Nov. 6, 1962 M. T. CICHELLI **3,061,940**

METHOD AND APPARATUS FOR HEAT TRANSFER

Filed Aug. 22, 1958

3 Sheets-Sheet 1

Fig. 1

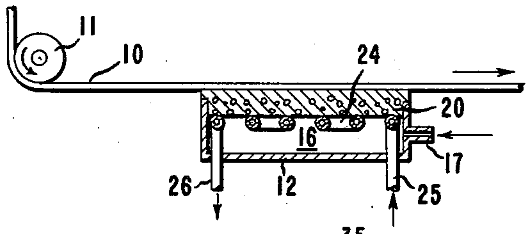


Fig. 2

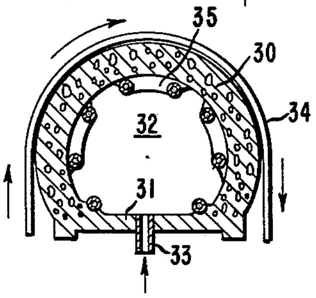


Fig. 3

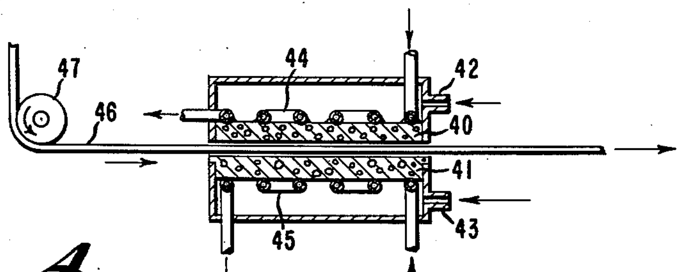
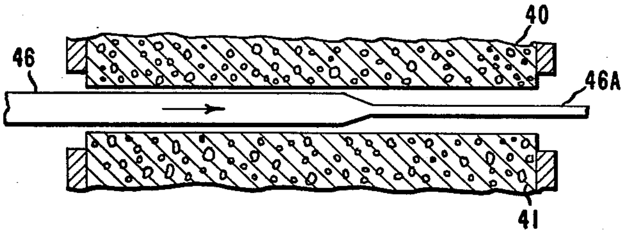


Fig. 4



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METHOD AND APPARATUS FOR HEAT TRANSFER

