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Methods and apparatus for manufacturing a glass ribbon

Abstract

A glass manufacturing apparatus includes a forming vessel including a first end and a second end. The first end includes a vessel surface defining a recess. The glass manufacturing apparatus includes a compression block positioned within the recess and including a first surface and a contact surface that contacts the vessel surface. The compression block applies a force to the forming vessel. The first surface includes a non-planar shape. The glass manufacturing apparatus includes a support apparatus including a support surface supporting the compression block. The support surface is in contact with a portion of the first surface.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS (1) This application claims the benefit of priority under 35 U.S.C. § 371 of International Application Serial No.: PCT/US2021/015997, filed on Feb. 1, 2021, which claims the benefit of priority under 35 U.S.C. § 119 of U.S. Provisional Application Ser. No. 62/969,282 filed on Feb. 3, 2020, the contents of which are relied upon and incorporated herein by reference in their entirety. (2) This application claims the benefit of priority under 35 U.S.C. § 119 of U.S. Provisional Application Ser. No. 62/969,282 filed on Feb. 3, 2020, the content of which is relied upon and incorporated herein by reference in its entirety.

FIELD
(1) The present disclosure relates generally to methods for manufacturing a glass ribbon and, more particularly, to methods for manufacturing a glass ribbon with a glass manufacturing apparatus comprising a compression block.
BACKGROUND
(2) It is known to manufacture molten material into a glass ribbon with a glass manufacturing apparatus. To reduce sag of a forming vessel of the glass manufacturing apparatus, a force can be applied to an end of the forming vessel with a compression apparatus. However, the application of the force can, over time, cause damage to the forming vessel and/or to the compression apparatus.
SUMMARY
(3) The following presents a simplified summary of the disclosure to provide a basic understanding of some embodiments described in the detailed description.
(4) In some embodiments, a glass manufacturing apparatus can comprise a compression apparatus that can apply a force to an end of a forming vessel. The compression apparatus can comprise a compression block that may be in contact with a vessel surface of the forming vessel. The compression block can move relative to a support apparatus, with a friction-reducing material applied between the compression block and the support apparatus to reduce friction and facilitate movement of the compression block toward the forming vessel. The compression apparatus can comprise one or more of an insulating block or a heating element that can be attached to the support apparatus. As such, the compression block can move independently of the insulating block and the heating element, thus allowing the insulating block and/or the heating element to remain in place.
(5) In accordance with some embodiments, a glass manufacturing apparatus can comprise a forming vessel that can comprise a first end and a second end. The first end can comprise a vessel surface defining a recess. The glass manufacturing apparatus can comprise a compression block

positioned within the recess and comprising a first surface and a contact surface that contacts the vessel surface. The compression block can be configured to apply a force to the forming vessel. The first surface can comprise a non-planar shape. The glass manufacturing apparatus can comprise a support apparatus that can comprise a support surface supporting the compression block. The support surface may be in contact with a portion of the first surface.

(6) In some embodiments, the first surface can comprise a first surface portion, a second surface portion, and a third surface portion. The first surface portion may be in contact with the support surface and can comprise a planar shape.

(7) In some embodiments, the second surface portion and the third surface portion can be positioned on opposite sides of the first surface portion. The second surface portion can form a first angle that is from about 1 degree to about 3 degrees relative to the first surface portion. The third surface portion can form a second angle that is from about 1 degree to about 3 degrees relative to the first surface portion.

(8) In some embodiments, the forming vessel can receive a molten material along a flow direction that may be parallel to a longitudinal direction of the forming vessel. The compression block can apply the force along a force direction that may be parallel to the flow direction and the longitudinal direction.

(9) In some embodiments, the compression block can comprise an edge surface that can connect the contact surface and the first surface. The edge surface can comprise a rounded shape.

(10) In some embodiments, the support surface can extend along a support plane. The compression block may be on a first side of the support plane.

(11) In some embodiments, the support apparatus can comprise a second surface spaced apart from the vessel surface to define a support opening, and one or more of an insulating block attached to the second surface and positioned within the support opening between the support apparatus and the vessel surface, the insulating block comprising a thermally insulating material configured to thermally insulate the support apparatus from the forming vessel, or a heating element attached to the second surface and positioned within the support opening between the support apparatus and the vessel surface, the heating element comprising an electrically conductive material configured to increase a temperature of a portion of the forming vessel.

(12) In accordance with some embodiments, a glass manufacturing apparatus can comprise a forming vessel that can comprise a first end and a second end. The first end can comprise a vessel surface defining a recess. The glass manufacturing apparatus can comprise a compression block positioned within the recess and comprising a contact surface that contacts the vessel surface. The compression block can be configured to apply a force to the forming vessel. The glass manufacturing apparatus can comprise a support apparatus that can comprise a support surface supporting the compression block and extending along a support plane. The compression block may be positioned on a first side of the support plane.

(13) In some embodiments, the support apparatus can comprise a second surface spaced apart from the vessel surface to define a support opening, and one or more of an insulating block or a heating element. The insulating block can be attached to the second surface and may be positioned within the support opening between the support apparatus and the vessel surface. The insulating block may be positioned on a second side of the support plane and spaced apart from the compression block. The insulating block can comprise a thermally insulating material configured to thermally insulate the support apparatus from the forming vessel. The heating element can be attached to the second surface and may be positioned within the support opening between the support apparatus and the vessel surface. The heating element may be positioned on a second side of the support plane and spaced apart from the compression block. The heating element can comprise an electrically conductive material and may be configured to increase a temperature of a portion of the forming vessel.

(14) In some embodiments, the compression block can comprise a second contact surface that may

be substantially perpendicular to the contact surface. The contact surface may be in contact with a first vessel surface portion of the vessel surface and the second contact surface may be in contact with a third vessel surface portion of the vessel surface.

