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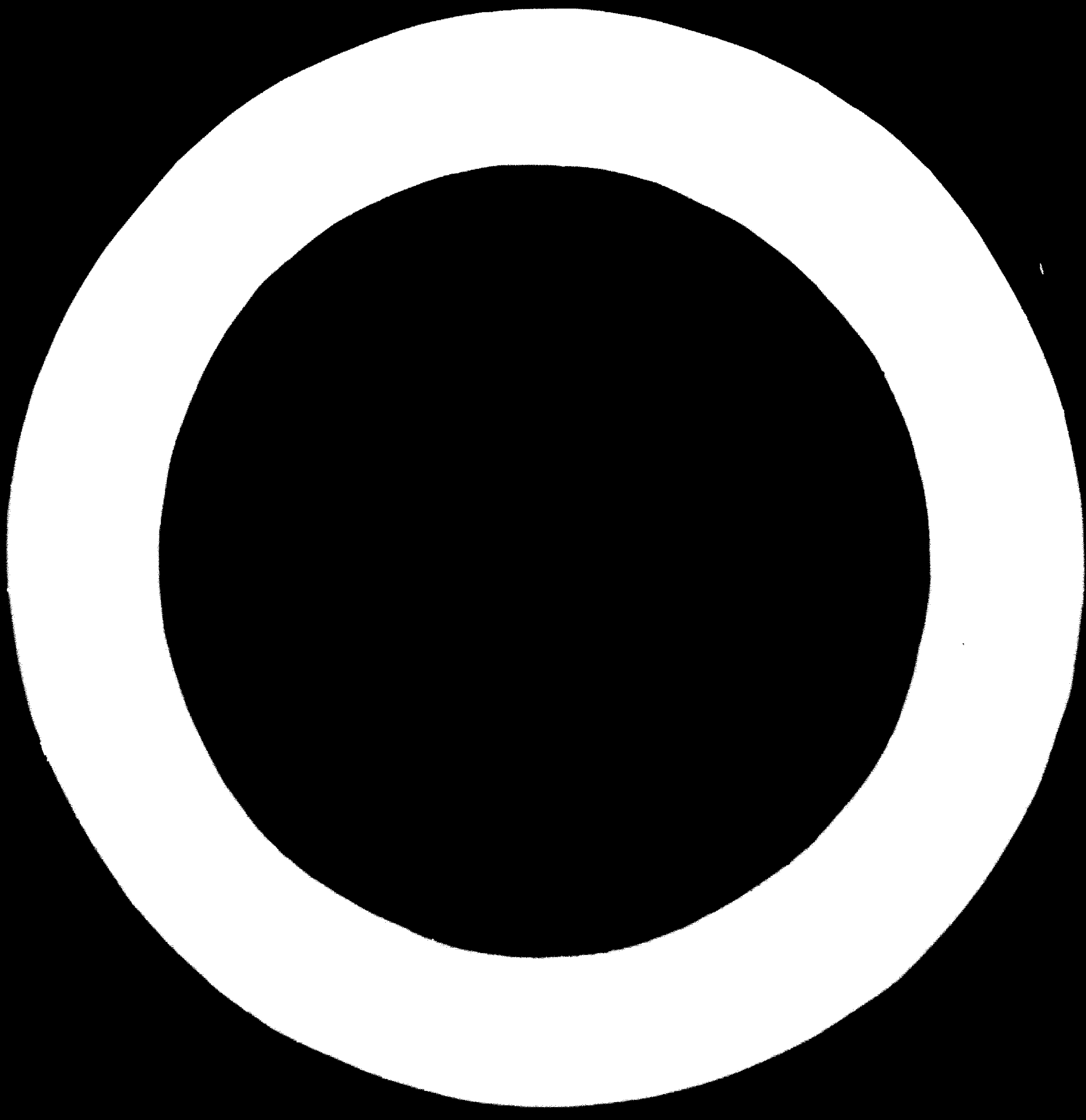
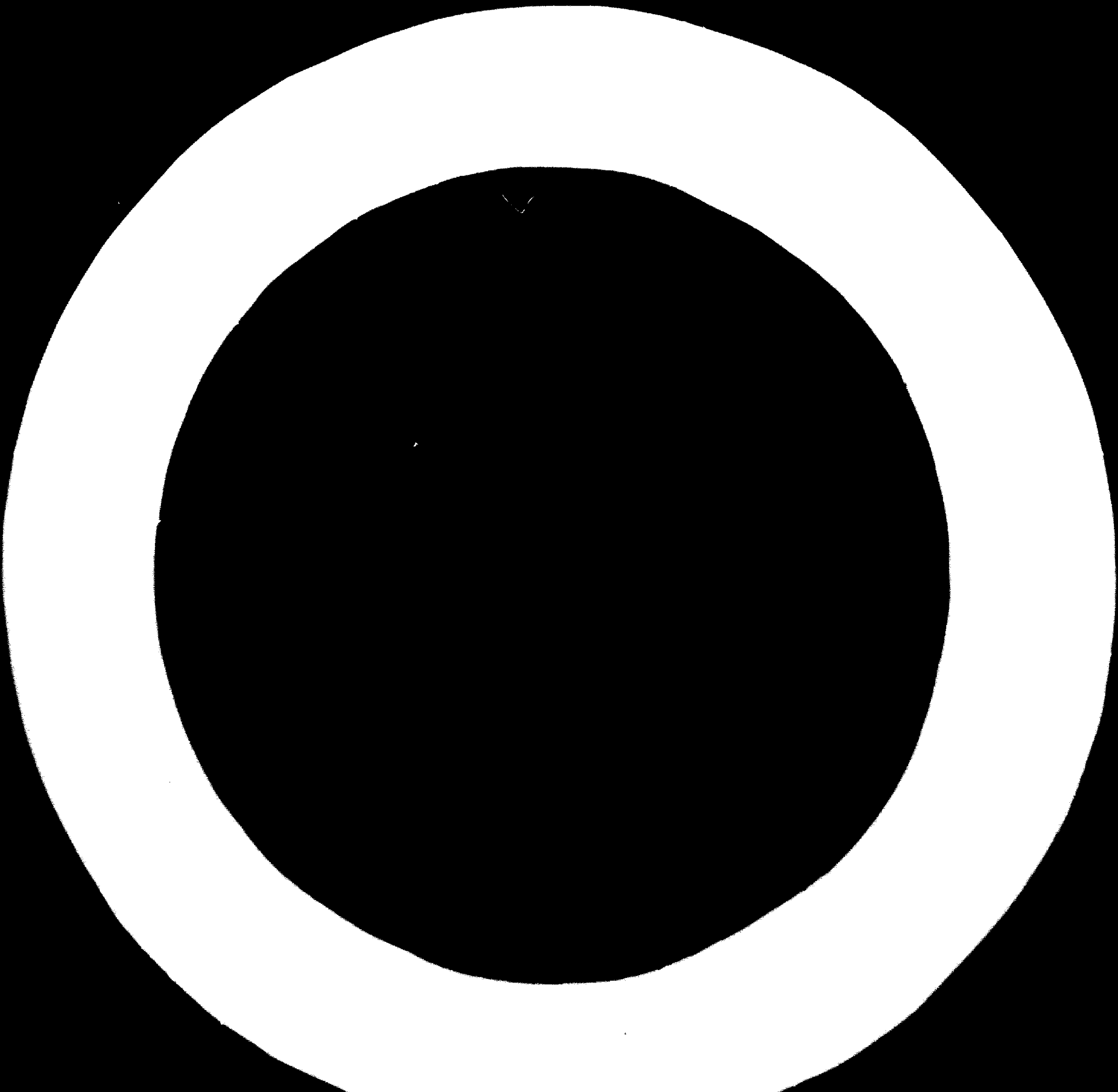


