The Plastics and Rubber Institute
and
The Society of Plastics Engineers, Inc

in association with Muoviyhdistys ry, Finland
VDI-Gesellschaft Kunststofftechnik, FDR
Drustvo Plasticara i Gumaraca, Yugoslavia

POLYCON '82

Injection moulding – the influence of processing on performance

Papers and proceedings

24 – 28 May 1982

Leeuwenhorst Congres Center,
Noordwijkerhout, Netherlands

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(Reported by J.E.Nightingale)

Edited by P.L. Clegg

POLYCON '82

INTRODUCTION:

POLYCON is a new venture for the Plastics and Rubber Institute, UK and the Society of Plastics Engineers, USA, which it is hoped will establish on a regular basis a European platform for high level contacts between experts in the various topic areas selected for in-depth discussion.

The first of the meetings was held at The Leeuwenhorst Congres Center between Amsterdam and The Hague, which is intended to become the permanent site for POLYCONs.

POLYCON '82 reviewed in depth the current state of the art of INJECTION MOULDING with particular reference to THE INFLUENCE OF PROCESSING ON PERFORMANCE and through an interchange of experience from practitioners in the field, pointed the way to possible solutions to practical problems raised by the plenary speakers or by those participating in the syndicate discussions. The meeting emphasized the systems approach, the mutual interactions between materials, processes, machines and moulds.

The organizing committee issued a number of invitations to specialists in the field to take part in the conference and a general call for delegates to identify themselves was also made. Only those having the necessary background and expertise enabling them to be contributors rather than observers were accepted.

PROGRAMME ORGANIZATION:

In general, each half-day session had the following format:

Plenary paper	30 minutes
Discussion (points of principle only)	10 minutes
Coffee	30 minutes
Syndicate discussions (five of ~10 people)	1 hour
Plenary report and discussion	1 hour

The conference language was English. A visit was made to N.V. Philips at Eindhoven to see their injection moulding facilities.

SYNDICATES:

Membership of the syndicates was chosen with care by the Organizing Committee to ensure that the best possible balance of nationality and experience was achieved.

Plenary speakers provided questions that the Syndicates could discuss if they so wished. In any event and regardless of whether attempts were made to provide answers, these questions certainly stimulated discussion.

These Proceedings contain edited versions of the Syndicates' reports on each of the five sessions.

ORGANIZING COMMITTEE

Mr. J.W. Bot (SPE Benelux Section: NV Philips Gloeilampenfabrieken, Eindhoven)

Dr. P.L. Clegg (Past-Chairman PRI: formerly ICI Petrochemicals & Plastics Division)

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Mr. C.W. Speas (Chairman SPE International Relations Committee)

INFLUENCE OF THE MACHINE AND MOULD ON THE QUALITY OF INJECTION MOULDED PARTS OF UNFILLED THERMOPLASTICS.

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Institut fur Kunststoffverarbeitung, Pontstr. 49, D1500 Aachen,
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Introduction:

The quality of moulded parts is of course a term which can be interpreted in many ways. Nevertheless, this can be correlated qualitatively to some extent with just a few material properties:

the appearance of the surface,
the structure of the material,
orientations and
inherent stresses.

These, together with the basic properties of the material, determine permanently the properties of the moulded parts.

These four material properties of an injection moulded part are determined by:

melting,
filling,
holding pressure and
cooling.

Therefore they are related both to machine and operating sequence as well as to the design and operation of the mould.

We must therefore examine all these processes with respect to their influence on quality.

The plasticizing process

Assuming that a uniform, dry, granulated material is available, the screw injection machine must carry out the following operations on the moulding material:

* Director, IKV, Aachen.

$$\frac{L}{L_o} = \left(\frac{D}{D_o}\right)^{1+\omega}$$

$$\frac{h}{h_o} = \left(\frac{D}{D_o}\right)^{\psi}$$

$$\frac{n}{n_o} = \left(\frac{D}{D_o}\right)^{-x}$$

$$\frac{S}{S_o} = \left(\frac{D}{D_o}\right)^{\varepsilon}$$

$$\frac{\dot{m}}{\dot{m}_o} = \left(\frac{D}{D_o}\right)^{\psi - x + \varepsilon + 1}$$

$$\frac{\Delta\vartheta_{MS}}{\Delta\vartheta_{MS_o}} = \left(\frac{D}{D_o}\right)^{-\frac{\psi(k+1)+(\varepsilon-1)-(1+\omega)+k(x-1)}{\zeta+1}}$$