(15) In some embodiments, the compression block can comprise a second edge surface that connects the contact surface and the second contact surface. The second edge surface can be angled relative to the contact surface and the second contact surface and may be spaced apart from the vessel surface.

(16) In accordance with some embodiments, a glass manufacturing apparatus can comprise a forming vessel that can comprise a first end and a second end. The first end can comprise a vessel surface defining a recess. The glass manufacturing apparatus can comprise a compression block positioned within the recess and can comprise a contact surface that contacts the vessel surface. The compression block can be configured to apply a force to the forming vessel. The glass manufacturing apparatus can comprise a support apparatus that can comprise a support surface supporting the compression block. The support apparatus can comprise a second surface spaced apart from the vessel surface to define a support opening. The glass manufacturing apparatus can comprise an insulating block attached to the second surface and positioned within the support opening between the support apparatus and the vessel surface. The insulating block can comprise a thermally insulating material configured to thermally insulate the support apparatus from the forming vessel.

(17) In some embodiments, the insulating block can comprise a first block portion attached to a second block portion. The first block portion can comprise a first protrusion and a first cavity. The second block portion can comprise a second protrusion and a second cavity. The first protrusion can be configured to be received within the second cavity and the second protrusion can be configured to be received within the first cavity.

(18) In some embodiments, the first block portion and the second block portion can comprise a first face that faces the forming vessel and a second face that faces the support apparatus. The second face can comprise a face opening that extends along an axis when the first block portion is attached to the second block portion.

(19) In some embodiments, the support apparatus can comprise a support protrusion extending from the second surface toward the forming vessel. The support protrusion can be configured to be received within the face opening to attach the first block portion and the second block portion to the support apparatus.

(20) In some embodiments, the glass manufacturing apparatus can comprise an insulating block attached to the second surface and positioned within the support opening between the support apparatus and the vessel surface. The insulating block can comprise a thermally insulating material that can be configured to thermally insulate the support apparatus from the forming vessel.

(21) In accordance with some embodiments, a glass manufacturing apparatus can comprise a forming vessel that can comprise a first end and a second end. The first end can comprise a vessel surface that can define a recess. The glass manufacturing apparatus can comprise a compression block positioned within the recess and comprising a contact surface that contacts the vessel surface. The compression block can be configured to apply a force to the forming vessel. The glass manufacturing apparatus can comprise a support apparatus that can comprise a support surface supporting the compression block. The support apparatus can comprise a second surface spaced apart from the vessel surface to define a support opening. The glass manufacturing apparatus can comprise a heating element attached to the second surface and positioned within the support opening between the support apparatus and the vessel surface. The heating element can comprise an electrically conductive material configured to increase a temperature of a portion of the forming vessel.

(22) In some embodiments, the support apparatus can comprise a plurality of attachment brackets that can extend from the second surface toward the forming vessel.

(23) In some embodiments, the heating element can comprise a first opening and a second opening. One of the plurality of attachment brackets can be received within the first opening and another of the plurality of attachment brackets can be received within the second opening when the heating element is attached to the second surface.
(24) In some embodiments, the heating element can extend a first length between a first end and a second end along a first axis parallel to the second surface. The compression block can extend a second length along a second axis parallel to the first axis. The first length may be substantially equal to the second length.
(25) Additional features and advantages of the embodiments disclosed herein will be set forth in the detailed description that follows, and in part will be clear to those skilled in the art from that description or recognized by practicing the embodiments described herein, including the detailed description which follows, the claims, as well as the appended drawings. It is to be understood that both the foregoing general description and the following detailed description present embodiments intended to provide an overview or framework for understanding the nature and character of the embodiments disclosed herein. The accompanying drawings are included to provide further understanding and are incorporated into and constitute a part of this specification. The drawings illustrate various embodiments of the disclosure, and together with the description explain the principles and operations thereof.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) These and other features, embodiments and advantages are better understood when the following detailed description is read with reference to the accompanying drawings, in which:
(2) FIG. **1** schematically illustrates example embodiments of a glass manufacturing apparatus in accordance with embodiments of the disclosure;
(3) FIG. **2** illustrates a perspective cross-sectional view of the glass manufacturing apparatus along line **2-2** of FIG. **1** in accordance with embodiments of the disclosure;
(4) FIG. **3** illustrates an enlarged portion of the glass manufacturing apparatus taken at view **3** of FIG. **1** in accordance with embodiments of the disclosure;
(5) FIG. **4** illustrates a perspective exploded view of a portion of a compression apparatus of the glass manufacturing apparatus in accordance with embodiments of the disclosure;
(6) FIG. **5** illustrates a perspective view of the portion of the compression apparatus of FIG. **4** in a fully assembled state in accordance with embodiments of the disclosure;
(7) FIG. **6** illustrates a front view of a contact surface of a compression block as viewed along line **6-6** of FIG. **5** in accordance with embodiments of the disclosure;
(8) FIG. **7** illustrates a front perspective view of a heating element in accordance with embodiments of the disclosure;
(9) FIG. **8** illustrates a rear perspective view of the heating element of FIG. **7** in accordance with embodiments of the disclosure;
(10) FIG. **9** illustrates a front perspective view of an attachment apparatus of a support plate in accordance with embodiments of the disclosure;
(11) FIG. **10** illustrates a top-down view of the heating element and the attachment apparatus as viewed along line **10-10** of FIG. **9** in accordance with embodiments of the disclosure;
(12) FIG. **11** illustrates a temperature of a support plate and an edge director in accordance with embodiments of the disclosure;
(13) FIG. **12** illustrates a temperature of a support plate and an edge director in accordance with embodiments of the disclosure; and
(14) FIG. **13** illustrates a temperature of a support plate and an edge director in accordance with

embodiments of the disclosure.