PETROCHEMICAL INDUSTRY SERIES

MONOGRAPH No. 6

GUIDELINES FOR THE PRODUCTION AND MARKETING OF ACRYLIC SHEET IN DEVELOPING COUNTRIES

UNITED NATIONS



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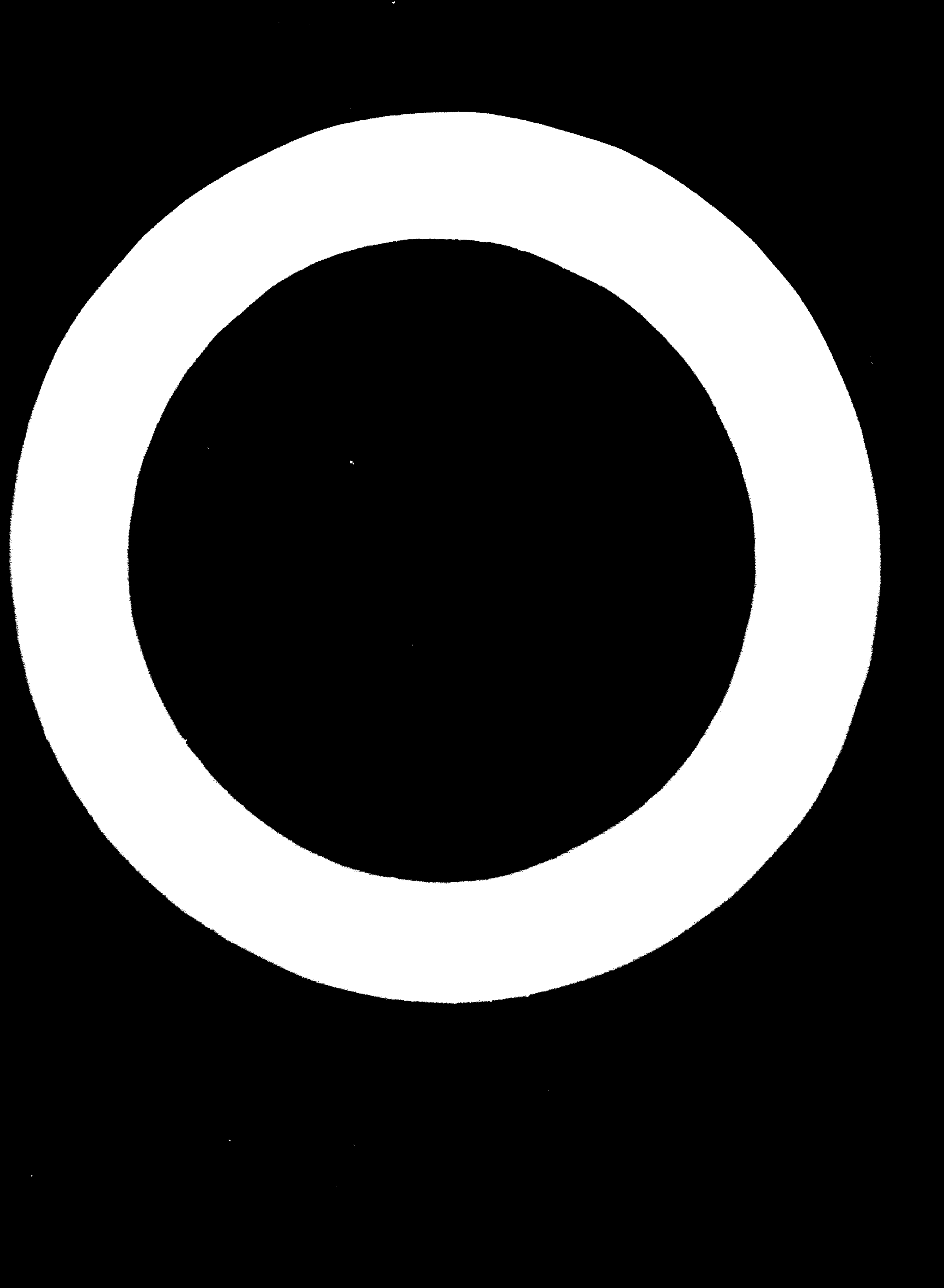

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
VIENNA

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UNITED NATIONS
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FOREWORD

This publication is the sixth of a series of monographs in the Petrochemical Industry Series to be published by the United Nations Industrial Development Organization. The titles of other studies in this series will be found on the back cover of this publication.

The world petrochemical industry has shown a high rate of growth during the last ten years. The industry supplies intermediate products for a number of other industries and provides substitutes for traditional materials such as steel, lumber, packaging materials, natural fibres, natural rubber and soap. It is considered to be one of the most strategic sectors of industrial development because most of its products go on to other producing sectors.

This series is designed to assist the developing countries in dealing with technical and economic problems related to the establishment and development of facilities for the manufacture of petrochemicals and consumer products. The series is concerned with basic and intermediate petrochemicals and end products, such as plastics, synthetic rubbers and synthetic fibres. Nitrogenous fertilizers[1] and textile production based on synthetic fibres are excluded from the series.

This monograph is designed for the use of persons, firms and governments who may be considering the establishment of plants for producing acrylic sheet, whether as the first step in setting up a plastics industry or to broaden an existing one. More fundamental purposes may be to meet local demand for this material, create employment, conserve foreign exchange by import substitution or even, perhaps, to achieve penetration of foreign markets.

The approach used and the criteria followed are based on the concept that processes and techniques must be adopted that will produce goods that can compete in quality, price and reliability of supply with goods from countries whose industrialization began earlier. This concept is considered valid even when capital for investment and skilled labour may be in short supply and present markets for the products limited or even non-existent. No country, and especially no developing country, can afford to waste its resources by creating industries whose products are too high in price, too low in quality or too unreliable in supply to become acceptable in the world market.

The purpose of UNIDO in publishing this study is therefore to help developing countries to gain a good technical insight into the problems of producing and marketing acrylic sheet. The study has been prepared by R. M. Kossoff and Associates, Inc., New York, United States of America, in the capacity of consultants to UNIDO. A major contribution was also made by Mr. Robert Maginn, Director of Research for the Polycast Technology Corp., Stamford, Connecticut. The views and opinions expressed in this publication are those of the consultant organization and do not necessarily reflect the views of the secretariat of UNIDO.

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[1]See the Fertilizer Industry Series published by the United Nations Industrial Development Organization (ID/SER.F, Nos. 1, 2, 3, 4, 5 and 6).

EXPLANATORY NOTES

Reference to dollars ($) is to United States dollars;
(one cent (¢) equals $0.01).
Reference to tons is to short tons.

The following abbreviations are used in this publication:

HDT acceptable heat distortion temperature
ppm parts per million
PVC polyvinyl chloride

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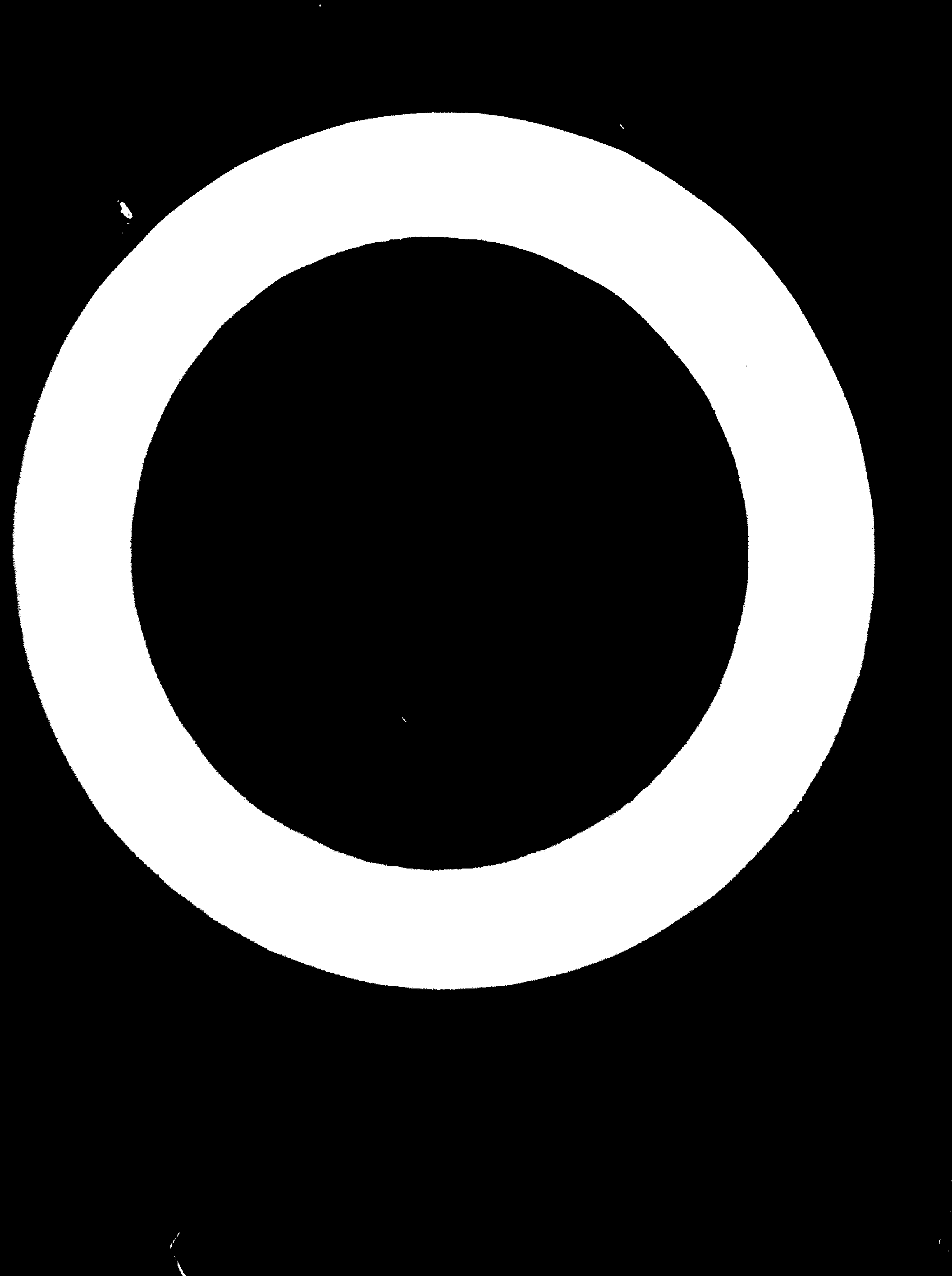


INTRODUCTION AND SUMMARY

The purpose of the present report is to assist firms and governments in developing countries that are considering entry into the production and marketing of acrylic (plastic) sheet. Compared with other plastics production processes, such as injection-moulding, compression-moulding and blow-moulding, the casting and extrusion of acrylic sheet have received little publicity or attention in many countries. Hardly any information is available on the technical and commercial aspects of this industry. During the last decade, however, there has been a rapid increase in imports of acrylic sheet into many countries for use in constructing outdoor signs, displays and lighting diffusers, for architectural applications such as glazing, building facings and the construction of domes, and in the production of windshields, bathtubs, desk and floor mats and many other products. In a great many instances, glass is being replaced by acrylic sheet. Local production of this material by the conversion of the liquid monomer (methyl methacrylate) to solid sheet can save valuable foreign exchange.