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Fig. 5

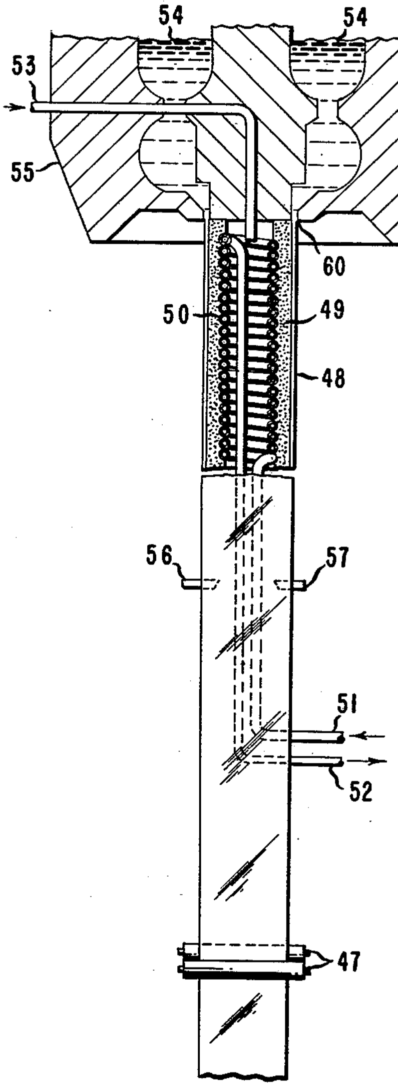

Fig. 6

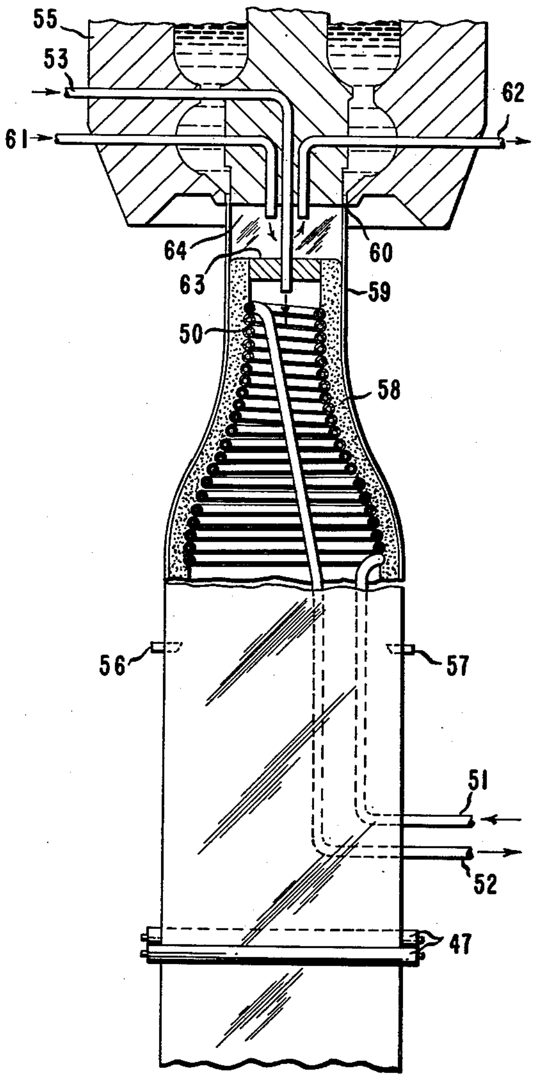

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Fig. 7

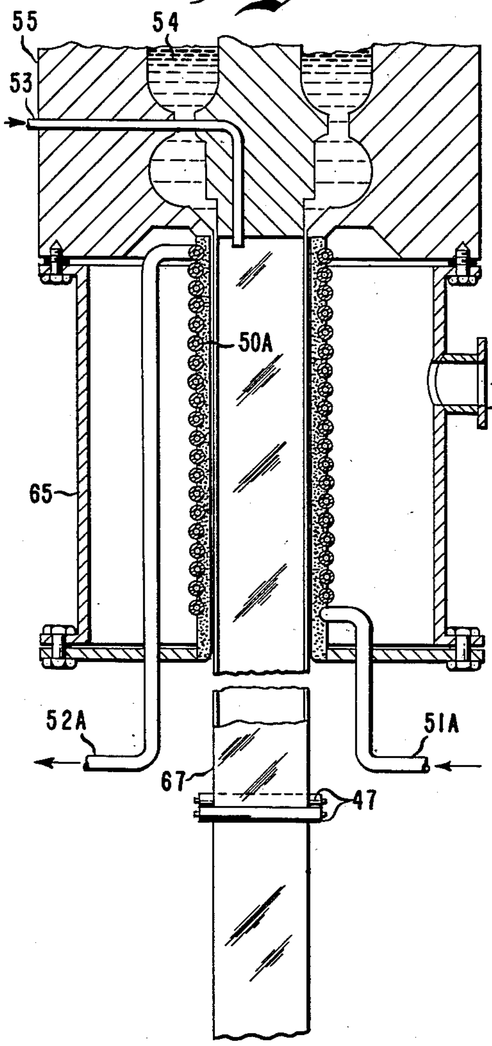
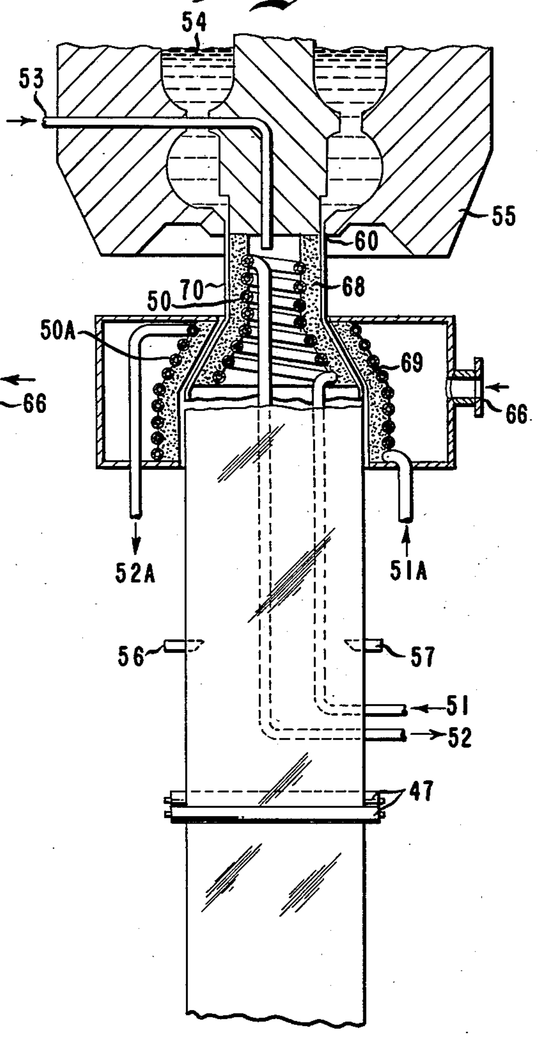


Fig. 8



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METHOD AND APPARATUS FOR HEAT TRANSFER

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Filed Aug. 22, 1958, Ser. No. 756,715
17 Claims. (Cl. 34—18)

This invention relates to a process and apparatus for improved heat transfer, and particularly to a method and apparatus for heat transfer to or from a running web without the necessity for surface contact therewith.

This application is a continuation-in-part of my copending application Serial No. 665,009, filed June 11, 1957, now abandoned.

Conventional methods for heating or cooling running webs may be classified generally in one of the three following categories:

(1) Heat exchange by conduction to or from a solid surface with which the web is in contact;

(2) Radiant heating, such as by exposure of the web to radiation of an infrared emitter, and

(3) Blowing a gas, such as air, into contact with the web and thereby effecting heat transfer by convection between the web and the gas.

The method of heat transfer selected for a particular use depends importantly on whether surface contact between the web and the heat transferring agency can be tolerated. The highest heat transfer rates are obtained where actual contact occurs, i.e., where heat exchange is accomplishd by conduction. However, in many cases, surface damage to the web results from contact, as in the case of thermoplastic materials where the web material is appreciably softened by exposure to heat. It may also result that scratching of the web or damage to its optical characteristics occurs upon contact with a solid surface and, of course, many materials exhibit a sticking tendency, especially at higher temperatures, which makes it inadvisable to bring them into contact with any solid materials, at least until after the heat transfer has been effected.