DETAILED DESCRIPTION

(15) Embodiments will now be described more fully hereinafter with reference to the accompanying drawings in which example embodiments are shown. Whenever possible, the same reference numerals are used throughout the drawings to refer to the same or like parts. However, this disclosure may be embodied in many different forms and should not be construed as limited to the embodiments set forth herein.

(16) The present disclosure relates to a glass manufacturing apparatus and methods for manufacturing a glass ribbon. Methods and apparatus for producing a glass ribbon will now be described by way of example embodiments for producing a glass ribbon from a ribbon of glass-forming material. As schematically illustrated in FIG. **1**, in some embodiments, an exemplary glass manufacturing apparatus **100** can comprise a glass melting and delivery apparatus **102** and a forming apparatus **101** comprising a forming vessel **140** designed to produce a ribbon of glass-forming material **103** from a quantity of molten material **121**. In some embodiments, the ribbon of glass-forming material **103** can comprise a central portion **152** positioned between opposite edge portions (e.g., edge beads) formed along a first outer edge **153** and a second outer edge **155** of the ribbon of glass-forming material **103**, wherein a thickness of the edge portions can be greater than a thickness of the central portion. Additionally, in some embodiments, a separated glass ribbon **104** can be separated from the ribbon of glass-forming material **103** along a separation path **151** by a glass separator **149** (e.g., scribe, score wheel, diamond tip, laser, etc.).

(17) In some embodiments, the glass melting and delivery apparatus **102** can comprise a melting vessel **105** oriented to receive batch material **107** from a storage bin **109**. The batch material **107** can be introduced by a batch delivery device **111** powered by a motor **113**. In some embodiments, an optional controller **115** can be operated to activate the motor **113** to introduce a desired amount of batch material **107** into the melting vessel **105**, as indicated by arrow **117**. The melting vessel **105** can heat the batch material **107** to provide molten material **121**. In some embodiments, a melt probe **119** can be employed to measure a level of molten material **121** within a standpipe **123** and communicate the measured information to the controller **115** by way of a communication line **125**.

(18) Additionally, in some embodiments, the glass melting and delivery apparatus **102** can comprise a first conditioning station comprising a fining vessel **127** located downstream from the melting vessel **105** and coupled to the melting vessel **105** by way of a first connecting conduit **129**. In some embodiments, molten material **121** can be gravity fed from the melting vessel **105** to the fining vessel **127** by way of the first connecting conduit **129**. For example, in some embodiments, gravity can drive the molten material **121** through an interior pathway of the first connecting conduit **129** from the melting vessel **105** to the fining vessel **127**. Additionally, in some embodiments, bubbles can be removed from the molten material **121** within the fining vessel **127** by various techniques.

(19) In some embodiments, the glass melting and delivery apparatus **102** can further comprise a second conditioning station comprising a mixing chamber **131** that can be located downstream from the fining vessel **127**. The mixing chamber **131** can be employed to provide a homogenous composition of molten material **121**, thereby reducing or eliminating inhomogeneity that may otherwise exist within the molten material **121** exiting the fining vessel **127**. As shown, the fining vessel **127** can be coupled to the mixing chamber **131** by way of a second connecting conduit **135**. In some embodiments, molten material **121** can be gravity fed from the fining vessel **127** to the mixing chamber **131** by way of the second connecting conduit **135**. For example, in some embodiments, gravity can drive the molten material **121** through an interior pathway of the second connecting conduit **135** from the fining vessel **127** to the mixing chamber **131**.

(20) Additionally, in some embodiments, the glass melting and delivery apparatus **102** can comprise a third conditioning station comprising a delivery chamber **133** that can be located downstream from the mixing chamber **131**. In some embodiments, the delivery chamber **133** can

condition the molten material **121** to be fed into an inlet conduit **141**. For example, the delivery chamber **133** can function as an accumulator and/or flow controller to adjust and provide a consistent flow of molten material **121** to the inlet conduit **141**. As shown, the mixing chamber **131** can be coupled to the delivery chamber **133** by way of a third connecting conduit **137**. In some embodiments, molten material **121** can be gravity fed from the mixing chamber **131** to the delivery chamber **133** by way of the third connecting conduit **137**. For example, in some embodiments, gravity can drive the molten material **121** through an interior pathway of the third connecting conduit **137** from the mixing chamber **131** to the delivery chamber **133**. As further illustrated, in some embodiments, a delivery pipe **139** can be positioned to deliver molten material **121** to forming apparatus **101**, for example the inlet conduit **141** of the forming vessel **140**.

(21) Forming apparatus **101** can comprise various embodiments of forming vessels in accordance with features of the disclosure, for example, a forming vessel with a wedge for fusion drawing the glass ribbon, a forming vessel with a slot to slot draw the glass ribbon, or a forming vessel provided with press rolls to press roll the glass ribbon from the forming vessel. In some embodiments, the forming apparatus **101** can comprise a sheet redraw, for example, with the forming apparatus **101** as part of a redraw process. For example, the glass ribbon **104**, which can comprise a thickness, may be heated up and redrawn to achieve a thinner glass ribbon **104** comprising a smaller thickness. By way of illustration, the forming vessel **140** shown and disclosed below can be provided to fusion draw molten material **121** off a bottom edge, defined as a root **145**, of a forming wedge **209** to produce the ribbon of glass-forming material **103**. For example, in some embodiments, the molten material **121** can be delivered from the inlet conduit **141** to the forming vessel **140**. The molten material **121** can then be formed into the ribbon of glass-forming material **103** based, in part, on the structure of the forming vessel **140**. For example, as shown, the molten material **121** can be drawn off the bottom edge (e.g., root **145**) of the forming vessel **140** along a draw path extending in a travel direction **154** of the glass manufacturing apparatus **100**. In some embodiments, edge directors **163**, **164** can direct the molten material **121** off the forming vessel **140** and define, in part, a width “W” of the ribbon of glass-forming material **103**. In some embodiments, the width “W” of the ribbon of glass-forming material **103** extends between the first outer edge **153** of the ribbon of glass-forming material **103** and the second outer edge **155** of the ribbon of glass-forming material **103**.