The present report is intended to provide sufficient information and direction to help prospective producers draw up logical and practical plans for investigation of the most appropriate means of entry into production and marketing under the conditions that prevail in their countries.

Particular emphasis is laid on the technical and economic requirements of small and medium-sized operations. However, in order eventually to participate in world markets, a new producer must understand the structure and operations of the larger, more sophisticated units with which he must compete; the study therefore includes some discussion of such large-scale operations.

The production of acrylic sheet offers an attractive possibility in many developing countries. Local production of this material can replace imports and thus conserve valuable foreign exchange and create new jobs.

The consumption of acrylic sheet has grown substantially in many parts of the world. It is fabricated into advertising signs, lighting fixtures and to a lesser extent, it is used in glazing and in certain other architectural applications.

Local production of acrylic sheet can be initiated on different investment and technological levels. While small casting operations to serve local markets, capitalized at about $20,000, are possible, the usual facilities for producing cast or extruded acrylic sheet for local and/or export markets normally require the investment of at least $100,000.

The profitability of acrylic sheet-producing operations can range from 2.5 to 25 per cent (on sales, before taxes). Return on invested capital can be good in a carefully controlled, low-overhead operation. The labour-intensive nature of the casting of acrylic sheet may give it a competitive advantage in countries that have favourable wage rates.

The relation between the price of acrylic sheet and the local demand for it can be determined easily. This is not true of export markets, however. Exports to some of the countries that consume the most acrylic sheet, such as the United States, are difficult to develop, since the distribution channels are complex and the performance standards are high. These factors often offset price advantages.

The technology required to begin local production of acrylic sheet may be obtained from a variety of sources. The smaller acrylic sheet producers are likely to be the best source of information about low-investment operations to supply local markets. Some possible contacts are cited.

Many firms in various parts of the world have begun successful production of acrylic sheet for the local market. However, there are many obstacles to achieving this goal. They must be carefully studied; many of them are considered in the present report.

1. SOME BASIC CONSIDERATIONS

Many firms have established acrylic sheet-producing operations in developing countries. The point at which enough acrylic sheet is imported to justify local production varies widely. In a number of cases, when local demand had caused imports to reach 2 to 3 million square feet (about 1.5 to 2.3 million pounds), local manufacturing has been initiated. In some countries, however, local operations were begun when imports were only 1 million square feet (about 0.8 million pounds), while in others local production did not occur even though demand was absorbing 3 to 4 million square feet (2.3 to 3 million pounds) of imported material. Often a combination of business instinct and direct or indirect experience with some aspect of acrylic sheet applications by an individual or firm leads to the decision to produce it.

All output of such new operations is normally sold locally, mostly for advertising sign fabrication, lighting fixtures and a variety of industrial and consumer items such as machine guards, display boxes, forms for window displays, lamps, bathtubs and costume jewellery.

The scale of operation may vary from a small one with a low investment (for example, $20,000) based on self-built equipment to a larger, more sophisticated firm requiring a minimum investment of $180,000. As in other segments of the plastics industry, it is not uncommon for a cluster of low-investment manufacturers to become established. Such operations are usually characterized by a medium-quality product at very competitive prices. Over the long run, units with higher investment have a greater chance of building exports with high-quality sheet. This achievement may require many years of product development and promotion to meet the quality standards of the more developed countries. For example, the value of imports of acrylic sheet into the United States in 1969 was probably less than $5 million, even though total sales volume was over $125 million.

Nevertheless, careful planning can help new producers to begin a viable operation that would replace imports, provide new jobs and eventually lead to some exports.

2. USES OF ACRYLIC SHEET

Advertising signs and displays account for 40 to 55 per cent of acrylic sheet usage in the United States, Europe and Japan. In most of the countries where acrylic sheet operations have just been started, the same emphasis on signs and displays is usually found. Table 1 provides a picture of how sheet is used in the three largest consuming areas.

TABLE 1. ESTIMATED PATTERNS OF CONSUMPTION OF ACRYLIC SHEET IN THREE IMPORTANT MARKETS

(Per cent)

Application	*USA*	*Europe*	*Japan*
Signs and displays	45	40	48
Lighting fixtures	16	25	16
Architectural	18	16	12
Industrial	4	14	14
Other	17	5	10
Total	100	100	100

Advertising signs and displays

Advertising materials constitute the most important uses of acrylic sheet in most countries. Wherever display advertising is desired, especially outdoors, acrylic sheet provides a strong balance of useful properties. It has been replacing painted metal, wooden and neon signs in many countries. A wide variety of signs and displays are fabricated from it. Industrial users in some countries include producers of oil, beer, soft drinks, paint, rubber, food, automobiles and chemicals, to name but a few. Many advertisers specify internally lighted outdoor signs made from white translucent acrylic sheet as a background, with raised letters in a contrasting colour. Attractive point-of-purchase displays are also becoming popular in many areas.

In some countries, acrylic sheet is sold to firms that specialize in the production of advertising signs. These firms may be large ones that supply the major industrial users, or they may be smaller custom shops. In either case, these firms perform a variety of services that includes painting, installing lighting equipment and vacuum-forming the flat sheets into other shapes.

The gauges used are mainly one-eighth, three-sixteenths and one-quarter inch, and sizes vary from 6 feet square to 6 feet by as long as 44 feet. In the United States, long signs are made in sections; but a new continuous process now permits some signs to be cut from long rolls of sheet. Sheet suppliers usually assist sign fabricators in colour matching. In the United States, there are more than 200 firms that form acrylic and other plastic sheet into signs.

One developing country has opened a number of new motels with signs fabricated from a translucent white acrylic sheet that is 13 feet square and one-quarter inch thick, on which thermoformed coloured letters are cemented. Internal lights flash off and on at night, and by day the sign is an attractive white structure.

Lighting fixtures

Cast and extruded acrylic sheet is used extensively for lighting shields in many countries. The light source is given primary direction by the reflection lens or diffuser. The acrylic shields diffuse the light, protect the light source (incandescent, fluorescent or vapour lamp) and minimize direct glare. Both glass and metallic shields have been replaced by acrylic sheet, which is lighter and shatter-resistant and provides maximum lighting efficiency over a long period without discolouration or deterioration. These properties are especially important for outdoor lighting diffusers.

Acrylic sheet can be formed into various three-dimensional shapes. Most acrylic plastics will tolerate temperatures above 180° F and higher before becoming distorted. Some suppliers recommend that the operating temperature be 20° to 25° F below the distortion temperature. Self-extinguishing grades of acrylic sheet have been developed, but to attain this property heat resistance has been sacrificed.

Extruded sheet can be formed and/or embossed to provide refractive light control. A matte surface can be made that has excellent light-diffusing characteristics. Cast sheet is often specified where the thickness is greater than one-eighth inch or where optically clear sheet is needed. Injection-moulded lighting parts are selected where the desired shape and prismatic surface cannot be achieved readily by extrusion or casting.

Most cast acrylic sheet used for lighting is white-translucent, although clear and coloured sheets are used also. Matte finishes are gaining in popularity. When clear sheets are used, they normally have a patterned surface or matte finish.

Architecture and glazing

Acrylic sheet is replacing glass in domes, skylights, swimming-pool enclosures shop fronts, window-panes and related applications. Most of the material used is clear sheet, but some is tinted to reduce glare. For developing countries, the use of acrylic sheet to replace glass in windows has been tried with success, particularly in industrial sites where breakage is frequent. Other plastics such as polycarbonate and polyvinyl chloride are also used. The specification of acrylic sheet for domed roofs, such as those of sporting arenas has come to be accepted in many areas. For example, in Houston, Texas, the roof of the Astrodome stadium was constructed of 9,200 acrylic sheets (about 350,000 pounds), each measuring 41 x 88 inches. The sheets are in two layers, those of the outer layer being one-eighth inch thick, and those on the inner layer three-sixteenths inch thick with a light-diffusing prismatic inner surface. In England, corrugated acrylic sheet is being used for the entire roofing of some factories and schools.

A more recent development is the use of this material for building facings. Acrylic sheets can be vacuum formed into panels of any configuration and pattern. They are lighter than glass and have better impact resistance, and they weather very well. Acrylic sheet panels can be installed by several methods, including a clip system for formed panels, a channel system for flat or formed panels, or by curtain-wall framing techniques.

