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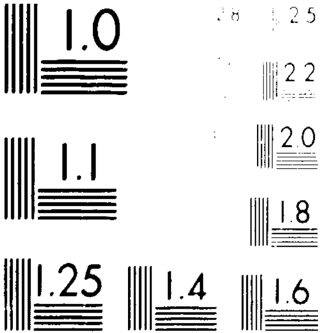
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China.
MISSION ON

POLYMER RHEOLOGY AND PLASTICS APPLICATIONS

rheology (*Phys.*). The science of flow of matter. The critical study of elasticity, viscosity, and plasticity.

<u>FINAL REPORT</u>

submitted

by

DR. R. S. LENK

Post: DP/CPR/80/006/11-5[illegible]

ACKNOWLEDGMENT.

The writer wishes to express his thanks and appreciation to the officers of the UNDP in China, to the representatives of the Peoples' Republic of China and to all the staff of the various research, technical and production establishments with whom he made contact during this visit, for the excellent cooperation and the friendliness which he has encountered on all occasions. These people are listed in Appendix 1.

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1. ARRIVAL AND INDUCTION.

I was met at Beijing airport on arrival of flight BA 003 from London by Mr. Liu from the Ministry of Light Industry on the afternoon of July 15th and taken to the Yanjing Hotel. A briefing at the UNDP office, collection of luggage-in-advance and the unpacking of books and notes followed the next morning.

During the afternoon I was introduced to the director and staff of the Polymer Development Centre where the proposed itinerary and the projected programme of lectures/seminars was agreed.

The opportunity was taken to look around the experimental facilities at the Centre. A useful collection of equipment is in operation, some of it made in China. A Brabender Plastograph has been installed recently which would be even more useful if a mixer/plasticorder were supplied in addition to the single screw extrusion setup. An Instron machine is in the process of installation which will eventually be available for stress/strain investigations as well as for extrusion rheometry.

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2. VISITS TO INSTITUTES AND FACTORIES.

2.1. The Beijing Plastics Research Institute. (July 17, a.m.)

This institute is remarkably well equipped, although the nature of the equipment varies in that some of it is not the most up-to-date, while others are of the most advanced kind. What was particularly impressive was the fact that both simple and complex items had been designed and manufactured in the country; this characterises the determination (observed again and again) to do the best with what is available at a given moment rather than to wait for the most sophisticated computer controlled and automated devices. That does not mean that the latter would not be welcome, but it does mean that when they do materialise - as they surely must eventually - the basic function will be fully understood without the purpose being obscured by press-button gadgetry and abstruse electronic circuitry.

There is an exceedingly well equipped testing section as well as laboratories for various spectroscopic techniques, a Perkin-Elmer differential scanning calorimeter and combustion calorimetry instruments for the detection of transition points and a laboratory for electrical testing.

Another section is devoted to PTFE technology, including coatings and the production of porous membranes, pressure compacting and sintering.

One of the features characteristic for the thinking in terms of production development is the gradual scale-up of machinery through several pilot stages to full production. This is an excellent concept in principle, but it could prove to be very time consuming once the demands of a fast growing consumer market arises; in other words, it is a luxury which can only be indulged in at a certain stage of economic development in the interest of gaining the widest possible experience, but beyond which the taking of faster scale-up risks cannot be avoided.

An impressive assembly of machinery in full production is the line making ABS sheet with an estimated thickness of 3-4 mm at the rate of 1.24 cm/sec. This is made by a crosshead-fed extruder supplying melt to a slit die, with subsequent calendering of the sheet which is then cut into lengths and used for vacuum forming of refrigerator liners.

Considerable attention is also paid to low temperature impact testing.

2.2. The Beijing No.1. Plastics factory. (July 17, p.m.)

This factory mainly produces beer crates and other crates by the injection moulding of polypropylene on machines which are not the most modern but which produce good quality mouldings at a cycle time of about 2½ minutes; other major items of production are laminated (PE) bubble film for packaging (2 lines), PVC cable compound by dryblending and extrusion-mixing,(followed by lace cutting, manual weighing and bagging), but a number of other mouldings are also produced from time to time and many of the tools are made in-house to their own design.

On both these visits one of the most striking features was the ingenuity with which existing and often less than eminently suitable accommodation was adapted to create space for the production facilities, for the laboratories and for the associated offices. These are clearly temporary expedients since purpose-built buildings are in the course of erection which will enhance every aspect of the various operations in the not very distant future.

Friendly discussions were conducted through the good offices of the interpreters. The writer believes that while expertise from abroad can assist in speeding up the development of the plastics industry in China, much can also be learned by foreign experts from the uncomplicated ingenuity with which Chinese technologists tend to approach a problem and solve it successfully with modest resources.

2.3. The Beijing Plastics Mould Factory. (July 19, a.m.)

There are 370 people working at this factory which has 74 machines, most of them made and designed in the country. They produce 500 to 600 moulds per annum, varying in size from shot capacities of 30 to 4000g. The heaviest of these moulds weighs 20 kg. Apart from mould making for injection moulding they also make moulds for compression moulding, dies and moulds for extrusion blow moulding, extrusion dies and moulds for vacuum forming. The products cover a variety of end uses such as household durables components, packaging items such as crates and tote boxes and small consumer items such as toys, soap dishes, etc. One-third of the products ultimately made from these tools was said to constitute pipe and fittings for agricultural (e.g. irrigation) purposes, using mostly PVC, but some of these products are also used for waste and sewage systems in the building industry. I saw some extrusion dies for PVC window frame profiles and other mouldings are made for automotive uses.

The tolerances achieved are good, but they are not claimed to be outstanding. There is a great deal of expertise in practical engineering and a design section which could do with some modern drawing boards. They have a shop for spark erosion equipment all of which has been made in China.

During the discussion session we mainly talked about design for packaging mould shrinkage problems and how flow analysis can help in correlating material, equipment and processing variables with output rates, pointing out the advantages and limitations of a scientific approach to production problems.

I left the following books with the director:

Spritzgiessen von Kunststoffen by Goetz Luepke, Vogel Verlag, Wuerzburg 1974
Extrudieren von Kunststoffen by F.W. Ebeling, Vogel Verlag, Wuerzburg 1974.

I believe that the very practical yet in-depth approach with many excell- drawings would be useful here, even though it does require translation from the German into Chinese which, I am told, presents no problem.

2.4. The Beijing No.4 Plastics Factory (July 19, p.m.).

This factory has 1000 employees and is spread over 11 locations. At the particular location visited the principal production items are blown film and extrusion-blow-moulded containers; printing and bagmaking is carried out at another location. 7000 tons of plastics are processed there annually most of which is film. The number of extruders and their screw diameters are tabulated below:

Screw dia (mm)	45	65	75	90	120	150
Number	45	12	7	6	1	1

LD and HDPE and EVA account for about 5000 tons, PP for 800 to 1000 tons and a little PVC shrink film is also produced. I was able to look at three production shops. Blown film of the smaller bubble size is extruded horizontally while the larger extruders blow vertically, some upward and some (the intermediate sizes) downward. Most of the equipment has been produced in China and all the accessories were made at the factory itself. Extrusion blow moulding accounts for an annual polymer consumption of about 1000 tons, almost exclusively LDPE. They are containers of various sizes ranging from baby feeding bottles and medium sized screw-capped jars and canisters to bulk containers of up to 100 litre capacity. The quality of the mouldings appears to be good, but the moulding machines are not of the most up-to-date type, there is much manual manipulation and cycle times are comparatively long. However, the expertise gained in operating simple machinery is an extremely valuable asset when more sophisticated equipment is eventually installed. Thickness variation - especially in the ultra-thin HDPE film, buttalso in other films - seems to be a problem, but I noted that the reels of finished film were never very great in diameter and this certainly avoids handling and warehousing difficulties to a considerable extent.

We did not discuss testing and standards, but I understand that the polymer used <u>is</u> a special film grade. I was surprised that some of the thicker film for conversion to printed shopping bags were made from polymer of quite a high melt flow index (7). Some sheet extrusion equipment is expected from Japan and thickness variation will be fairly easily monitored (beta ray gauges?) and corrected by automatic feedback control and adjustment. We aalso discussed film applications in medical packaging and agriculture. In the latter field the factory produces a long-life agricultural film for greenhouses with an expected service life of 2 years as a result of the incorporation of suitable UV stabilisers to the compound. The converse (photodegradable film) has not yet been considered.

The printing of the corona-discharge pretreated film is carried out at another location, but I saw an example of a five-colour printed LDPE carrier bag with very good colour registration and cardboard edge reinforcement fitted with (brought-in) injection moulded sturdy clip-fitted handles which, judging from the feel and appearance, have been made from HDPE or PP. Some shrink film is also made from PE for the overwrapping of bulk items and small diameter shrink film is also made for the covering of fishing rods. Another ingenious application of PE shrink film of substantial thickness is its use for the closure of bottles without a threaded top but with with a rolled or thickened bottle rim; this should provide an effective yet inexpensive closure of the disposable variety.

2.5. The Beijing No. 2 Plastics Factory. (July 20, a.m.)

This factory was established in 1965 and employs in excess of 700 people. It is one of the biggest plastics factories in China and achieved a turnover of YRMB 32 Million, with a profit of 6 Million. The principal product is plasticised PVC film. It has a modern calender line (a Berstorff machine) with an annual production of about 6000 tons of film of which some 20% is exported. Some of this film is converted to raincoats, shower curtains, etc. by other companies in China. The particular speciality of this factory is their gravure printing of PVC film in up to 5 colours and about 2000 tons of printed sheet is produced annually. The calender which had been installed some number of years back is producing very efficiently, the bowls can be crossed slightly (15mm distance at the ends with a 1500 mm bowl length) and the thickness is monitored by beta ray gauges. The compounding and feed line is somewhat more basic, but entirely adequate. The components are weighed out mechanically into lots which are dispensed down into the mixer blender manually.

A second calender which is really of the rubber processing type is built in China and the compounding for it is carried out on two-roll mixers. This is used for producing UPVC foil which is subsequently laminated in multi-daylight presses to produce sheet up to 2 cm thick. This represents another major production activity. The thinner sheet is used for a variety of purpose including corrugation and industrial uses. The thicker sheet is used for making up welded containers, housings for fans and pumps and the rotating blades of extractor fans which are partly welded with PVC welding rod (extruded on the premises) and partly bolted together with steel nuts and bolts. The design is oldfashioned since one would expect these structures to be made by injection moulding of engineering plastics such as nylon or glass-filled nylon, PP or glass-filled PP or acetal, but it is highly creditable that, in the absence of the large capital investment necessary to install the appropriate machinery, a functionally perfectly adequate product is being manufactured with enterprise and skill rather than do nothing and wait until sophisticated equipment (maybe) materialises. This attitude has already been noted and commented upon previously.

By way of contrast, the production of their own gravure rolls presents an altogether different story. Here the equipment is the best that can be obtained. It is of West German manufacture with the most sophisticated electronic controls. It is backed with equally sophisticated large scale photographic equipment and a highly creative design staff who produce the most excellent art work. As a result printed film is produced which is second to none in appearance anywhere in the world.

The discussion centred around technical efficiency and education. I had the impression that our hosts were well aware of the comments which figure in the preceding paragraphs which are offered by way of comment and commendation and in no way ~~as an~~ (implied) criticism . Although their operators are skilful and full of resource the training of sufficient numbers remains a problem. I thought that the handbook entitled "Kunststoffverarbeitung" by Ebeling, Luepke, Schelter & Schwarz (Vogel Verlag, Wuerzburg 1978) might be useful to them if it were translated into Chinese and therefore left them the copy in the original German that I had brought with me.

<u>2.6. The Plastics Machinery Plant.</u> (July 20, p.m.)

This was stated to be a small factory of about 300 employees which is more than 20 years old, but at least two huge machine shops are evidently of quite recent construction with a very large floor area and high roof. They have been making injection moulding machines from 30 to 1000g shot capacity but are now mainly producing extruders and 45 and 65 mm screws, as well as ancillary equipment for film blowing, for making PVC tape. They also make excellent and very well finished mixers and kneaders of 10, 100 and 200 litre capacity. Altogether they produce seven types of machines, about 400 of them annually, supplying factories throughout the country. All these machines are built to their own design. They have seven graduate engineers (design, mechanical and electrical), but also a number of assistant engineers (new graduates) , senior technicians and craftsmen of many years' experience who are highly skilled. Together with the administration they establish company policy. Production is based on a combination of a planned and a market economy. We discussed a few minor points of screw design, and the possibility of at least partial (major) adiabatic heating operation of the extruder operation; the latter seems to be precluded because the maximum speed of the screws was stated to be 125 r.p.m. We also discussed the problems of technical education, including day release and the difficulty that faces people who might be sent abroad for a technical eductaiom when it comes to learning enough English to profit from such opportunitie We briefly talked about in-country liaison through suitable publications t hat might be produced by the plastics industry (a kind of Plastics Institute on the British model) as well as the need to maintain a close watch on the technical and scientific literature published in the field abroad.

3. Summary of topics covered in the lectures/seminars.

July 21 Introduction. RHEOLOGY

Definition of Rheology. Deformation and flow. Ideal and real solids and liquids. The existence of non-typical responses - elasticity in liquids, viscous flow (creep) in solids. Solid/liquid transition in simple materials such as water and common chemicals. Solid/liquid transition (i.e. softening rather than abrupt melting) in heterogeneous materials such as plastics. Viscoelasticity. Rheology as a universal science in that it concerns itself with deformation and deformation rates of identifiable volume elements when these are subjected to a static or dynamic force field, the latter including all manner of excitations such as infrared, visible light, ultraviolet, magnetic or electrical force fields.

Newton's law and Hooke's law. A generalised flow theory capable of accounting for all experimentally observable flow behaviours (Newtonian, pseudoplastic, dilatant, Bingham, "plastic") using the generalised flow curve . The double logarithmic plot of shear stress vs. shear rate and the Power law. Dimensional differences between Young's modulus and the coefficient of viscosity. A brief mention of relaxation time. Apparent and true viscosity; apparent and true modulus. The random ground state and the shear oriented state, melt fracture (turbulence, cavitation, cessation of laminar flow) and an explanation of changes in flow regime on the basis of structural considerations. Examples of non-Newtonian systems well known in everyday life - "silly putty", sand and water, China clay suspensions, tomato ketchup, sauces, custard, toothpaste, oil well drilling muds. Evidence in favour of the Generalised flow theory - shear induced crystallinity (van der Vegt & Smit). Reference to Jearl Walker's paper in the Scientific American 1978, 239 (5), 142-149 to demonstrate anamlous flow behaviour and elastic effects, including die swell and the Weissenberg effect.

July 22.