(22) In some embodiments, the width “W” of the ribbon of glass-forming material **103**, which extends between the first outer edge **153** of the ribbon of glass-forming material **103** and the second outer edge **155** of the ribbon of glass-forming material **103**, can be greater than or equal to about 20 millimeters (mm), for example, greater than or equal to about 50 mm, for example, greater than or equal to about 100 mm, for example, greater than or equal to about 500 mm, for example, greater than or equal to about 1000 mm, for example, greater than or equal to about 2000 mm, for example, greater than or equal to about 3000 mm, for example, greater than or equal to about 4000 mm, although other widths less than or greater than the widths mentioned above can be provided in further embodiments. For example, in some embodiments, the width “W” of the ribbon of glass-forming material **103** can be within a range from about 20 mm to about 4000 mm, for example, within a range from about 50 mm to about 4000 mm, for example, within a range from about 100 mm to about 4000 mm, for example, within a range from about 500 mm to about 4000 mm, for example, within a range from about 1000 mm to about 4000 mm, for example, within a range from about 2000 mm to about 4000 mm, for example, within a range from about 3000 mm to about 4000 mm, for example, within a range from about 20 mm to about 3000 mm, for example, within a range from about 50 mm to about 3000 mm, for example, within a range from about 100 mm to about 3000 mm, for example, within a range from about 500 mm to about 3000 mm, for example, within a range from about 1000 mm to about 3000 mm, for example, within a range from about 2000 mm to about 3000 mm, for example, within a range from about 2000 mm to about 2500 mm, and all ranges and subranges therebetween.

(23) FIG. **2** shows a cross-sectional perspective view of the forming apparatus **101** (e.g., forming vessel **140**) along line **2-2** of FIG. **1**. In some embodiments, the forming vessel **140** can comprise a trough **201** oriented to receive the molten material **121** from the inlet conduit **141**. For illustrative purposes, cross-hatching of the molten material **121** is removed from FIG. **2** for clarity. The forming vessel **140** can further comprise the forming wedge **209** comprising a pair of downwardly inclined converging surface portions **207**, **208** extending between opposed ends **210**, **211** (See FIG. **1**) of the forming wedge **209**. The pair of downwardly inclined converging surface portions **207**, **208** of the forming wedge **209** can converge along the travel direction **154** to intersect along the root **145** of the forming vessel **140**. A draw plane **213** of the glass manufacturing apparatus **100** can extend through the root **145** along the travel direction **154**. In some embodiments, the ribbon of glass-forming material **103** can be drawn in the travel direction **154** along the draw plane **213**. As shown, the draw plane **213** can bisect the forming wedge **209** through the root **145** although, in some embodiments, the draw plane **213** can extend at other orientations relative to the root **145**. In some embodiments, the ribbon of glass-forming material **103** can move along a travel path **221** that may be co-planar with the draw plane **213** in the travel direction **154**.
(24) Additionally, in some embodiments, the molten material **121** can flow in a flow direction **156** into and along the trough **201** of the forming vessel **140**. For example, the forming vessel can receive the molten material **121** along the flow direction **156** that may be parallel to a longitudinal direction of the forming vessel **140**. The longitudinal direction of the forming vessel **140** may extend between the first end **210** and a second end **211** (e.g., wherein the longitudinal direction may be transverse to the travel direction **154** illustrated in FIG. **1**). The molten material **121** can then overflow from the trough **201** by simultaneously flowing over corresponding weirs **203**, **204** and downward over the outer surfaces **205**, **206** of the corresponding weirs **203**, **204**. Respective streams of molten material **121** can then flow along the downwardly inclined converging surface portions **207**, **208** of the forming wedge **209** to be drawn off the root **145** of the forming vessel **140**, where the flows converge and fuse into the ribbon of glass-forming material **103**. The ribbon of glass-forming material **103** can then be drawn off the root **145** in the draw plane **213** along the travel direction **154**. In some embodiments, the ribbon of glass-forming material **103** comprises one or more states of material based on a vertical location of the ribbon of glass-forming material **103**. For example, at one location, the ribbon of glass-forming material **103** can comprise the viscous molten material **121**, and at another location, the ribbon of glass-forming material **103** can comprise an amorphous solid in a glassy state (e.g., a glass ribbon).
(25) The ribbon of glass-forming material **103** comprises a first major surface **215** and a second major surface **216** facing opposite directions and defining a thickness “T” (e.g., average thickness) of the ribbon of glass-forming material **103**. In some embodiments, the thickness “T” of the ribbon of glass-forming material **103** can be less than or equal to about 2 millimeters (mm), less than or equal to about 1 millimeter, less than or equal to about 0.5 millimeters, for example, less than or equal to about 300 micrometers (nm), less than or equal to about 200 micrometers, or less than or equal to about 100 micrometers, although other thicknesses may be provided in further embodiments. For example, in some embodiments, the thickness “T” of the ribbon of glass-forming material **103** can be within a range from about 20 micrometers to about 200 micrometers, within a range from about 50 micrometers to about 750 micrometers, within a range from about 100 micrometers to about 700 micrometers, within a range from about 200 micrometers to about 600 micrometers, within a range from about 300 micrometers to about 500 micrometers, within a range from about 50 micrometers to about 500 micrometers, within a range from about 50 micrometers to about 700 micrometers, within a range from about 50 micrometers to about 600 micrometers, within a range from about 50 micrometers to about 500 micrometers, within a range from about 50 micrometers to about 400 micrometers, within a range from about 50 micrometers to about 300 micrometers, within a range from about 50 micrometers to about 200 micrometers, within a range from about 50 micrometers to about 100 micrometers, within a range from about 25

micrometers to about 125 micrometers, comprising all ranges and subranges of thicknesses therebetween. In addition, the ribbon of glass-forming material **103** can comprise a variety of compositions, for example, borosilicate glass, alumino-borosilicate glass, alkali-containing glass, or alkali-free glass, alkali aluminosilicate glass, alkaline earth aluminosilicate glass, soda-lime glass, etc.

