions in the Circular Gate and Circular Runner for PA Under Balanced Conditions.

FLOW NUMBER 1
TOTAL VOLUME ALL FLOWS 5.764 cu.cm
MOLD TEMP 60. deg C MELT TEMP 280. deg C TIME 3.0 sec
FLOW RATE 1.92 cu.cm/sec

SECT NUMBER	PRESS	PRESS DROP	PRESS GRADIENT	STRESS	SHEAR RATE	TEMP	COOLING TIME
	MPa	MPa	MPa/m	Pa	1/sec	deg C	sec
1)	75.00	17.83	445.8	334399.	725.	285.	5.7
2)	57.17	27.79	347.3	259907.	475.	289.	5.7
3)	29.38	23.12	17786.2	3557585.	24850.	298.	0.7
4)	6.26	6.26	62.6	93897.	83.	281.	10.5

FLOW NUMBER 2
TOTAL VOLUME ALL FLOWS 5.764 cu.cm
MOLD TEMP 60. deg C MELT TEMP 280. deg C TIME 3.0 sec
FLOW RATE 1.92 cu.cm/sec

SECT NUMBER	PRESS	PRESS DROP	PRESS GRADIENT	STRESS	SHEAR RATE	TEMP	COOLING TIME
	MPa	MPa	MPa/m	Pa	1/sec	deg C	sec
1)	75.00	17.83	445.8	334399.	725.	285.	5.7
2)	57.17	37.97	474.7	305822.	400.	288.	4.0
3)	19.19	16.84	12954.7	2591191.	13374.	295.	0.8
4)	2.35	2.35	47.0	70565.	45.	278.	10.0

*MAX PRESSURE 75.00 MPa
*MIN PRESSURE 75.00 MPa
*PROJECTED AREA 0.0019 sq.m
*ESTIMATED CLAMP TONNAGE 3. TONNES

Appendix 9. Operating Conditions in the Rectangular Runner for PA Under Balanced Conditions.

FLOW NUMBER 1
TOTAL VOLUME ALL FLOWS 5.886 cu.cm
MOLD TEMP 60. deg C MELT TEMP 280. deg C TIME 3.0 sec
FLOW RATE 1.96 cu.cm/sec

SECT NUMBER	PRESS	PRESS DROP	PRESS GRADIENT	STRESS	SHEAR RATE	TEMP	COOLING TIME
	MPa	MPa	MPa/m	Pa	1/sec	deg C	sec
1)	65.00	18.02	450.5	337912.	740.	285.	5.7
2)	46.98	13.84	173.1	225473.	374.	286.	8.6
3)	33.14	26.41	20319.0	4064203.	25259.	296.	0.9
4)	6.72	6.72	67.2	100810.	85.	280.	10.4

FLOW NUMBER 2
TOTAL VOLUME ALL FLOWS 5.836 cu.cm
MOLD TEMP 60. deg C MELT TEMP 280. deg C TIME 3.0 sec
FLOW RATE 1.96 cu.cm/sec

SECT NUMBER	PRESS	PRESS DROP	PRESS GRADIENT	STRESS	SHEAR RATE	TEMP	COOLING TIME
	MPa	MPa	MPa/m	Pa	1/sec	deg C	sec
1)	65.00	18.02	450.5	337912.	740.	285.	5.7
2)	46.98	24.74	309.2	307216.	351.	284.	5.4
3)	22.24	19.66	15122.4	3024768.	13776.	292.	0.3
4)	2.58	2.58	51.6	77437.	46.	276.	10.0

*MAX PRESSURE 65.00 MPa
*MIN PRESSURE 65.00 MPa
*PROJECTED AREA 0.0020 sq.m
*ESTIMATED CLAMP TONNAGE 3. TONNES

Appendix 10. Operating Conditions in the Rectangular Gate for PA6 Under Balanced Conditions.

FLOW NUMBER 1
TOTAL VOLUME ALL FLOWS 5.364 cu.cm
MOLD TEMP 80. deg C MELT TEMP 300. deg C TIME 3.0 sec
FLOW RATE 1.79 cu.cm/sec

SECT NUMBER	PRESS	PRESS DROP	PRESS GRADIENT	STRESS	SHEAR RATE	TEMP	COOLING TIME
	MPa	MPa	MPa/m	Pa	1/sec	deg C	sec
1)	25.00	3.66	91.5	68609.	675.	300.	9.7
2)	21.34	14.80	184.9	106682.	973.	301.	6.3
3)	6.55	5.42	4171.0	1459864.	17963.	303.	2.2
4)	1.12	1.12	11.2	16857.	78.	288.	17.2

FLOW NUMBER 2
TOTAL VOLUME ALL FLOWS 5.364 cu.cm
MOLD TEMP 80. deg C MELT TEMP 300. deg C TIME 3.0 sec
FLOW RATE 1.79 cu.cm/sec