$$\frac{p_{St}}{p_{St_o}} = \left(\frac{D}{D_o}\right)^{-\frac{\psi(k+1)+(\varepsilon-1)-(1+\omega)+k(x-1)}{\zeta+1}}$$

$$\frac{P_{pl}}{P_{pl_o}} = \left(\frac{D}{D_o}\right)^{\psi - x + \varepsilon + 1 - \frac{\psi(k+1)+(\varepsilon-1)-(1+\omega)+k(x-1)}{\zeta+1}}$$

$$\frac{M_d}{M_{d_o}} = \left(\frac{D}{D_o}\right)^{\psi + \varepsilon + 1 - \frac{\psi(k+1)+(\varepsilon-1)-(1+\omega)+k(x-1)}{\zeta+1}}$$

$$\frac{\dot{Q}_H}{\dot{Q}_{H_o}} = \frac{T_o/t_{pl_o}}{T/t_{pl}} \left(\frac{D}{D_o}\right)^{\psi - x + \varepsilon + 1 - \frac{\psi(k+1)+(\varepsilon-1)-(1+\omega)+k(x-1)}{\zeta+1}}$$

$$\frac{\Delta\vartheta_H}{\Delta\vartheta_{H_o}} = \frac{T_o/t_{pl_o}}{T/t_{pl}} \left(\frac{D}{D_o}\right)^{2\psi - x + \varepsilon - (1+\omega) - \frac{\psi(k+1)+(\varepsilon-1)-(1+\omega)+k(x-1)}{\zeta+1}}$$

$$\frac{\dot{q}}{\dot{q}_o} = \frac{T_o/t_{pl_o}}{T/t_{pl}} \left(\frac{D}{D_o}\right)^{\psi - x + \varepsilon - (1+\omega) - \frac{\psi(k+1)+(\varepsilon-1)-(1+\omega)+k(x-1)}{\zeta+1}}$$

$$\frac{\dot{\gamma}}{\dot{\gamma}_o} = \left(\frac{D}{D_o}\right)^{-(\psi + x - 1)}$$

$$\frac{t_v}{t_{v_o}} = \left(\frac{D}{D_o}\right)^{\omega + x - \varepsilon + 1}$$

$$\frac{D_D}{D_{D_o}} = \left[\left(\frac{\frac{t_{pl}}{t_{sp}}}{\frac{t_{pl_o}}{t_{sp_o}}}\right)^{k} \left(\frac{D}{D_o}\right)^{\psi(1+2k)+k-(1+\omega)}\right]^{\frac{1}{3k-\omega_D}}$$

Exponents in the scale-up rules

ω = screw length exponent
ψ = channel depth exponent
x = screw speed exponent
ε = flight exponent
k = shear rate exponent
ζ = temperature exponent

Fig. 1: Scale-up theory for single screw injection moulding machines.

feeding

ventilation

compression

melting

mixing

and must prepare an extremely uniform melt volume.

Regarding the quality, there are still great differences possible, even when a machine is running properly with constant cycles. The differences concern the homogeneity of the melt. A well-known rule says that a machine must have a sufficient injection capacity as well as a certain plasticization rate. These are related to one another as follows/8/:

$$0.4 \times S < P < 0.8 \times S$$

S = maximum shot volume of the machine (cm^3)

$$P = \frac{\text{plasticization rate } (cm^3/min)}{\text{shot volume } (cm^3) \times \text{number of cycles } (min^{-1})}$$

Therefore it can be seen that the machine must neither be too large, since then the residence time will be too long, nor too small, since then the melt will be thermally and mechanically inhomogeneous. In addition to this, some materials can be processed only by the use of well-adapted screws. Such materials are being used more and more for technical parts. These types of materials include partially crystalline thermoplastics and blends or copolymers.

Design rules have been worked out in order to find suitable screws. We have found the so-called energy-model-theory of Potente to be very useful, which has now also been adapted to the intermittent mode of operation of the screw injection moulding plasticizing unit (cf Fig. 1) /1,2 /. As can be seen from the diagram, all the important design data for a screw of any size can be calculated by knowledge of data of a satisfactorily operating model screw. The only thing which is then required is the viscosity as a function of shear-rate and temperature within the operational range of the material. For designing a model screw each company involved in manufacturing machines or raw material should have sufficient experience. This information can be found in numerous publications, mainly for extruders (which makes no difference here), assuming that the model screw has to be designed first.