There have been attempts in the prior art to use moving gases to isolate running webs from adjacent machine surfaces, a particular system for molding thermoplastic tubing being taught in 2,519,375 and a method and apparatus for drying such a material as a paper web coated on one side being taught in 2,130,665. In the former, heat transfer appears to be merely an incidental consideration and, in any case, the utilization of a substantially conductive heat transfer mechanism is not described, whereas in the latter surface contact of the paper web with a supporting screen is required for the drying action contemplated.

A primary object of this invention is to provide a method and apparatus for high heat transfer to or from a running web. Another object is to provide such heat transfer by conduction so that very high heat transfer rates are obtained. Another object of this invention is to provide a method and apparatus for heat transfer wherein the running web is supported at all times out of contact with the surface of the heat exchanger. Yet other objects of this invention are the provision of a method and apparatus for heat transfer to or from a running web which is inherently self-centering as regards the web, which is adapted to heat exchange on one or both sides of a planar web, which is also applicable to a tubular web, which is regulable to correlate the heat transfer in accordance with the thickness or mass of material at any given point in the web, and the apparatus for which is relatively economical to fabricate and maintain. The manner in which these and other objects of this invention are achieved will become apparent from the detailed description and the following drawings, in which:

FIGURE 1 is a schematic representation in longitudinal section of a planar apparatus according to this invention adapted to heat or cool a running web from one side only;

FIGURE 2 is a schematic representation in cross section of an arcuate apparatus effecting heat transfer to a running web;

FIGURE 3 is a schematic representation in longitudinal section of an apparatus similar to that of FIGURE 1 except that it is adapted to heat or cool both sides of the running web simultaneously;

FIGURE 4 is a schematic representation in enlarged section showing how heat transfer according to this invention can be controlled in accordance with the thickness of the web in process, so that thicker portions of the web can be heated to higher temperatures than thinner portions, thereby obtaining enhanced gage control; and

FIGURES 5–8 are schematic representations in longitudinal section of apparatus according to this invention adapted to effect heat transfer to or from, i.e., to heat or cool, a running (continuously moving) tubular web.

In FIGURE 5 the gas-pervious surface is positioned within the moving tubular film.

In FIGURE 6 the gas-pervious surface is also positioned within the moving tubular film and the apparatus is adapted to reduce the wall-thickness of the tubing by stretching the tubular film while the film is in a formative plastic state.

In FIGURE 7 the gas-pervious surface is positioned outside of the moving tubular film.

In FIGURE 8 gas-pervious surfaces are positioned both within and outside of the moving tubular film.

Generally, the method for heat transfer according to this invention comprises supporting the web by gas pressure, the gas pressure being applied through a pervious heat exchanger transverse to the web, while maintaining a very thin layer of not more than 10 mils of the gas substantially uniformly in the interfacial area between the web and the external surface of the pervious heat exchanger, and apparatus for carrying out this method.

The success of the present invention is attributable to the discovery that high heat transfer rates, substantially conductive heat transfer rates (as opposed to convective or radiant heating rates) are obtained by maintaining a clearance of not more than 10 mils between the moving film and the porous surface. Thus, by the present invention heat transfer heretofore obtained only by direct contact, is obtained without such contact to mar the surface of the moving film web. The preferred buoying gas thickness between the heat exchanger and the running web is about 3–5 mils. With a thickness of 5 mils, it is easily possible to obtain heat-transfer coefficients of the order of about 45 using air or nitrogen as fluid, and over 100 using helium, expressed in engineering units, as compared to values of 3 to 10 for convective air heating. The reason for this 10–15 fold improvement is believed to lie in the fact that the bulk of the resistance to heat transfer by conduction is provided by the buoying fluid; however, such a small thickness of fluid exists between the web and the exchanger that very high heat transfer rates exist.

Several other advantages flow from the use of the extremely low gas thickness. Where an attempt is made to support a moving film at any appreciable distance from a gas supply surface, control is very difficult. A slight change in differential pressure causes a weak film to expand too much or to collapse appreciably. On the other hand, where a film is passed in close clearance with respect to a porous metal air supply surface, a self-corrective buoying action is obtained. This is true whether gas pressure or film tension is used to hold the film close to the buoying surface. Thus, for example, if a 5 lbs./sq. in. pressure is supplied on the high-pressure side of the porous metal surface, and the pressure at the low pressure side adjacent to the film is, for example, normally at 0.3 lb./sq. in., closing off entirely the downstream surface will cause an increase in pressure at the low-pressure surface to 5 lbs./sq. in. This pressure would be available to prevent contact. If blockage of the downstream surface should occur locally the pressure available for pushing the film away from the surface will depend on the extent of surface coverage. For example, if a rectangular area is covered which has a width equal to twice the porous metal thickness, the pressure developed beneath the center of this region will be 70% of the upstream pressure. This means that about 3.5 lbs./sq. in. would be available to prevent film contact. If the width of area covered is equal to 1 thickness of porous metal surface then about 10% of the upstream pressure will be available or 0.5 p.s.i. Even prior to actual blockage of the porous surface, the pressure underneath the film increases as the clearance between the film and the air supply surfaces decreases. For example, if an area of film 1 inch wide and several inches long moves from an initial 5 mils clearance from the buoying surface to a clearance of 2.5 mils, the pressure will rise relative to the surrounding areas from 0.08 lb./sq. in to 0.7 lb./sq. in. This increase in pressure tends to restore the film to its initial position. Actual film displacements will be maintained to within one or two mils of the original design position. The restoring pressure varies (inversely) as the cube of the clearance and consequently the corrective action increases in intensity as the film approaches the surface. Thus, except for cases where they may be small dimples and wrinkles in the film, air-supplied porous metal surfaces will maintain good film support without contact, and close dimensional control.

