METHOD FOR MANUFACTURING
ROTATION-SYMMETRIC ARTICLES
BY CENTRIFUGAL CASTING

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ABSTRACT

The invention concerns centrifugal casting of articles which solidify either by a chemical reaction or by physical solidification, wherein a cast liquid is brought into contact only with at least one shaping liquid, or, if desired, also with a gas phase, at least one of the shaping liquids being specifically heavier and the other shaping liquid or liquids being specifically lighter than the cast liquid, all the liquids forming a sharp boundary with each other. Thus, any contact of the cast liquid with a solid phase such as with the wall of the rotating container is excluded and the cast article is shaped only by centrifugal force, gravity and surface tension.

8 Claims, 9 Drawing Figures
METHOD FOR MANUFACTURING ROTATION-
SYMMETRIC ARTICLES BY CENTRIFUGAL
CASTING

It was known to mold various objects by centrifugal casting, such as, for example parabolic mirrors from epoxy resins and hydrogel contact lenses from monomer mixtures capable of three-dimensional polymerization. In all known cases, the cast liquid is shaped not only by centrifugal force, gravity and surface tension, but also by contact with a concave mold. All attempts to use a bearing liquid as a "mold" instead of a concave solid mold failed. The product was either irregular or formed a parabolically curved sheet with both surfaces roughly parallel to each other. Attempted lens manufacture was never successful by the known methods. It was only possible to shape first a concave mold by centrifugal casting so that a thin slurry of plaster of paris solidified during the spinning of a solid container. Then an epoxy resin or similar material was centrifugally cast in the mold thus obtained.

All known processes of the above mentioned kind have the common feature that a phase boundary between the cast liquid (e.g. a monomer mixture) and a solid phase exists, either on the whole bottom surface or, at least, on the edge. If the mold is solid, the cast liquid forms, when spun around the vertical axis of the mold, a concave top surface which is near to an ideal paraboloid if the diameter of the mold is large and the surface tension is low. In such cases, only the border is markedly deformed by surface tension. According to the acknowledged theory, the shape of the rotating surface is not explicitly dependent on the specific weight of the liquid.

It can be deduced from the above mentioned discussion that the shape of the surface of a rotating liquid may be influenced mainly by the angular velocity of the mold, by the surface tension of the liquid (which may be changed within narrow limits only) and by the size of the product. The size is, however, predetermined, and the possibility of choosing the shape of the surface is practically restricted to more or less exact paraboloids. This is disadvantageous.

Another shortcoming of the known methods mentioned above is a sometimes rather difficult separation of the cast product from the mold surface. If the product may be swelled or deswelled after the finished polymerization casting as it is the case with glycol methacrylate contact lenses formed by polymerization outside equilibrium swelling, (i.e. either in absence of swelling liquids, or in presence of an insufficient amount of the same bellow the equilibrium value, or, eventually, in presence of a water-miscible liquid in an amount above 40 percent by volume so that the article deswells when washed in water), then the separation from the mold is easy. In other cases, however, the separation is so difficult that either the article or the mold or both are often damaged or destroyed. This results particularly when a separation layer cannot be used because a very smooth, regular surface is required. Even if separation by swelling is possible, it may be disadvantageous when the product is to be dried again for subsequent treatment.

Another disadvantage of the known methods using solid molds is the high price of the molds which have to be very accurately made or shaped. In addition, the molds are often damaged and the quality of the casting is gradually decreased. The molds must be carefully cleaned and it is necessary to keep a wide and varied assortment of molds in sufficient numbers which may be very high, as for example, where the molds are to be used in the manufacture of contact lenses. Some shapes of molds, such as paraboloid or hyperboloid ones, are manufactured with difficulty and are thus expensive. It is to be noted, however, that paraboloid concave molds are particularly desirable for making contact lenses.