The building codes in some countries incorporate strict fire laws which regulate where acrylic sheet can be used. Usually, acrylic sheet is not subject to code regulation when used in exterior structures such as domes or building facings, but interior applications such as ceilings or lighting fixtures may be regulated.

Primary uses of acrylic sheet in a major user country

Table 2 summarizes the uses of acrylic sheet, both cast and extruded, in building construction in a large industrialized country.

TABLE 2. CONSUMPTION OF ACRYLIC SHEET IN BUILDING CONSTRUCTION IN A LARGE INDUSTRIALIZED COUNTRY

(Millions of pounds)

Homes		2.5
Glazing	1.7	
Curtain walls	0.5	
Bathtubs	0.3	
Industrial		35.0
Light diffusers	15.0	
Interior partitions	5.4	
Domes and skylights	14.6	
Maintenance		6.5
Panels	3.0	
Glazing	2.5	
Light diffusers	1.0	
Total		44.0

Plumbing fixtures

Bathtubs produced from vacuum-formed acrylic sheet are sold in many parts of the world, including some developing areas. Reinforcing agents such as glass-fibre matting are usually incorporated into their structure. Significant savings in weight and cost are possible in comparison to the heavier traditional materials. This product has become an important export item; for example, one firm in a developing country sells acrylic bathtubs in a variety of colours and shapes for several hundred dollars each. Sales have increased substantially over three years. Countries with favourable wage rates may find this product an attractive possibility. Good contacts with distributors in the importing country are needed, however. Also, while bathroom shower doors of acrylic sheet are popular in some countries, they must often compete with ones made from less costly materials such as reinforced polyester.

Floor- and desk-mats

The market for floor- and desk-mats is large, and user specifications for them are lower than for most other acrylic sheet applications. As a result, pricing is very competitive. It is not uncommon for a firm to produce these goods with a capital investment of less than $20,000 Since quality requirements are not great and much labour is involved in shaping the sections, many countries import these goods from areas with favourable labour rates and pricing. One firm in a developing country built its own ovens and other equipment and now produces about 100 sheets a day for a relatively low capital cost. Again, good contacts with distributors are required for export purposes.

Aircraft enclosures

Transparent acrylic sheet enclosures are widely used for commercial and military aircraft; windows, windshields and canopies are examples. These enclosures must meet critical optical and strength standards and be resistant to shattering and crazing. Most of the enclosures are produced from cast sheet that has been stretched. Stretching produces a tougher, craze- and shatter-resistant sheet. Laminates of acrylic sheet are also used by the aircraft industry. However, the lack of a local aircraft industry, combined with the high level of technology required for stretching, all but eliminates this application for developing nations.

3. ECONOMIC CONSIDERATIONS

Prices

The price of acrylic sheet can vary according to gauge, sheet type (cast or extruded), optical properties, colours, size of purchase, end-use (for example, for floor-mats or for architectural applications) and so on.

In the United States in 1971, the list price for one-eighth inch clear acrylic sheet was about 68¢ per square foot. (Assuming a weight of three-quarter pound per sheet, the price per pound was about 91¢). At that time white sheet generally cost about 3¢, and coloured sheet about 10¢ more per square foot. Large-quantity purchases (that is, those of 6,000 pounds or more) were priced at about 41¢ per square foot (54¢ per pound) or even less. However, imported acrylic sheet for certain purposes was available for 45¢ to 50¢ per pound.

In Japan, clear and opaque cast acrylic sheets have been priced at 40¢ to 50¢ per pound, and coloured sheet at from 50¢ to 55¢ per pound. Extruded sheets are quoted at from 15 to 20 per cent less than cast sheets.

In planning to engage in the production of acrylic sheet, the price that must be offered to prospective purchasers to induce them to obtain some of their requirements from this new source must be estimated very carefully. If this is not done, the projected figures for plant income and profits may be unrealistically high. In this connexion, it should be borne in mind that locally produced acrylic sheet normally has a competitive advantage, with respect to transportation costs, over imported sheet.

The price of acrylic sheet is influenced by the price of the monomer (13¢ to 19¢ per pound) from which it is made, and this price has tended to decline in recent years. However, the major purchasers of acrylic sheet are generally aware of reductions in monomer prices, so it is usually necessary to pass such decreases on to them in the form of lower prices.

Many producers of acrylic sheet supplement price inducements with technical and marketing assistance to their customers. This policy gives these producers a competitive advantage over firms that offer only low price.

Investment, equipment and operating costs

This section attempts to summarize the types of equipment and investment needed to establish an acrylic sheet plant. It must be realized that investment will vary substantially owing to many factors, such as the volume of output, the cost of land and buildings, and the cost of equipment (fabricated locally or imported).

Because of the many possible cost differences, the data below attempt only to show a range of possible investment costs. In many countries it will be possible to start operations at lower capital costs by fabricating some or most of the machinery domestically, and because of other factors, such as inexpensive land. It must be stressed, however, that the casting of acrylic sheet is considerably more demanding than most other plastics-producing processes. Therefore, as noted below, great care must be taken in selecting the key equipment, which should be purchased from outside sources rather than produced locally.

Table 3 presents estimates of the requirements for a cast-acrylic plant with a capacity of 500 tons per year. Requirements are shown for land, buildings, equipment and working capital.

TABLE 3. REAL ESTATE AND FIXED CAPITAL REQUIREMENTS FOR A CAST ACRYLIC SHEET PLANT WITH A CAPACITY OF 500 TONS PER YEAR

1. ***Buildings and land*** — 5,000 to 15,000 square feet

Note: The plans for the factory building should provide for electrical power, water, drainage, steam and heating. Also, in addition to the land for the plant itself, 1,000 to 3,000 square feet of land will also be needed for storage of the monomer.

2. ***Equipment*** — $100,000

Boiler
Vacuum system
Syrup kettles
Cold room
Storage and mixing containers
Transfer containers
Glass (plate or tempered) sheets
Clamps
PVC strip or tubing
Glass-handling conveyors
Glass-washing machines
Mould-carrying trucks
Oven(s) and/or water-bath(s)
Saws
Inspection station
Miscellaneous (materials-handling trucks and the like)

Note: Prospective producers should give serious consideration to quality as well as to prices in the purchase of key items such as boilers, glass oven components and saws.

TABLE 3 *(cont.)*

3. *Working capital*		$80,000
Monomer (30 days)	$15,000	
Sheet inventory (15 days)	15,000	
Labour (15 days)	3,000	
Accounts receivable (30 days)	30,000	
Miscellaneous (cash, certain materials)	17,000	

Note: Accounts receivable require particular attention from new producers, since customers in some areas do not pay promptly. Indeed, cases are known where the average length of time before payment is received may be as long as 90 days.

Table 4 presents a partial cost breakdown from an actual acrylic sheet-casting plant with a yearly sales volume of $2.5 million. These costs, shown by type (labour, rent, administration etc.) are given as percentages of total sales. The percentages for raw materials, taxes etc. are not shown. While the actual percentages can vary considerably, this table may be used as a guide to cost identification and the relative importance of specific cost centres.

TABLE 4. PARTIAL COST BREAKDOWN FOR AN ACRYLIC SHEET-CASTING PLANT WITH A SALES VOLUME OF $2.5 MILLION YEARLY

(Per cent of sales dollar)

Direct labour costs		14.8
Mixing	2.0	
Gasket installation	0.3	
Casting	9.0	
Shrinking	0.4	
Masking	0.7	
Trimming	1.5	
Purging (removal of inhibitor)	0.9	
Indirect labour costs		7.7
Supervision	1.9	
Inspection	1.0	
Packaging and shipping	2.3	
Glass processing	0.6	
Maintenance	1.0	
Other	0.9	

Fixed costs		8.0
Rent	2.8	
Production, inventory control	1.1	
Depreciation of equipment	1.6	
Quality control	0.7	
Research and development	0.6	
Property taxes	0.3	
Insurance	0.4	
Other	0.5	
Variable costs		11.0
Mould breakage	3.0	
Shipping supplies	1.4	
Light, heat, power	1.9	
Repairs, maintenance	0.9	
Freight	1.5[a]	
Insurance	0.8	
Taxes	1.0	
Other	0.5	
Selling and administrative expenses		9.1
Selling expenses		
Agents' commissions	1.9	
Salaries: Executives	0.9	
Salesmen	0.6	
Office workers	0.6	
Travel, entertainment	0.5	
Advertising	0.1	
Other	0.2	
Administrative expenses	4.3	
Total		50.6[b]

[a]Assuming that freight charges are often paid by the purchaser.

[b]The remaining 49.4 per cent is made up of raw materials cost (35 to 40 per cent), taxes and profit.

Table 5 presents the capital investment, working capital and manpower needs for acrylic sheet-casting plants of three progressively larger sizes. Inspection of this table reveals that the larger the plant, the lower the per-ton inputs of these three cost elements tend to be.