After a suitable screw has been found and put into operation, the customer has a further simple possibility of adjusting the machine. He can improve the mixing of the screw by changing the back pressure. Fig. 2 shows some diagrams which have been recently worked out by us, which indicate clearly how speed, output, back pressure and temperature influence homogeneity. We obtained these diagrams from samples, in which very small quantities of a master batch were mixed with the naturally coloured granules /3/. The uniformity of the colour distribution was assessed visually by several testers. It can be assumed that crystalline macro-structure formation or mixing, in the case of blends, are influenced in exactly the same way as the colour distribution.

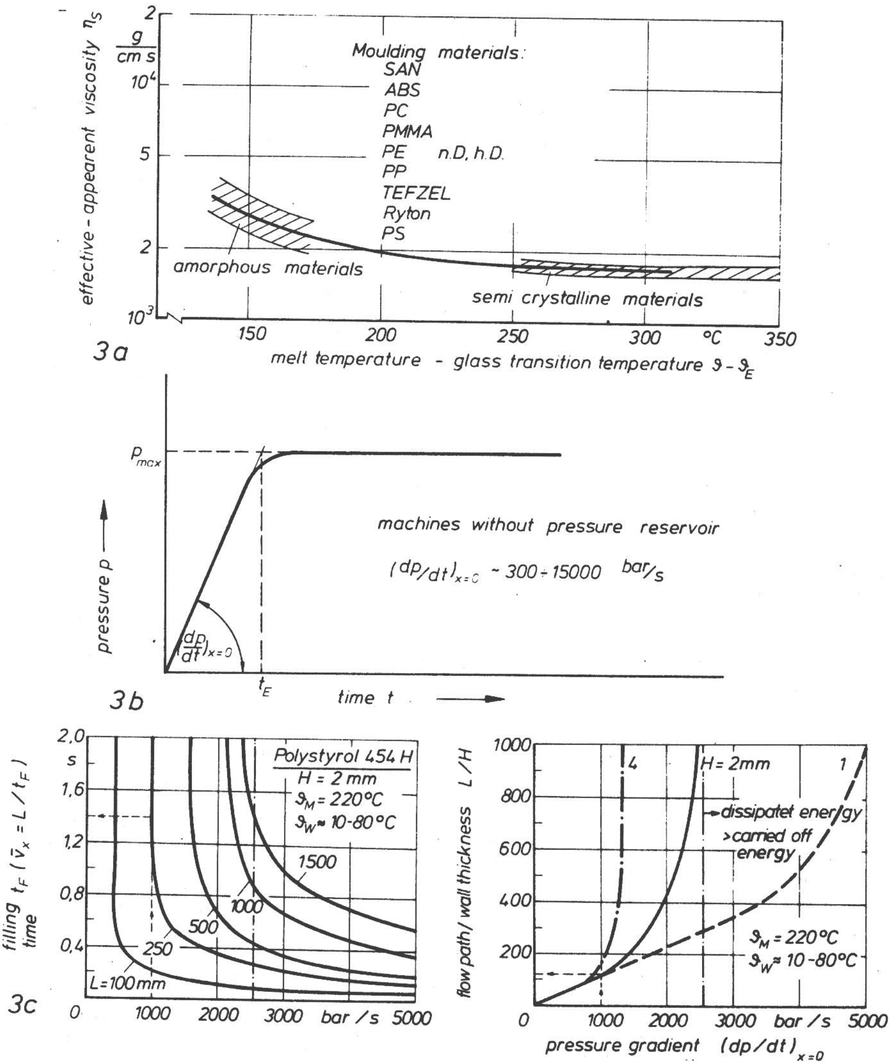


Fig. 3: Flow path wall thickness ratio and pressure capacity of an injection cylinder

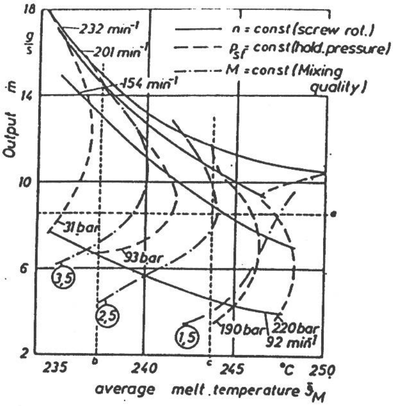


Fig. 2: Mixing of an injection moulding screw as a function of pressure and screw speed.