It has now been found that the seemingly unavoidable presence of a boundary between the cast liquid and a solid phase, i.e. with the wall of the mold, results in many drawbacks when a specifically heavier liquid is used as the paraboloid bottom of the mold. If any contact of the cast liquid with any solid phase is avoided, then, according to the invention, all deformations of the desired shape are removed. It is then, surprisingly, possible to obtain any rotation-symmetric shape of a lens or similar article, with any desired dioptic value in the plus and minus regions, provided that the cast liquid, e.g. a polymerizing mixture, is from the beginning in contact only with the liquid phase or, if desired, also with a gas phase.

In attempts to obtain such articles by pouring a solution of a polymer in a volatile solvent onto a paraboloidal surface of a rotating liquid immiscible with the polymer solution, the obtained article is not a lens but a curved sheet with both surfaces geometrically very similar to each other, so that no dioptic values substantially distinct from zero are achieved.

In the present process, different dioptic values are achieved mainly by properly choosing the amount of the cast liquid with respect to the bearing (shaping) liquid and the revolutions per minute. Avoiding any contact between the cast liquid and the wall of the rotating container is established easily by lighting the rotating system from above and observing or photographing it from the side, preferably against a dark background. Generally, the shaped liquid does not contact the wall of the container if the interphase energy on the boundary between the cast liquid and another immiscible shaping liquid or surrounding gas phase is approximately equal to potential energy of the cast liquid in the gravitational and centrifugal fields, and if the amount of the cast liquid is sufficiently low so as not to reach the solid wall at the chosen revolutions. The limits of the utilisable amount of the cast liquid at given rotational speed, or the limits of revolutions per minute at given amount of the cast liquid may be easily determined by said method.

A very interesting phenomenon can be seen if the cast liquid either by itself or together with the specifically heavier shaping liquid is covered by a layer of another, specifically lighter liquid forming a sharp boundary with both of them. The third liquid which may or may not be in contact with the solid wall of the rotating container, makes it possible to shape the upper surface of the cast liquid to extremely high negative and positive dioptic values (see FIG. 4 to 9.). FIG. 6, 7 and 9 show clearly that the specifically lightest top liquid is thrown by centrifugal force to the wall of the rotating container, while the cast liquid is surprisingly pushed down to the center of rotation proportionally with the amount of the top shaping liquid.
The method according to the invention is illustrated in annexed drawings, where \( g \) is gas phase, \( s \) is solid phase, i.e. the wall of the rotating container, \( L_1 \) is the specifically heavier bearing liquid, \( L_2 \) is the cast liquid (monomer mixture, melt or similar), \( L_3 \) specifically lighter shaping liquid, \( D \) signifies the diameter of the cast article, e.g. a contact lens, \( D' \) the diameter of the rotating container, which does not have the function of a mold, and \( X \) is the sagittal depth.

FIG. 1 shows the typical situation of shaping by centrifugal casting according to the invention.

FIG. 2 illustrates the surface of the bearing bottom liquid alone, prior to adding the cast liquid;

FIG. 3 shows the failing experiment according to the prior art, the cast liquid being in contact with the wall of the rotating container.

FIG. 4 shows the case where further, specifically lighter shaping liquid is added in a small amount. The meaning of further drawings will be explained in the following text.