(26) In some embodiments, the glass separator **149** (see FIG. **1**) can then separate the glass ribbon **104** from the ribbon of glass-forming material **103** along the separation path **151** to provide a plurality of separated glass ribbons **104** (i.e., a plurality of sheets of glass). According to other embodiments, a longer portion of the glass ribbon **104** may be coiled onto a storage roll. The separated glass ribbon can then be processed into a desired application, e.g., a display application. For example, the separated glass ribbon can be used in a wide range of display applications, comprising liquid crystal displays (LCDs), electrophoretic displays (EPD), organic light emitting diode displays (OLEDs), plasma display panels (PDPs), touch sensors, photovoltaics, and other electronic displays.

(27) FIG. **3** illustrates an enlarged view of a portion of the forming vessel **140** at view **3** of FIG. **1**. In some embodiments, the forming vessel **140** can comprise a first end **210** and a second end **211** (e.g., the first end **210** and the second end **211** illustrated in FIG. **1**), with the forming vessel **140** extending along an axis between the first end **210** and the second end **211**. In some embodiments, due to the weight of the forming vessel **140** and the temperatures at which the forming vessel **140** may be exposed, the forming vessel **140** may experience sag, wherein a portion of the forming vessel **140** may bend along the travel direction **154**. To reduce the likelihood of sagging of the forming vessel **140**, the glass manufacturing apparatus **100** can comprise one or more compression apparatuses **305**. For example, one compression apparatus **305** can be positioned at the first end **210** of the forming vessel **140** while another compression apparatus **305** can be positioned at the second end **211** of the forming vessel **140**. In some embodiments, the one or more compression apparatuses **305** can apply a compressive force to the first end **210** and/or to the second end **211** of the forming vessel **140**. The compressive force can reduce the sag of the forming vessel **140**. In some embodiments, the compression apparatuses **305** at the first end **210** and the second end **211** can be substantially identical.

(28) In some embodiments, the first end **210** can comprise a vessel surface **307** defining a recess **309**. The recess **309** (e.g., a void, a space, an opening, etc.) can receive a portion of the compression apparatus **305**. In some embodiments, the vessel surface **307** can comprise a plurality of surface portions, for example, a first vessel surface portion **311**, a second vessel surface portion **313**, and a third vessel surface portion **315**. The first vessel surface portion **311**, the second vessel surface portion **313**, and the third vessel surface portion **315** may together form a non-planar surface. For example, the first vessel surface portion **311** can comprise a planar surface while the second vessel surface portion **313**, which may be contiguous with and/or connected with the first vessel surface portion **311**, may comprise a non-planar surface. In some embodiments, the second vessel surface portion **313** can comprise a rounded surface. In some embodiments, the third vessel surface portion **315** can comprise a planar surface and may be contiguous with and/or connected with the second vessel surface portion **313**. As such, in some embodiments, the second vessel surface portion **313** may be attached to, and positioned between, the first vessel surface portion **311** and the third vessel surface portion **315**. In some embodiments, the first vessel surface portion **311** and the third vessel surface portion **315** can form an angle relative to one another, for example, by extending substantially perpendicular to one another. For example, the first vessel surface portion **311** can extend substantially parallel to the travel direction **154** while the third vessel surface portion **315** can extend substantially perpendicular to the travel direction **154**.

(29) The compression apparatus **305** can comprise one or more structures for providing a force to the forming vessel **140**. For example, in some embodiments, the compression apparatus **305** can comprise a compression block **321**, a force block **323**, a support apparatus **325**, and an insulating

block **327**. With reference to the compression block **321**, the glass manufacturing apparatus **100** can comprise the compression block **321** that may be positioned within the recess **309** and can comprise a first surface **331** and a contact surface **335** that contacts the vessel surface **307**. In some embodiments, the first surface **331** can face the travel direction **154**, for example, by being oriented to face a direction that is downstream from the forming vessel **140** relative to the movement of the ribbon of glass-forming material **103** along the travel direction **154**. In some embodiments, the first surface **331** may be non-planar relative to the contact surface **335**. For example, the first surface **331** may form an angle relative to the contact surface **335**, for example, a 90° angle, such that the first surface **331** may be substantially perpendicular to the contact surface **335**. The first surface **331** and the contact surface **335** can be connected by an edge surface **337**. For example, the compression block **321** can comprise the edge surface **337** that may connect the contact surface **335** and the first surface **331**. In some embodiments, the edge surface **337** can comprise a rounded shape with a radius of curvature. For example, in some embodiments, a radius of curvature of the edge surface **337** can be within a range from about 6 mm to about 10 mm, or about 8 mm. Due to the rounded shape of the edge surface **337** with the radius of curvature, the stress within the compression block **321** may be below a desired value during the application of the force to the forming vessel **140**.

