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Steinberg

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[54] **APPARATUS FOR QUENCHING POLYMER FILMS**

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Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 88,911, Nov. 12, 1970, abandoned.

[52] **U.S. Cl.** **425/223,** 425/72

[51] **Int. Cl.** **B29c 13/04**

[58] **Field of Search** ..... 425/71, 72, 223, 233, 235; 264/210 R, 216

[56] **References Cited**

UNITED STATES PATENTS

3,042,968	7/1962	Kraszeski	425/71 X
3,085,292	4/1963	Kindseth	264/216 X
3,175,026	3/1965	James	264/210 R
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FOREIGN PATENTS OR APPLICATIONS

633,269	7/1936	Germany	425/72

Primary Examiner—R. Spencer Annear

[57] **ABSTRACT**

A quenching apparatus comprising an extrusion die; a casting drum; a trough for a liquid coolant into which the casting drum is partially immersed; a stripping roller; and a chilling roll, partially immersed in the liquid coolant, to compress the cast film onto the drum and chill the surface of the film to form a temporary hard skin on the exposed surface of this film just prior to immersion in the liquid bath. Air-knives may be provided for removing liquid from the surface of the chilling roll and the cast film.

6 Claims, 2 Drawing Figures

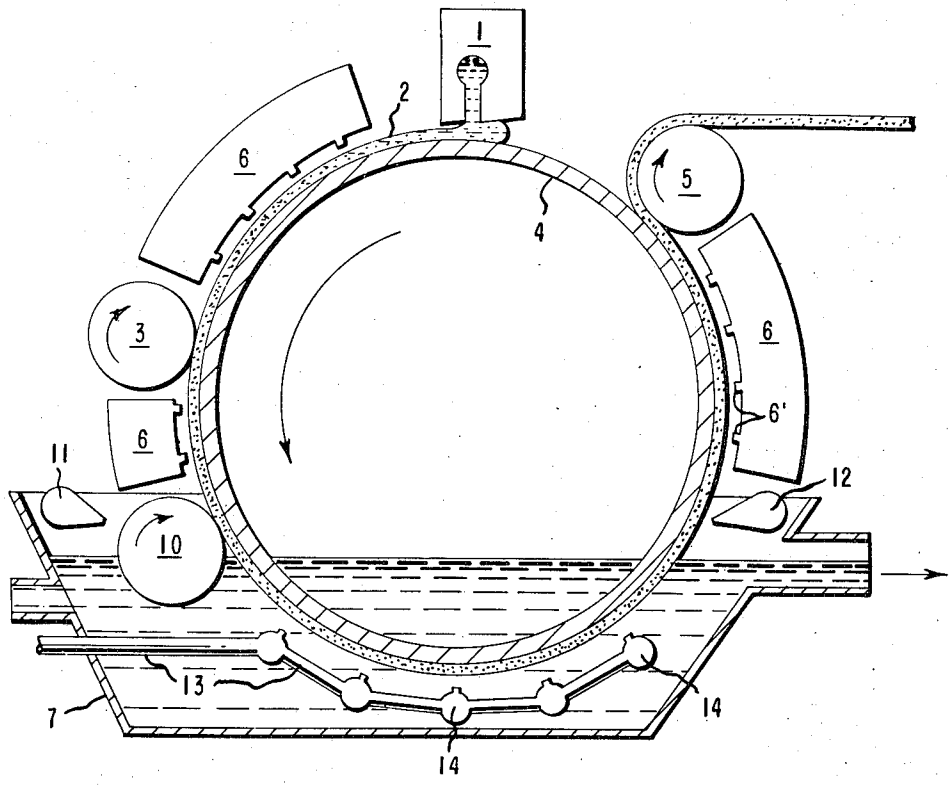


FIG. 1

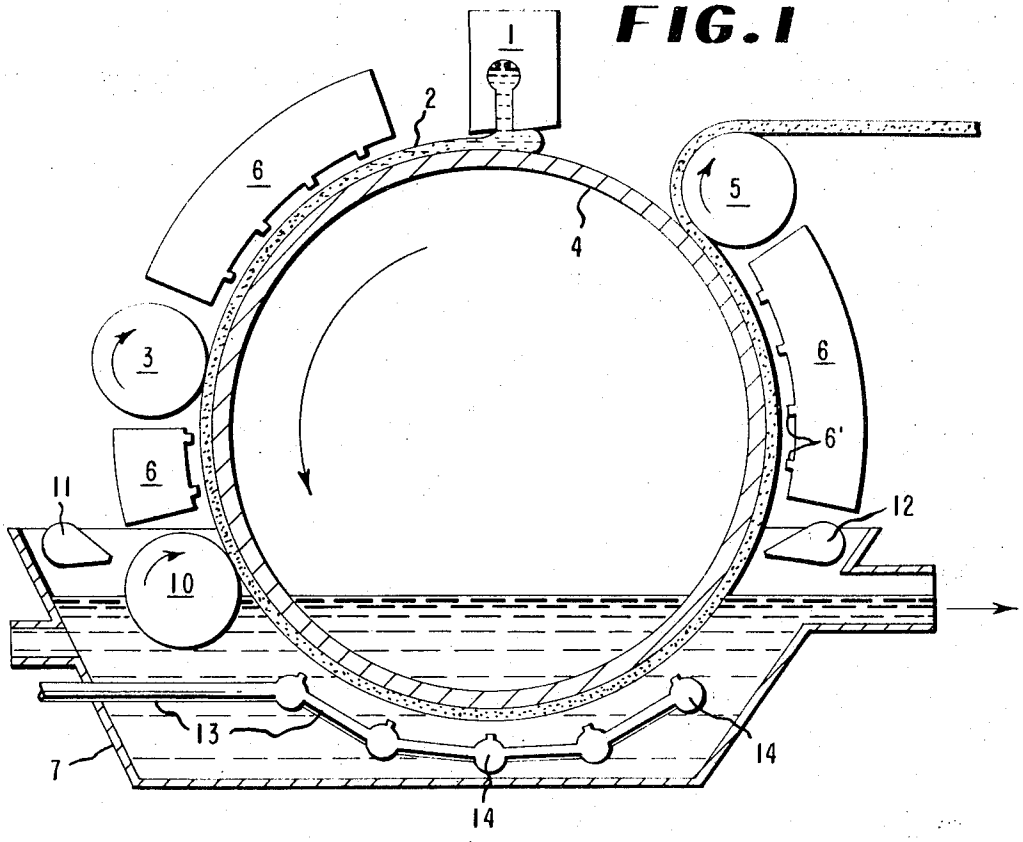
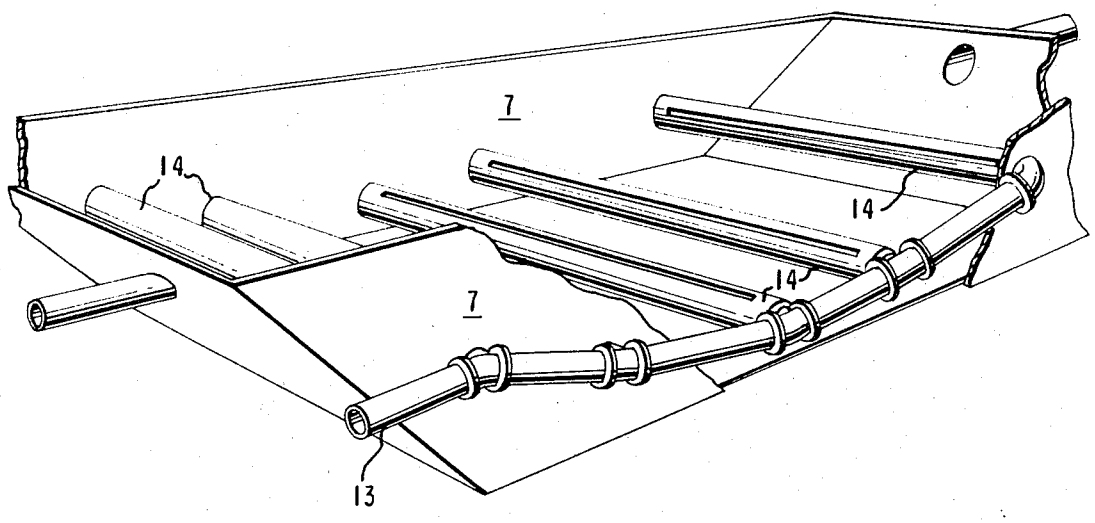


FIG. 2



APPARATUS FOR QUENCHING POLYMER FILMS

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of U.S. Patent application Ser. No. 88,911, filed on Nov. 12, 1970 (now abandoned).