It is possible, according to the invention, to manufacture by centrifugal casting various articles having rotationally symmetric shape, bounded by two or more contunuate and defined planes generally different from each other, the intersection of said planes being also fully defined and rotationally symmetric round the same axes like the bounding planes, without using any mold at all. As a matter of fact, the system cannot be considered a liquid mold either because the shape of all phase boundaries is variable and mutually influenced as will be shown in the following disclosure. In absence of any contact of the centrifugal-cast liquid with a solid phase which is often wetted but with difficulty, the edge of the cast article such as a contact lens is absolutely even and round, provided of course that no solid impurities are contained in the whole system of liquids. The impurities, if any should be present would be accumulated on the boundaries. Preferably a non-aqueous, undiluted monomer mixture is used in practising the invention so that a hard solid article is obtained immediately and is capable of being mechanically worked e.g. by brushing or polishing, if desired. For that purpose, a transient deformation, such as planarization above the glass transition temperature, can be carried out immediately without drying. The lens is absolutely free of spherical distortion, its both main surfaces being paraboloid. The necessity of manufacturing and storing a large number of exact molds is avoided. The separation of the cast articles is extremely easy because they float on the surface of the bearing liquid. The cast liquid may be diluted, if desired, with water or glycerol, provided that the diluents are immiscible with the shaping liquids. The contact of the cast liquid with the shaping liquid or liquids aids in dissipating the polymerization heat as well as the heat necessary to decrease the enthalpy. Thereby, any occurrence of bubbles and vacuum voids is avoided. The polymerization takes place at such homogeneous, uniform conditions that the material can relax easily without any internal stresses or deformations, particularly when the article is small. The relaxation is not disturbed by adhesion to a solid wall as it is the case of all known processes of centrifugal casting.

The performing of the process according to the invention is by no means confined to empirical determination of the conditions which make the manufacture of predetermined exact shapes rather difficult. It is possible to compute any desired shape of a cast article on the basis of usual and sufficiently exact measurements as will be exemplified in detail. For better orientation following symbols will be used:

Solid phase \( s \), and gas phase \( g \) occur in all of the considered systems as a single species so that no index need be used. Since there is more than one liquid phase in each system, they will be marked in accordance with specific weight, subscript with indices 1, 2 and 3 the heaviest liquid having index 1; All parameters of these liquids will be marked with corresponding indices. Interphase boundaries will be denoted as \( S-L_1 \), meaning boundary between solid phase and the heaviest liquid, or \( L_1-L_2 \), meaning boundary between the heaviest shaping liquid and the cast liquid etc. The same symbols will be used in corresponding drawings. Further symbols are:

- \( \rho_i = \) specific weight of a liquid or g = surface tension or energy of a surface unit of the same liquid,
- \( \omega = \) gravity acceleration,
- \( \alpha = \) angular velocity of rotation,
- \( V_1 = \) volume of a liquid,
- \( D' = \) characteristic size of the rotating container,
- \( \xi \) = any length size of the cast article (e.g. if the article is a lens, then \( X = \) sagittal depth, \( t = \) central thickness, \( r_1 = \) external central curvature, \( D_l = \) lens diameter bounded by the boundary \( L_1-L_2 \), \( D_2 = \) another diameter in a system of three liquid phases, bounded by the intersection of boundaries \( L_2-L_3 \) and \( L_2-g \).

An example for a system of two liquid phases is shown in FIG. 1. Examples for 3 liquid phases are illustrated in FIGS. 4 to 9.

The method according to the invention may be carried out in a system of two liquid phases, the specifically heavier liquid being the shaping (or bearing) liquid, the lighter liquid being the cast liquid. According to FIG. 1 there are four interphase boundaries \( S-L_1 \), \( L_1-L_2 \), \( L_2-g \) and \( L_1-g \). The cast liquid \( L_2 \) forms a body with boundaries \( L_1-L_2 \) and \( L_2-g \), having different shapes. The boundary \( L_1-L_2 \) is deformed by the weight of the cast liquid \( L_2 \), and as the height of the liquid column varies in different diameters, the shape of the boundary is substantially different from that of the boundary \( L_1-g \) (FIG. 2) without the cast liquid. Said boundary \( L_1-L_2 \) is further deformed by the influence of interphase energy.