(30) In some embodiments, the compression block **321** can comprise a second contact surface **341** that may be substantially perpendicular to the contact surface **335**. For example, the second contact surface **341** can extend along a plane that forms an angle relative to a plane along which the contact surface **335** extends, for example, a 90° angle. In some embodiments, the second contact surface **341** can face a direction opposite the travel direction **154**, for example, an upstream direction relative to the movement of the ribbon of glass-forming material **103** along the travel direction **154**. In some embodiments, the second contact surface **341** may be substantially parallel to the first surface **331**. The compression block **321** can comprise a second edge surface **343** that connects the contact surface **335** and the second contact surface **341**. For example, the second edge surface **343** can be positioned between the contact surface **335** and the second contact surface **341**. In some embodiments, the second edge surface **343** can be angled relative to the contact surface **335** and the second contact surface **341** and may be spaced apart from the vessel surface **307**. For example, by being angled relative to the contact surface **335** and the second contact surface **341**, the second edge surface **343** can extend non-planar relative to the contact surface **335** and non-planar relative to the second contact surface **341**. In some embodiments, the second edge surface **343** can form an angle relative to the contact surface **335** that is within a range from about 90 degrees to about 180 degrees, or within a range from about 120 degrees to about 150 degrees. In some embodiments, the second edge surface **343** can form an angle relative to the second contact surface **341** that is within a range from about 90 degrees to about 180 degrees, or within a range from about 120 degrees to about 150 degrees. In some embodiments, one or more of the contact surface **335** or the second edge surface **343** can comprise a heating element **602**. The heating element **602** can comprise an electrically conductive material that can extend along and/or within the contact surface **335** and/or the second edge surface **343**. The heating element **602** can generate heat to increase a temperature of a portion of the forming vessel **140**.

(31) In some embodiments, the compression block **321** can contact the vessel surface **307** while the compression block **321** is positioned within the recess **309**. For example, the contact surface **335** can be in contact with the first vessel surface portion **311** of the vessel surface **307** and the second contact surface **341** can be in contact with the third vessel surface portion **315** of the vessel surface **307**. In some embodiments, with the contact surface **335** in contact with the first vessel surface portion **311** and the second contact surface **341** in contact with the third vessel surface portion **315**, the second edge surface **343** may be spaced apart from the second vessel surface portion **313** of the vessel surface **307**. The contact surface **335** may be substantially parallel to the first vessel surface portion **311** such that when the contact surface **335** is in contact with the first vessel surface portion

311 the contact surface **335** may be flush with the first vessel surface portion **311**. The second contact surface **341** may be substantially parallel to the third vessel surface portion **315** such that when the second contact surface **341** is in contact with the third vessel surface portion **315** the second contact surface **341** may be flush with the third vessel surface portion **315**. In some embodiments, due to the contact between the third vessel surface portion **315** and the second contact surface **341**, a portion of the weight of the forming vessel **140** can rest upon and/or be supported by the compression block **321**.

(32) With the compression block **321** in contact with the vessel surface **307**, the compression block **321** can apply a force to the forming vessel **140**. For example, the glass manufacturing apparatus **100** can comprise the force block **323** that can be positioned adjacent to and in contact with the compression block **321**. The force block **323** can be positioned in contact with a surface of the compression block **321** that is opposite the contact surface **335** such that the compression block **321** may be positioned between the first vessel surface portion **311** and the force block **323**. In some embodiments, the force block **323** can apply a force to the compression block **321** along a force direction **345** that may be transverse to the travel direction **154** and toward the forming vessel **140**. In some embodiments, by moving in the force direction **345**, the force block **323** can cause the compression block **321** to apply a compressive force to the forming vessel **140**, for example, the first vessel surface portion **311**. For example, the compression block **321** can apply a force along the force direction **345** (e.g., to the forming vessel **140**) that may be parallel to the flow direction **156** (e.g., illustrated in FIG. **2**) and the longitudinal direction of the forming vessel **140**. The compressive force can mitigate sag of the forming vessel **140**.

(33) In some embodiments, the glass manufacturing apparatus **100** can comprise the support apparatus **325**, which can comprise a support surface **347** supporting the compression block **321**. In some embodiments, the support surface **347** can be in contact with a portion of the first surface **331**. For example, the compression block **321** can rest upon the support apparatus **325**, with the first surface **331** facing the support surface **347**. In some embodiments, support apparatus **325** can comprise one or more structures that can support the compression block **321**. For example, in some embodiments, the support apparatus **325** can comprise a movement plate **349** and a support plate **351**. The movement plate **349** can comprise the support surface **347** such that the compression block **321** can rest upon the movement plate **349** with the first surface **331** in contact with the support surface **347** of the movement plate **349**. In some embodiments, the compression block **321** can move relative to the movement plate **349** of the support apparatus **325**. For example, as the compression block **321** moves toward the forming vessel **140** (e.g., along the force direction **345**), the compression block **321** can move relative to the movement plate **349**. To facilitate movement and reduce friction between the compression block **321** and the movement plate **349**, in some embodiments, a friction-reducing material may be applied to the support surface **347** and/or to the first surface **331**. For example, in some embodiments, the movement plate **349** can comprise an alumina material and the compression block **321** can comprise a zircon material. In some embodiments, the friction-reducing material can comprise a copper-oxide based thermal paste. The friction-reducing material can reduce friction between the compression block **321** and the movement plate **349** such that the compression block **321** can move, in response to the force applied by the force block **323**, relative to the movement plate **349**. In some embodiments, the support plate **351** can support the movement plate **349**, wherein the movement plate **349** may be in contact with and may rest on the support plate **351**. In some embodiments, the movement plate **349** can support the compression block **321**, wherein the compression block **321** may be in contact with and may rest on the movement plate **349**, with the compression block **321** spaced apart from and not in contact with the support plate **351**. In some embodiments, the movement plate **349** can comprise a height that is within a range from about 6 mm to about 18 mm, or about 12.7 mm.