Referring to FIGURE 1, which, with the other figures, constitute schematic representations in which the relative proportions of the showing are greatly exaggerated for simplification of explanation, an apparatus for heating or cooling a web from one side only is depicted, the web being in this case a planar polymeric film **10** which is derived from any convenient source of supply, not shown, and trained around tension-maintaining roller **11** prior to effecting the heat transfer operation. The heat exchanger, indicated generally at **12**, consists of a plenum chamber **16** supplied with buoying gas under pressure through supply line **17**. In the event that film **10** might be deleteriously affected by air, the gas utilized may be nitrogen, helium or some other inert gas, it being understood that the word "gas" as employed herein is intended to comprehend vapor as well, and particularly superheated steam.

The top side of plenum chamber **16** is closed off by heat exchanging wall section **20**, which is fabricated from a gas-pervious material such as a sintered metal, e.g., sintered bronze or the like. Instead of sintered metal other gas-pervious structures may be employed, such as, for example, aggregates of small metal balls of the size of bird shot point-welded or soldered together so as to provide through-going air passages relatively uniform in both size and distribution. Or sintered wire matrices in a variety of forms are satisfactory, as are pervious metal-ceramic composites characterized by thermal conductivities approaching those of metals. In a typical apparatus, wall **20** was fabricated from ½" thick sintered bronze metal having a porosity of about 27% on the volumetric basis, which permitted the passage of about 5 ft.^{3}/min./ft.^{2} of heat exchanger area of air at 5 lbs./sq. in. gage differential across the metal. To maintain the temperature of wall **20** at the desired level, the wall is provided with a tubular heater **24** which, in the apparatus of FIGURE 1, is a hairpin-type steam coil which is supplied with steam through inlet line **25** and from which condensate is withdrawn through line **26**. Heater **24** is preferably brazed or otherwise firmly attached to wall **20**, thereby insuring good heat conduction to the gas-pervious mass.

The buoying gas is distributed evenly over the surface of the heat exchanger confronting web **10** by divided flow through the multiplicity of interstices in wall **20** and the film of gas formed next to the web is substantially even in thickness, so as to support the web out of any contact with wall **20**. At the same time the gas film is so thin (e.g., 3 to 10 mils) as to interpose only small resistance to the conduction of heat through the gas from the heat exchanger to the web, whereupon highly efficient heat transfer is obtained. This method is also characterized by a high uniformity of heat transfer, except at the edges of the web where, of course, certain edge effects exist. Such edge effects can sometimes be compensated for by employing non-cylindrical feed rolls, or in other ways, or can, as a practical matter, often be tolerated due to the presence of beads at the web edges.

Referring to FIGURE 2, an arcuate surface heat exchanger may be utilized in place of the planar type of FIGURE 1 and one embodiment of this type is shown in FIGURE 2. In this apparatus, the gas-pervious heat exchanging wall section is indicated at **30**, which is closed off at the bottom by impervious wall **31** to thereby define with it plenum chamber **32**. The buoying gas is supplied to chamber **32** through line **33** and escapes through pervious wall section **30** over which running web **34** is trained. Again, wall section **30** is heated by a steam coil, indicated generally at **35**, which is supplied with steam and from which condensate is removed through auxiliary lines, not shown.

The apparatus of FIGURE 2 operates in the same manner as described for FIGURE 1, the web in process being "floated" over the external surface of wall section **30** out of contact therewith, while at the same time being heated as a function of the linear speed of the web past the heat exchanger. Since there is practically zero friction in the travel of the web past the exchanger, only a low tension need be applied to the web in its transit past the heat transfer apparatus.

Referring now to FIGURES 3 and 4, it is frequently desirable to heat a web from both sides, which can be done by providing two opposed planar heating elements, identical with that described in connection with FIGURE 1 and passing the running web therebetween. Thus, in FIGURE 3 the top heater is designated generally at **40**, whereas the bottom heater is designated at **41**. Independent sources of buoying gas supply **42** and **43**, respectively, are shown, it being understood that these may be supplied from a common primary source through a piping system not further detailed. Heater **40** is provided with interiorly mounted steam coil **44**, while heater **41** is provided with the same service by steam coil **45**. The running web **46** passes between the opposed heaters **40** and **41**, being directed along course by roll **47**.

In a typical instance, the faces of heaters **40** and **41** were disposed apart a distance of 23 mils where the web to be processed was 13 mils thick, whereupon, with equal buoying gas pressures on opposite sides of the web a clearance of 5 mils was maintained between the surfaces of the web and the surfaces of heaters **40** and **41**. A vary high coefficient of heat transfer was obtained with apparatus of this design, which, where helium was used as the buoying gas, attained levels of 142 and higher, as compared with conventional rates of the order of 10 and below.

It is oftentimes desirable to heat a web to higher temperatures in the thicker portions than in the thin regions so that, when tension is applied lengthwise of the web, more contraction will occur in the thicker parts than in the thin, the net result being an overall evening of gage throughout the entire web. Previous methods of web heating involved heat transfer to the webs in the reverse manner, i.e., thicker parts of the web were heated to lower temperatures than thinner parts. Thus, when the web was stretched to obtain polymer orientation, or even to draw it through the processing equipment, preferential stretching occurred with very great reduction of the softer, thin parts of the film, but with zero or very little stretching in thicker parts, aggravating web gage variations. Instances have been known where an initial variation in gage of the order of 0.5% before heating and stretching resulted in a final variation in gage of 10% or more after the heated web had been stretched. Such gage variations are, of course, objectionable where a uniform gage of product is desired.