TABLE 5. INVESTMENT AND LABOUR REQUIREMENTS FOR ACRYLIC SHEET-CASTING PLANTS OF VARIOUS SIZES

Plant capacity (tons/year)	*Capital investment ($)*	*Working capital ($)*	*Manpower needs per year*
50	10,000	10,000	12– 24
500	100,000	80,000	36– 70
1,000	175,000	150,000	65–100

Profitability

The range of profitability in the acrylic sheet industry is very wide. On the low end of the scale, some firms are known to show only a 2.5 per cent profit on sales before taxes, and others as high as 25 per cent. Profitability is strongly influenced by the selling price of the product, the cost of labour (since the production of acrylic sheet is labour intensive) and the control of administrative expenses and selling costs. The interaction of these and other factors is shown in table 6, which is a rough guide of profitability ranges.

TABLE 6. RANGE OF PROFITABILITY IN THE CAST ACRYLIC SHEET INDUSTRY

(Cents per pound)

Selling price	50
Business costs	
Materials	17–20
Labour	4– 8
Plant overhead (with depreciation)	4– 7
Administrative expenses	5– 6
Miscellaneous	7– 8
Total	37–49
Profit (before taxes)	13– 1

Some factors that merit particular attention if profitability is to be maximized are: incorrect materials handling resulting in spillage of the monomer; improper sealing of the moulds, with consequent leakage; poor cure control in the ovens or water-baths resulting in low yields; and excessive breakage of the glass sheets. Many producers of acrylic sheet have experienced drastic reductions in profitability stemming from the last of these factors. Such losses usually can be reduced by the use of tempered glass, even though it is nearly twice as costly as plate glass. Also, some techniques, such as the Rostero process, are based on a fixed-cell principle that reduces handling, and hence breakage.

Sources of information and technology

Firms that are interested in the technology of acrylic sheet production have a large choice of companies from which to seek information. There are small, medium-sized and large producers of this material in various countries throughout the world. It is worthy of note, however, that the large corporations generally charge substantial licence and royalty fees, and that often a small or medium-sized company is able and willing to provide technology and know-how at a considerably lower cost, perhaps on a joint-venture or similar basis. A partial list of producers in various parts of the world is given below:

United States	American Cyanamid	Wayne, New Jersey
	Cast Optics	Hackensack, New Jersey
	Polycast Technology	Stamford, Connecticut
	Rohm & Haas	Philadelphia, Pennsylvania
	Swedlow	Gardena, California
Europe	Imperial Chemical Industries	London, England[1]
	Peterlit	Jarrow, England
	Lenning Chemicals (Rohm & Haas)	London, England
	Stanley	Chichester, England
	Altulor (Ugilor)	Paris, France
	France Peterlite (St. Gobain)	Paris, France
	Dacryl (Altulor)	Paris, France
	Mazzuccheli Celluloid (Fiat)	Varese, Italy
	Impla	Naples, Italy
	Montecatini-Edison	Milan, Italy[1]
	Feldelgas	Milan, Italy
	Chemishe Industrie Polyplastic	Rotterdam, Netherlands
	Casolith, N.V.	Leeuwarden, Netherlands
	Polyplastic	Rotterdam, Netherlands
	Para-Chemie Chem. Fabr. GmbH	Vienna, Austria
	De Gussa–Wolfgang	Hanau, Federal Republic of Germany

[1] Produces extruded sheet also.

Europe *(cont.)*	Resart	Mainz/Rhein, Federal Republic of Germany
	Rohm & Haas	Darmstadt, Federal Republic of Germany
	Bofors	Tidaholmsverken, Sweden
Japan	Asahi Chemical	Osaka
	Kyowa Gas	Tokyo
	Mitsubishi Rayon	Tokyo
	Sumitomo Chemical	Osaka
	Toyo Rayon	Tokyo
China (Taiwan)	Chi-Mei	Tainan
South America	Paskin	Brazil
	Naufal	Brazil
	Plasticos do Brasil	Brazil
Australia	Nylex	Victoria
Israel	Orkal Industries	Haifa

Other names can be supplied by plastics trade groups and by suppliers of methyl methacrylate monomer in various parts of the world. Some of the more important of the latter are listed below:

United States	American Cyanamid	Wayne, New Jersey
	E. I. DuPont de Nemours	Wilmington, Delaware
	Rohm & Haas	Philadelphia, Pennsylvania
Europe	Imperial Chemical Industries	London, England
	Lennig Chemicals	London, England
	Rohm & Haas	Darmstadt, Federal Republic of Germany
	Montecatini-Edison	Milan, Italy
	Ugilor	Paris, France
Japan	Kyowa Gas	Tokyo
	Mitsubishi Rayon	Tokyo
	Mitsui-Toatsu	Tokyo
	Sumitomo Chemical	Osaka

4. THE MANUFACTURE OF ACRYLIC SHEET

Acrylic sheet is normally made either by casting, whereby a thin layer of liquid monomer is cured between two flat sheets of glass, or by the extrusion of an acrylic polymer through a slot die to form a sheet of predetermined thickness. While cast acrylic sheet has superior finish, is tougher and has better solvent-craze resistance than extruded sheet, the latter material is more easily formed into deep-draw parts and is capable of being embossed with a variety of surface patterns during the extrusion operation. Such surface patterns are quite often used in the lighting industry. The extrusion process can also produce shapes other than flat sheets, such as corrugated or channel sections that can be used to enclose lighting fixtures. In the United States, extruded sheet is used most commonly in the lighting industry and in thicknesses up to one-eighth inch. The price of this extruded sheet is normally lower than that of cast sheet of up to one-eighth inch in thickness.

Cast sheet is used in applications such as advertising signs, window glazing, shower doors, building facings, floor mats, sky domes, shop display racks, furniture guards and miscellaneous household items. Many of these items are manufactured from acrylic sheet whose thickness ranges from one-eighth inch through one inch.

Since cast acrylic sheet can be manufactured in a broader range of colours, thicknesses and sizes than can extruded sheets, the emphasis of this report is placed on the casting process.

The casting process

The casting of acrylic sheet involves the preparation of a liquid chemical monomer (methyl methacrylate), which is placed between two sheets of glass separated by a gasket to control the thickness (gauge) of the product. This device (called a mould or cell), with the liquid monomer in it, is loaded on a rack and placed in an air-circulating oven or hot-water bath for a prescribed time to complete the polymerization of the monomer to a hard, clear plastic sheet. A detailed description of the casting process follows.

Methyl methacrylate monomer, the raw material, is a liquid with the following properties:

Boiling point	101°C (214°F)
Specific gravity	0.94
Viscosity (centipoises) at 25°C (74°F)	0.569
Flash point (closed cup)	10°C (50°F)

The monomer is flammable, and its explosive limit is in the range of 2 to 12 per cent in air. It is quite volatile and has a sweet-smelling odour. Personnel working with the material should avoid prolonged contact with high concentrations of the vapour. Indeed, it is not recommended that anyone be exposed continuously to methyl methacrylate vapours in concentrations in excess of 100 parts per million (ppm).

Methyl methacrylate monomer can be obtained from a considerable number of suppliers around the world, as listed in the previous section. It is normally shipped in 55-gallon (430-pound) drums, but it is also available in bulk shipments from some of the larger manufacturers. Methyl methacrylate monomer to be used for casting acrylic sheet should be colourless (much like distilled water) and contain less than 0.1 per cent moisture.

Equipment requirements

A storage area must be provided for the monomer drums. It should be out of direct sunlight and maintained at a temperature below 80°F (27°C), and it should be free from flames, sparks and electric motors. A drum dolly is necessary to move these containers conveniently. The use of grounding cables is recommended when the monomer is discharged from the drums. Stands, valves and drum openers are also necessary.

This monomer is shipped mixed with an inhibitor, in order to prevent the material from polymerizing and hardening in the drum. It is usually necessary to remove this inhibitor in order to cast a satisfactory sheet. It is best to consult with the monomer manufacturer to determine what grades he has available, and the type and concentration of the inhibitor, as well as his recommendation for the removal of this inhibitor.

One popular grade of monomer contains 25 ppm of hydroquinone. This inhibitor may be removed by distillation under vacuum (25 inches of mercury) or by washing with caustic soda. For example, 20 parts of a 5-per cent sodium hydroxide solution are mixed with 100 parts of monomer. The monomer and water separate into two phases, with the inhibitor (hydroquinone) being removed into the bottom (water) phase. The water is drained from the bottom of the separation vessel, and the process is repeated with clean water until all traces of the caustic have been removed. This "purged" monomer is then stored at a temperature of 40°F or lower to prevent polymerization. The caustic washing should be carried out in a vessel made from stainless steel or glass. The monomer may be stored for at least 30 days at this temperature; at 70°F it would be safe to hold the monomer for only about 8 hours. The volume of the monomer, the presence of sunlight, and the presence of impurities of a catalyst type (even iron rust) will shorten the storage life of purged monomer. Rohm & Haas (USA) supplies an ion-exchange resin, called Amberlyst A-27, which can be used to remove hydroquinone inhibitors.

Various suppliers have made available drum quantities of methyl methacrylate monomer with lower inhibitor levels, such as 5 or 10 ppm of hydroquinone. At the

5-ppm level, the monomer could possibly be used without removal of the inhibitor for certain products where very slight colour could be tolerated (for example, edge yellowness in a trimmed, polished sheet). Thus, a factor to be reviewed with the monomer supplier is the use of low levels of inhibitor that are less likely to cause colour problems.