BACKGROUND OF THE INVENTION

1. Field of the Invention

Conventional quenching systems for melt-extruded materials generally employ at least one bath, casting drum, spray, air impingement or various combinations thereof. Such systems are designed to adequately cool the thermoplastic material whereby the same being no longer readily deformable becomes a self supporting film. Non-volatile liquids which will not appreciably attack or react with the film such as water or aqueous-glycol solutions are most suitable coolants. The coolant must have a relatively high boiling point so as to not boil under operating conditions. Also a coolant temperature sufficiently below the melting range of the polymer must be maintained throughout the system to render the same effective.

Water or any liquid treatment cooling processes such as bath, spray or a combination thereof may cause surface deformations to appear on the malleable surface of cast polymer, because of non-uniform heat transfer at the point of contact with liquid coolant. The danger of incurring such defects as droplet or "splotchy" formations is even greater in spray systems. Droplets of the coolant carried by a partially immersed roll or the film can produce the particular-repeated-surface defects characteristic of bath systems. These defects which limit the use of the film or render the same useless can be partially eliminated by reducing machine speed and pressures. The instant invention is directed to an improved method and apparatus for quenching extrusion-cast polymer film, thus providing a means for processing the same at a greater rate than that practiced heretofore.

2. Description of the Prior Art

It is known in the art of film casting, that the three main systems for forming continuous sheets or films of polymeric materials are solvent casting, solvent extrusion and dry or melt extrusion. Unlike the first two systems, the melt extrusion process does not require any expensive solvent recovery apparatus, and is generally operated at relatively greater speeds than other systems or processes.

Conventional melt casting operations for synthetic linear, polymeric materials, e.g., polyethylene terephthalate generally involve the extrusion of the molten polymer from an extrusion die onto a casting drum or some suitable smooth, highly polished drum, belt or support mechanism. Said extrusion die may contain one or more extrusion ducts or slot-orifices through which the molten material is evenly discharged. In those instances other than that involving a casting drum, the apparatus may be provided with mechanism to facilitate conveyance such as rollers and belts. Because the rate of extrusion is high, and the liquid polymeric materials have high viscosities, such systems are designed to accommodate a maximum capacity of molten polymer for sufficient residence time to allow the extruded film to solidify.

Film quenching bath systems generally comprise a common tank or tray which serves as the pool for the coolant wherein a casting drum or some film transfer apparatus such as a series of rolls may be partially immersed. The desired level and temperature of the pool are normally maintained by any convenient manner such as continuous flow and drain and coils. The casting wheel and another roll in close proximity thereof or any suitable multiroll combinations may form a nip(s) to convey the film during cooling.

A multi-roll system such as that disclosed in U.S. Pat. No. 2,585,156, Feb. 12, 1952, comprises an assembly of partially immersed driven rolls two of which form a nip wherein the molten material is pressed into a film and conveyed by additional non-driven rolls below the surface.

In another multi-roll film quenching process, shown in U.S. Pat. No. 3,090,076, the molten thermoplastic material is cast on a cooling roll. A second, resilient pressure roll is used, so disposed as to apply pressure on the film passing through the nip formed by the casting roll and the resilient roll. By maintaining the resilient roll wet through a suitable liquid, a quenching pool is formed at the nip which helps prevent air entrapment and resulting defects. This quenching also hardens the molten film to provide a surface that is firm enough to resist deformation by the pinching effect of the resilient roll at high extrusion rates. The quality of liquid in the quenching pool and therefore the uniformity and degree of cooling of the surface is enhanced by use of a doctor blade to control the amount of liquid carried over by the resilient roll.

Other spray quenching systems for film polymer deposited from an extrusion head onto a casting drum may be of the type shown in U.S. Pat. No. 3,071,810, Jan. 8, 1963, wherein an assembly of spray nozzles is adjacent to said drum. Also, there is provided, in addition to conventional stripping rolls, a spring-biased roller which corrugates the film strip and presses the same into the foraminous surface of said casting drum whereby the cooling rate is increased.

Various problems of surface deformation and process speed limitations are inherent in the above-mentioned systems. Though air impingement systems generally do not incur the surface deformations or bubbles produced upon irregular occlusion of air between the molten polymer and the roll, they are limited to relatively low operating rates dependent on the cooling efficiency.

SUMMARY OF THE INVENTION

The present invention provides an apparatus for quenching a film of liquified organic polymer to form a solid film of the type comprising:

a moving casting surface;

means for casting a film of molten polymer on the casting surface;

a trough for a liquid coolant into which the lower segment of the casting surface and the film attached to it is immersed; and means for removing the film from the casting surface;

the improvement wherein the apparatus further comprises a chilling roll adjacent to the casting surface, disposed relative to the trough so that it is immersed in the cooling liquid to a depth not exceeding its radius and adapted to press the film against the casting surface at a point just prior to the point where the film enters the

liquid coolant to momentarily harden the exposed surface of the film and form a hardened skin which will resist deformation due to the quenching process.