(34) In some embodiments, the support surface **347** can extend along a support plane **355**. The support plane **355** can define a first side **357** and a second side **359** (e.g., wherein the support plane

355 extends between the first side **357** and the second side **359**). In some embodiments, the compression block **321** can be positioned on the first side **357** of the support plane **355**, while the support plate **351** can be positioned on the second side **359** of the support plane **355**. For example, by being positioned on the first side **357** of the support plane **355**, in some embodiments, an entirety of the compression block **321**, including the first surface **331**, may be positioned on the first side **357**, with no portions of the compression block **321** intersecting the support plane **355** to lie on the second side **359**. In some embodiments, by being positioned on the second side **359**, an entirety of the support plate **351** may be positioned on the second side **359**, with no portions of the support plate **351** intersecting the support plane **355** to lie on the first side **357**. In some embodiments, the support apparatus **325** can comprise a second surface **363** spaced apart from the vessel surface **307** to define a support opening **365**. For example, the support plate **351** can comprise the second surface **363** and the movement plate **349** can comprise a third surface **367**. In some embodiments, the second surface **363** of the support plate **351** and the third surface **367** of the movement plate **349** can face the forming vessel **140**. The second surface **363** of the support plate **351** and the third surface **367** of the movement plate **349** can be spaced apart from the forming vessel **140**, for example, the vessel surface **307**, to define the support opening **365**. In some embodiments, the support opening **365** may be located between the forming vessel **140** and the support apparatus **325** (e.g., the movement plate **349** and the support plate **351**).

(35) In some embodiments, the glass manufacturing apparatus **100** can comprise a thermal element, for example, the insulating block **327**. The insulating block **327** may be attached to the second surface **363** and positioned within the support opening **365** between the support apparatus **325** and the vessel surface **307**. The insulating block **327** can be attached to the second surface **363** in several ways. For example, in some embodiments, mechanical fasteners (e.g., screws, bolts, etc.) can attach the insulating block **327** to the second surface **363** of the support plate **351**. In some embodiments, an attachment apparatus (e.g., similar to an attachment apparatus **901** illustrated in FIG. **9**) can facilitate removable attachment of the insulating block **327** to the second surface **363**. The insulating block **327** can comprise a thermally insulating material that can thermally insulate the support apparatus **325** from the forming vessel **140**. For example, in some embodiments, the insulating block **327** can comprise a refractory material comprising one or more of zircon, zirconia, alumina, magnesium oxide, silicon carbide, silicon nitride, silicon oxynitride, xenotime, monazite, or alloys thereof. In some embodiments, the support plate **351** can comprise a metal material, for example, steel, such that the insulating block **327** can shield the support plate **351** from the temperatures of the forming vessel **140**. For example, by being positioned within the support opening **365**, the insulating block **327** can thermally insulate the support plate **351** from the forming vessel **140**, thus reducing the temperature that the support plate **351** may experience.

(36) In some embodiments, the insulating block **327** may be positioned on the second side **359** of the support plane **355** and may be spaced apart from the compression block **321**. For example, by being spaced apart from the compression block **321**, a gap may exist between the insulating block **327** and the first surface **331** of the compression block **321** such that the compression block **321** may move (e.g., in the force direction **345**) independently of the insulating block **327**. In some embodiments, the insulating block **327** may remain attached to and/or in contact with the support apparatus **325** while the compression block **321** is moved in the force direction **345** and applies a force to the forming vessel **140**. By providing the insulating block **327** separately and spaced apart from the compression block **321**, inadvertent detachment of the insulating block **327** from the support apparatus **325** may be avoided when the compression block **321** applies a force to the forming vessel **140**.

(37) Referring to FIG. **4**, an exploded illustration of the compression apparatus **305** of FIG. **3** is illustrated. In some embodiments, the insulating block **327** can comprise a unitary, one-piece structure that can be attached to the second surface **363**. However, as illustrated in FIG. **4**, the insulating block **327** is not limited to a one-piece structure, but, rather, can comprise a plurality of

portions. For example, in some embodiments, the insulating block **327** can comprise a plurality of block portions, for example, a first block portion **401**, a second block portion **403**, and a third block portion **405**. The first block portion **401**, the second block portion **403**, and the third block portion **405** can be attached to one another and may be attached to the support apparatus **325**. For example, the insulating block **327** can comprise the first block portion **401** attached to the second block portion **403**. In some embodiments, the first block portion **401** can comprise a first protrusion **407** and a first cavity **409**. The second block portion **403** can comprise a second protrusion **413** and a second cavity **415**. The first protrusion **407** can be received within the second cavity **415** and the second protrusion **413** can be received within the first cavity **409**. For example, the first block portion **401**, the second block portion **403**, and the third block portion **405** can be arranged along an axis **419**, wherein the first block portion **401**, the second block portion **403**, and the third block portion **405** may intersect the axis when attached together, with the axis **419** extending substantially parallel to the second surface **363**. In some embodiments, the first protrusion **407** can extend from the first block portion **401** along the axis **419** toward the second block portion **403**. The first cavity **409** may be bordered by the first protrusion **407**. In some embodiments, the second protrusion **413** can extend from the second block portion **403** along the axis **419** toward the first block portion **401**. The second cavity **415** may be bordered by the second protrusion **413**. In some embodiments, the first protrusion **407** may be aligned with the second cavity **415** and the second protrusion **413** may be aligned with the first cavity **409**. As such, the first block portion **401** and the second block portion **403** may be brought into contact with one another such that the first protrusion **407** may be received within the second cavity **415** and the second protrusion **413** may be received within the first cavity **409**.