The equations of Continuity, Energy and Momentum (derivation of the first in explicit form and of the others by analogy). The usefulness of tensor notation (compactness and general validity for all coordinate systems). The rheological equation. Other potentially relevant equations. Parallel plate drag flow of a Newtonian - the model, the simplifying assumptions, and the derivation of the velocity and temperature profiles by integration of the differential equations and the use of the stated boundary conditions. Extension of the velocity and temperature profiles to the pressure flow in a cylindrical channel to power law liquids. An alternative method for the velocity profile in cylindrical channels. The volume flow rate - derivation of the Hagen-Poiseuille equation for a general power law liquid and its reduction to the Newtonian case (the original H-P equation). Reduced velocity and temperature profiles. Calculation of the average velocity and the maximum velocity. Derivation of the equation for the true shear rate and its relationship to the Newtonian shear rate (the Rabinowitsch correction), Statement of the Rabinowitsch correction for rectangular channels. A brief discussion of the importance of wide-slit channels in profile extrusion. An example of a calculation based on temperature and velocity profiles. An exercise was set for practising the manipulation for a modified temperature profile in parallel plate drag flow through which we will run on a following day. The problem of rotating dies was raised but deferred.

July 23.

Solution of the temperature profile problem set previously. The temperature dependence of viscous flow: Proof that the viscosity change with changing temperature at constant shear rate is not identical with the viscosity change with changing temperature at constant shear stress except in the Newtonian case.The activation energies of viscous flow at constant shear rate and at constant shear stress. Derivation of an equation which enables one to predict viscosities at different temperatures but at the identical shear rate (or shear stress), provided activation energy data are available. The relationship of the power index n and the activation energies of viscous flow. Actual applications to numerical problems.

July 24.

The pressure dependence of viscous flow. Compressibility of polymer melts - bulk modulus. Free volume as a function (a) of temperature and (b) of pressure. The isoviscous condition (pressure/temperature superposition). The determination of the coefficient of viscosity change with temperature at constant pressure and of the coefficient of viscosity change with pressure at constant temperature. The significance of the determinable function $-(\Delta T/\Delta P)$ at constant viscosity and its particular importance in processes such as the injection moulding of large components where the pressures used are of the order of 10^8 Nm^{-2}. The similarity of the above function with certain thermodynamic functions which holds out a prospect of obtaining data relevant for polymer processing from fundamental thermodynamic data. A compilation of those functions.

Most of the afternoon was devoted to a discussion of observed anomalous flow behaviour in HDPE and in PP in certain temperature ranges (i.e. within about 50°C of the crystalline melting point) at certain pressures and some attempt at explaining these phenomena in molecular or rheological structural terms.

July 26.

To complete the discussion on pressure a brief description of recorded effects of hydrostatic pressure on the tensile properties of plastics in the solid state were given, referring to a paper by Pugh et al. (1971).

Viscosity and molecular weight - Introduction. A brief description of the Rouse model and the random coil theory. Zimm's modification, including Kirkwood & Riseman's ideas of hydrodynamic interaction. Williams' extension of the Zimm theory which established the proportionality of the first normal stress difference and the square of the shear rate, and the relationship of shear rate, MW and relaxation time on the basis of molecular considerations. Extension to polydisperse systems. Bueche's theory which results in the prediction of shear dependent viscosities which earlier theories did not. The extension of Bueche's theory to apply to polymer melts. Lodge's network theory for concentrated polymer solutions. Entanglement concepts. Graessley's contribution. The dependence of rheological properties on molecular parameters. Shift factor. Fox & Flory's "critical MW" criteria. The onset of non-Newtonian flow at "M_c" as a function of shear rate (Schreiber, Bagley & West). Cross' theory based upon entanglement probabilities. Discussion.

July 27.

The effect of MWD on the rheological properties. Middleman's extension of Bueche's theory to polydisperse systems. Master curves for polydispersity and and MW predictions from viscosity measurements. Viscosity/temperature shift factor and superposition. The use of Arrhenius type equations for the construction of viscosity master curves. Mendelson's experimental evidence for the superposition (LDPE over the range of 120°C to 300°C. Locati, Gargani & de Chirico's work on MWD from rheological measurements. Han & Villamizar's work on the determination of normal wall stresses, viscosity, MWD and long chain branching (LCB) as well as extrudate swelling from entrance and exit pressure losses in dies. Concordance of the results with earlier work of Middleman, Graessley & Segal, Ballman & Simon and others. A summary of Pearson & Garfield's work and reference to the work of White and the Tennessee group of rheologists on the influence of MWD on the rheological properties of PP melts. Pearson & Garfield's work.

The afternoon was largely devoted to a question-and- answer type seminar mainly relating to type of information which the Brabender Plasticorder can provide and on some unusual and apparently inconsistent results obtained with the melt flow indexer.

July 28.

The time dependence of viscous flow. Thixotropy and rheopexy. Viscometer and experimental techniques. Vortex formation. Shear acceleration. Superimposed memory (elastic)effects. Application and uses of thixotropic materials (PVC pastes, dispersion paints, thixotropic agents for glass reinforced polyester wet layups). "Hyperrheopexy" (rheopexy with exaggerated elastic memory effect).

The afternoon was again devoted to discussion, this time on moulding problems, mainly on ways of minimising distortion after demoulding and minimising the amount of residual stresses, including sensible mould design, material selection, temperature control, cycle times and annealing procedures. Equilibration in the case of Nylon 66.

July 29.

Simple flow problems of die design - statement of the common problems; isovels; unidirectional and twodirectional flow; die swell effects; the wide-slit approximation and its importance in profile extrusion; the application of the power law to die design and process variables establishment. Calculation of effective slit widths in a number of typical profiles. Entrance corrections.

The whole of the afternoon was spent working through numerical examples of the application of rheology to die design problems, with the listeners being invited to attempt the solution prior to being shown how.

July 30.

Completion of problem solving. Shear viscous flow in converging channels. Wide slit channels with (i) horizontal, (ii) vertical, (iii) simultaneous horizontal and vertical tapers with (a) variable W/H ratio and (b) constant W/H ratio. Rectangular channels in general, without the restriction that the W/H ratio must be large, i.e., the general case covering channels from a square to a wide slit. Circular channels with taper(truncated cones). About half the afternoon was devoted to questions and discussion such as the possible causes for slight differences in the flow curves of various PP's and for the observed discontinuity in the temperature/shear stress curve for PP in the low shear rate region at temperatures not too far above the crystalline melting point. It was possible to indicate the probable or possible explanation of these phenomena on the basis of molecular and morphological parameters such as MWD and shear-induced crystallinity (vide Cogswell and Vander Vegt & Smit). The afternoon was concluded with a brief committee-style discussion on progress so far in which satisfaction was expressed as to the coverage and technique employed.

July 31.

Derivation of the approximated Rabinowitsch correction for flow in regular polygonal channels. The balance of forces and the use of the Rabinowitsch-corrected shear rate, together with the Power law, for obtaining the appropriate flow equation in parallel-sided channels. Checking the equation by (i) setting the number of sides in the polygon to infinity, and (ii) for the Newtonian case. Extension of the equation to tapering polygonal dies by the technique which had already been established earlier on (q.v.). Estimated errors in the approximation when the number of sides is small, i.e. triangle and square. The reduction of the error to negligible levels as the power index attains levels commonly associated with polymer melts under normal processing conditions, i.e. about $\frac{1}{3}$.

Discussion and review.

August 2.

Flow in elliptical channels - the rectangular approximation. This was treated on lines analogous to the circular approximation for polygonal dies and adapted to both parallel-sided and converging channels. The potential practical use for certain applications of elliptical rods for pressure gasketing and for welding rod was indicated.

The development of the idea of "swan-necked" dies with the aim of optimising the flow was described. Some advanced die design concepts based on rotating mandrels were broached, with particular emphasis on the analytical problems involved in combining pressure flow and drag flow. Advantages of rotating dies for the extrusion of chopped-fibre reinforced polymer melts. Orientation of the fibres and, by implication, of the molecules. The improvement of the strength of the weld which arises following recombination of the divided melt streams following passage past the spider legs. Some analogies with continuous monofilament winding with polyester resin impregnation for pipes and vessels requiring a high hoop strength. The optimum winding angle (and, by analogy, the optimum angular velocity of the rotating mandrel in extrusion) for isometric strength.

The discussion involved questions on the extrusion of profiles which functionally tend to replace corrugated paper board, on details about the treatment of swan-necked dies (referred to the original paper), "coat-hanger" and "inverted fishtail" dies and their uses. This was the opportunity for a brief discourse on adjustible die lips and "bead"formation, paper coating and extrusion calendering.

August 3.

Summary of all the flow equations for parallel and tapered dies of the various cross-sectional shapes derived earlier on.
Numerous examples of actual calculations based upon real or simulated design data.

Part of the afternoon was devoted to a brief sketch on the history of rheology, the British Society of Rheology with its associated groups in India, Australia, and its cordial relationship with other European Rheological Societies (France, Germany, Italy, Holland, Austria, etc.), Rheology Abstracts , major textbooks on Polymer Rheology and the most important journals in the field.

I expressed the view that the acquisition of two video tapes on Rheology, one by Prof. Walters (Univ. Coll. of Wales, Aberystwyth) and the other by Prof. White (Univ. of Tennessee, Knoxville) would be an invaluable educational aid for the Polymer Centre and elsewhere in Beijing.

August 4.

Processing of plastics a review. Principles of processing and definition of terms such as homogenisation, forming, gelation, compounding. Homogenisation and the degree of mixing. Statistically random mixing. Pressure/volume/temperature relationships. A summary of processes used for plastics: Mixing, compounding, granulation, shaping by the various methods such as compression and transfer moulding, injection moulding, extrusion, blow mouldin calendering, casting and spreading, sheet forming, welding and cementing, machining. Factors involved in these which are of a fundamental physical or chemical nature. Mixing problems with diverse additives. Mixing and compounding equipment. Sprues, runners and gates. Prevention of sink marks and voids. Extrudate handling equipment. Output and power requirements in screw extruders. Problems in calendering. Casting, coating, laminating, vacuum forming and difficulties such as thickness control and "finning". Methods of cementin

The screw pump. Identification of screw parameters. An introduction was provided for the development and the analysis of the screw pump which will be the subject of treatment on the following day.

August 5.

Screw extrusion. Its importance in polymer processing, principally of thermoplastics. The geometrical parameters of the screw pump. Statement of the principal problems: calculation of flow rate and discharge temperature based upon the physical properties of the fluid, the screw geometry and the operating conditions. Drag flow and pressure flow, their individual and combined significance for the operation of the screw pump. Parallel plate representation of the screw channel. The hydrodynamic analysis of screw pumps. Differential equations for flow and power in the Newtonian case and an indication of how this would have to be adapted to accommodate (i) non-Newtonian fluids and (ii) viscosity changes due to changes in the temperature of the fluid as it passes through the screw pump. Leakage flow. Isothermal and adiabatic screw pump operation.

Plasticating extruders. Division of the screw into identifiable zones for the conveyance of solid particles, for melting and for pumping. Conditions for stability and achieving good extrudate quality.

Solids transport (zone 1): Motion of an "elastic plug" in the screw channel: speed of plug advancement down-channel, the frictional forces acting on the plug, shape factors for drag flow and pressure flow and limiting cases, the balance of forces which act on the plug from screw and barrel surfaces and the use of their ratio for predicting the plug velocity; limiting conditions for the speed of the plug; the relationship between drag flow/pressure flow ratio and the helix angle. Equations for the optimisation of the helix angle and the appropriat[illegible]s transport rate.

August 6.

Continuation of the consideration of plasticating extrusion screws. The melting zone (zone 2). Mechanisms of melting (heat transfer and conversion of mechanical energy into heat by shear deformation of the material itself). Factors limiting either mechanism. Advantages of "adiabatic" operation. The transition from the melting zone to the metering zone. Screw length apportionment for the three zones. Heat transfer when scaling up. The phenomenology of the melting process. Power input and limits on the extruder capacity. Modifications for adiabatic operation, including provision for screw heating (and possibly cooling). Performance characteristics.

Pressurisation in the screw pump. Velocity and shear rate profiles. A worked example for a typical case where the Newtonian approximation can be justified. Adaptation to power law fluids.

The evolution of the modern extruder screw from basic concepts and models: Channel and plate, channel within a hollow revolving cylinder, the helically curved channel, the channel carved out of a solid cylinder. Description of the manifold additional advantages available from a rotating screw withing a stationary barrel.

Discussion of the principles and design problems for extrusion screws. I put forward some ideas for the practical demonstration of the existence of the three distinct screw zones by extracting the screw and its contents from the barrel after attaining steady state operation and cooling, using variations in the speed of rotation, barrel temperature, material grades and types (e.g. LDPE, LLDPE, PP and olefine copolymers), followed by variations in the type of screw used. The Brabender extruder could conceivably be adapted to this, although rapid cooling is a problem there. Unfortunately there was no opportunity of using a small experimental single screw extruder at the Polymer Research Institute or the Plastics Machine Factory for this type of experiment at the time.

August 7.

Since no screw extractor tool or suitable die for the Brabender was available to carry out the experimental work suggested above a small extruder was found and made available at the campus. Unfortunately it turned out that the pressure gauge and the heating controls were not working and that the screw could not be extracted at the time. We therefore discussed a workable programme to demonstrate the action of a plasticating screw and this took up most of the available time.

August 9.

Starting with a summary of the coverage on flow in extruder screws the analysis of flow was extended from the uniaxial Newtonian flow model to a model which treats the flow as biaxial and which applies to Newtonian fluids. Screw/die interaction. Frictional effects due to metal/melt interaction, including the effects of temperature, pressure, flow rate, molecular weight, particle size of the feed, particle shape and additives.

Coextrusion. Its potential for practical application: Film and sheet for packaging, sheet for vacuum forming, wire and cable coating, profile and tubing, fibre and monofilament. Advantages obtainable by coextrusion. Equipment - feedblocks and multi-manifold internal and external combining dies; their suitability for specific purposes. Example of a parison forming die with three different and separate extruder feeds, accumulators and hydraulically operated ring pistons. Conjugate fibres and monofilament. The pressure gradient reduction factor and other viscosity considerations, interface changes and viscosity crossover as a result of altering the shear stress and the coextrusion temperature.

The discussion session was brief because of lack of time and was adjourned until the following morning.

August 10.

The keen interest in coextrusion indicated that a modification of the original intentions regarding the day's work was desirable. I therefore asked several of the accomplished "artists" among the engineers to reproduce some elaborate sketches of coextrusion dies for the production of blown and chill roll cast film on the blackboard which were then described more fully. Multi-microlayer film production using rotating die systems and feedblocks. Coextrusion as a new method of obtaining fibrillation reinforcement of fibres.

Polymer selection for coextrusion. Adhesion problems in polymer coextrusion. "Glue" layers. Applications of coextrusion, especially in packaging, (film and sheet), exploiting such features as heat sealability, barrier properties, modification of tough/brittle behaviour, increasing strength and ductility. Scrap rework possibilities and problems. Some thoughts on the tremendous scope for design advances, with mention of a recently available spiderless coextrusion die developed in the U.K. (Durapipe Ltd.), and exciting application possibilities for new products in a number of fields. The perusal of the 2-volume "Polymer Blends" (Newman & Paul, eds.) was ighly recommended.