Preparation of the casting syrup

As noted above, methyl methacrylate monomer has a very low viscosity, a characteristic that presents problems in sealing it into casting moulds and in the suspension of pigments, as well as by slowing reactivity. For these reasons, it is usually necessary to convert the monomer to a syrup, although some processes omit this step. This is done by adding a small amount (for example, 0.05 per cent) of catalyst and heating the solution to 90°C under agitation until the viscosity reaches about 1 poise. This syrup is then cooled immediately to about 40°F (4°C).

A casting formulation should contain the following ingredients:

The methyl methacrylate monomer or syrup.

A catalyst such as benzoyl peroxide or azoisobutyronitrile (DuPont), in concentrations of 0.01 to 0.1 per cent. The concentration must be established by the manufacturer and is a function of such factors as sheet thickness, curing temperature and types of pigments used.

A release agent such as stearic acid, at a level of about 0.05 per cent. This level must also be adjusted to suit the process.

An ultraviolet stabilizer is recommended to prohibit the yellowing caused by some ingredients.

The pigments or dyes used to colour cast acrylic sheet should be carefully selected. They should be extremely colour-fast and must be properly dispersed in the casting syrups to attain satisfactory results.

The casting syrup should be mixed in clean mixing vessels. Figure 1 shows the key elements of a small-sized mixing/vacuum vessel. Figure 2 shows a larger unit of the same general kind.

Some materials that are suitable for constructing equipment for handling methyl methacrylate monomer or syrups prepared from it are stainless steel, aluminium, glass, and certain plastics, such as high-density polyethylene and nylon. Carbon steel or galvanized steel also may be used, but care must be taken to avoid rusting, chipping or other surface deterioration that could contaminate the monomer. Copper, brass and bronze are not recommended for use with the monomer, nor is rigid vinyl pipe. Indeed, vinyl should never be in permanent contact with the monomer.

Figure 1. A single-stage mixing vacuum vessel for the preparation of the casting mix

a – inlet suction line (of clear plastic hose); *b* – filter cartridge; *c* – air-driven mixing blade (to prevent explosion of the monomer vapours); *d* – closed vessel, capable of withstanding a full vacuum; *e* – bottom drain line; *f* – grounding wire to prevent static sparking during discharge of the vessel.

Source: Cast Optics Co., Hackensack, N. J.

Figure 2. A mixing vessel capable of treating 400 to 500 pounds of casting mix at a time

It has been mounted on a scale to facilitate batch weighing.

***Source:* Cast Optics Co., Hackensack, N. J.**

Elimination of air from the mix

After the ingredients have been properly blended into the casting syrup, the mix is subjected to a high vacuum (more than 25 inches of mercury). This operation should continue long enough to remove all dissolved air from the syrup. The vacuum step is necessary to prevent the formation of bubbles in the finished cast sheet. The de-aerated mix should next be poured into the mould within a few hours.

Batch mixing

A separate area should be provided for the handling of the raw materials. This area should be clean, well ventilated and equipped with the facilities described below.

A mixing/vacuum vessel (syrup reactor) such as those shown in figure 1 and figure 2 is needed. It should provide for good blending and the convenient addition or removal of materials. It should have a round or conical bottom, a powerful agitator and a sufficiently large number of coils for heating and cooling. It is also advisable to have a second, similar vessel to continue the cooling of the syrup. After treatment in this mixer, the syrup is drawn off into a vacuum tank in a manner that will ensure maximum exposure of the syrup to the vacuum.

Following the vacuum step, the prepared syrup is drained into a container made of glass, metal or plastic, for pouring into the casting cell or mould. At this point the monomer is carefully weighed in accordance with the size and thickness of the sheet to be cast. The weight is calculated on the basis of three-quarter pound per square foot of a final sheet one-eighth inch thick.

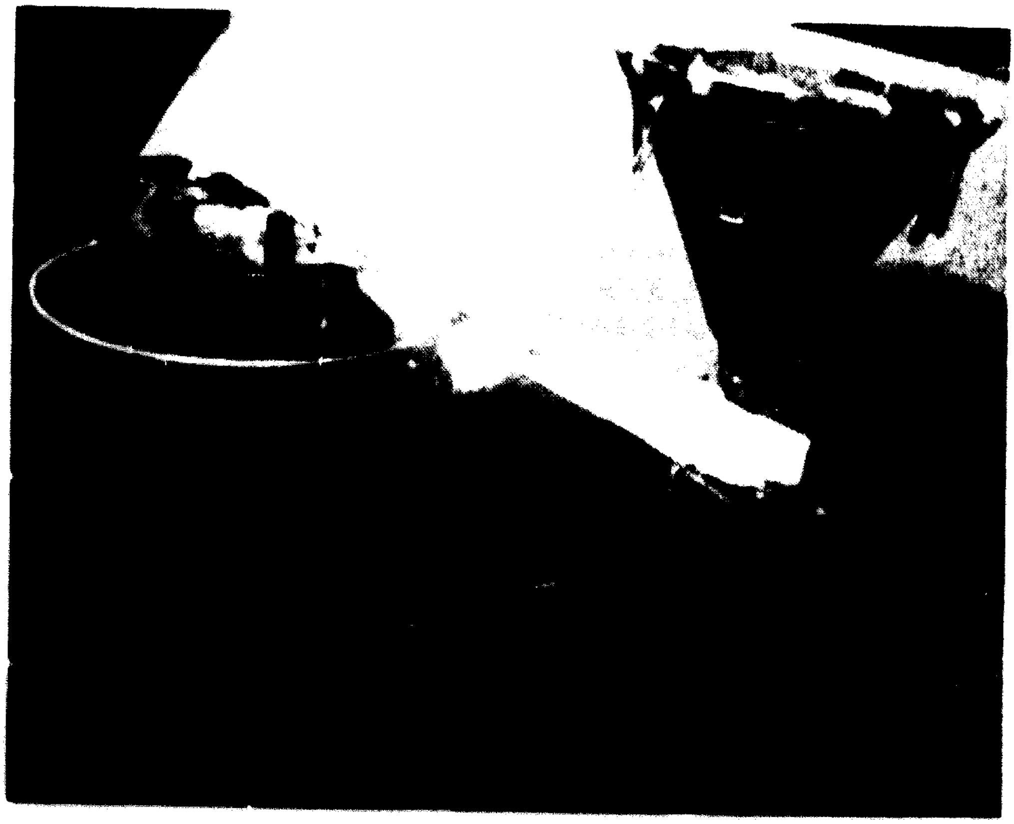
It is advisable to isolate coloured materials from vessels used to produce clear sheet. Separate vessels should be used for coloured sheet. (Colours for casting can be obtained for about $3.00 per 100 pounds.)

Preparation of the mould

As noted above, acrylic sheet is normally cast between flat glass surfaces; a casting mould or cell is made by assembling two sheets of glass to form a cavity of a predetermined thickness between them. The glass must be selected plate or tempered glass, one-quarter to three-eighths inch thick, free of scratches and with bevelled edges. Plate glass is suitable for sheets up to 3 X 4 feet in size made by the air-oven process, but tempered glass is required for the water-bath process and is more suitable for larger sheets such as 4 X 6 feet or 4 X 8 feet. Such glass should be obtained from a source that can supply "casting-quality" glass. Tempered glass is both tougher and considerably more resistant to thermal shock than is plate glass. It costs about $2.00 per square foot.

The glass sheets should be matched carefully so as to construct moulds of uniform cavity thickness; otherwise the acrylic sheet cast between them might have unacceptable variation in thickness. Glass must be handled with great care so as to avoid scratching, chipping or breakage, which can be an important reason for declining profitability, as noted above.

Figure 3. Preparation of a mould ("cell") for casting acrylic sheet



Two sheets of plate glass are separated by a plastic strip (a sample of which may be seen at the upper left) and held together by metal clamps. At the upper right is a specially designed funnel, which adapts to the interior form of the mould, for filling with the casting mix.

Source: Cast Optics Co., Hackensack, New Jersey.

Gaskets. A PVC spacer strip or tube can be used as a gasket to seal the acrylic syrup in the mould and to serve as a thickness gauge (see figure 3). Since the casting syrup shrinks during the curing (polymerization) process, the plastic sealing gasket should be about 25 per cent thicker than the acrylic sheet that is desired.

The formulation of material used to form this sealing gasket is critical, if casting problems are to be avoided. It is best established in collaboration with a local producer of extruded plastics.

Clamps. Clamps are used to hold the mould together. These devices must exert enough pressure to prevent initial leaking and sheet defects during the curing when the syrup shrinks. Figure 3 shows a simple but effective clamp which is manually engaged or removed from the mould. Such clamps are available from stationery suppliers almost everywhere.

The following steps are involved in the assembly of a mould:

Glass washing. After removal of the acrylic sheet made during the previous cycle, the glass sheets may be washed with clean water and by vigorous scrubbing with nylon brushes. Certain soaps or glass-grade pumice may be used, but a final rinse with clear, demineralized water is necessary. Finally the water must be removed from the glass with air or a dust-free cloth. This operation is critical, since dust or water residue left on the glass will mar the surface of the cast acrylic sheet. Elimination of the glass-washing step may result in excessive product contamination.