For the above stated case of two liquid phases any length size \( \xi \) of the formed article may be expressed as critical dependence on other variables, e.g.,

\[
\left( \frac{\xi}{D} \right) = \frac{A_1}{\xi_0 \gamma \sigma^\beta} \left( \frac{\omega D'}{\gamma} \right)^\alpha \left( \frac{\omega D'}{\gamma} \right)^\beta \left( \frac{\omega D'}{\gamma} \right)^\gamma \left( \frac{\omega D'}{\gamma} \right)^\delta \left( \frac{\omega D'}{\gamma} \right)^\epsilon
\]

where \( A_1, a, b, c_1, d_1, e_1 \) are constants for a freely chosen simplex (\( \xi / D' \)), said constant being generally different for different simplexes. If the experimental conditions are changed so that the value of the simplex (\( D_1/D' \)) reaches 1, the phase boundary \( L_1-g \) ceases to exist, while a new boundary \( L_2-g \) is formed. By this change of boundaries the distribution of energies for single components is changed abruptly, the sum of energies remaining constant. The shape for (\( D_1/D' \))1 is shown in FIG. 3, where \( D_l \) signifies double distance of the intersection \( L_1-L_2 \) from the axis of rotation. It is clear that in
this case the considered intersection is but an interpreted one, obtained by interpolation of sections of the two surfaces. At such conditions the two bounding surfaces are abruptly changed to mutually similar surfaces, approaching ideal paraboloids. From the above it is clear that the condition limiting the applicability of the new method could be also expressed

\[ \frac{D_1}{D'} = 1. \]

Since in the above described case of two liquid phases the shape of the two surfaces may be changed by changing seven mutually independent parameters, it is apparent that the possibility of choosing the shape of the surfaces is considerably higher than in the case of centrifugal casting in a solid mold, where the outer convex surface is defined by the shape of the mold bottom and the shape of the concave surface is influenced by angular rotation velocity and surface tension.

In the case of three liquid phases the situation is considerably more complicated and articles having widely varying shapes may be obtained, for example articles bonded by three different surfaces, or by two surfaces with opposite first curvature (biconvex lenses) and the like. If, for example, onto the cast liquid L₄ another shaping liquid L₃ is poured in a small amount, a shape shown in FIG. 4 is obtainable, bounded by phase boundaries L₁-L₂, L₃-L₄ and L₆-g.

By increasing the amount of L₃, i.e. the value of V₃, it is possible to reach the state illustrated in FIG. 5, where the cast liquid is bounded by boundaries L₁-L₂ and L₁-L₃, where the boundary L₆-g has just disappeared and L₁-L₃ is not yet formed.

In FIG. 6 there is shown the shape obtained by further increasing V₃, where the cast article is bounded by boundaries L₁-L₃, L₁-L₄ and L₁-g, having of course an entirely different shape from that shown in FIG. 4 because the boundary L₁-g disappeared and new boundaries L₁-L₃ and L₁-L₄ are formed.

If V₃ is further increased the parameters are changed continuously till to the moment when the boundary L₁-g disappears. At that moment the shape is abruptly changed again to the situation shown in FIG. 7. From the above Examples it is clear that the possibilities of choice are very broad. Besides the parameters stated in the case with two liquid phases, there are further possible variables, namely L₆, β₃ and V₃. The system may be equally described by a similar criterial equation as in the case of two liquids.

The criterial equation for three liquid phases may be put e.g. as

\[ \left( \frac{\xi}{D'} \right)^{2/3} = A_2 \frac{V_2}{D'^{4/3}} \left( \frac{V_3}{D'^{4/3}} \right)^{2/3} \left( \frac{\xi_2}{\xi} \right)^{2/3} \]

\[ \left( \frac{\xi_3}{\xi} \right)^{2/3} \left( \frac{\beta_1}{D'^{2/3}} \right)^{2/3} \left( \frac{\xi_1}{\xi_2} \right)^{2/3} \left( \frac{\beta_3}{D'^{2/3}} \right)^{2/3} \left( \frac{\xi_3}{\xi_2} \right)^{2/3} \]

Even here the limiting condition is that no phase boundary must be formed between the cast liquid and the solid wall of the container. The same holds for the case of more than 3 liquids. This means that the number of boundaries s - L must be always lower than the number of liquid phases. In other words the simplex (D₁/D') must be always lower than 1, or, in the extreme case, it can equal 1. With 3 liquid phases and (D₁/D') > 1 the undesirable situation arises shown diagrammatically in FIG. 8, where the shapes of the L - L boundaries are geometrically similar.