Referring to FIGURE 4, which is an enlarged view of the web in transit through the apparatus of FIGURE 3, it will be apparent how this invention make it possible to transfer heat in predetermined amounts in relationship to web mass.

If it is assumed that the web **46** varies in thickness to the extent that a region **46A**, thinner than the remainder of the web, passes between heaters **40** and **41** first, it will be seen that the thickness of the buoying gas is greater for this region than it is for the thicker web immediately following. Heat transfer increases approximately in inverse proportion to the thickness of the gas film existing between the heat exchanger and the web, wherefor less heat will be imparted to the thin region **46A** than to the thicker part of the web. The reason accounting for the fact that heat transfer is only approximately in inverse proportion to the thickness of the gas film, and not exactly so, is that the web resistance to heat transfer itself constitutes an appreciable percentage of the total resistance opposed to heat transfer, and we are concerned with total heat transfer because the temperature attained by the web results from heat transfer to the interior of the web. It is practicable to maintain the spacing and operation of heaters **40** and **41** with respect to the web so as to obtain higher heating relative to existing mass for thicker portions of a given web than for thinner portions. If desired, the disposition and operation of heaters may be such as to obtain precise heat transfer proportionate to mass, thereby maintaining web temperature uniform throughout, which is sometimes desirable where temperature criticality exists as to certain web properties. Heat transfer as related to web mass has been investigated by careful experiments wherein a web has been provided with a strip of the same stock adhered thereto, so that a known variation in thickness was artificially created in the web. It was found that the thicker part of the web was heated to a greater extent than the thinner sections of the web, and that increased heating occurred sharply at the boundaries of increased thickness.

The foregoing description is concerned exclusively with planar webs; however, it will be understood that my invention is equally applicable to tubular polymeric stock and, in fact, is particularly advantageous in the enlargement of the cross section of polymeric tubing by conjoint use of the buoying gas as a forming agency, all as taught in application Serial No. 665,053, of applicant as co-inventor, filed June 11, 1957.

Apparatus for treating tubular polymeric stock are shown in FIGURES 5–8. With regard to the apparatus shown in these figures, the use will be described with respect to extruding an organic thermoplastic polymeric film at a temperature above its melting point, and above its crystalline melting point[1] in the case of crystallizable polymers, and thereafter quenching the molten tubing to a condition suitable for wind-up.

Referring to FIGURE 5, molten polymer **54** is extruded through a circular die **60** of the extrusion apparatus **55** to form continuous tubing **48**. Pull rolls **47** are employed to advance the tubular film **48** over a gas-pervious, cylindrical mandrel **49**. The mandrel **49** is hollow and contains cooling coils **50** which may be soldered to the internal surfaces of the gas-pervious walls of the mandrel. The temperature of the mandrel is regulated by the temperature and flow of cooling water in at **51**, through the coils and out at **52**. Gas, under sufficient pressure to maintain a steady flow through the gas-pervious walls of the mandrel, is injected into the hollow portion of the mandrel at **53**, and the flow of gas through the gas-pervious surfaces buoys the moving molten tubing away from contact with solid surfaces. Heat transfer between solid surfaces and molten tubing is rapid and efficient, and the advancing tubing is cooled to a temperature low enough to permit slitting of the tubing by knives **56** and **57** and then passage through the nip of pull rolls **47**. The planar films are then in condition for winding up on rolls not shown. The extrusion apparatus **55** may also be adapted to contain the inlet **51** and outlet **52** for the cooling water. In this latter case, the pull rolls **47** would serve to collapse the tubing and the tubing could then be wound up directly or then slit into planar films.

FIGURE 6 illustrates an apparatus which operates in essentially the same way as that illustrated in FIGURE 5, except that the mandrel **58** is not in direct contact with the circular die **60** of the extrusion apparatus **55** and the tubing is expanded. The molten film **59**, in tubular form, is permitted to pass through an air gap **64** wherein air is injected through **61** and out at **62** under low pressure to inflate the molten tubing. The tubing is then expanded over a frustoconical mandrel **58** while the tubular film is in an essentially formative plastic state. This apparatus permits drawing-down or reducing the initial wall thickness of the molten tubing and increasing the diameter of the tubing to that desired without effecting any significant molecular orientation. The pull rolls **47**, the slitter knives **56** and **57**, and the cooling coils **50** serve the same purpose as described for FIGURE 5. The gas to buoy the moving tubing **59** is supplied similarly through inlet **53**. The seal **63** prevents the buoying gas from penetrating the gap **64** to any excessive degree.

The apparatus in FIGURE 7 is designed to accomplish essentially the same result obtained by that illustrated in FIGURE 5, except that the molten tubing **67** is advanced through instead of over the gas-pervious cylinder **65**, and gas under sufficient pressure to buoy the tubing away from the solid internal surface of the cylinder is applied through **66** to the outer wall of the tubing instead of against the inner wall of the tubing as shown in FIGURE 5. The extrusion apparatus **55**, the pull rolls **47**, the coils **50A** and inlets **51A** and **52A** serve the same purposes as described for the corresponding parts in FIGURE 5. The gas supplied through inlet **53** serves to prevent collapse of the tubing **67**.