August 11.

Flow analysis of multi-layer coextrusion for non-Newtonians. Discussion on coextrusion.

The rheology of wire coating. Introduction. The (Newtonian) model of McKelvey. The treatment of Fenner & Williams (non-Newtonian). The treatment of Han & Rao which incorporates the mutual interaction of drag flow and pressure flow.

August 12.

Conclusion of Han & Rao's treatment, with results and comments. Endo's treatment of the problem which brings it into the realm of high-speed operation and which involves three constitutive equations. Discussion of wire coating, in the light of the results obtained in both Han & Rao's and Endo's treatments. An extensive list of references was provided.

The rheology of extrusion blow moulding. Description of the process. Affinities with profile extrusion, injection moulding and thermoforming. The importance of extrusion blow moulding, especially for the production of bottles and hollow containers, with a minimum of material wastage and at a good production rate. An approach to modelling of the process, omitting the initial stage of the supply of homogeneous melt material to the "accumulator" by a plasticating screw extruder. The outline model of Cogswell, Maskell, Rice, Webb & Weeks. The rate of volume displacement by the accumulator ram (piston), including bulk compression; description of typical crosshead dies for the production of the parison, including the"variator", noting convergen in the die channel. Pressure drop due to extensional flow. Inertial effects ("bounce") and calculation of the "bounce and recovery" length.

August 13.

The sequences of events during the parison inflation stage. Comments on the inflation stage. The improvement of circumferential uniformity for non-cylindrical mouldings. The use of profiled dies and dies with non-uniform lengths (recent work by Worth & Wilson at UMIST). Among the references give was also some work by Petrie and Ito on the prediction of the wall thicknes of blow moulded containers.

During the afternoon a number of questions were set for individual worki and/or discussion. (See Appendix 3).

August 16.

The morning was devoted to a consideration of laminar mixing. An expression for the increase in mixedness as a result of some arbitrary deformation of the material was given which is a function of the principal values of the strain tensor and the orientation of the fluid. Mixing was considered in pure shear, simple shear and pure elongation. The rate of mixing in steady flow was considered in each. It is pointed out that the high viscosity of polymer melts makes turbulent mixing impossible, so that mixing has to be achieved in laminar flow. The treatment was based on Erwin's analysis for Newtonians in threedimensional flow. Applications start with the area changes in the surfaces of the components and a consideration of (i) plane strain deformation (e.g. uniaxial stretching of sheet with constrained sides), (ii) pure elongation (as in a tensile test) and simple shear (as in Couette flow). The rate of mixing was compared to energy consumption for uniaxial and biaxial extensional flow, uniform steady pure shear and simple shear for a typical viscosity of the order of 10^4 Nsm^{-2} and an arbitrary degree of mixedness. It was seen that biaxial extensional flow gives the lowest energy consumption and that simple shear is extremely inefficient in this respect. The discussion involved statements about the following facts: (i) Viscosity reduction, whether due to non-Newtonian behaviour, or the heat generated during the process present formidable obstacles to a rigorous analysis and (ii) that time-dependent effects such as thixotropic behaviour constitute even more severe problems.

During the afternoon the subject of Rheology in Injection Moulding was introduced. A list of relevant pressure drop equations was drawn up for flow in the various channels between the screw (acting as a piston) and the mould entrance, allowance being made for pressure losses due to extensional flow and friction between piston and barrel wall. The problem of non-isothermal and discontinuous flow in the mould was overcome by means of the concepts of a freeze-off layer of constant thickness and by "magnification in time". A simple diagram of injection pressure vs. volume flow during mould filling and the practical implications thereof from the moulder's and the user's point of view.

August 17.

Injection moulding (continued). Practical calculations for mould filling. Entrance pressure/log volume output diagram and its significance. Analysis of the mould filling process. Freeze-off thickness, its dependence on mould filling time, thermal diffusivity of the melt and the temperatures of the mould, the melt and the freeze-off temperature of the material. Calculation of the pressure drop in spreading disc flow, the minimum moulding pressure and the minimum clamping force. The mouldability index for polymer melts. Shape factors. Feasibility diagrams for mould filling. The rheological limitations imposed by the maximum flow ratio and the maximum clamping pressure, as obtained for materials of different mouldability indices but having the same power index. Spiral flow moulds; the significance of spiral flow length vs. temperature curves for various polymers. Experimental determination of freeze-off thickness. General review and discussion of the injection moulding process.

August 18.

The rheology of calendering. Similarities to extrusion. Statement of the analytical problems. The analysis of calendering, assuming Newtonian flow and a simplified flow model based on Gaskell's work. Pressure profiles and reduced pressure profiles in the flow channel.

Since this is a process which, despite the same treatment, in principle, as that applicable to die flow in extrusion, presents some manipulative complexity, it was considered wise to leave its continuation until the next day and to devote the afternoon session to a review of the process of rotational moulding and related processes such as dip coating, sinter moulding and fluidised bed (powder) coating.

Rotational moulding. Description of the process. PVC pastes and typical formulations. Moulding defects, the problem of heat transfer, mould design limitations, tolerances compared to those obtainable in other processes. Advantages (e.g. the ability to produce closed or nearly closed hollow objects, economy in mould and machine costs, especially for prototype work). The use of PE and other powdered polymers. Undercuts and stiffening ribs. Double wall constructions. The possibility of using materials of higher MFI than in extrusion blow moulding. The role of rheology in the evaluation of PVC pastes. Summary on rotational moulding and related processes.

August 19.

Resumption of the rheology of calendering. Analysis of velocity profiles: Two places along the x-axis where the profile is flat, between them it is convex while further upstream it is concave; the stagnation point (point of zero flow along the plane of symmetry); backward (i.e. circulating) flow developing quantitatively upstream from the stagnation point.

The shear rate as a function of both the x- and y-direction.

Expressions for the power required to drive the rolls and for the hydrostatic pressure generated which exerts a thrust tending to separate the rolls. Solution of a numerical prototype example to illustrate the use of the derived equations.

Extension of the hydrodynamic analysis of calendering to non-Newtonians. Comparison of the results of the equations thus derived using a similar numerical prototype to the Newtonian case above, but applying to a power law fluid.

August 20.

Summary on the flow analysis of the calendering process ("Calendering without tears") and discussion.

Introduction to elastic effects in capillary flow and melt fracture. The significance of residence time in the die. The die inlet region as the locus of primary flow disturbance. Die entry taper angles. The effects of pressure (i.e., shear rate, shear stress and volume output rate), temperature, and material properties, notably elasticity in addition to viscosity, as well as MW and MWD. Relaxation time as a function of free volume. Effect of additives. The proneness to flow disturbance (in increasing order) from compression moulding and milling through calendering, extrusion to injection moulding. The various parameters which make the occurrence of melt fracture more (or less) likely in profile extrusion, wire coating, extrusion blow moulding, tubular and chill-roll-cast film extrusion, and in injection moulding. The conflicting requirements of production efficiency and product quality; the necessity of compromise. Surface mattness, sharkskin and orange peel, bambooing and corkscrewing as secondary flow disturbances. Slip-stick effects and the underlying dynamic (sinusoidal) defects in extrusion which are damped out in steady state stable extrusion. The work of Tordella, Merz, Kircher & Hamilton, Schreiber & Bagley, Corey & West, and the flow visualisation experiments of Clegg. Phillippoff's work on disentanglement by filtration of solutions and the consequent loss of elastic effects such as die swell. Mieras' work on the correlation of elasticity and die swell. Critical entanglement lengths. Molecular weight fractionation on the die wall and its lubrication effect which tends to eliminate slip-stick effects.

August 21.

Melt fracture and melt elasticity (continued). Direct evidence for the existence of discontinuities, in addition to Cleggs work: Galt & Maxwell, Van der Vegt & Smit. The largely satisfactory explanation of both primary and secondary elastic and viscous responses of viscoelastic fluids in die flow under pressure and take-off forces (if any) developed by Cogswell & Lamb. Further extension thereof and the inclusion of "draw resonance" in fibre spinning. The mass/accelerational effect - the underlying dynamic situation in all extrusion based processes.

August 23.

Melt fracture and melt elasticity (continued). Melt flow instabilities as encountered in polymer processing. Further consideration of melt fracture and "draw resonance" in the extrusion of fibre, sheet and blown film. Flow in the upstream reservoir. Pressure fluctuations at various axial positions at different shear rates, dies with different L/D ratios and with different temperatures, and the implications for the occurrence of melt fracture. The recoverable elastic strain and the relationship between the first normal stress difference and shear stress. Its significance for the critical conditions for melt fracture. Some currently popular ideas on draw resonance and on whether it is related to melt fracture (as I believe, and many others do not !). Recoverable elastic strain as a function of temperature. Flow instability in the film blowing process.

Implications of extensional flow in polymer processing; (uniaxial, biaxial and pure shear extensional flows) and their deformation tensors. Extensional flow into a mould cavity. Extensional flow of a cylindrical parison in blow moulding. The influence of various deformation histories on the extensional properties of molten LDPE. Attempts at correlating melt extensibility and the force required for draw-down. The determination of the strength of polymer melts in tension (polyolefines, PMMA, PS). Possible analysis of vacuum forming on the basis of extensional viscosity. The proposed use of a power law for relating stress to the extensional strain rate. The implications of extensional flow and melt elasticity as well as melt strength for extrusion coating and vacuum forming operations.

August 24.

Solid state - large deformations. The strength of plastics. Tough and brittle failure. Definitions and criteria: Stress at yield and at break (i.e. strength at yield and at break), strain at yield and at break, energy to yield and break, stiffness (i.e. initial modulus). Comparison of tensile and flexural tests. The concept of "severity of test" which can be varied by changes in temperature, straining rate, the type of applied stress, the geometry of the specimen, specimen preparation, etc. Stress/strain curves. Conventional stress and true stress, apparent modulus and true modulus. The seven parameters of a fully developed stress/strain curve. Tough/brittle transitions.

The effect of temperature changes on stress/strain curves.

The effect of changes in straining rate on stress strain curves.

Impact tests and their limitations. Time/temperature superposition as a tool for predicting impact behaviour from "slow" tests at correspondingly low temperatures.

August 25.

During the morning the normal pattern of the seminar was suspended in order to substitute for it a talk on the development and scope of the science and application of rheology in Britain, the continent of Europe, the USA and Japan. This was followed by an account by Dr. Yuan-Tse Hsu who had just returned from Prof. Menges' institute in Aachen where he wrote his doctoral thesis under Prof. Schuemmer. It was felt that this was a most worthwhile exercise in that it underlined the central significance of rheology in science and technology and emphasised the need for a determined effort to widen and intensify the activities in this field in China.

During the afternoon the discourse on tough and brittle failure was resumed: The effect of notches. Modification of the stress system by notching. The ration of tension to shear as a criterion of severity. Triaxial tension in an incompressible solid producing brittle fracture whatever the material, even if it is a rubber (theoretical experiment). The way in which notching increases the triaxial tension fraction in a notched specimen and so causes embrittlement in an otherwise (just) tough material. Severity of notching. Shock brittleness. Crack initiation and crack propagation energies. The scope and limitations of impact tests. The unifying principle of relaxation time. Summary.

THIS MARKED THE END OF THE LECTURES ON RHEOLOGY.

August 26.

APPLICATIONS OF PLASTICS.

Material selection, materials classification and the place of plastics among the materials. The discovery and exploitation of new material resources and the technological changes resulting therefrom which, at each step, in turn brings about tremendous changes in the lifestyle of man. The accelerating rate of this development and the problems which this presents (finite fossil resources, psychological disorientation, etc.) Plastics as the most recent class of materials and their effect in the light of the above. Seven classes of materials of which plastics are but one class. The general properties of each of these classes. Material selection: Why use a plastic for any specific purpose? In the event of a convincing answer - which plastic? Weighting factors. What method of processing? How are properties affected by processing? What (if any) after treatment and finishing is necessary? What production hazards? Environmental problems? Commercial and financial considerations before launching a product? Is a combination of materials possible and/or desirable? What previous experience with the same or similar functional components? Any glaring misapplications from which a lesson should be learned?

Plastics in Building.

Criteria for suitability. Classification of components into a number of systems. The plastics in widespread use in the building industry. Advantages of plastics vs traditional materials (where such exist). Plastics in connection with foundations, concreting and flooring. Plastics in "services": Water supply and distribution; cisterns and tanks; surface water removal (gutters and downpipe); waste water removal, sewerage and stackpipes; gas supply; heating and ventilation; conduit and electrical fittings. What makes plastics of interest to builders and architects?

August 27.

Plastics in Building (continued). Sanitary ware (baths, sinks, washbasins, urinals, drinking fountains, etc.). The superior properties of acrylic sheet for thermoforming these structures. Taps (tops and bodies), toilet seats (UF thermoset mouldings, but also PMMA and PP). Walls - internal and external: Curtain walling, infill panels and cladding; safety requirements in fire. Flame retardant modified resin and flame retardation additives. Sandwich structures. Internal walls, partititions (incl. demountable partitions), doors and windows. False ceilings and ceiling lighting systems.

The afternoon was entirely devoted to a long session of discussing and describing various building elements, their structure, design and fabrication, questions on formulations and problems in connection with the extrusion of precise profiles and on many other specific items. Dome and roof structures, folded plate structures and similar architectural developments. This was based on a wealth of brochures and cuttings which were freely circulating in the audience who were then asking relevant questions. This material remained available to the audience throughout the evening if they cared to take advantage of this. A number of addresses of firms and corporate bodies, mainly in the U.K., the U.S.A and in West Germany were given who can supply precise details on such matters as, for example, the design of PVC window frames and glazing systems. The latter is a subject of particular interest in China at present. This is also true for PVC rainwater goods and sewage stackpipes and fittings.

August 28.

Plastics in Packaging. Historical. Packaging as a fairly new branch of industry. Traditional materials, incl. paper, metal and glass, ceramics and wood. The impact of plastics. New forms of marketing based upon prepackaging, especially of foodstuffs, liquids and powders, cosmetics and pharmaceuticals. Classification into unsupported and laminated flexible film and coatings; semirigid containers; rigid containers; closures; large bulk containers and "containerisation".

Flexible packaging materials: the polyolefines, EVA, $PVCl_2$, PVC, nylon film, combinations by copolymerisation, coatings, hotmelt and extrusion lamination and dispersion coating involving various substrates such as paper, cellophane, Al foil, board and other plastics, coextruded film. The required properties and the performance of various materials. Cost, relative importance of various polymers in packaging. Barrier and heatseal properties, printability. "Under-" and "overpackaging".

Small moulded containers. Replacement of glass beakers, pottery dishes, paste containers, ointment jars, etc. Replacement or partial replacement of metal cans and the use of polymeric coatings where the former are retained. Injection moulded containers (PE), e.g. for ice cream, soft cheeses, yoghurt. Nesting egg trays and boxes, vacuum formed layer dividers (PS or expanded PS) for soft and hard fruit, base trays (expanded PS) for all kinds of food items, followed by a cling film overwrap with EVA. Toothpaste and fish paste collapsible tubes, pillow packs for shampoos and cosmetic creams,"tins" for shoe polishes, small bottles, vials and tubes for pills (polyolefines, PS, PC), including blow mouldings, blister and vacuum packs.