The cast liquid may be of various kind, such as monomeric styrene, methyl methacrylate, glycol methacrylate, glycidyl methacrylate, diglycol diallyl dicarbonate or similar monomers or mixtures of monomers capable of copolymerization to form optically homogeneous transparent bodies, filled with polymerization initiators, cross-linking agents, solvents, diluents, dyestuffs, drugs and other admixtures, according to the desired result. It is possible to use prepolymer of the above mentioned or other monomers, further liquid reactive resins, molten polymers, molten inorganic glasses or other liquids capable of solidifying by changing temperature or inducing a chemical reaction. The nature of the process indicates that the method of the invention is particularly advantageous for making contact lenses or lenses for optical instruments of various kinds, lenses for spectacles and the like.

The bottom shaping liquid L₄ may be chosen from concentrated solutions of inorganic and organic salts, molten salts, metallic mercury, gallium, low melting alloys and the like.

As the top shaping liquid L₄ for instance paraffin oil, silicone oil or similar materials may be used. The choice is determined by the necessity of forming a sharp boundary with the monomer mixture or melt (L₂). Simultaneously, the surface tension and density must be consistent with the conditions derived from the corresponding equations for the intended shape of the product.

Neither the bottom bearing liquid nor the top shaping liquid must interfere with the polymerization or deteriorate the quality of the cast article in any undesirable way, such as by causing bubbles, staining, retardation or inhibition of polymerization etc. The parameters of the adjuvant liquids may be changed in various manners, such as by changing temperature, concentration of dissolved salts, using eutectic mixtures of salts or metals, adding surface active agents etc.

The shape of the cast article in the process of the invention does not depend on the chemical composition of the cast liquid but only on the physical parameters of the system. Thus, the illustrative experiments were carried out always with the same cast liquid in order to secure reproducibility and to show differences in a clear uncomplicated way. The cast liquid employed was ethylene glycol monomethacrylate containing 0.4 percent of ethylene glycol dimethacrylate as cross-linking agent and 0.3 percent of di-isopropyl perchlorate as polymerization initiator. The polymerization lasted 25 minutes at 60°C under a pure nitrogen atmosphere. The results stated in the Examples were obtained by evaluating the photostatic copies of the rotating system with the still liquid monomer mixture. The evaluation was corroborated by measurements of solid cast articles. The differences corresponded to the shrinkage caused by cooling to room temperature and by polymerization.
The values of the specific weight (density) \( \zeta \) and surface tension \( \beta \) were measured at 25° C. The significance of the symbols used in the following Examples is the same as in the preceding text and in the drawings. All percents are meant by weight, if not stated otherwise.

**EXAMPLE 1**

A mixture of ethylene glycol monomethacrylate with 0.4 percent ethylene glycol dimethacrylate and 0.3 percent di-isopropyl percarbonate was cast at 28° C and 423 revolutions per minute in a glass container having internal diameter \( D' \) of 14.5 mm. As bearing liquid \( L \), an aqueous solution of potassium dihydrogenphosphate \( KH_2PO_4 \), density \( \zeta = 1.643 \) (25° C) and surface tension \( \beta = 78.6 \text{ dyn/cm} \) was used. The surface tension of the monomer mixture was 37.6 \text{ dyn/cm}, its density \( \zeta = 1.03 \), both measured at 25° C. The volume of the bearing liquid \( V_1 = 3.5 \text{ ml} \), of that of the cast liquid \( V_2 = 0.066 \text{ ml} \).