FIGURE 8 shows an apparatus wherein gas-pervious surfaces, **68** and **69**, are utilized internally and externally of the tubing for continuously quenching an advancing

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[1] Crystalline melting temperature or crystalline melting point, as used in the present specification, refers to the lowest temperature at which complete disappearance of a crystalline structure of a polymer is observed under a visible light microscope using polarized light as the sample is being heated. In most cases, a crystalline polymer will melt over a temperature range, an dthis crystalline melting range begins at a temperature where the crystalline structure begins to disappear and extends to a temperature at which the crystalline structure completely disappears, this being the crystalline melting temperature or point. Polymer masses at temperatures above their crystalline melting point are considered to be in "a formative plastic state," and little or no molecular orientation is effected during drawing or stretching of a film in such a temperature range.

polymeric tubular film **70** from its molten state to a state in which it can be collapsed and wound up. In this case the molten tubular film is advanced over a short section of a gas-pervious cylindrical mandrel **68** having a cross-section essentially the same as that of the circular die **60** of the extrusion apparatus **55**. The latter portion of the cylindrical mandrel **68** flares out in the form of a frusto-conical section for the purpose of controlling the path of the advancing tubing and serves to draw or expand the tubing **70** as it is in a formative plastic state. Completion of this quenching step is facilitated by an external ring **69** having an inner surface which is gas-pervious, and the tubing is quenched in the form desired, i.e., the desired wall thickness and inside diameter. The coils, **50** and **50**A, cooling water lines **51**, **52**, **51**A and **52**A, and the gas lines **53** and **66** are similar to those shown in FIGURES 5 and 7.

An important advantage of the method of this invention where applied to the two-sided heating of webs is that the buoying gas has a self-centering action on the web, which results in automatic spacing of the web from the heaters to a degree precisely proportioned to the ambient pressures of the gas escaping the heaters. When equal pressures and temperatures are maintained on opposite sides of the web, the heat input is substantially uniform to both sides of the web, which is highly desirable in many manufacturing operations from the standpoint of product uniformity and characteristics which are affected by subsequent processing steps. Another advantage lies in the very low gas flow rates that are necessary in the invention. Such low rates reduce the gas consumption and the size of pumps and other equipment required for gas supply.

The present invention is applicable to effecting highly efficient and rapid heat transfer between a solid surface and a continuously moving web. In its most useful application, the invention may be applied to heating and cooling of continuously advancing films fabricated from a wide variety of organic, polymeric film-forming materials, particularly organic thermoplastic polymeric materials. This process may be applied to films, in flat or tubular form, from the following types of polymers:

(1) Organic thermoplastic polymers which are normally amorphous (those which do not crystallize). This class includes polystyrene and polymethyl methacrylate.

(2) Organic thermoplastic polymers which are "crystallizable" or can be made to crystallize but which can be quenched in an essentially amorphous state. This class includes various polyesters, such as polyethylene terephthalate, copolyesters of ethylene terephthalate/ethylene isophthalate, wherein the ethylene terephthalate component is at least 65%, by weight, of the total composition, polyethylene-2,6-naphthalate, polytetramethylene-1,2-dioxybenzoate, polyethylene-1,5-naphthanate, etc., and various polyamides such as polyhexamethylene adipamide, polyhexamethylene sebacamide and polycaproamide. Polyvinyl chloride may also be included in this class.

(3) Organic thermoplastic polymers which are normally crystalline and which cannot normally be quenched from a melt in an essentially amorphous (non-crystalline) form. This class usually includes polyethylene (low, intermediate and high density types), polypropylene, polyvinyl fluoride and polyoxymethylene (see U.S. Patent 2,768,994).

(4) Organic polymeric film-forming materials, other than the so-called organic polymeric thermoplastic polymers, such as various cellulosic films, e.g., regenerated cellulose. Viscose (an alkaline solution of cellulose xanthate) of relatively high viscosity may be extruded from a die, either flat or circular, in accordance with the present invention, and regenerated cellulose film may be formed in accordance with so-called "dry casting" techniques.

It should be pointed out that the present process may also be used to form films from various organic thermoplastic polymers which are in the form of homogeneous mixtures or dispersions in organic solvents, particularly in organic materials which are solvents for the polymer at elevated temperatures, and are essentially non-solvents at normal temperatures. For example, high solids dispersions of polyvinyl fluoride in gamma-butyrolactone may be extruded at an elevated temperature to form a homogeneous coalesced film in flat or tubular form which may then be cooled to a desired temperature in apparatus illustrated herein.

The following examples will serve to illustrate certain embodiments of the process of this invention.

Example I

Medium-density polyethylene ("Bakelite" DYNH-3, having a density less than 0.95 gm./cc. and greater than 0.92 gm./cc.) was extruded from a 1" extrusion apparatus equipped with a circular die having an outside diameter of 2". The rate of polymer throughput was within the range of 6–10 lbs./hr., and the temperature of the molten polymeric tubing, as it issued from the die was about 250° C.

The arrangement of apparatus was similar to that shown in FIGURE 5 wherein the molten tubing was advanced over a gas-pervious cylindrical surface fabricated from sintered bronze. The overall length of the mandrel was 6". The outside diameter of the mandrel at a point adjacent the circular die was 1.94", and the mandrel tapered 8 mils/inch to a smaller diameter. The tapered construction permitted shrinkage of the advancing tubing during the quenching. The mandrel was cooled by introducing water at a temperature of 28° C. and a rate of 1 gal./min. through the cooling coils running through the mandrel.