Bottles and other containers for liquids, granular products and powders. Comparison with glass and metal. Milk bottles. Coated cartons, blow mouldings, coextruded bottles, sheet bottles, injection-blowmoulded bottles (PET) for carbonated drinks, "single trip" containers. PVC bottles and cans. Small aerosol containers.

Some consumption statistics of plastics within the packaging industry, breakdown of specific applications within the field, correlation of the extent of supermarket shopping and per capita consumption of plastics in packaging in a number of European countries, the former mainly in the U.K.

August 30.

Drums, kegs, bulk containers. Conventional materials with plastics liners. Injection moulded, rotationally cast, sinter moulded and GRP containers, incl. spirally wound monofilament bottles for pressurisation. Spirally and cylindrically wound laminated paper drums (fibre drums) with a coating layer such as bitumen or hotmelt polymeric adhesive to act as a barrier. Containers for bulk storage and tanker trucks and rail cars.

Devices for the mechanical and thermal protection for goods in transit. Expanded plastics: Cushioning, space filling, squaring off, load spreaders, heat insulation. The various types of packaging foams (PE, PS, PU).

Crates, pallets, tote boxes. Collapsible crates (flat stacking on return).

Closures. Screw tops, press lid, snap closures, shrink film tops.

Gathering and bundling devices: String, monofilament, netting, tape, strips of film (cold drawn).

Summary, review and discussion, with questions.

August 31.

Plastics in Agriculture and Horticulture.

Historical. Planned food production superseding hunting and gathering. Technological developments as a result of the industrial revolution and the emergence of new materials, notably plastics. Control over the environment.

Growing aids. PE film and acrylic sheet for hothouses, "tunnels", mulches. Light exclusion sheet for controlled ripening/flowering. Water and CO_2 as well as warm air supply with plastics pipe and layflat film. Pots, seed trays, growing boxes, watering troughs, irrigation equipment.

Disease and pest control. Barrier film and thermal insulation to prevent loss of fumigants and excessive steam condensation. Spray equipment: pressure containers, handles, nozzles, connections (PP,PVC), housings for pumps (various engineering plastics). Netting to protect orchards against bird depredations.

Water management. Reservoir construction and storage tanks. Distribution piping to irrigation points and cattle drinking troughs. Drainage. Evaporation control. PE, PVC and butyl rubber sheet for liners. "Mole ploughing" for laying pipes. Slotted drainage pipes. Moulded floating spheres to prevent evaporation and coverage of these by netting to prevent their blowing away.

Fertiliser management. Solids and liquids in individual and bulk containers. Compost and manure. Fertiliser application equipment (engineering plastics).

Crop conservation. Grain stores and storage for tropical products: humidity control, pest barriers. Pillow packs, pneumatic silos. Accelerated ripening in (e.g.) banana storehouses; "clamping" of potatoes and other root crops. Silage and rick construction.

Livestock rearing. Egg production, poultry rearing,(batteries and hatcheries), piggeries and stabling, temporary cattle shelters in the field. Transportation of live poultry.

Produce collection and transportation. Butts, crates, tote boxes, netting. Long distance transportation of lettuce and the like.

Tools and machinery. Gardening tools, hover mowers, tool handles, guards,nets. Pumps and housings in engineering plastics.

Buildings and Construction. Urbanisation of food production - the Ruthner tower

Soil stabilisation. Examples: the "planting" of PP tufts to encourage the growth of coarse grass in sandy coastal areas and the prevention of "saltation" (i.e. the shifting of desert sands) using UF resin solutions to"make the desert bloom" (Ayrshire coast of Scotland and Negev desert in Israel respectively).

September 1.

Plastics in Agriculture (continued). Illustrated comments and discussion. Photodegradable film for temporary and precisely planned crop protection and growing without subsequent litter pollution of the terrain.

Plastics in Road Transport. (by special request).

Plastics in bodywork; in engine and transmission systems; for secondary mechanical functions; in electrical systems; for sound and vibration damping; for fuel systems; for air conditioning, safety devices and interior trim; for exterior finish and corrosion protection. The economics and growth of plastics uses in the automotive industry. The need for weight saving and fuel economy. Industrial and commercial vehicles, personnel transport and bulk delivery systems. Private cars. A list of components made in a variety of plastics. Recent developments (battery cases, fuel pipes, petrol tanks, bumpers and other reaction moulded structures, grilles, steering columns, wheel hubs, propeller shafts and chassis), using specialised engineering plastics. Springs and lubrication systems, the former with carbon fibre reinforcement. Summary.

September 2.

Plastics in Household Durables. (by special request).

A review of the range of gadgets such as:

Simple accessories; electrically operated cleaning equipment; water softeners; refrigerators and freezers; fans and ventilators; electrically operated food processing equipment; gadgets for personal hygenie and comfort; audiovisual equipment; optical and photographic equipment; telephones; gardening equipment and tools; miscellaneous items such as typewriters, watches, clocks and instruments. The various polymers used. Summary.

September 3.

The plating of plastics. (by special request).

An extended review of metallisation by electrodeposition and vacuum deposition, electrode and molten powder spray methods. Suitability criteria, problems such as "outgassing", the detailed preparation of the substrate and the types of metals used. Application of the products.

September 4.

In the morning Prof. Laurence very kindly agreed to give an illustrated talk about the polymer research done in the plastics and chemical engineering departments of the University of Massachusetts (Amherst).

In the afternoon, by special request:

Plastics in Medicine and Surgery: Uses based on specified materials: PVC, LDPE, HDPE, PP, EVA, acrylics, silicones, nylon, PTFE, acetal polymers, mouldable thermoplastic polyesters and PU, GRP, PS.

Prostheses, surgical aids, instruments and techniques and how these have been affected by the availability of an entirely new range of materials when plastics came on the scene. Machines (heart/lung and kidney machines). Organ replacements (ear ossicles, tear ducts, heart valves, pacemakers, hip joints, hinged finger joints, etc.). Tubes, catheters, airways. Diagnostic aids such as fibre optical equipment and associated tubing, cannulae. Contact lenses. Restorations of the face. Disposable membranes. Sterilisation and toxicity problems. Summary.

Postscript. Future Plastics Developments: A personal view.

(This concluded the formal lectures on plastics applications)

September 6: This day was devoted to an introduction by special request to the concept of "critical strain". This is defined as the strain which causes sub-microscopic but irreversible structural damage which ultimately results in the long term failure of components. Pohrt's work on the prediction of long term in-service performance. Stress corrosive media and simple standardized mechanical tests using the ball impression method and their value, additionally, in the optimization of the processing of plastics.

September 7: Discussion and exchange of ideas on future activities at the Centre.

September 8: Visit to the chemical laboratories of the Chinese Academy of Sciences. This was followed by a lecture on the rheology of shear-viscons non-Newtonian flow in tapering dies, and a discussion.

September 9: Review and evaluation of the mission at the Centre.

September 10: Finalization and preparation of copies of this report.

September 11: Preparation for departure early on the following day.

4. RECOMMENDATIONS.

1. I suggest that access to the wellknown textbooks and monographs on rheology and the processing of polymers is the most urgent requirement and indeed a precondition for the rapid development of plastics technology in China. This means that copies should be available in every university and college as well as in every research and development establishment which teaches or is otherwise germane to the plastics industry. Some of the books should also be available for the perusal of technical staff in plastics processing and plastics machinery production factories and in engineering design establishments.
Herewith a list (by no means exhaustive) of recommended titles:

E.C. Bernhardt (editor), "Processing of Thermoplastics", Van Nostrand - Reinhold, 1959.
F.R. Eirich (editor), "Rheology" (all volumes), Acad. Press, around 1960.
R.B. Bird, W.E. Stewart & E.N. Lightfoot, "Transport Phenomena", Wiley, 1960.
J.M. McKelvey, "Polymer Processing", Wiley, 1960.
J.R.A. Pearson, "Mechanical Principles of Polymer Processing", Pergamon Press, 1966.
G. Schenkel, "Plastics Extrusion Technology and Theory", Iliffe, 1966.
Z. Tadmor & C.G. Gogos, "Principles of Polymer Processing", about 1972.
Z. Tadmor & I. Klein, "Engineering Principles of Plasticating Extrusion", Van Nostrand - Reinhold, 1970.
C.D. Han, "Rheology in Polymer Processing", Acad. Press, 1976.
R.S. Lenk, "Polymer Rheology", Applied Science Publishers, 1978.
S. Haenle, B. Gnauck & G. Harsch, "Praktikum der Kunststofftechnik", Carl Hanser Verlag, Munich, 1972. (In German).
Newman & Paul (editors), "Polymer Blends", Academic Press, 1978.
All the volumes in the ongoing series entitled "Developments in ....." (e.g. extrusion, etc.) published or in the process of being published by Applied Science Publishers.
The excellent "Kurz-und-buendig" series ("Kamprath Reihe") on polymers published by Vogel Verlag, Wuerzburg in the 1970's, (in German).

2. In addition to the above a number of international journals should also be available, such as:
J. of Polymer Sci. and J. of Appl. Polymer Sci., (all editions), "Polymer", "Macromolecules", J. of non-Newtonian Flow, Plastics & Rubber International, J. of Polymer Engineering & Sci., Ind. Eng. Chem., Ind. Eng. Chem. Fundamentals, Am. Ind. Chem. Eng. J., European Polymer J., Rheologica Acta, Kolloid-Z., "Kunststoffe", etc.

3. Consideration should be given to the setting up of a Chinese Society of Rheology similar to the ones which exist in the U.K. (the British Society of Rheology), the U.S.A., Japan, the Netherlands, France, Italy, Germany and elsewhere. Association with the British Society exists in the case of India and Australia and overseas individual membership offers considerable advantages, including the right to receive "Rheology Abstracts", a world-wide review of publications in the field, quarterly and free of charge for personal use only, in consideration of the very low membership fee payable annually. This is published by Pergamon Press under the aegis of the B.R.S.

4. The continued provision of both technical expertise and specialised research and testing equipment is, of course, of abiding importance, second only to the preceding items. Thus it is essential to provide the mixing chambers and kneaders for the Brabender Plasticorder at the Plastics Processing and Applications Centre. There should also be provision for a good rotational cone-plate viscometer such as the Ferranti-Shirley instrument which has a continuously variable and wide range of shear rates as well as accurate temperature control and elctronic recording facilities. An instrument for the measurement of normal stress differences (Weissenberg Rheogoniometer or Rheometrics instrument)mcapable of working over a wide temperature range is also most important. The latter two instruments are not cheap, probably around £15000 and between £30000 and £100000 respectively, depending on the amount and sophistication of the accompanying hardware. An instrument for measuring extensional viscosities is probably a much cheaper proposition. There are such instruments available, for instance Toyo Seiki Seisaku-Sho of Japan were making one at one time and may still do so, Sangamo Research Ltd. (U.K.) are said to have an instrument on offer and advice on these instruments can probably be obtained from Prof. Walters of Aberystwyth. Another device which may not be too expensive and highly desirable would be a pressurised Couette-Hatschek type rotational viscometer for the study of polymer melts under pressure at variable temperatures. Advice on this may be obtained from Mr. Cogswell of I.C.I. Plastics Division, Welwyn Garden City, Herts., U.K. The expensive normal force instruments one could expect to be installed by the manufacturers who would also commission them and train operatives, either at their home base or in the country of installation. They would probably be best sited at the laboratories of the Academy of Sciences and should be operated by authorised suitably trained technicians under the supervision of a senior scientist.

5. In addition to the continuing hoped-for assistance on the part of UNDP in sponsoring and helping to finance students in various countries, the British Council may be able to help in placing polymer physicist, chemical engineers and engineers in centres of advanced research and technological excellence such as the following, provided that the candidates have a good command of the English language:

   Imperial Sollege of Science & Technology, London (Prof. Rowe, Prof. Williams);

   Cambridge University (Prof. Pearson);
   University of Wales (Aberystwyth, Prof. Walters);
   University of Glasgow (Prof. Ferguson);
   Queen Mary College, London, (Prof. Allen);
   University of Manchester Institute of Science & Technology;
   University of Newcastle-upon-Tyne (Prof. Petrie);
   University of Technology, Loughborough.

   There are also some excellent institutes for polymer studies at all levels, such as the London School of Polymer Technology at the Polytechnic of North London, Holloway Road and the Brunel University in West London (Mddx).

6. The coverage of standard specifications for plastics materials and products is extensive but not yet complete in China, as far as I am informed. This should be attended to and the people concerned are aware of this fact.

7. It may be considered appropriate that this mission be followed up by a similar visit of an expert on plastics mould and machinery design and an expert in the field of the mathematical modelling of engineering processes.

5. SUMMARY AND CONCLUSIONS.

1. This mission entailed a lecturing assignment of 5 hours per day 6 days per week, with translation, for an almost solid 8 weeks, including 1 day at the Academy of Sciences, in addition to a 1 week period of visiting plastics machinery and processing plants in Beijing.

2. It is believed that the mission was successful, to judge by the comments and untiring attention of the audience, whose good humour, enthusiasm and friendliness was remarkable.

2. This was due to the help given by the director of the Centre and his deputy, the excellent cooperation of the moderator of the proceedings, but most of all to the linguistic and technical competence of the several translators on whose cheerful and unstinting support I was able to rely at all times.

3. The audience was perfectly capable, on the basis of their experience and mathematical background knowledge, to cope with the subject matter (see Appendix II). Some classwork was set on one occasion (see Appendix III).

4. The lectures fell into two series. The first series on the rheology of non-Newtonian flow - fundamentals, flow analysis and process analysis of molten polymers as well as their implications. The second series consisting of an account of the application of plastics materials in building, packaging and agriculture. A number of other fields of applications were also dealt with by special request (road transport, household durables, medicine and surgery, and "the plating (metallisation) of plastics.

5. A number of papers (original publications, personal handouts as teaching aids and technical literature) were either given to the Centre or loaned for photocopying. A set of extended essays on material selection and 8 of the most important fields of plastics applications was handed over; a copy of the latter is attached to this report.

6. Discussions in class were not easy, mainly because of a quite unwarranted shyness on the part of some (though by no means all) of the audience. Several ad-hoc topics were raised. These included the very doubtful desirability of trying to prolong the functional life of agricultural PE film beyond one year which I am convinced is a false economy. It was sometimes difficult to convince people that apparently expensive materials or products work out cheaper as well as being technically superior in solving a design or marketing problem than making do with makeshift expedients, such as making baths by injection moulding PP rather than by thermoforming acrylic sheet.

7. It is hoped that this work will be followed up by further expert visits and that the contacts established will be maintained.

APPENDIX I. List of people met in the course of visits to institutes and factories.

Plastics processing and applications centre - 16th July, p.m.