Obtained lens was of the type shown in Fig. 1 with following parameters: \( D_1 = 10.0 \text{ mm}, r_1 = 7.9 \text{ mm}, r_2 = 14.5 \text{ mm}, t = 1.58 \text{ mm}, X = 0.67 \text{ dioptric strength} +28.4 \text{ Diopeters}.\)

**EXAMPLE 2**

The shaping was carried out with the same bearing and cast liquids as in Example 1, at equal temperature but at 465 r.p.m. At \( D' = 14.5, V_1 = 3.5 \text{ ml}, V_2 = 0.067 \text{ ml} \) a lens of the type shown in Fig. 1 was obtained having following parameters: \( D_1 = 10.8 \text{ mm}, r_1 = 7.9 \text{ mm}, r_2 = 11.15 \text{ mm}, t = 1.22 \text{ mm}, X = 1.31 \text{ dioptric strength} +19 \text{ D}.\)

**EXAMPLE 3**

The process according to Example 1 was repeated except that rotation velocity was 501 r.p.m., and \( V_2 \) amounted to 0.11 ml. The obtained lens of the same type and had following parameters: \( D_1 = 14.2 \text{ mm}, r_1 = 8.4 \text{ mm}, r_2 = 8.8 \text{ mm}, t = 1.19 \text{ mm}, X = 2.88 \text{ dioptric value} +5 \text{ D}.\)

**EXAMPLE 4**

The same monomer mixture as in Example 1 was centrifugally cast at 379 r.p.m. and +28° C in the same container on an aqueous kitchen salt solution with density \( \zeta = 1.208, \text{ surface tension } \beta = 85.2 \text{ dyn/cm}. V_1 \) was 3.5 ml, \( V_2 = 0.108 \text{ ml}, D' = 14.5 \text{ mm}. \)

The obtained lens of the type shown in Fig. 1 had following parameters: \( D_1 = 14.0 \text{ mm}, r_1 = 10.7 \text{ mm}, r_2 = 11.6 \text{ mm}, t = 0.94 \text{ mm}, X = 2.23 \text{ mm} \) and dioptric value \(+4.3 \text{ D}.\)

**EXAMPLE 5**

Monomeric mixture of Example 1 was cast at 28° C and 423 r.p.m. on the surface of an aqueous sodium sulphate solution, density \( \zeta = 1.127, \text{ surface tension } \beta = 75.6 \text{ dyn/cm}. \)

At the volume \( V_1 = 3.5 \text{ ml}, V_2 = 0.045 \text{ ml} \) and \( D' = 14.5 \text{ mm} \) a lens of the type shown in Fig. 1 was obtained, having \( D_1 = 10.6 \text{ mm}, r_1 = 0.0 \text{ mm}, r_2 = 8.9 \text{ mm}, t = 0.53 \text{ mm}, X = 1.45 \text{ mm} \) and dioptric strength \(+7.2 \text{ D}.\)

**EXAMPLE 6**

Monomeric mixture of Example 1 was cast at 28° C and 379 r.p.m. on the surface of an ammonium sulphate solution, \( \zeta = 1.127, \beta = 89.1 \text{ dyn/cm} \) (25° C).

At \( V_1 = 3.5 \text{ ml}, V_2 = 0.065 \text{ ml} \) and \( D' = 14.5 \text{ mm} \) a lens of the type shown in Fig. 1 was obtained, having following parameters: \( D_1 = 13.9 \text{ mm}, r_1 = 11.2 \text{ mm}, r_2 = 11.7 \text{ mm}, t = 0.56 \text{ mm}, X = 2.12 \text{ mm} \) and dioptric value \(+2.6 \text{ D}.\)

**EXAMPLE 7**

The shaping was carried out like in Example 6 except that the container was spun at 465 r.p.m. and the volume \( V_2 \) amounted to 0.1 ml. The obtained lens was of the type shown in Fig. 1 and had following parameters: \( D_1 = 13.8 \text{ mm}, r_1 = 9.4 \text{ mm}, r_2 = 9.85 \text{ mm}, t = 1.05 \text{ mm}, X = 2.95 \text{ mm} \) and dioptric power \(+3.8 \text{ D}.\)