In the preferred embodiment, the apparatus further comprises a plurality of spaced jet orifices disposed within the trough beneath the casting surface for projecting streams of coolant liquid against the surface of the film while it is immersed in the coolant liquid. Plenum chambers, spaced around the periphery of the casting surface for directing a current of gaseous coolant onto the exposed surface of the film may also be provided, along with airknives to remove the liquid coolant from the chilling roll and the surface of the film as it is stripped from the casting surface.

It is the primary objective of this invention to provide a chilling roll and bath system for quenching a molten polymer, particularly one which melts above 120°C., in a manner improved over prior conventional methods.

Another objective of the instant invention is to provide a means for adequately chilling the outer surface of a cast film prior to immersion in a liquid.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The apparatus of this invention is useful for casting any of the thermoplastic organic resins or polymers that are described in Bicher U.S. Pat. No. 2,754,544, July 17, 1956, and U.S. Pat. No. 2,821,746, Feb. 4, 1958.

In the case of casting polyethylene terephthalate, the molten polymer is extruded onto a casting drum whereupon it is quenched from melt temperature (275°C.) to that of glass transition (75°C.). Most of the heat is transferred from the film by conduction into the casting drum and subsequently absorbed by the internal cooling of the casting drum and some heat is normally removed by air currents from air plenum chambers.

It is preferred that the casting drum calender roll and chilling roll be provided with internal cooling ducts or coils for circulation of a heat-exchange liquid. The chilling roll surface is maintained at a temperature considerably below that of the film surface to render the same slightly hardened, thus preventing surface deformations upon immersion into the cooling bath. In this instance, the casting drum cooling system can be similar to that described in Bicher U.S. Pat. No. 2,754,544. The extrusion die may be spaced from the casting wheel to form an appreciable air gap. The extruded film may be stretched in this gap.

It is preferred that the chilling roll and casting drum substance be that of high conductivity (about 10 pcu's per hour ft.°C.) such as stainless steel or any suitable non-resilient material, as disclosed in the Bicher patent. Also, the means of liquid distribution throughout the rolls and drum can be like those in Bicher U.S. Pat. No. 2,754,544.

The apparatus of this invention will be understood more readily by reference to the accompanying drawing which forms part of this application. In the drawing,

FIG. **1** is a side elevation with parts in section of the apparatus, and

FIG. **2** is an isometric view of the coating trough, jet orifices, and supply manifold.

Referring to the drawings (FIG. **1**), the film extrusion die **1**, casting drum **4**, and stripping roller **5** assembly is similar to that disclosed in U.S. Pat. Nos. 2,754,544 and 3,422,494 for extruding linear polymeric films. The molten polymer **2** is extruded through the extrusion die at an elevated temperature. The molten polymeric material, e.g., polyethylene terephthalate, is deposited onto the surface of the casting drum which is driven at a peripheral speed usually greater than or equal to the rate of extrusion. The peripheral speed and polymer through-put may be adjusted using the following formula:

$$W = uwya$$

wherein W is a mass flow rate in pounds per hour, u is film speed in feet per hour, w is film width in feet, y is film thickness in feet and d is density in pounds per cubic foot. The melt-extruded polymer is immediately subjected to a current of air from the first of a series of air-impingement jets emanating from plenum air chamber **6.** Said jets are located above the bath about the perimeter of said drum and in close proximity to the outer surface of the traversing film.

Shortly thereafter, said film is passed downwardly through a nip formed between the calender roll **3** and the outer surface of the cast film on drum **4.** The film is then subjected to air jets from a second air plenum chamber prior to contacting a preimmersion chilling roll **10** which forms a nip with the film on the drum. Said chilling roll which rotates in a direction opposite to that of the casting drum, is immersed in a trough **7,** containing a liquid coolant, to a distance less than that of its radius.

Since it is imperative that the chilling roll has a water-free surface at the point of contact with the film, particularly at the nip formed there with said casting drum, and air-knife **11** is located adjacent to it and positioned just above the trough **7** of coolant and above the point of emergence to prevent water being carried by the roll to the surface of the film.