Finally the question of degradation in the case of sensitive materials should be mentioned. Generally it has been found that the temperature-time-effect can influence molecular degradation much more than can shear degradation. Furthermore it is well-known, for example in the processing of PVC that the melt must never be left to stand at high temperatures. On the other hand, the melt can be rotated for a relatively long time at high temperature, for example on a set of mixing rollers. It must be concluded therefore that the well-known practical rule is correct: the plasticization time, i.e. the speed of the screw, must be set in such a way that it rotates during the full cycle-time except during the injection and holding phase. Furthermore, the melt pool for the holding pressure should be as small as possible. Finally, the last strip heater of the cylinder and the nozzle should have the same temperature as the melt, or be slightly lower than this, in order that the portion of moulding material which is forced to stagnate here is not subjected to a high temperature /4/.

<u>The filling phase</u>/24/

This part of the process is certainly of greater importance than is plasticization, for all moulding mixtures are influenced here. On the machine side hydraulics have the most significant effect; this will be discussed first.

The first requirement, which is by no means satisfactorily fulfilled in all machines, concerns the adjustability of injection pressure or screw speed. It is true that this adjustment is often available but the machine works entirely differently. It has even been said that there are controlled machines with closed loop which cannot control at all ! These deficiencies are usually discovered at extreme working situations in border line cases, and for this reason we are going to build up a special test program for our own use.

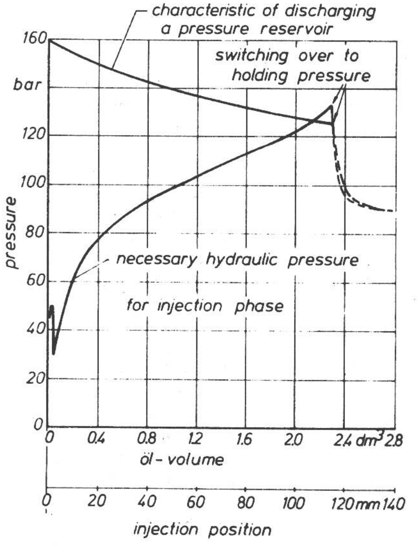
A very important but less known demand concerns the injection rate, which is determined by the hydraulics. It is obvious that the flow front can only be pressed further as long as the injection pressure rises (Fig. 3c). At the same time the characteristic p = f(t) should be linear, since it is well-known that the flow front should have a definite speed of approx. 30 - 50 cm/sec /5/. In the case of expanding streams this speed is reduced with the square of the distance from the gate, and this sets certain requirements on the mould, which will be discussed later. It should just be noted at this point that for a certain flow-path to wall-thickness ratio a specific injection rate $\frac{dp}{dt}$ is also required (cf Fig. 3c).

Diagrams can be drawn similar to the example shown in Fig. 3c, from which these data can be obtained. It can be seen from these results that controlling the injection rate can certainly be very significant, but it is much more important that the machine is functioning according to the way it is adjusted. The mistakes which can occur will be serious. Too rapid an injection, caused for example by a too narrow and incorrectly designed gate, can be immediately detected by the eye; defects caused by too slow filling are more pernicious. If the flow front becomes too slow, the solidified layer increases in thickness, since less heat is dissipated. This causes different orientations, different macro-structures in the case of partially crystalline melts, and with fibre filled moulding mixtures results in a different volume fraction of the aligned fibres. Therefore it is essential that the filling process is reproducible from shot to shot. This is probably the reason why the conclusions drawn from tests with pressure reservoirs are so different. Since the characteristics of the reservoir discharge are actually contrary to the requirements (cf Fig. 4), its use is only advisable with certain moulds.

Switch over from injection pressure to holding pressure /24/

Differences in the machine quality are particularly noticeable here. The accuracy of reproducibility depends strictly on a precise switch-over, since even 1/100 sec difference in the response of the hydraulic valve can result in considerable differences in the maximum injection pressure (cf Fig. 5). Such differences cause either flashes - if the switch over is late, resulting from the pressure peak or, as is known in the production of rear-lights, only poor definition of the edges - if the switch over is too early and the mould is filled by the holding pressure. If the effect of filling with holding pressure is particularly dominant, i.e. the switch over is made much too early (Fig. 5), a completely different type of orientation and macro-structure is produced.

Fig. 4: Characteristic of pressure reservoir discharge and necessary injection moulding pressure.