**EXAMPLE 8**

To the system described in Example 1 there was added 0.018 ml of paraffin oil, density \( \zeta = 0.91 \) and surface tension \( \beta = 32.5 \text{ dyn/cm}. \)

The obtained lens was of the type shown in Fig. 4, with \( D_1 = 11.45 \text{ mm}, D_2 = 9.35 \text{ mm}, r_1 = 8.0 \text{ mm}, r_2 = 8.9 \text{ mm}, t = 0.84 \text{ mm}, X = 1.425 \text{ mm, dioptric power} +8.2 \text{ D}.\)

**EXAMPLE 9**

To the system according to Example 1 there was added 0.071 ml of paraffin oil of the quality indicated in Example 8. The obtained lens was of the type shown in Fig. 5, with \( D_1 = 10.2 \text{ mm}, D_2 = 7.95 \text{ mm}, r_1 = 7.95 \text{ mm}, r_2 = 6.1 \text{ mm}, t = 0.98 \text{ mm}, X = 1.27 \text{ mm, dioptric power} -14 \text{ D}.\)

**EXAMPLE 10**

To the system of Example 1 there was added \( V_3 = 0.325 \text{ ml} \) of paraffin oil according to Examples 8 and 9. The lens corresponded to Fig. 6 and had following parameters: \( D_1 = 8.45 \text{ mm}, D_2 = 2.64 \text{ mm}, r_1 = 7.7 \text{ mm}, r_2 = 3.75 \text{ mm}, t = 2.45 \text{ mm}, X = 0.17 \text{ mm, dioptric power} -51 \text{ D}.\)

**EXAMPLE 11**

To the system according to Example 1, 0.43 ml of paraffin oil like in Example 8 was added. The obtained lens was of the type shown in Fig. 7 and \( D_1 = 8.45 \text{ mm}, r_1 = 7.1 \text{ mm}, r_2 = 14.1 \text{ mm}, t = 2.54 \text{ mm} \) and dioptric power \(-94 \text{ D}.\)

Further Examples only illustrate suitable shaping and cast liquids, the parameters of the obtained lenses not being measured.

**EXAMPLE 12**

The cast liquid employed is glycol methacrylate and the procedure was as in Example 1, the bottom shaping liquid being aqueous sodium chloride solution like in Example 4. At 501 r.p.m. and \( V_2 = 0.032 \), the cast liquid was driven to the wall of the container. The situation corresponded to that shown diagrammatically in Fig. 3. The obtained casting was irregular, with rough-jagged edge, irregular thickness and non-circular shape.

**EXAMPLE 13**

A container having diameter \( D' = 57 \text{ mm} \) was filled up with distilled water, heated to 90° C and spun at 612 r.p.m. Then 16.7 ml of melted paraffin was poured onto
the water surface and the spinning continued until the temperature has sunk to 25°C, then the rotation was stopped. The obtained lens-like casting had a sharp edge and a smooth surface. It was suitable as a positive mold.

**EXAMPLE 14**

A container with diameter $D' = 62$ mm was filled with 500 ml of technical grade mercury at 20°C. 18 ml of fine and thin plaster of Paris slurry were then poured onto the mercury which spinning at 400 r.p.m. After an hour the solidified lens-like casting was removed from the mercury surface. It was smooth and sharp-edged and was suitable for use as a positive mold for manufacturing plastic lens blanks.

**EXAMPLE 15**

The process according to Example 14 was repeated with pure mercury (polarography grade) and 12 ml of diethyleneglycol diallyl-bis-carbonate, initiated with 2 percent by weight of di-isopropyl percarbonate. During two hours of spinning the temperature was raised gradually to 50°C and then during 4 hours gradually to 80°C and held at the same level for 10 hours. Thereafter the temperature was raised again to 115°C and maintained at the same level for further 6 hours.

Then the rotation was stopped and the system cooled down slowly to 25°C. A smooth optically homogeneous abrasion-resistant lens was obtained.