Name	Designation	Work place
Zhou Gang	Director	Bureau of Plastics & Chemicals
Zhang Luan	Engineer	ditto
Liu Guang-Lu		Bureau of Foreign Affairs of tthe Ministry of Light Industry
Qi Zong-Neng	Vice Research Fellow	Academy of Science of China
Ge Chun-lin	Director	Academy of Science of the Ministry of Light Industry
Chen Wen-Ying	Chief Engineer & Project Director	Bureau of Plastics & Chemicals

Beijing Plastics Institute - 17th July, a.m.

Chen Yu-E	Vice Director	Beijing Plastics Institute
Huang Yan-Ping	Engineer	Beijing Plastics Company
Zhang Luan		ditto
Qi Zong-Neng		ditto
Jiang Jie Yi	Engineer	Plastics Processing & Applications Centre

No.1 Plastics Factory - 17th July, p.m.

Liu Zhi Ying	Engineer
Zhou Xieng Lueng	Director
Li Lin Chun	Engineer
Xu Cheng Fu	Engineer & Workshop Director
Qi Ming Bi	Director of the Testing Group
Qi Ming Lan	Director of the Testing Group

Beijing Plastics Mould Factory - 19th July, a.m.

Liu Qi Zhen	Director
Liu Fu Zheng	Engineer

Beijing No.4. Plastics Factory - 19th July, p.m.

Liu Qing Gan	Director	also included: Huang Yan Ping, Zhang Luan, Jiang Jie Yi
Qien Li Jie	Engineer	

Beijing No.2. Plastics Factory - 20th July, a.m.

Zhang Yu Chuan	Director	also included: Liu Guang Lu, Zhang Luan, Huang Yan Ping, Jiang Jie Yi
Li Bin	Engineer	
Jiang Yin-Yu	Engineer	

Beijing Plastics Machinery Plant - 20th July, p.m.

Zhang Yin Shan	Director	also included: the above
Sun Qian Jie	Engineer	
Zheng Zhi Sheng	Engineer	

APPENDIX 2 - PARTICIPANTS OF THE SEMINAR ON RHEOLOGY.

Liu Ji-Chen	Moderator at the Seminar and Associate Research Fellow.
Qi Zong-Meng	Adviser and interpreter
Yu Xin-Nian	Senior Engineer
Zhang Ming-Shan	Associate Professor
Li Lian-Huang	Engineer
Zhang Luan	"
Yang Xiu-Feng	"
Sun Hong-Qiu	"
Shen Man-Ying	"
Xioa Ming	"
Wu De-Zhen	"
Bai Hong-Wen	"
Guo Yun-Wei	"
Tang Sai-Zhen	"
Wang Hai-Xin	"
Diao Mei-Zhu	Assistant Engineer
Zhu Tong-Chun	" "
Wang Pei-Hua	Lecturer
Wang Zhi-Jie	"
Znao Ming-Shan	"
Wu Chong-Feng	"
Liu Min-Jiang	"
Tang Zhi-Yu	"
Zhao Su-He	Assistant teacher
Chen Ke-Yu	" "
Du Xue	Research Trainee
Man Ze-Ying	" "
Shui Li	" "
Wang Ze-Sheng	" "
Liu Liang	" "
Liu Qiu-Ning	" "
Zheng Meng-Xun	" "

APPENDIX 3. QUESTIONS FOR WORKING AND DISCUSSION.

1. Prove that the change of viscosity with temperature at constant shear rate and at constant shear stress respectively are not equal, except in two trivial cases upon which latter you may wish to comment.

2. Describe Cross' treatment of the molecular weight dependence of viscosity based upon the concept of entanglement probabilities. What experimental method is available to determine the constants involved and how does their magnitude affect the magnitude of the higher exponential terms?

3. Describe in words the successive steps by which one may obtain an equation for the pressure drop in parallel-sided and linearly tapering die channels of rectangular dies of any width/height ratio between unity and infinity.

4. Identify and discuss the function of a plasticating extrusion screw.

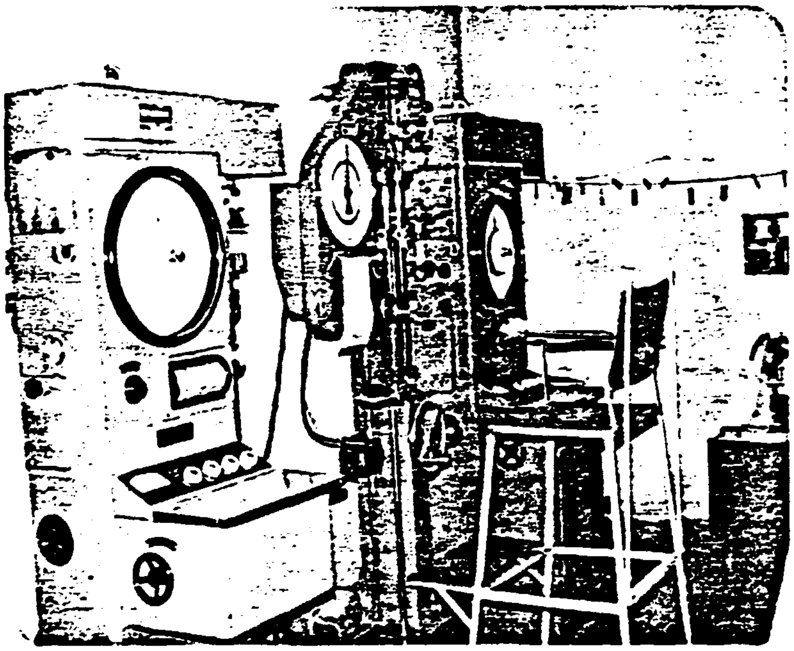
5. Outline the modelling steps which have led to the development of the screw pump.

6. Write an essay on coextrusion.

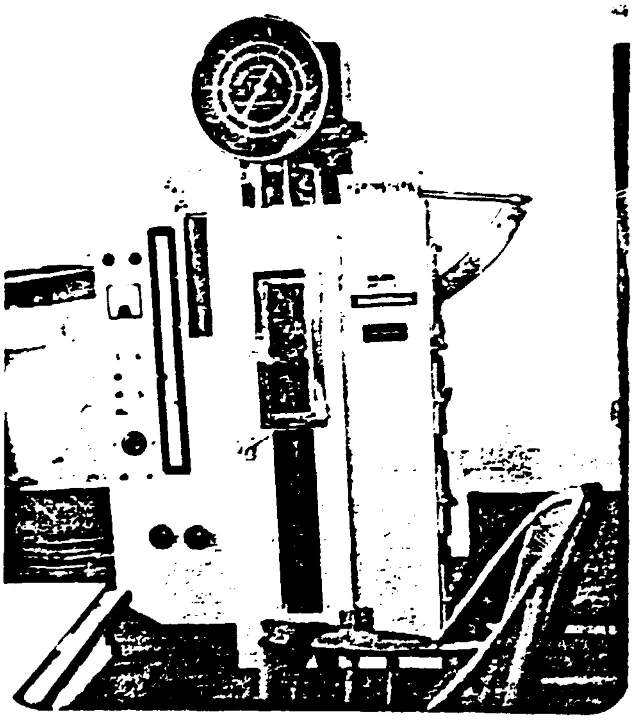
7. Describe in words and with the aid of diagrams (where appropriate) the ideas behind the analytical treatment of flow in wire coating dies, with comments on the stepwise evolution of the more recent approach to this subject.

8. Do you think that it is desirable to establish a Chinese Society of Rheology and to develop a lively exchange of information with other Societies of Rheology such as the British, Japanese, American, Dutch, German, Italian and French ones or the Indian or Australian branches of the British Society of Rheology? If so, what steps would you consider necessary to bring this about and how would you see a Chinese Society of Rheology function both nationally and internationally?

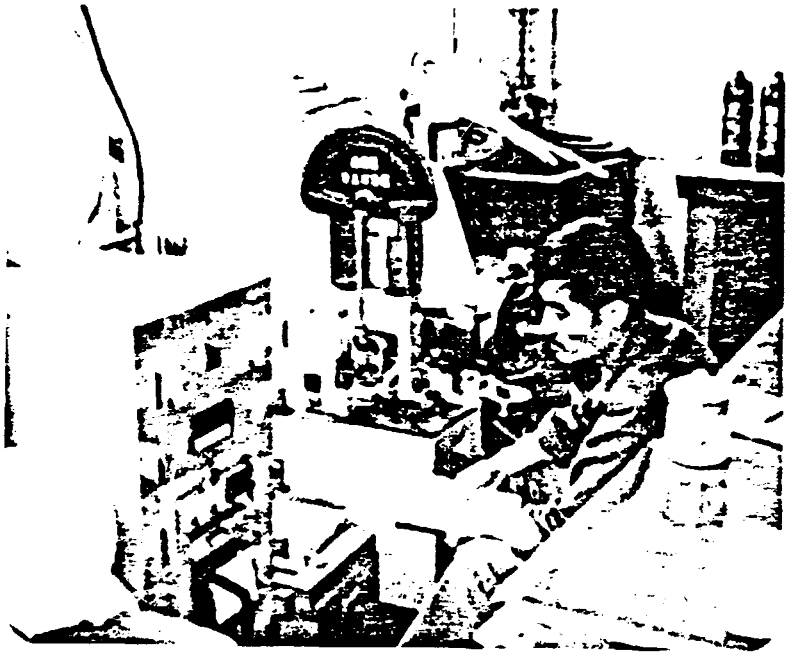
2.1 POLYMER INSTITUTE



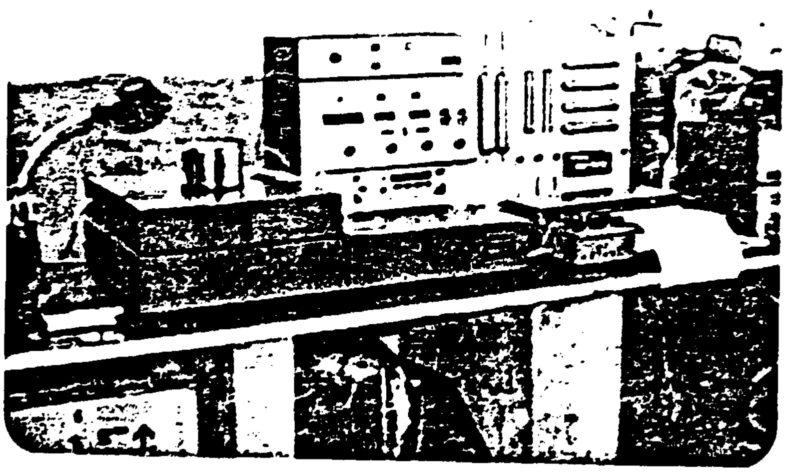
LOW TEMPERATURE AND HIGH TEMPERATURE TENSILE TESTING MACHINES



2.1 POLYMER INSTITUTE

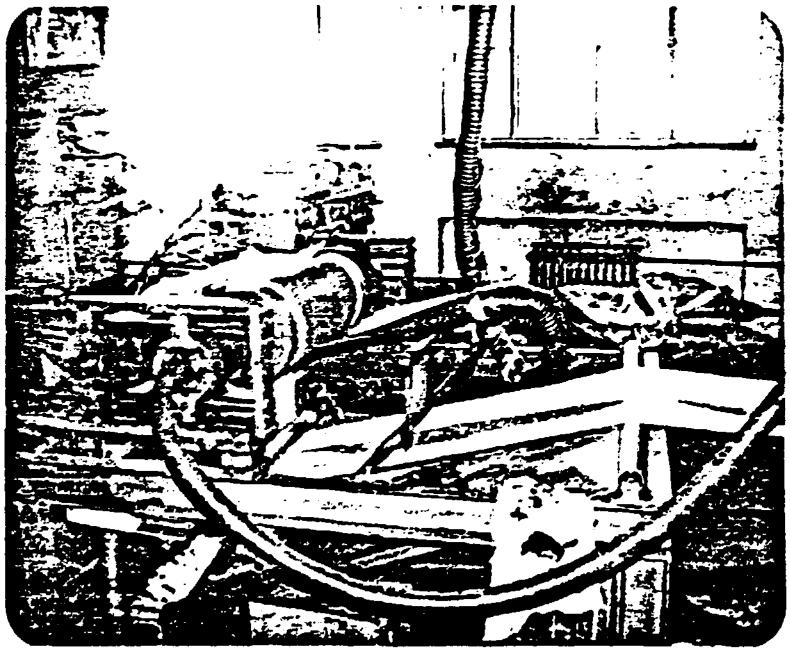


VARIABLE (H.+ L.) TEMPERATURE IMPACT MACHINE



DIFFERENTIAL SCANNING CALORIMETER

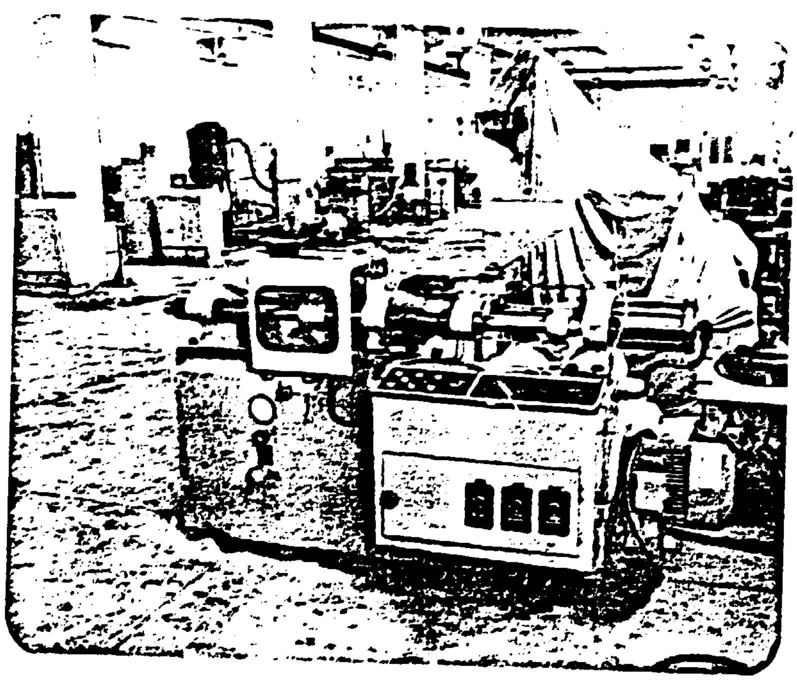
2.1 POLYMER INSTITUTE



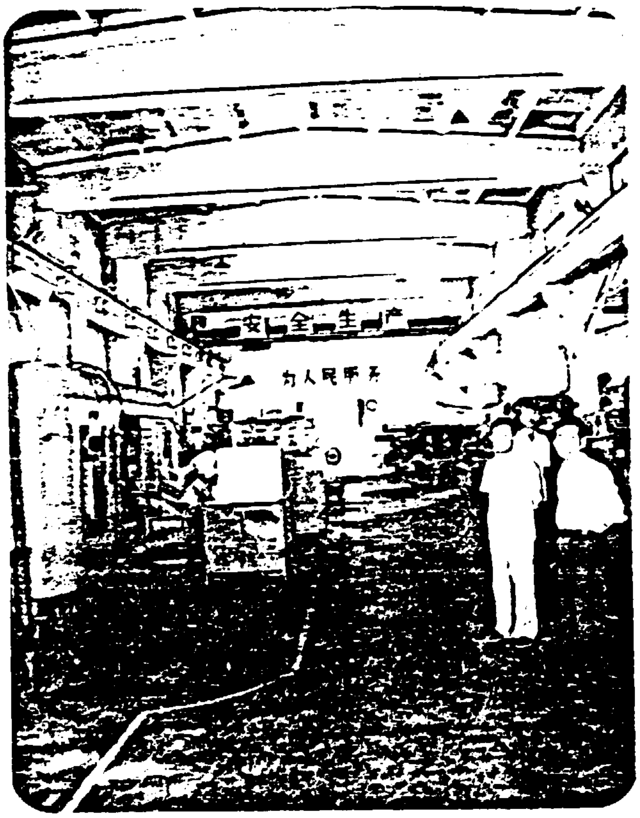
PRODUCTION OF ABS SHEET USING AN EXTRUDER-FED (CROSSHEAD) CALENDER FOR SUBSEQUENT VACUUM FORMING INTO REFRIGERATOR LINERS