Mould assembly. It is important to keep the glass aligned so that it will be put back in its pre-matched manner. The casting side of the glass should be kept face-up to avoid marring it on supports or rollers during washing. The two glass sheets are then re-assembled by moving the bottom sheet to the assembly station. Wooden pins are next clamped to the corners of this lower sheet. Next, the upper glass sheet is placed on the wooden pins. This precaution prevents the glass surfaces from touching each other before the gasket has been placed between them. With a special tool, one side of the upper glass sheet is raised slightly higher than the thickness of the gasket, which is then inserted between the two surfaces. This operation is continued around the entire circumference of the mould, save for one corner, which is left open for the filling operation.

As the gasket is inserted, the wooden spacer pins are removed and external clamps are affixed, as shown in figure 3, to keep the gasket in place and hold the mould together. This entire assembly operation must be done with care and in a clean area so as to avoid contamination of the mould and of the sheet cast in it.

Filling the mould

The next step is the pouring of the pre-weighed charge of syrup into the mould. During this operation, the mould must be tilted so that the corner that was left open is at the highest point. The syrup is then poured into the mould through a specially designed funnel that adapts to the inside cavity of the mould, as shown in figure 3.

Special hinged tilt tables should be provided for the pouring operation. The filled moulds are rolled or carried onto them. Here again, care must be exercised to exclude the possibility of foreign matter getting into the syrup or mould.

Also, during the pouring operation, care must be taken to ensure that no air bubbles get into the syrup, and once the syrup has been completely poured from its container into the glass mould, it must be inspected for air bubbles. All air must be allowed to float to the top of the mould.

Next, the mould is tilted to the vertical position, and the syrup rises up to the open corner, expelling whatever air remains within the mould. During this step, the gasket must be inserted between the glass sheets in the place where the pouring spout was, so that only a small (one quarter inch or 1 centimetre) space remains for the escape of the last air. When this has passed, the gasket is then drawn against the other gasket edge to complete the sealing of the mould. Not a single air bubble should remain at this point. The final corner clamps are put in place, and the gasket is cut so that the seal will be secure.

Curing (polymerization)

Depending on the size of the mould, it is then carried or rolled to a truck, loading rack or support frame, the exact conveying method depending upon the process being used. If the sheet is to be polymerized in an air oven, one means of conveying and supporting the moulds is by the use of a multi-shelf truck. Such a truck might hold about 10 moulds with about 3 to 5 inches of space between them to permit air to circulate. This truck must be quite sturdy to support the heavy glass moulds. The shelves should also be designed to permit adequate air flow as well as level support of the glass for good tolerance control. An alternate support technique might be to have the shelves permanently mounted in the oven, but with the individual shelves being capable of being rolled out of the oven through a series of side doors.

Two suitable techniques for polymerization of acrylic sheet are: high-velocity air-circulating ovens and water-baths. The oven process is slower but is somewhat easier to control and is mechanically simpler. A water-bath is simply a pit in which a complete mould can be submerged and maintained at a desired temperature. The water-bath provides better heat transfer than the air oven and thus permits polymerization at higher temperatures, with consequently shorter polymerization cycles. However, this process is rather more delicate than air heating and requires more mechanized equipment, and the clamps and other devices must be made from materials that do not rust. Also, as mentioned above, tempered glass must be used.

In the water-bath process, the mould is normally supported vertically and filled as it is lowered into the water. The cure cycle in this system, for a sheet one-eighth inch thick, would be about 5 hours at a temperature of 65°C (150°F), plus a 1-hour post-cure period at 100°C (212°F) in an air oven. This last step is necessary to complete the conversion of the liquid monomer into a hard, solid sheet. This final step can also be carried out by heating the water-bath to 90°C (194°F), thereby eliminating the need for an air oven. However, some product qualities such as acceptable heat distortion temperature (HDT) may be sacrificed.

The air oven process is probably the safer of the two polymerization techniques for the manufacturer who has had no previous experience in the casting of plastics. A suitable oven design would be a unit about 30 feet long, able to hold three trucks of 6 X 4 foot moulds, and which thus could heat 30 to 40 moulds at a time. The oven should be about 2 feet wider than the trucks and about 5 or 6 feet longer. The inside of the oven should not be much higher than the trucks, so as to ensure maximum air flow between the moulds.

It is necessary to have access to the moulds during the curing step so that it can be ascertained just when conversion has been completed. The oven air would be heated with coils containing a hot fluid or steam. Coils must also be provided to cool the oven, using water. The air circulation in such an oven should be in the range of 500 to 1,000 feet per minute.

5. THE MARKETING OF ACRYLIC SHEET

In some countries, small casting operations have been established at very low capital investment (for example $20,000) to supply local demand. The output of such operations may range from 50 to 100 tons yearly and is used for advertising signs etc.

In other areas, larger operations have been set up, aimed both at supplying local demand previously met by imports and at building and export business. For example, a firm in one country began production in 1960 with technology obtained from another country. As this was written, this firm was casting about 2,200 tons per year of acrylic sheet, worth about $1.8 million. About 20 per cent of its output is sold locally (population of about 15 million), mostly as 3 X 4 feet sheet; the balance is exported to Southeast Asia (60 per cent as 4 X 6 feet sheet and 20 per cent as 4 X 8 feet sheet). Exports have been growing, since local labour costs are from 10 to 20 times lower than in many other countries, a circumstance which permits very competitive prices to be offered. Nevertheless, this firm, like many others, has encountered difficulty in exporting to other areas.

Indeed, a major problem of many producers of acrylic sheet is an inability to export their product to industrialized countries. The quality of the sheet offered may not meet the rather exacting standards and, even when the sheet offered is satisfactory from the quality standpoint, a complex distribution system is needed. Attempts to establish connexions with suitable distributors by mail often fail; personal visits to potential distributors appear to achieve the best results.

Distribution in the United States: an example of marketing problems

Much of the acrylic sheet sold in the United States passes from the sheet caster to a variety of small and medium-sized distributors, which include wholesale sign supply houses, glass distributors and firms that distribute many types of plastic sheet and shapes. One major caster there has more than 150 distributors throughout the country, who in turn supply fabricators. While acrylic sheet seems relatively easy to produce, the difficulty of achieving widespread distribution has limited the number of competing producers.

Direct sales of sheet to large users does not require great distributive abilities. However, the concentration of sales volume at a few large users results in bid pricing and in prices that are too low even for imports.

Because of the extensive technical and sales aids that domestic producers provide to distributors and sheet users (that is, to fabricators and specifiers), plus many other unpublicized but important services, it is difficult for an exporting country to obtain distribution on the basis of price alone.

It is likely that the same types of problems will face firms that attempt to export to countries that have complicated distribution networks. In one case a developing country established an arrangement with an existing acrylic sheet producer in a large sheet-consuming country whereby the sheet was exported and distributed by the producer, who already had a strong selling organization and who could import the sheet more cheaply than it could be made locally. This approach can be a good short-term export programme but should the programme be discontinued, the exporter would have to find a new outlet for his sheet.

Quality requirements and standards

New producers of acrylic sheet who are interested in exporting their output must determine the minimum quality standards of the prospective importers. Around the world, there are wide differences in acceptable quality. In some countries, for example, the minimum acceptable heat distortion temperature (HDT) is 85°C while lower values are permitted elsewhere. In the United States, a range between 85° and 100°C is permitted, with many firms striving to attain the upper limit. The HDT of acrylic sheet is a function of production-cycle time, the catalyst used etc., all of which are related to the process that is employed. Consequently, the choice of the production process can affect a producer's ability to export his product to some countries.

Some performance tests for acrylic sheet that should be understood by new producers are the ASTM standards, which are used in the United States. They are listed in table 7. Similar data can be obtained for other major importing areas such as Europe and Japan.

TABLE 7. ASTM STANDARDS FOR ACRYLIC SHEET

Property	*ASTM test*[a]
Tensile strength	D 638
Flexural strength	D 790
Izod impact rating	D 256
Hardness	D 785
Optical	D 1003, 1223
Thermal (HDT)	D 648
Deformation under load	D 621

[a]Information on the ASTM standards may be obtained from the American Society for Testing Materials, 1916 Race Street, Philadelphia, Pa. (19103), USA.

Gauge control is a very critical aspect of acrylic sheet quality in many markets. In the United States, for example, acrylic sheet for military use may require a gauge variation as small as 0.015 inch; in commercial applications it may vary from 0.085 to 0.155 inch for large sheets and from 0.095 to 0.145 inch for the smaller sizes, such as 3 X 4 feet.

Product mix

Before setting up any plant for casting or extruding acrylic sheet, it is of critical importance to determine the range of product sizes that are to be offered on the market. In this connexion, it is important to note that the standard dimensions of acrylic sheet vary from country to country. This information is needed to permit the correct selection of important items of capital equipment such as casting cells and extrusion dies.