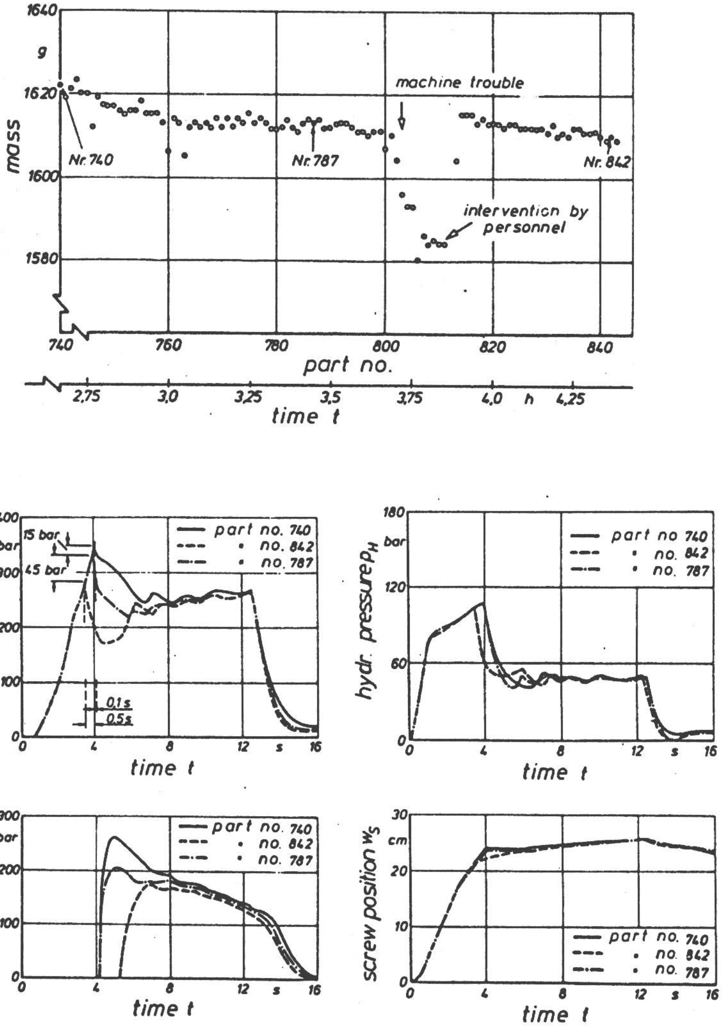


Fig. 5: Differences in pressure course for different switching times.

Considerable inherent stresses are also developed at corners and edges, because they are relatively cold formed owing to the long filling time (Fig. 6). We have achieved a method of regulation by continuously reducing the injection pressure down to the holding pressure. This prevents overshooting under all circumstances as well as filling with holding pressure (6,7).

Holding pressure /24/

Holding pressure, and its variation, has a particularly strong influence on quality, primarily on dimensional accuracy, but it also influences the orientation and macro-structure in partially crystalline thermoplastics, and of course alignment in fibre filled thermoplastics.

There has been a lot of discussion concerning the question of what profile the holding pressure should have. We have always supported the theory of properly reproducing the material state course in the p-v-T-diagram (Fig. 7). Of course if this uniform course is guaranteed by means of an internal pressure control or clamping force control, it is possible with this type of computer control on a p-v-T basis to compensate for temperature changes in the melt, too, and therefore to achieve very narrow tolerances. Experience with process control equipment - as reported for example in the Rohrick dissertation /9/, shows that not only the variations in dimensions become smaller, but also that more difficult parts can be produced with low scrap rates and that starting up times after interruptions in the operation become shorter.

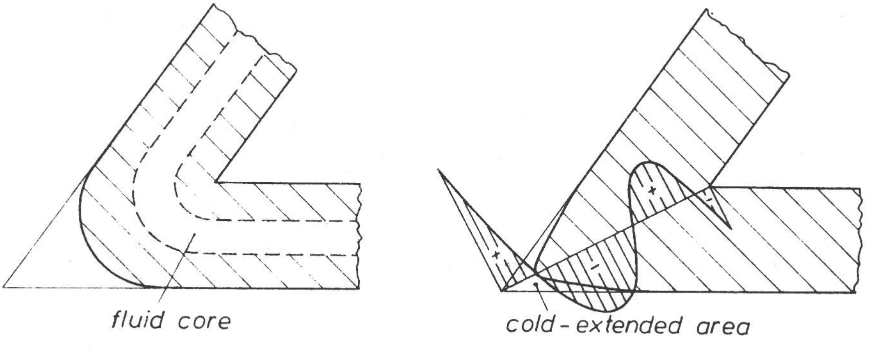


Fig. 6: Formation of internal stress in corners and edges.