The film is then submerged in and passed through the bath (FIG. **1**) having a jet supply device therein. In this instance, the preferred jet supply apparatus comprises a single-tubular manifold **13** and a plurality of lateral conduits **14** which form the jet supply **13, 14.** In addition to fixed trajectories, said spray jets have slot orifices to assure maximum vertical flow of the liquid coolant toward the surface of the film. As the film is conveyed, a segment approximately one-third that of the entire circumference of said casting drum is submerged and subjected to the action of the circulating coolant. Immediately upon emerging therefrom, the exposed surface of the film is subjected to a moderate stream of air from a second air-knife **12** to blow back and remove the liquid coolant adhering thereto.

As the film is further conveyed, it is subjected to a final stream of air from orifices **6'** in plenum chamber **6.** At this point, the quenched film is slightly hardened and appreciably flexible, but rigid enough to be removed therefrom without incurring any appreciable defects. The quenched film then passes through a nip formed thereof between the casting drum and a stripping roller **5** by which it is transferred prior to undergoing biaxial orientation, heat treatments, substrata coating, and subsequent wind-up into rolls of oriented flexible, thin film.

In the practice of quenching melt-cast materials such as polymeric films wherein the surface temperature of the air-side is important, it is imperative that a safe-operable temperature be achieved and maintained

prior to any liquid spray or bath treatment to avoid surface deformation Since the temperature of the cooling liquid must be sufficiently below that of the highly polymeric compound to cause the molten film to solifify, it is necessary to determine the maximum temperature at which a particular extruded material may be applied to a quenching system to yield a clean, smooth film. It can be established experimentally that the air-side surface temperature for polyethylene terephthalate, when applied to the process et forth in the instant invention, must be below about 160°C. to avoid deformation upon immersion as follows:

1. A quantity of melt polyethylene terephthalate is extruded as a ribbon onto a steel block of 1-inch thickness by means of a Prep Center Model 250 1-inch laboratory extruder equipped with a ribbon die. The Model 250 extruder is manufactured by C. W. Brabender Instruments Incorporated.
2. The air-side surface temperatures of a series of extruded polymer samples on the surface of the block are measured as they cool by means of an infrared pyrometer. In this instance a Thermal Master Model 1T-4D polyester filter pyrometer manufactured by the Barnes Engineering Company was used.
3. The air-side of each polymer sample is cooled to a selected temperature at which point the film and block is immersed in a water bath, and the resulting film immediately inspected to evaluate surface quality.

Steps **1-3** are repeated until the maximum air-side surface temperature at which no deformation results is determined. The test procedure can be used to determine the correct air-side temperature of polymers other than polyethylene terephthalate in a similar manner.

The invention will be further illustrated but is not intended to be limited by the following specific examples in which polyethylene terephthalate is quenched in the prescribed manner:

EXAMPLE I

An experiment designed for evaluating the effectiveness of the preferred chill roll and immersed-multiple jet spray systems, in combination with the air plena, was conducted as follows:

A large quantity of PET was prepared in the manner disclosed in assignee's U.S. Pat. No. 2,905,707 using the extrusion and casting apparatus similar to those described in the respective U.S. Pat. Nos. 2,754,544 and 3,422,494 having the preferred quenching system incorporated therewith.

A solution of 25 percent or more by volume of glycol in water was used as a coolant in the casting drum and chill roll. The temperature of the bath water was maintained by controlling the flow rates, particularly that of inflow. The bath level was controlled by a weir.

An infrared pyrometer with an appropriate filter was used to measure the polymer surface temperature. Since the filtered infrared radiation is highly absorbed by polyethylene terephthalate, only the surface radiation was detected as responses to the sum of the emitted and reflected flux from the as-cast film.

Upon frequent checking of the polymer surface temperature at several locations, it was concluded that the effect of the chilling roll on the bulk average temperature is small but the effect on the surface is great. The outer surface of the polymer layer was cooled rapidly to approximately one-fifth its total depth.

The film extrusion die was set at a tolerance which allowed a continuous, uniform extrusion of the molten polymer. Accordingly, the particular settings and necessary adjustments were fixed in anticipation of the various inherent and resulting parameters to be expected thereof during casting and quenching and were as follows:

As-cast gage	85 mils
Percent of surface immersed in bath	32%
Wheel (internal coolant temperature)	−10°C
Calender and stripping roll temperature	15°C
Polymer (molten) temperature	275°C
Impingement air temperature	20°C
Impingement air velocity head	5 inches H_2O
Chill roll temperature	15°C
Bath water inlet temperature	5°C
Bath water outlet temperature	15°C
*Bath water flow rate (through jets)	1/6 (W) (D-0.5) gal./min.
Capacity	(39.0) (W) (D-.5) lb./hr.