6. ACRYLIC SHEET TECHNOLOGY

Analysis of acrylic sheet production facilities in various countries shows a variety of production approaches, for example:

Production of cast sheet, using a relatively simple and inexpensive self-developed process;

Production of cast sheet, using acquired technology;

Production of both cast and extruded sheet or of extruded sheet alone;

Production of cast sheet, utilizing more than one process;

Other combinations.

These variations depend largely on the specific markets that a given firm is attempting to reach. Table 8 shows the sources of the technology for casting acrylic sheet in two major producing countries.

TABLE 8. SOURCES OF TECHNOLOGY FOR CASTING ACRYLIC SHEET IN JAPAN AND THE UNITED STATES OF AMERICA

	Sources of technology[a]
Japan	
Asahi Chemical (Delta Plastics)	Rohm & Haas
Kyowa Gas	Rostero
Mitsubishi Rayon	Original
Sumitomo Chemical	Imperial Chemical Industries
Toyo Rayon	Resart Gesellschaft and original
United States	
American Cyanamid	Imperial Chemical Industries
Cast Optics	Original
DuPont	Original (not producing sheet)
Polycast Technology Corp.	Original
Rohm & Haas	Original
Swedlow	Original

[a]In some cases, licensing firms have used acquired technology to supplement or improve upon their own processes.

While suppliers of raw materials may help prospective new producers of acrylic sheet to find suitable technologies, it should be borne in mind that some of these suppliers also cast sheet and are thus potential competitors. Also, while the larger corporations in the more developed countries may also be good sources of technical information, a firm or country that seeks a relatively simple process at a minimal investment is more likely to obtain a suitable one from the small to medium-sized firms that have developed their own processes.

Recent changes in technology

The most important change in acrylic sheet technology has been the development of the continuous sheet-casting processes. It was first introduced by Swedlow, Inc. (Gardena, California, USA) in the mid-1960s. Rohm & Haas announced a continuous process in 1969, and several other firms are likely to follow. The advantages of continuous casting include uniformity of thickness and the availability of rolls or sheets in almost unlimited lengths. However, the optical properties of this material are not as good as those of cell-cast sheet.

Most of the sheet produced by continuous processes will probably be used for outdoor advertising signs where optical clarity is not usually required. The pricing of continuously cast sheet has been competitive with or, in many cases, cheaper than that of cell-cast sheet.

This technology will have an impact on markets in countries where acrylic sheet is well established, especially for advertising signs. It is not likely, however, to be used in developing countries for many years, as the costs of licensing or local development are prohibitive.

Another development that already has found commercial application involves technologies that reduce the time and cost of converting the liquid monomer to sheet polymer. One such process produces sheet directly from the monomer by the use of a stationary, fixed, plate-glass cell that does not require washing etc. between cycles. The entire operation is conducted in one temperature-controlled oven, with the costs of labour, space and glass damage all being reduced. Reportedly, the production cycles have been speeded by fluid cooling of the permanent casting units. The elimination of several steps and the use of only one oven lessen space requirements. Also, labour costs may be as much as 25 per cent lower than with other processes. Licensing costs for this process are about $100,000, depending upon installed capacity, and royalties on sales are 3 per cent.

Obtaining technology for acrylic sheet extrusion

Europe has placed greater sales emphasis on extruded acrylic sheet than has either the United States or Japan. For example, in Europe in 1966 about 35,000 tons of cast sheet were produced, and 9,000 tons of extruded sheet, or about 20 per cent of total production. In contrast, in 1968 Japan manufactured only 600 tons of extruded sheet, which was only about 3 per cent as much as the nearly 20,000 tons of cast sheet produced in that year. In the United States, extruded sheet production accounts for about 5 per cent of total acrylic sheet usage. It is expected that extruded sheet will represent more than 30 per cent of European production by the early 1970s.

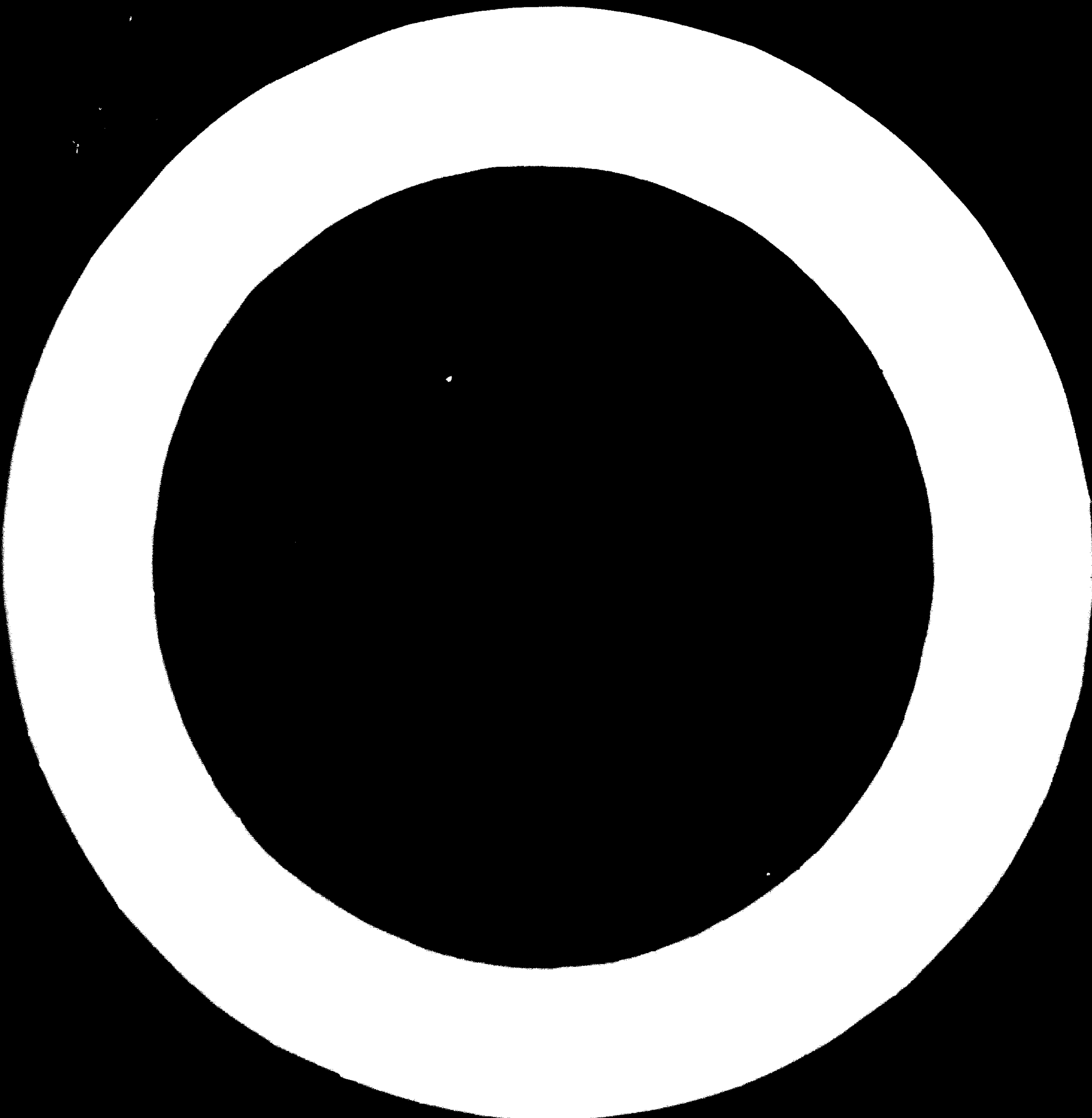
The acquisition of technology for extruding acrylic sheet is less difficult than obtaining casting know-how. Marketing opportunities are, however, likely to be considerably less. Suppliers of the polymeric extrusion pellets can provide some help, as can equipment manufacturers. Because of Europe's extensive plastics extrusion experience, firms such as Montecatini and Imperial Chemical Industries, as well as several smaller firms, can be contacted.

The advantages of producing extruded sheet are largely based on the lower capital cost of entering the business. A company that already has extrusion equipment may be able to produce acrylic sheet without substantial outlays. Even a firm starting from the beginning will probably have to spend less over the long run to set up an extrusion plant than for a casting operation which, as we have seen, requires monomer-handling equipment, glass, ovens etc. Establishing an extrusion line is not cheap, however; fixed costs can easily total $100,000 or even more.

It is somewhat easier to produce acrylic sheet by extrusion than by casting, since polymer pellets for extrusion are available commercially. However, the qualities desired in the finished sheet must sometimes be tailored into the pellets by the supplier. Equipment alterations may be needed as well.

An advanced technology for producing extruded sheet directly from the monomer rather than from polymer pellets has been announced by Imperial Chemical Industries. This new process is reported to yield a product that falls between cast and extruded acrylic sheet as regards quality and, probably, cost.

As noted earlier, the advantages of lower capital cost and ease of starting production of extruded sheet are offset by the limited market for this material in many areas. It cannot, for example, compete with optically clear cast sheet in many applications, and it thus tends to be specified for less demanding, lower-priced products. In some countries, extruded sheet may satisfy a large portion of local needs, but export markets may be more difficult to penetrate, since individual markets in large sheet-consuming areas such as the United States are small, hard to find and probably supplied at low prices by local extruders.



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