**EXAMPLE 16**

In a container with $D' = 100$ mm 750 ml of melted Woods' metal having a melting point of 79°C, were spun at 680 r.p.m. and 82°C. 21 ml of a thin epoxy resin (Epoxy 1,200) having 1.6 percent by weight of hexamethylene diamine added thereto was poured onto the melted metal to shape a lens. After 5 hours spinning the rotation was stopped. The lens so obtained was transparent and smooth. It was suitable for use either directly or as a positive mold for molding plastic lenses.

**EXAMPLE 17**

In a container with $D' = 17$ mm the bearing liquid was spun as in Example 1 at 70°C and 423 r.p.m. 0.112 ml of glycicylid methacrylate, containing 0.25 percent of dibenzoyl peroxide, was metered onto the spinning surface to shape a lens. The lens so obtained was similar to that according to Example 5.

It is to be understood that instead of ethylene glycol monomethacrylate containing a small amount of ethylene glycol dimethacrylate, any other liquid monomer mixture, initiated with any suitable polymerization catalyst may be used. The lenses may be manufactured from any polymerizable liquid yielding transparent polymers or copolymers. An example of a suitable hydrophobic polymer is poly(methyl methacrylate), initiated with dibenzoylperoxide and $p$-toluene sulphinic acid. Another example of a suitable hydrophobic polymer is polystyrene, azo-bis-isobutynitrilte being used as polymerization catalyst. A suitable hydrophilic material is a copolymer of acrylonitrile with methacrylic acid, cross-linked, if desired, with a small amount (up to 3 percent by weight) of a suitable cross-linking agent such as divinyl sulfone, ethyleneglycol dimethacrylate, triacyriloxy phenhydrotriazine, and the like. The only condition is that the mutually immiscible liquids not interfere with the chemical and/or physical process and the centrifugally cast liquid must not get in contact with the wall of the container. Thus, any polymerization, polyaddition, polycondensation and similar reactions may be used, the cross-linking, if necessary at all, being carried out also by means of peroxides or by ionizing radiation.

What is claimed is:

1. Method of manufacturing rotation-symmetric articles having different paraboloid upper and lower surfaces comprising the steps of rotating at least one liquid in a container to form a mold having a parabolic surface, placing a second liquid less dense than the first in an axial concentric position on its parabolic surface, said second liquid being capable of conversion from liquid to solid by chemical or physical action on said parabolic liquid surface, and capable of forming a sharp boundary between said liquids, each of said liquids being substantially immiscible with any other of the liquids in contact therewith and rotating said liquids at sufficient speed so that said more dense liquid forms a parabolic surface confining said less dense material and preventing its contact with the surfaces of said container, maintaining said liquid under such rotation until the cast liquid has solidified, wherein the solidification of said cast liquid does not result in a change of density such as to make the cast solidified liquid more dense than the rotating liquid.

2. Method as defined in claim 1, wherein at least one fluid phase in addition to the rotating liquid is rotated therewith to form the mold and said fluid phase is specifically lighter than the rotating liquid and the cast liquid, said rotating liquid, cast liquid and fluid phase constituting three substantially immiscible phases of properly graduated density.

3. Method as defined in claim 2, wherein the specifically lighter fluid phase is a gas.

4. Method as defined in claim 1, wherein there are present two specifically lighter fluid phases in addition to the rotating liquid and are rotated therewith to form the mold, said fluid phases being specifically lighter than the rotating liquid and the cast liquid, said fluid phases consisting of a liquid phase and a gas phase and forming with the rotating liquid and casting liquid four substantially immiscible phases or properly graduated density.

5. Method as defined in claim 4, wherein the most dense liquid forms the mold and wherein the second most dense liquid constitutes the casting liquid.

6. Method as defined in claim 1, wherein said cast liquid constitutes a monomer or mixture thereof capable of being polymerized during said rotation.

7. Method as defined in claim 1, wherein said rotation symmetric article formed is an optically homogeneous transparent body.

8. Method as defined in claim 7, wherein said article is an optical lens.