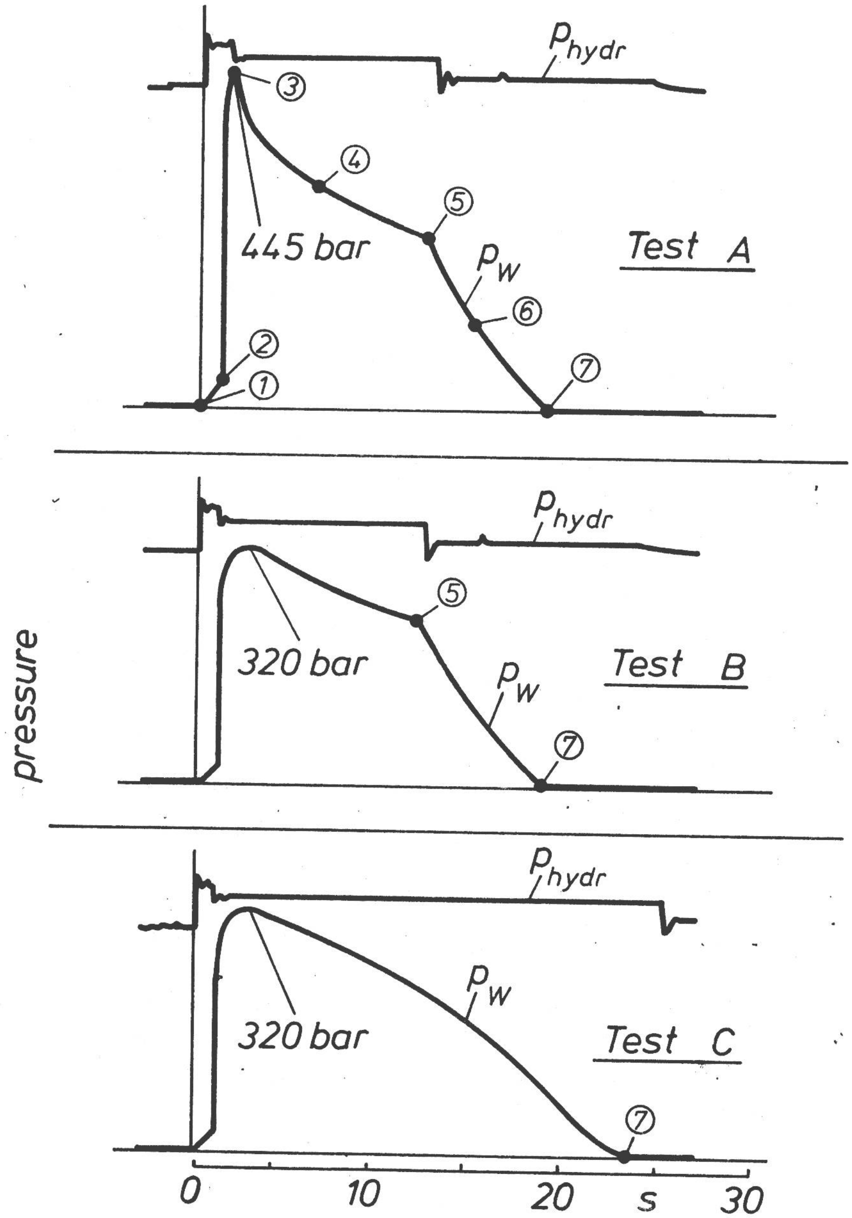


Fig. 7a: pvT - course with holding pressure.