2.1 POLYMER INSTITUTE

INSTALLATION OF MACHINERY FOR NEW SCALING-UP WORKSHOP

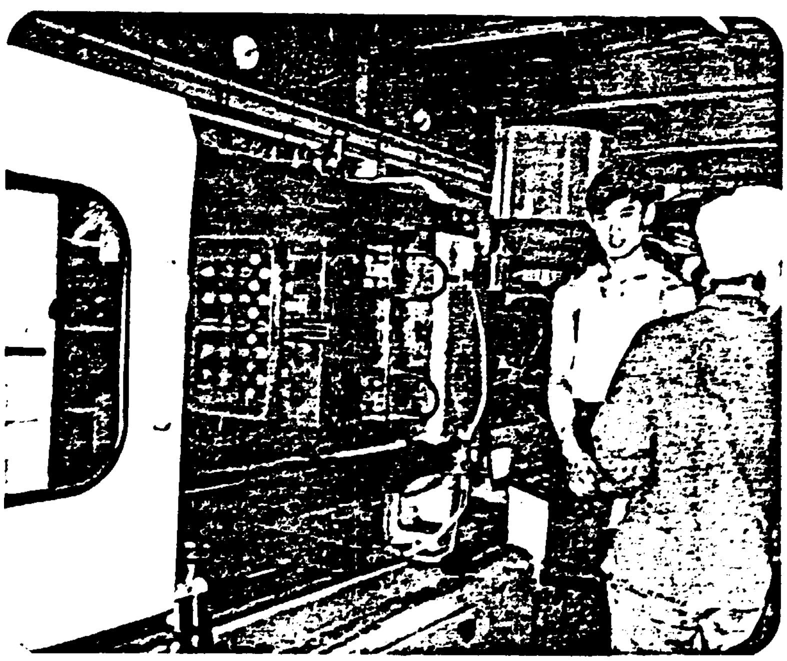


2.2 NO 1 - INJECTION MOULDING SHOP



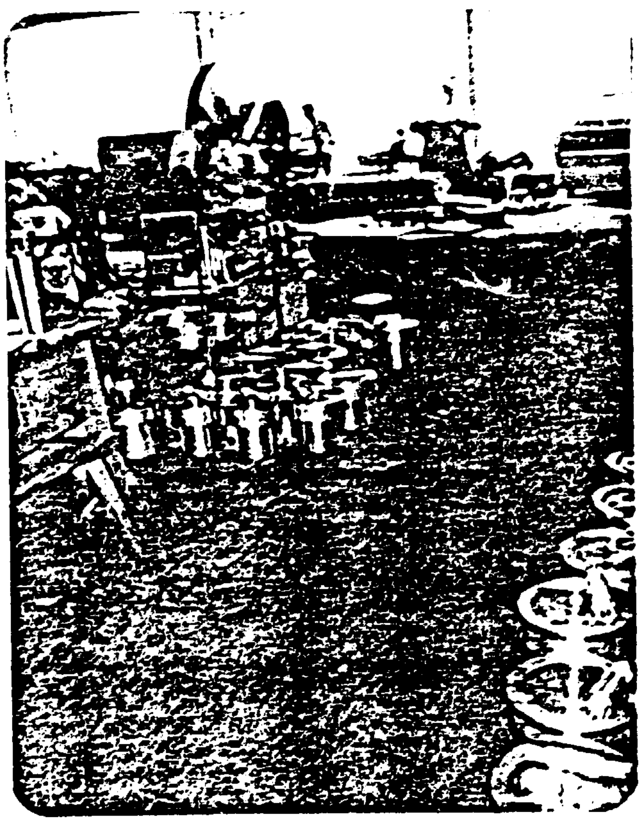
2.2 NO 1

LARGE SEMIAUTOMATIC INJECTION MOULDING
MACHINE FOR BEER CRATES

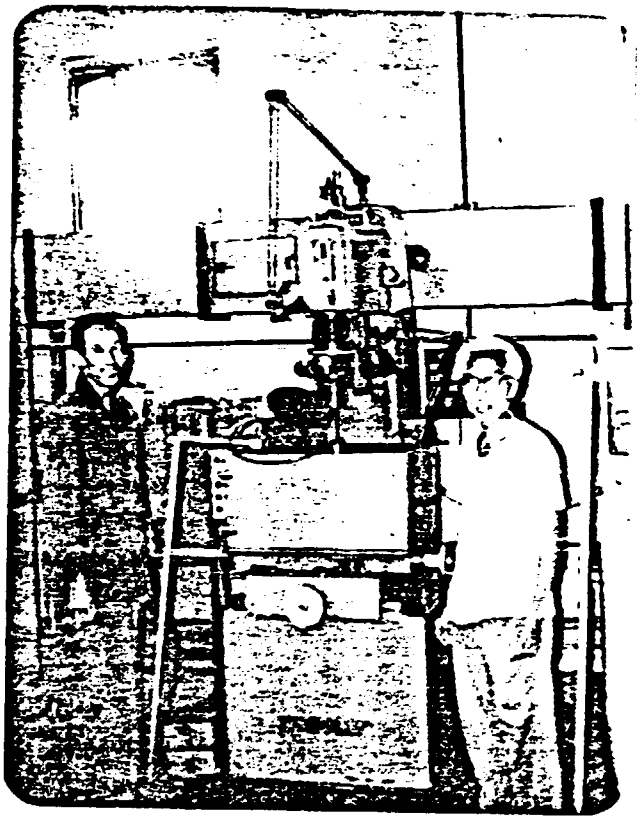


2.3 MACHINE FACTORY (MOULDS)

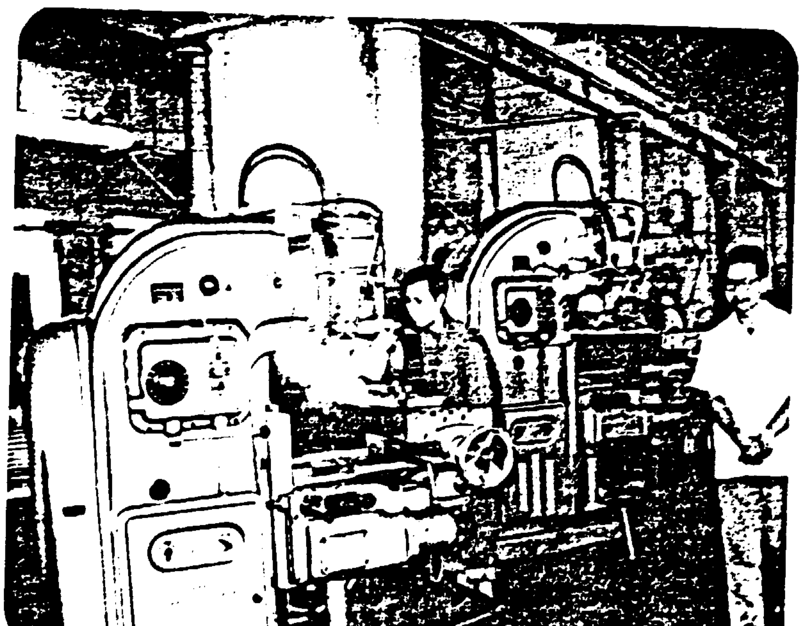
MOULD MAKING



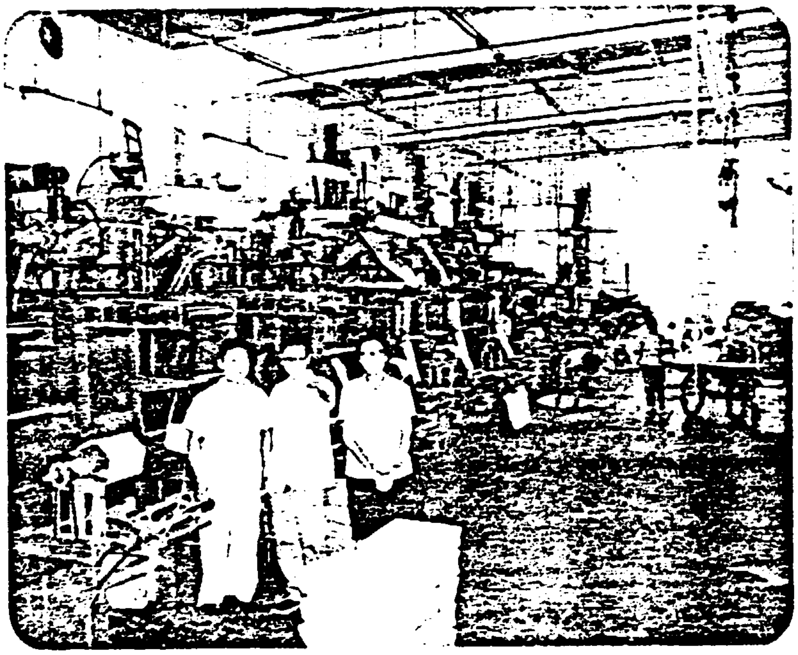
2.3 MACHINE FACTORY (MOULDS)