Air, at a pressure of about 3 lbs./sq. inch was applied to the internal hollow portion of the mandrel, the hollow portion having an inside diameter of about ⅝", this pressure being sufficient to force the air through the sintered bronze of the gas-pervious mandrel.

The molten tubing issued from the circular die (having a lip opening of 18 mils) and the tubing was advanced over but out of contact by not more than 10 mils with the mandrel at a linear rate of 6–14 feet/minute by pull rolls which also served to collapse the tubing. The wall thickness of the quenched tubing was about 5 mils, and its internal diameter was 1.94 inches.

When air was employed for pressuring the gas-pervious mandrel, the coefficient of heat transfer was about 50 B.t.u./hour/square foot/° F., and when helium was used, the coefficient was essentially doubled.

Example II

Molten polyethylene terephthalate at a temperature of 275° C. was extruded continuously into the form of a tubular film through a circular die 2.3" outside diameter and a throughput of 10–25 pounds of polymer/hour. The molten tubing which issued from a die having a lip opening of 28 mils was quenched in essentially the same type apparatus and same manner as described in Example I to form quenched tubular film having a wall thickness of about 2.5 mils and an inside diameter of about 1.94". The gas-pervious mandrel was pressurized with air at a pressure of 10–15 pounds/square inch to keep the tubing out of contact by not more than 10 mils with the mandrel, and the mandrel was cooled with water (at 27° C.) introduced into cooling coils at a rate of 2 gals./minute. The tubing was wound up at a rate of 20–40 feet/minute.

Example III

Polyoxymethylene of the type described and claimed in U.S. Patent 2,768,994 was extruded into the form of continuous tubing at a temperature of 200° C. through a circular die 2.3" outside diameter. The polymer was extruded at a rate of 7–12 lbs./hour from a circular die having a lip opening of 28 mils. The apparatus described in

Example I was employed to continuously quench but not contact the advancing tubing, and the final quenched tubing had a wall thickness of 1–2 mils and an inside diameter of 1.94". The mandrel was continuously cooled with water (at 27° C.) introduced at a rate of 1 gal./minute through the cooling coils. The tubing was wound up at a rate of 20–35 feet/minute.

Example IV

The following composition was continuously extruded and quenched in an apparatus of the type illustrated in FIGURE 5:

	Percent
Polyvinyl chloride	92.5
3,5-dibutyl tin mercaptide	3½
"Paraplex" G–62	3
Calcium stearate	1

Polymer was extruded through a 1" die having a lip opening of 60 mils at the rate of 120 grams of polymer/minute. The temperature of the melt was about 175° C. A gas-pervious bronze mandrel, attached to the die face but insulated therefrom was maintained at a temperature of about 20° C. by introducing cooling water into the coils in the mandrel. The outside diameter of the mandrel was ⅞" and the length of the mandrel was 6½". The tubular film was drawn over but out of contact by less than 10 mils with the mandrel at a rate of 6 feet/minute by means of pinch rolls which also served to collapse the tubular film.

The resulting tubular film had the following physical properties:

Pneumatic impact strength	kg.-cm./mil	0.44
Thickness	mils	7
Tenacity (p.s.i.) MD/TD		6,530/5,208
Elongation (percent) MD/TD		220/44
Modulus (p.s.i.) MD/TD		296,000/307,000
Tear strength (g./mil) MD/TD		57/69

From the foregoing it will be understood that this invention consists of an improved method and apparatus for obtaining heat transfer with respect to running webs, either for heating or cooling, and that it is capable of relatively wide modification without departure from its essential spirit, wherefor it is intended to be limited only by the scope of the following claims.

What is claimed is:

1. A method of obtaining heat transfer between a web existing at a first temperature and a heat exchanger maintained at a second temperature different from said first temperature comprising advancing said web continuously past said heat exchanger; supporting said web out of contact with said heat exchanger but closely adjacent thereto by buoying said web away from the surface of said heat exchanger with a layer of gas under pressure supplied across a complete width of said web substantially uniformly to the interfacial area between said web and said heat exchanger, the thickness of said gas layer being no greater than 10 mils; and removing said web from the zone of heat transfer after said web has acquired a predetermined temperature of a magnitude between said first temperature and said second temperature.

2. A method as in claim 1 wherein the web is heated.

3. A method as in claim 1 wherein the web is cooled.

4. A method of obtaining heat transfer between a web existing at a first temperature and a heat exchanger maintained at a second temperature different from said first temperature comprising advancing said web continuously past said heat exchanger; supporting said web out of contact with said heat exchanger but closely adjacent thereto by buoying said web away from the surface of said heat exchanger with a layer of gas under pressure supplied across a complete width of said web substantially uniformly to the interfacial area between said web and said heat exchanger, the thickness of said gas layer being 3–10 mils; and removing said web from the zone of heat transfer after said web has acquired a predetermined temperature of a magnitude between said first temperature and said second temperature.

5. A method of obtaining heat transfer between a web existing at a first temperature and a gas-pervious heat exchanger maintained at a second temperature different from said first temperature comprising advancing said web continuously past said gas-pervious heat exchanger in close proximity thereto; flowing gas through said gas-pervious heat exchanger in a direction transverse to the direction of advancement of said web across a complete width of said web at a substantially uniform pressure sufficient to buoy said web from the surface of said gas-pervious heat exchanger a distance of 3–10 mils; and removing said web from proximity to said gas-pervious heat exchanger after said web has acquired a predetermined temperature of a magnitude between said first temperature and said second temperature.