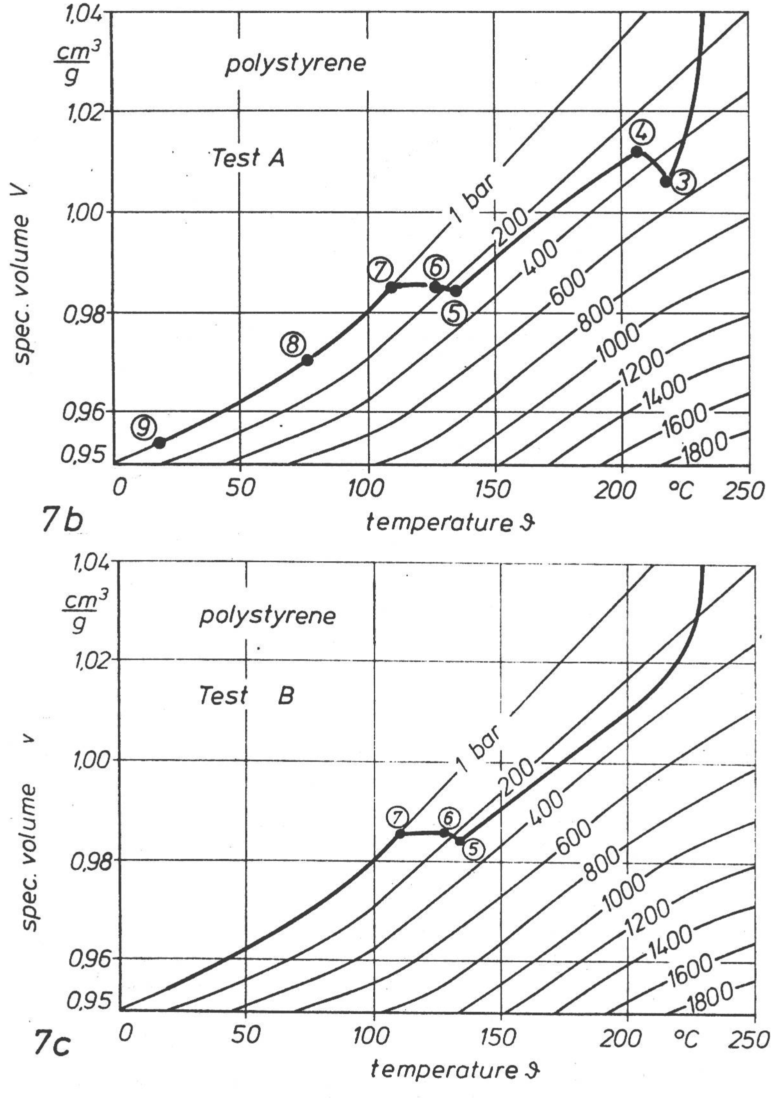
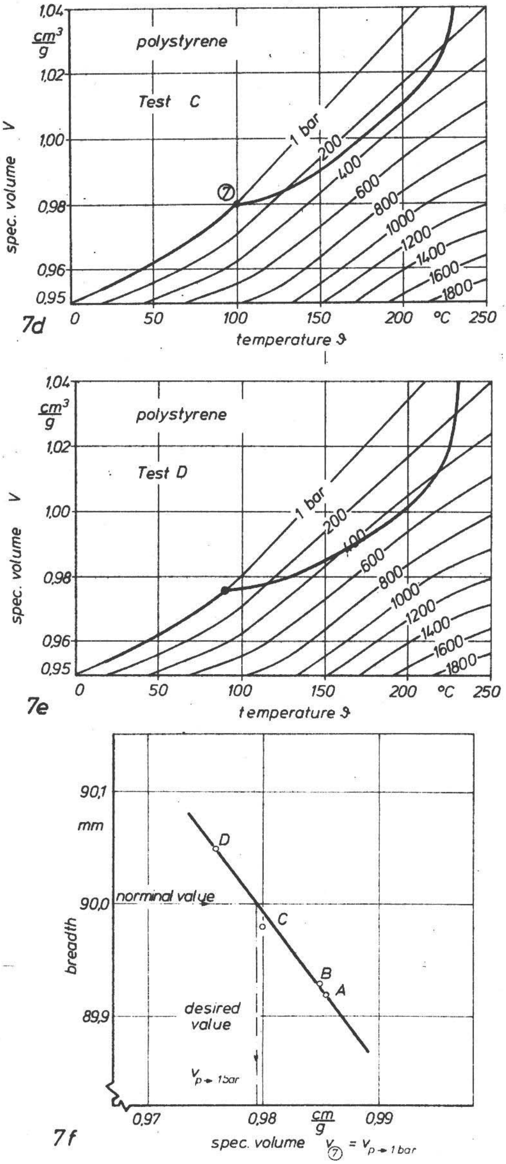


Fig 7b, 7c: pvT - course with holding pressure



Figs. 7d, 7e and 7f: pvT - course with holding pressure.