MOULD MAKING - SPARK EROSION AND MILLING



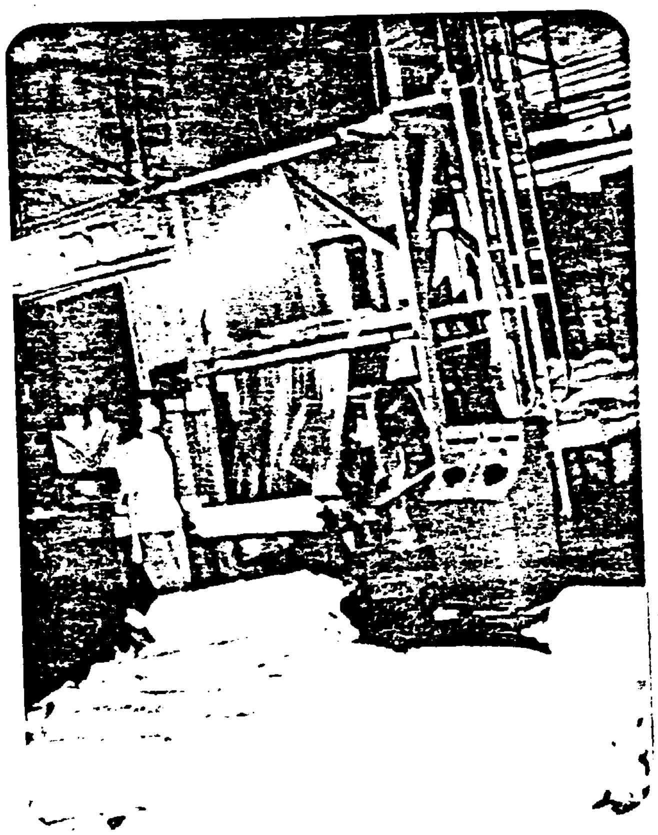
2.4 NO 4



VERTICAL (DOWNWARD) AND HORIZONTAL PE LAYFLAT FILM EXTRUSION

2.4 NO 4

VERTICAL (UPWARD)
PE LAYFLAT FILM
EXTRUSION



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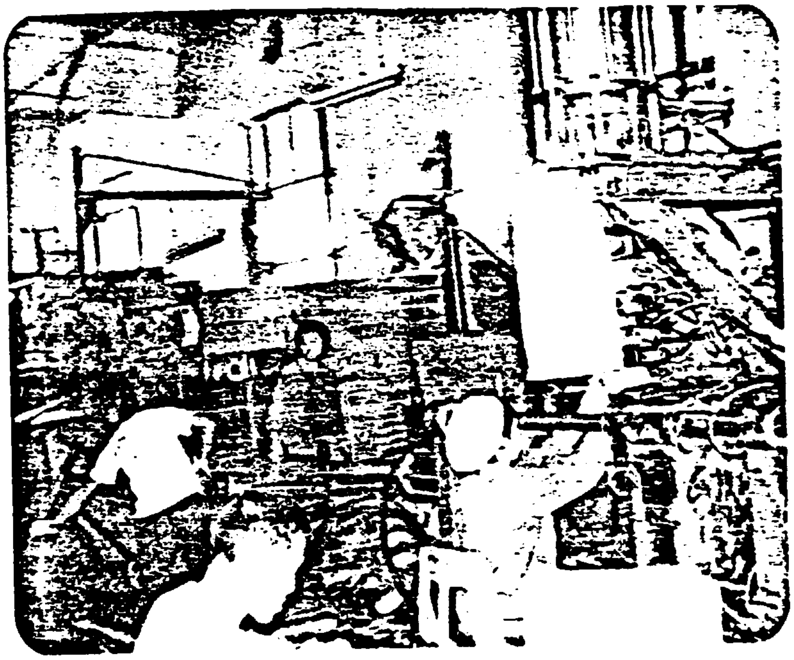
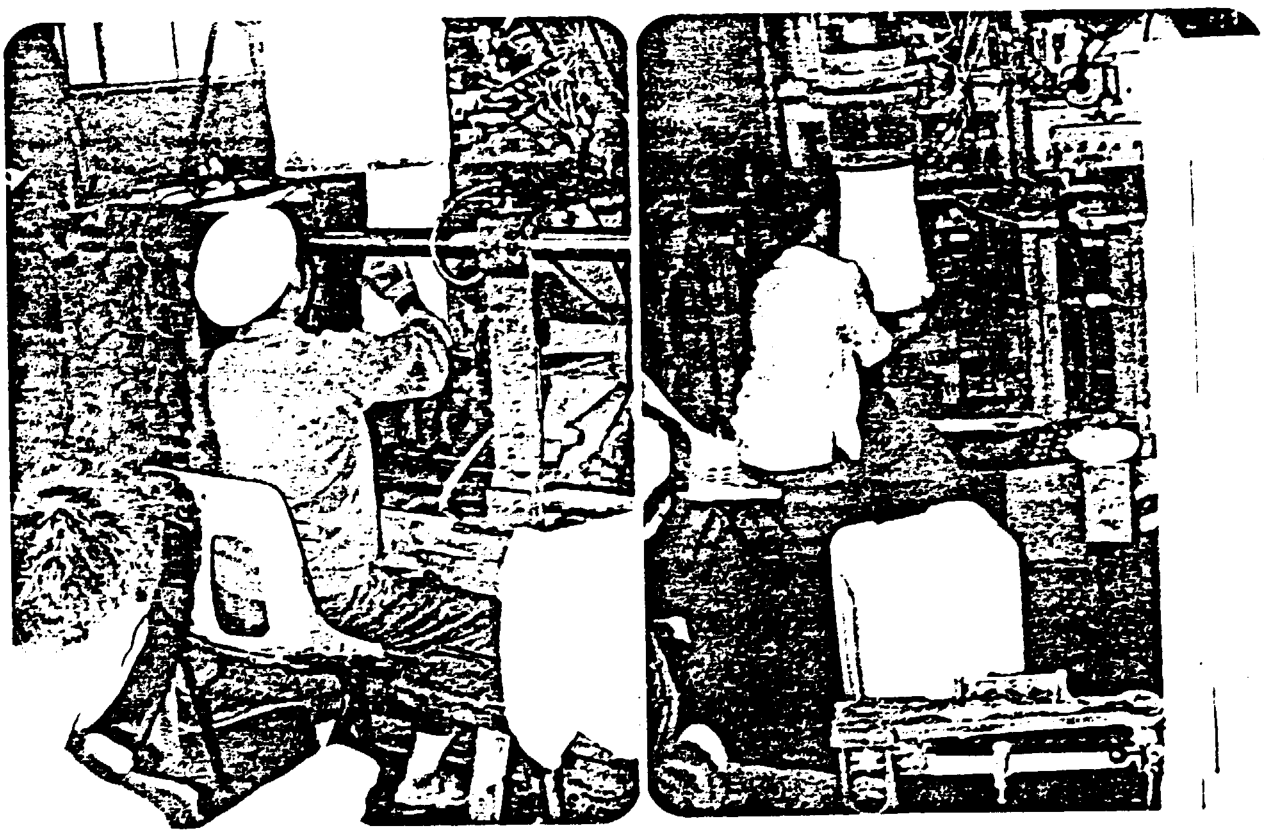
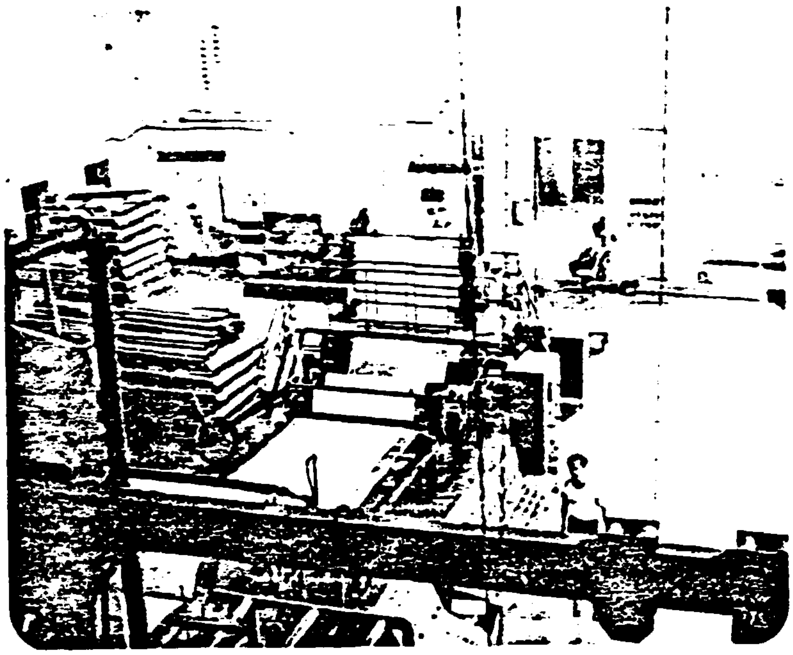


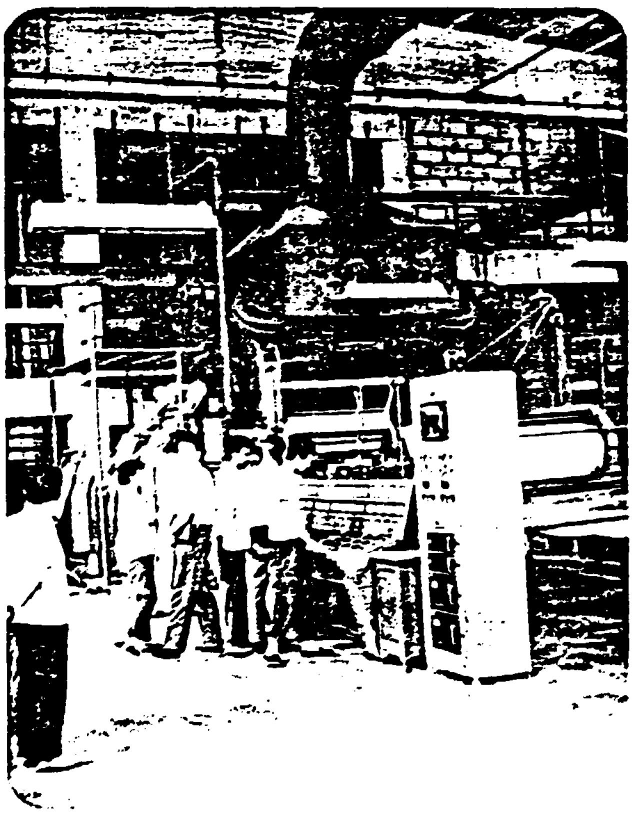
EXTRUSION BLOW MOULDING OF LARGE CONTAINERS

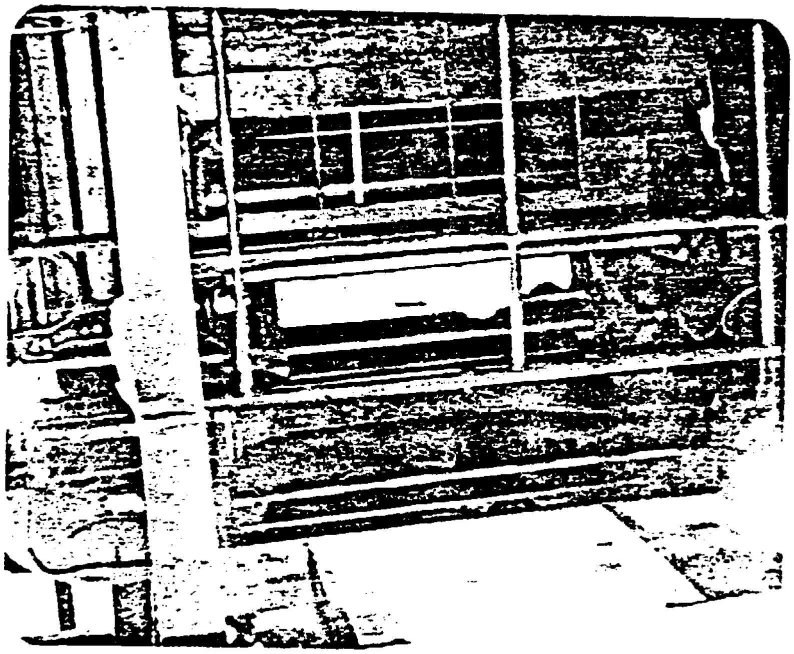


2.5 "NO 2"



CALENDERING

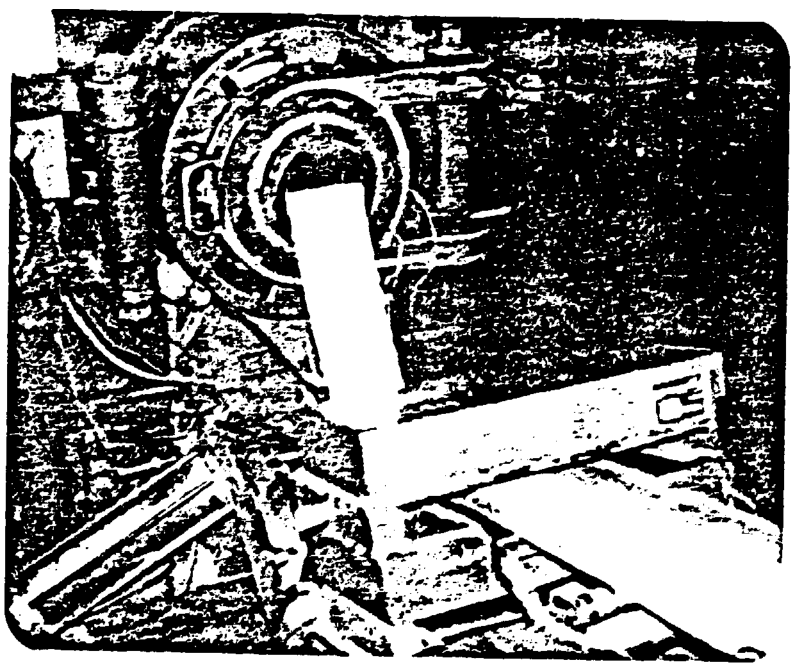




NIP ROLL FEED

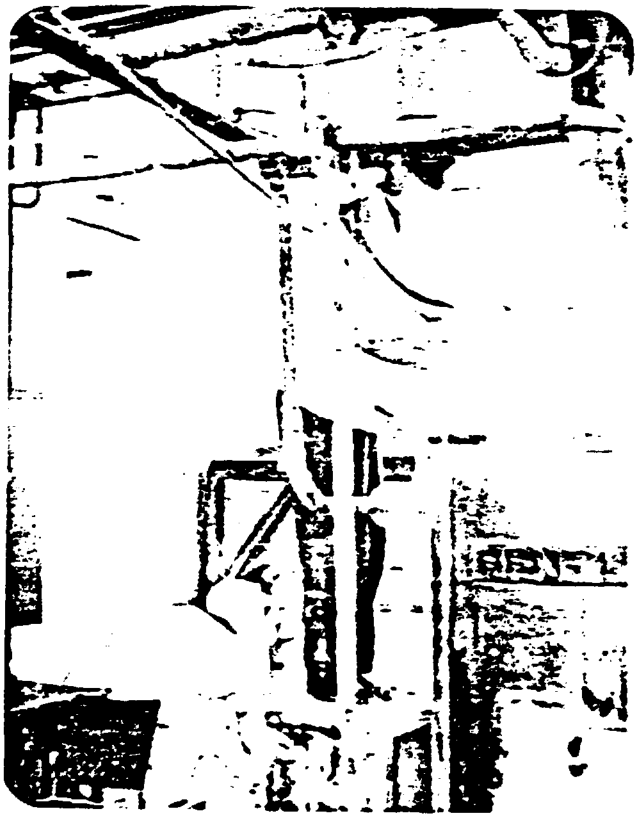
(CALENDER)

SUPPLY FROM MIXER EXTRUDER



2.5 NO 2

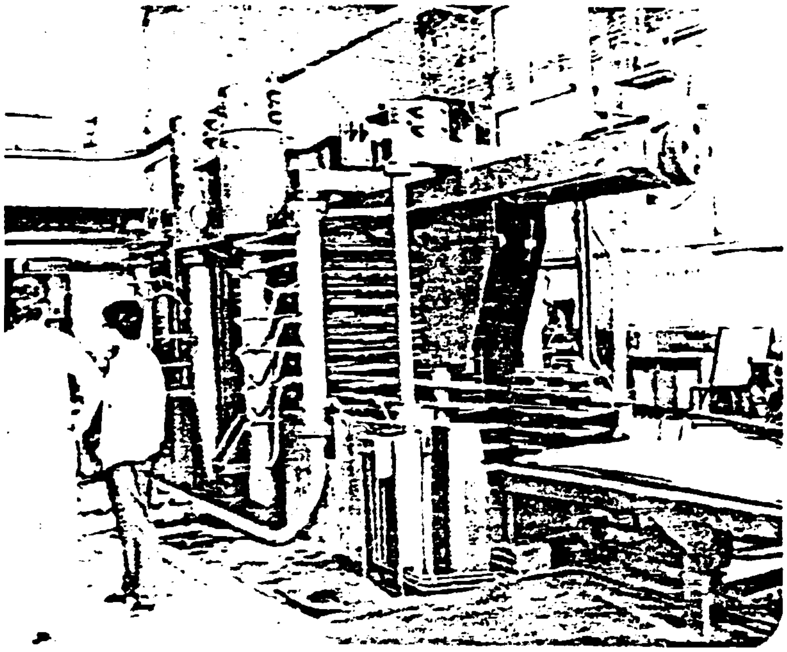
CALENDER



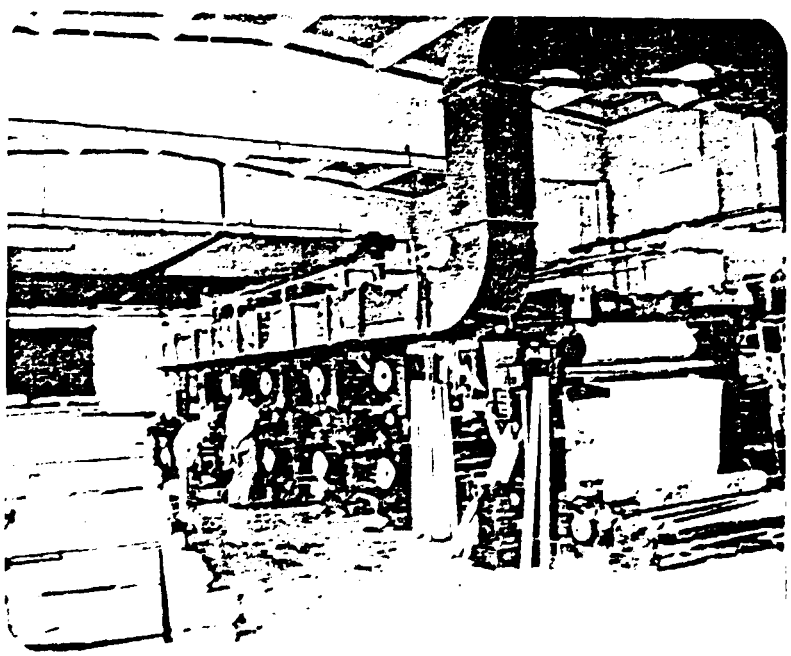
COMPOUNDING
(TOP OF CALENDER HOUSE)