*W = as cast width in inches
D = diameter in feet

Upon completing the quenching cycle and prior to further treatment and rewinding, representative film samples were examined.

The processed film was of excellent uniformity and exhibited excellent optical clarity. In addition to being relatively free from bubbles and surface defects, said film possessed excellent physical properties.

EXAMPLE II

Under conditions comparable to those disclosed in Example I but with elimination of the immersed spray jets, an additional quantity of polyethylene terephthalate was extruded and quenched to evaluate the effectiveness of the chill roll. Processing and temperature reading operations were repeated.

Casting and quenching operations were maintained at approximately the following conditions:

As-cast gage	.085 inch
Length of surface immersed in bath	80 inches
Wheel (internal coolant temperature)	−10°C
Calender and stripping roll temperature	15°C
Polymer (molten) temperature	275°C
Impingement air temperature	20°C
Impingement air velocity head	5 inches
Bath water inlet temperature	5°C
Bath water outlet temperature	10°C
Bath water flow rate through jets)	1/12 (W) (D-.5) gal./min.
Capacity	(33.5) (W) (D-.5) lb./hr.

Upon completion of quenching and subsequent stripping from the casting drum, it was observed that the film so produced had excellent uniformity in optical clarity. In addition to being relatively free from bubbles and surface defects said film possessed excellent physical properties. However, the capacity was 14 percent less than in Example I.

COMPARATIVE EXPERIMENT

The method described in Example I was employed to make an additional quantity of polyethylene terephthalate quenched in the previously described manner but without the chill roll.

Operating conditions were similar to those of the aforementioned example. Shortly thereafter the film was inspected in the prescribed manner.

The film quenched without the chill roll had deep hammered or "mottle" depressions.

While most of the heat in the film is removed by conduction into the drum and removed therefrom by cooling by the water-glycol solution, a small portion is removed by convection into the air from the air plenum adjacent the calender roll.

The film so produced wherein the chill roll had been applied was of excellent quality and there were no surface defects. It became apparent that the chill roll causes a very sharp drop in the surface temperature of sufficient magnitude and duration to render the film surface firm enough to avoid deformation upon immersion. In this instance it is necessary that the drop in temperature be maintained to the point of immersion occurring immediately thereafter.

This invention offers the advantage of a controllable system for quenching melt, extruded polymer having improved surface quality and uniformity particularly when manufacturing superpolymeric films that require rapid cooling.

An additional advantage offered by the instant invention is a substantial increase in the quench drum capacity and subsequent output of quality rapidly chilled film.

Another advantage offered when practicing the present invention is a means of rendering the surface (air side) of the extruded film sufficiently hardened and insusceptible to the deleterious defects normally incurred upon contact of the film with a liquid coolant.

I claim:

1. In an apparatus for quenching a film of liquefied organic polymer to form a solid film of the type comprising: a movable casting surface; means for casting a film of molten polymer onto said casting surface; a trough for a liquid coolant into which the lower segment of said casting surface and the film attached to it is immersed; and means for removing the film from said casting surface; the improvement wherein said apparatus further comprises a chilling roll adjacent to said casting surface, disposed relative to said trough so that it is immersed in the cooling liquid to a depth not exceeding its radius, means adjacent to said chilling roll to dry the the surface of said chilling roll before it contacts the film, said chilling roll being further adapted to press the film against said casting surface, at a point just prior to the point where the film enters the liquid coolant, to momentarily harden the exposed surface of the film and form a hardened skin which will resist deformation due to the quenching process.

2. The apparatus of claim **1** further comprising a plurality of spaced jet orifices disposed within said trough beneath said casting surface for projection stresses of coolant liquid against the surface of the film while it is immersed in the coolant liquid.

3. The apparatus of claim **1** further comprising plenum chambers spaced around the periphery of the casting surface for directing a current of gaseous coolant onto the exposed surface of the film.

4. An apparatus according to claim **2** wherein the jet orifices are narrow slots.

5. An apparatus according to claim **2** having means for recirculating liquid coolant to and from the trough.

6. An apparatus according to claim **2** wherein said means to dry the surface of said chilling roll comprises an air-knife adjacent the chilling roll for removing liquid coolant therefrom and an air-knife for removing liquid coolant from the surface of the film.

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