SECT NUMBER	PRESS	PRESS DROP	PRESS GRADIENT	STRESS	SHEAR RATE	TEMP	COOLING TIME
	MPa	MPa	MPa/m	Pa	1/sec	deg C	sec
1)	25.00	3.66	91.5	68609.	675.	300.	9.7
2)	21.34	17.43	217.9	107599.	812.	298.	4.8
3)	3.91	3.55	2727.6	954650.	9403.	299.	2.2
4)	0.37	0.37	7.3	10968.	41.	285.	16.8

*MAX PRESSURE 25.00 MPa
*MIN PRESSURE 25.00 MPa
*PROJECTED AREA 0.0018 sq.m
*ESTIMATED CLAMP TONNAGE 1. TONNES

Appendix 11. Operating Conditions in the Circular Gate and Circular Runner for PA6 Under Balanced Conditions.

FLOW NUMBER 1
TOTAL VOLUME ALL FLOWS 5.541 cu.cm
MOLD TEMP 80. deg C MELT TEMP 300. deg C TIME 3.0 sec
FLOW RATE 1.85 cu.cm/sec

SECT NUMBER	PRESS MPa	PRESS DROP MPa	PRESS GRADIENT MPa/m	STRESS Pa	SHEAR RATE 1/sec	TEMP deg C	COOLING TIME sec
1)	25.00	3.75	93.7	70246.	697.	300.	9.7
2)	21.25	8.23	102.8	70420.	605.	298.	8.2
3)	13.03	11.88	9141.2	1828412.	24262.	303.	1.4
4)	1.14	1.14	11.4	17150.	81.	289.	17.2

FLOW NUMBER 2
TOTAL VOLUME ALL FLOWS 5.541 cu.cm
MOLD TEMP 80. deg C MELT TEMP 300. deg C TIME 3.0 sec
FLOW RATE 1.85 cu.cm/sec

SECT NUMBER	PRESS MPa	PRESS DROP MPa	PRESS GRADIENT MPa/m	STRESS Pa	SHEAR RATE 1/sec	TEMP deg C	COOLING TIME sec
1)	25.00	3.75	93.7	70246.	697.	300.	9.7
2)	21.25	13.42	167.8	89413.	660.	296.	5.4
3)	7.83	7.46	5740.3	1148170.	12482.	299.	1.3
4)	0.37	0.37	7.4	11080.	42.	285.	16.8

*MAX PRESSURE 25.00 MPa
*MIN PRESSURE 25.00 MPa
*PROJECTED AREA 0.0019 sq.m
*ESTIMATED CLAMP TONNAGE 1. TONNES

Appendix 12. Operating Conditions in the Rectangular Runner for PA6 under Balanced Conditions.

FLOW NUMBER 1
TOTAL VOLUME ALL FLOWS 5.546 cu.cm
MOLD TEMP 80. deg C MELT TEMP 300. deg C TIME 3.0 sec
FLOW RATE 1.85 cu.cm/sec

SECT NUMBER	PRESS MPa	PRESS DROP MPa	PRESS GRADIENT MPa/m	STRESS Pa	SHEAR RATE 1/sec	TEMP deg C	COOLING TIME sec
1)	25.00	3.75	93.7	70289.	697.	300.	9.7
2)	21.25	8.41	105.1	94336.	749.	298.	7.9
3)	12.84	11.71	9005.0	1801186.	23977.	303.	1.4
4)	1.13	1.13	11.3	17003.	80.	289.	17.2

FLOW NUMBER 2
TOTAL VOLUME ALL FLOWS 5.546 cu.cm
MOLD TEMP 80. deg C MELT TEMP 300. deg C TIME 3.0 sec
FLOW RATE 1.85 cu.cm/sec

SECT NUMBER	PRESS MPa	PRESS DROP MPa	PRESS GRADIENT MPa/m	STRESS Pa	SHEAR RATE 1/sec	TEMP deg C	COOLING TIME sec
1)	25.00	3.75	93.7	70289.	697.	300.	9.7
2)	21.25	12.92	161.5	111348.	677.	294.	5.2
3)	8.33	7.94	6108.9	1221906.	12798.	278.	1.3
4)	0.39	0.39	7.7	11596.	43.	284.	16.7

*MAX PRESSURE 25.00 MPa
*MIN PRESSURE 25.00 MPa
*PROJECTED AREA 0.0020 sq.m
*ESTIMATED CLAMP TONNAGE 1. TONNES

13. MATERIALS USED IN THE SIMULATIONS

MATERIAL	SUPPLIER	TRADE NAME	GRADE
1. ABS	*ENICHEM*	*RAVIKRAL SKI*	*E106*
2. PC	*ENICHEM*	*SINVIT 251/R*	*E106*
3. PA	*DUPONT*	*ZYTEL ST801*	*D124*
4. PA6	*ENICHEM*	*NIVION PLAST 303 HV*	*E202*