2.5 NO 2

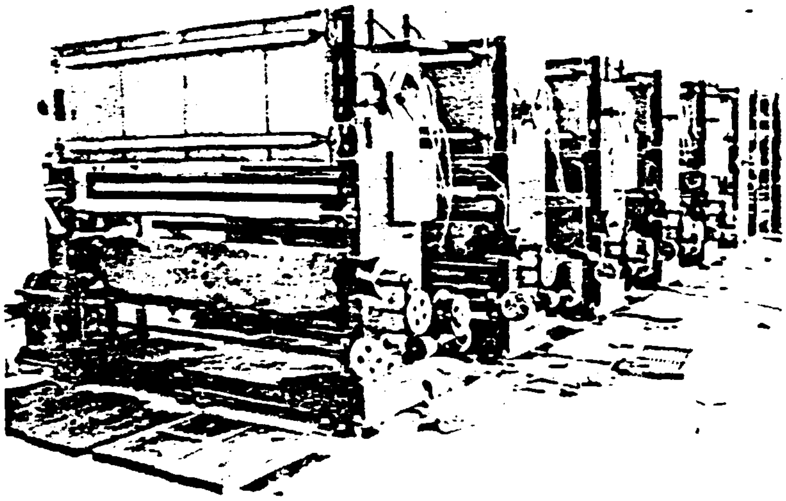
LAMINATING CALENDERED PVC FOIL
MULTI-DAYLIGHT PRESS



FIVE-COLOUR ROTOGRAVURE PRINTING OF CALENDERED
PVC SHEET

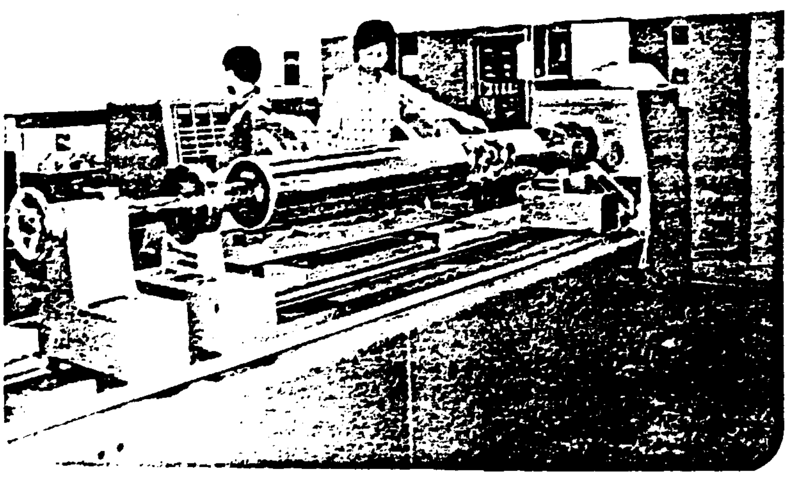


2.5 NO 2



NEW PRINTING MACHINE

ROTOGRAVURE ROLL MAKING



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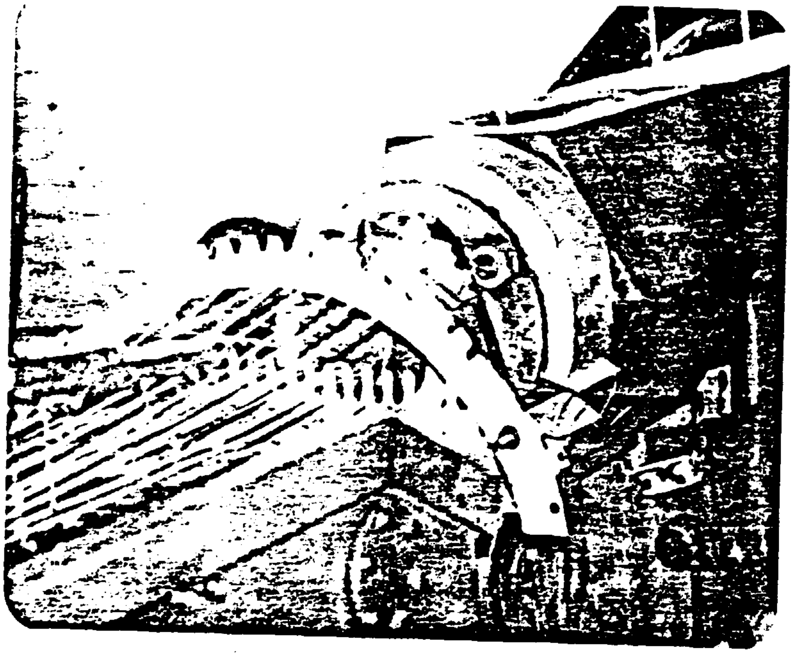
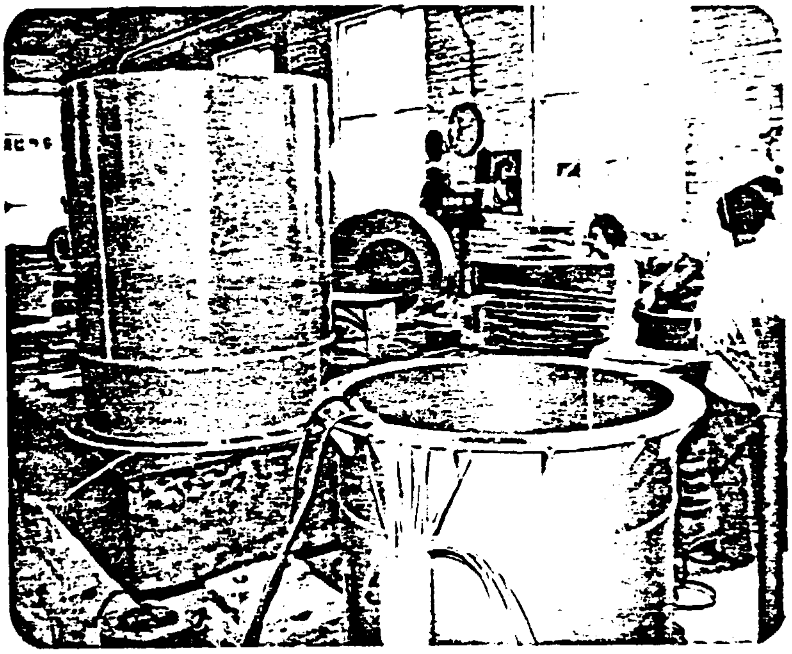


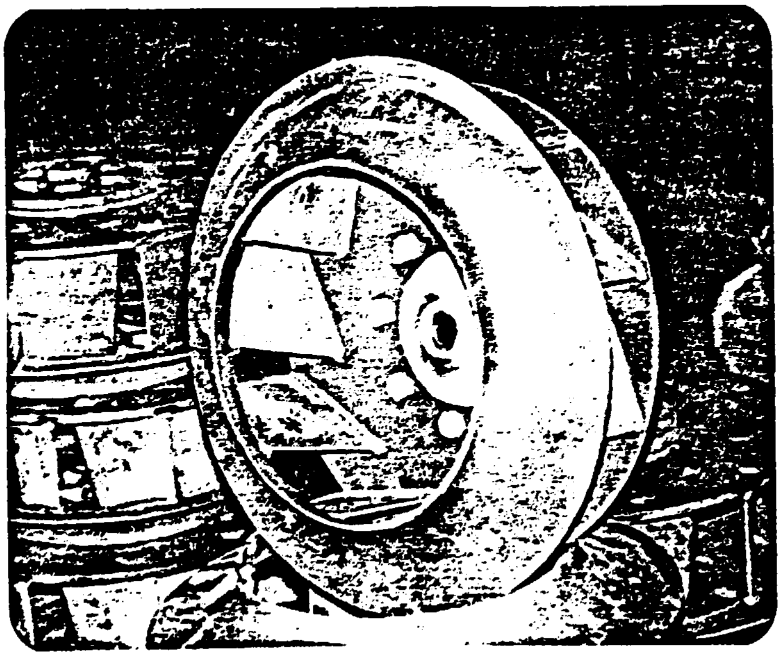
EXTRUSION OF PVC WELDING ROD

PVC WELDING

2.5 NO 2



WELDED STRUCUTRES



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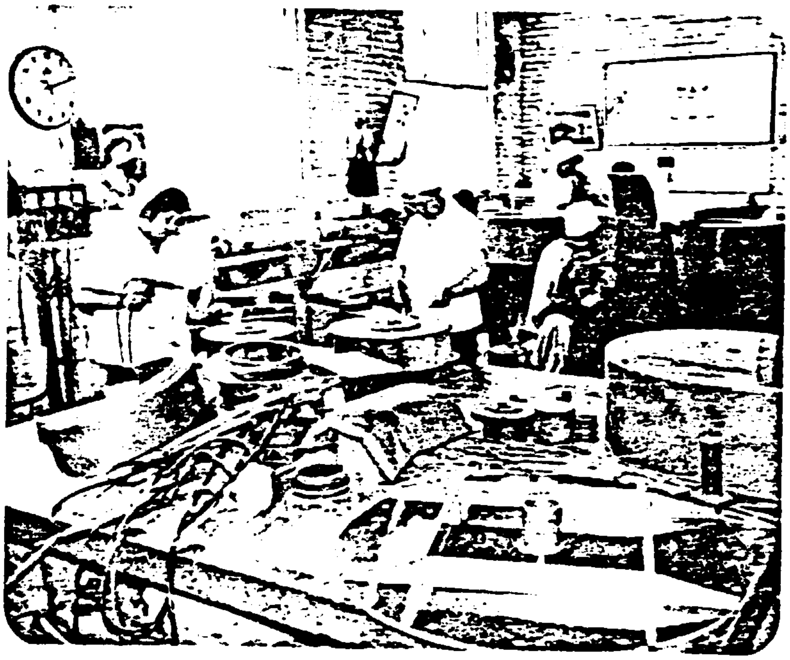
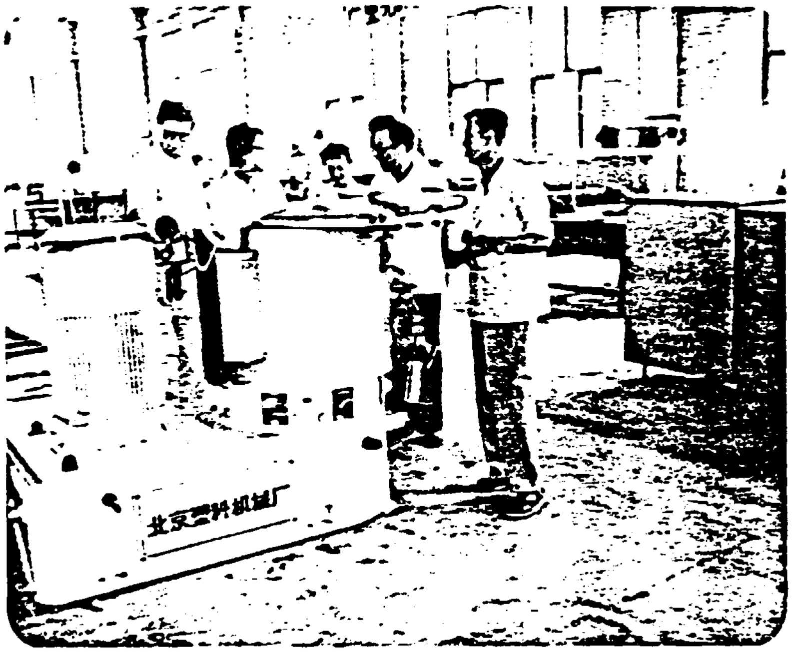


WELDING SHOP

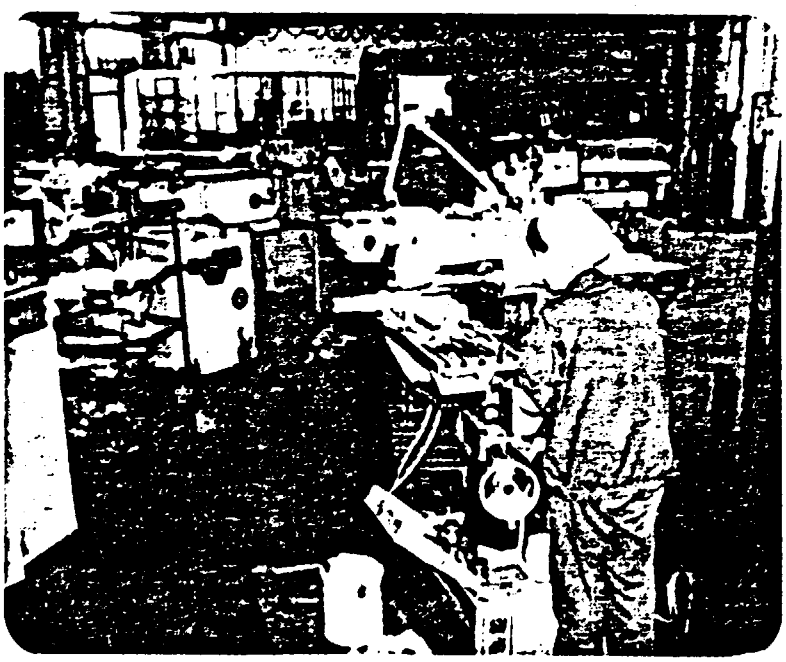
TEA GIRLS

2.6 MACHINE FACTORY

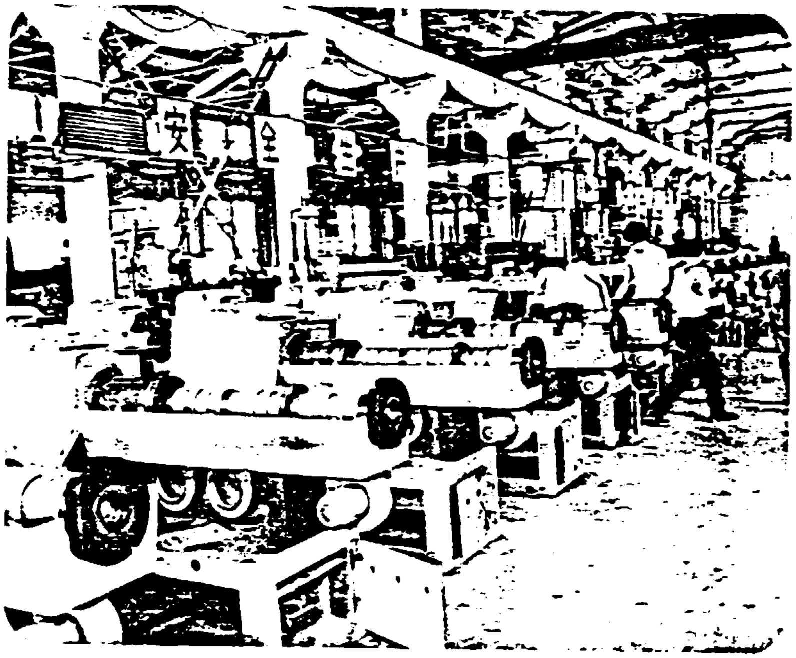


MIXERS

MOULD MAKING



2.6 MACHINE FACTORY



EXTRUDERS AND SCREWS