6. A method of obtaining heat transfer between a web existing at a first temperature and a gas-pervious heat exchanger maintained at a second temperature different from said first temperature according to claim 5 wherein an individual gas-pervious heat exchanger is disposed on both sides of said web.

7. A method of obtaining heat transfer between tubing existing at a first temperature and a heat exchanger maintained at a second temperature different from said first temperature comprising advancing said tubing continuously over a tubular heat exchanger; supporting said tubing out of contact with said heat exchanger but closely adjacent thereto by buoying said tubing away from the surface of said heat exchanger with a layer of gas under pressure supplied to a complete ring of surface of said tubing substantially uniformly to the interfacial area between said tubing and said heat exchanger, the thickness of said gas layer being 3–10 mils; and removing said tubing from the zone of heat transfer after said tubing has acquired a predetermined temperature of a magnitude between said first temperature and said second temperature.

8. A method as in claim 7 wherein the tubing is heated.

9. A method as in claim 7 wherein the tubing is cooled.

10. A method of obtaining heat transfer between tubing existing at a first temperature and a heat exchanger maintained at a second temperature different from said first temperature comprising advancing said tubing continuously within a tubular heat exchanger; supporting said tubing out of contact with said heat exchanger but closely adjacent thereto by buoying said tubing away from the surface of said heat exchanger with a layer of gas under pressure supplied around a complete ring of surface of said tubing substantially uniformly to the interfacial area between said tubing and said heat exchanger, the thickness of said gas layer being 3–10 mils; and removing said tubing from the zone of heat transfer after said tubing has acquired a predetermined temperature of a magnitude between said first temperature and said second temperature.

11. A method of obtaining heat transfer between tubing existing at a first temperature and a heat exchanger having openings therein maintained at a second temperature different from said first temperature comprising advancing said tubing continuously over a tubular heat exchanger in close proximity thereto; flowing gas through said openings in the heat exchanger in a direction transverse to the direction of advancement of said tubing to a complete ring of surface of said tubing at a substantially uniform pressure sufficient to buoy said tubing from the surface of said heat exchanger a distance of 3–10 mils; and removing said tubing from proximity to said heat exchanger after said tubing has acquired a predetermined temperature of a magnitude between said first temperature and said second temperature.

12. A method of obtaining heat transfer between tubing existing at a first temperature and a gas-pervious heat exchanger maintained at a second temperature different from

said first temperature comprising advancing said tubing continuously within said gas-pervious heat exchanger in close proximity thereto; flowing gas through said gas-pervious heat exchanger in a direction transverse to the direction of advancement of said tubing around a complete ring of surface of said tubing at a pressure sufficient to buoy said tubing from the surface of said gas-pervious heat exchanger a distance of 3–10 mils; and removing said tubing from proximity to said gas-pervious heat exchanger after said tubing has acquired a predetermined temperature of a magnitude between said first temperature and said second temperature.

13. A method of obtaining heat transfer between tubing existing at a first temperature and gas-pervious heat exchangers maintained at a second temperature different from said first temperature comprising advancing said tubing continuously through the annular space defined by two concentric gas-pervious heat exchangers; flowing gas through said gas-pervious heat exchangers in a direction transverse to the direction of advancement of said tubing around and within a complete ring of surface of said tubing at a pressure sufficient to buoy said tubing from each of the surfaces of said gas-pervious heat exchangers a distance of 3–10 mils; and removing said tubing from proximity to said gas-pervious heat exchangers after said tubing has acquired a predetermined temperature of a magnitude between said first temperature and said second temperature.

14. An apparatus for obtaining heat transfer between tubing existing at a first temperature and a gas-pervious heat exchanger maintained at a second temperature different from said first temperature comprising a gas-pervious wall of circular cross-section; means for drawing said tubing axially along the exterior of said gas-pervious wall; a heat exchanger disposed in heat-transfer relationship with said gas-pervious wall; gas means for supporting said tubing uniformly out of contact with said gas-pervious wall; and means for supplying gas to said gas-pervious wall at a pressure sufficiently high to maintain a uniform layer of gas 3–10 mils thick adjacent the outside surface of said gas-pervious wall.

15. An apparatus for obtaining heat transfer between tubing existing at a first temperature and a gas-pervious heat exchanger maintained at a second temperature different from said first temperature according to claim 14 wherein two gas-pervious walls are employed, one disposed within said tubing and one disposed around said tubing.

16. A method of obtaining heat transfer between tubing existing at a first temperature and a heat exchanger maintained at a second temeperature different from said first temperature comprising advancing said tubing continuously over a tubular heat exchanger; supporting said tubing out of contact with said heat exchanger but closely adjacent thereto by buoying said tubing away from the surface of said heat exchanger with a layer of gas under pressure supplied substantially uniformly to the interfacial area between said tubing and said heat exchanger, the thickness of said gas layer being no greater than 10 mils; and removing said tubing from the zone of heat transfer after said tubing has acquired a predetermined temperature of a magnitude between said first temperature and said second temperature.

17. A method of obtaining heat transfer between tubing existing at a first temperature and a heat exchanger having openings therein maintained at a second temperature different from said first temperature comprising advancing said tubing continuously over a tubular heat exchanger in close proximity thereto; flowing gas through said openings in the heat exchanger in a direction transverse to the direction of advancement of said tubing at a substantially uniform pressure sufficient to buoy said tubing from the surface of said heat exchanger a distance no greater than 10 mils; and removing said tubing from proximity to said heat exchanger after said tubing has acquired a predetermined temperature of a magnitude between said first temperature and said second temperature.

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