(38) In some embodiments, the second block portion **403** and the third block portion **405** can be attached in a similar manner as the attachment between the first block portion **401** and the second block portion **403**. For example, the second block portion **403** can comprise a third protrusion **423** and a third cavity **425**. The third block portion **405** can comprise a fourth protrusion **427** and a fourth cavity **429**. The third protrusion **423** can be received within the fourth cavity **429** and the fourth protrusion **427** can be received within the third cavity **425**. For example, the third protrusion **423** can extend from the second block portion **403** along the axis **419** toward the third block portion **405**. The third cavity **425** may be bordered by the third protrusion **423**. In some embodiments, the fourth protrusion **427** can extend from the third block portion **405** along the axis **419** toward the second block portion **403**. The fourth cavity **429** may be bordered by the fourth protrusion **427**. In some embodiments, the third protrusion **423** may be aligned with the fourth cavity **429** and the fourth protrusion **427** may be aligned with the third cavity **425**. As such, the second block portion **403** and the third block portion **405** may be brought into contact with one another such that the third protrusion **423** may be received within the fourth cavity **429** and the fourth protrusion **427** may be received within the third cavity **425**.

(39) The attachment of the first block portion **401**, the second block portion **403**, and the third block portion **405** yields several benefits. For example, when the first block portion **401**, the second block portion **403**, and the third block portion **405** are attached, gaps through the insulating block **327** (e.g., through the first block portion **401**, the second block portion **403**, and the third block portion **405**) may be avoided. In some embodiments, a first intersecting axis **433** can extend substantially perpendicular to the axis **419** along which the first block portion **401**, the second block portion **403**, and the third block portion **405** are arranged. The first intersecting axis **433** can intersect the insulating block **327** and the support plate **351**, for example, by being substantially perpendicular to the second surface **363**. In some embodiments, the first intersecting axis **433** can be oriented to extend through a location between the first block portion **401** and the second block portion **403**. However, due to the first protrusion **407** being received within the second cavity **415** and the second protrusion **413** being received within the first cavity **409**, the first protrusion **407** and the second protrusion **413** can extend adjacent to and parallel to one another. As such, the first

intersecting axis **433** may intersect the first protrusion **407** and/or the second protrusion **413**. By avoiding a gap between the first block portion **401** and the second block portion **403**, heat transfer between the first block portion **401** and the second block portion **403** to the support plate **351** may be reduced, thus increasing the thermal insulation of the support apparatus **325** from the forming vessel **140**.

(40) Similarly, in some embodiments, a second intersecting axis **435** can extend substantially parallel to the first intersecting axis **433**. The second intersecting axis **435** can intersect the insulating block **327** and the support plate **351**, for example, by being substantially perpendicular to the second surface **363**. In some embodiments, the second intersecting axis **435** can be oriented to extend through a location between the second block portion **403** and the third block portion **405**. However, due to the third protrusion **423** being received within the fourth cavity **429** and the fourth protrusion **427** being received within the third cavity **425**, the third protrusion **423** and the fourth protrusion **427** can extend adjacent to and parallel to one another. As such, the second intersecting axis **435** may intersect the third protrusion **423** and/or the fourth protrusion **427**. By avoiding a gap between the second block portion **403** and the third block portion **405**, heat transfer between the second block portion **403** and the third block portion **405** to the support plate **351** may be reduced, thus increasing the thermal insulation of the support apparatus **325** from the forming vessel **140**.

(41) In some embodiments, the first block portion **401**, the second block portion **403**, and the third block portion **405** can comprise a first face **441** that faces the forming vessel **140** and a second face **443** that faces the support apparatus **325**. For example, when the first block portion **401**, the second block portion **403**, and the third block portion **405** are attached to one another, the first face **441** may comprise a substantially planar surface that faces the forming vessel **140**. When the first block portion **401**, the second block portion **403**, and the third block portion **405** are attached to one another, the second face **443** may comprise a substantially planar surface that faces the support apparatus **325**. In some embodiments, the second face **443** can comprise a face opening **445** that extends along the axis **419** when the first block portion **401** is attached to the second block portion **403**, and when the second block portion **403** is attached to the third block portion **405**. For example, the face opening **445** can comprise a groove, a channel, an indentation, or the like formed in the second face **443**, wherein the face opening **445** in the first block portion **401**, the second block portion **403**, and the third block portion **405** can be aligned such that the face opening **445** may extend linearly along the axis **419**.

(42) Referring to FIGS. **4-5**, in some embodiments, the support apparatus **325** can comprise a support protrusion **451** extending from the second surface **363** toward the forming vessel **140**. For example, the support protrusion **451** can comprise an outcropping, a protuberance, an extension, etc. that extends from the second surface **363** toward the forming vessel **140**. In some embodiments, the support protrusion **451** can extend substantially linearly along the second surface **363**. The support protrusion **451** may be sized to be received within the face opening **445** of the first block portion **401**, the second block portion **403**, and the third block portion **405**. For example, in some embodiments, the support protrusion **451** can comprise a shape that may substantially match a shape of the face opening **445**, with the support protrusion **451** comprising a smaller cross-sectional size than a cross-sectional size of the face opening **445**. The support protrusion **451** can be received within the face opening **445** to attach the first block portion **401**, the second block portion **403**, and the third block portion **405** to the support apparatus **325**. For example, when the support protrusion **451** is received within the face opening **445**, movement of the first block portion **401**, the second block portion **403**, and the third block portion **405** relative to the support plate **351** may be limited, such that the first block portion **401**, the second block portion **403**, and the third block portion **405** may be attached to the support plate **351**.

(43) FIG. **6** illustrates a front view of the contact surface **335** of the compression block **321** as viewed along line **6-6** of FIG. **5**, with the compression block **321** supported by the movement plate **349**. In some embodiments, the first surface **331** can comprise one or more surface portions. For

example, the first surface **331** can comprise a first surface portion **601**, a second surface portion **603**, and a third surface portion **605**. The first surface portion **601** may be positioned between the second surface portion **603** and the third surface portion **605** such that the second surface portion **603** and the third surface portion **605** may be positioned on opposite sides of the first surface portion **601**. In some embodiments, the first surface **331** can comprise a non-planar shape. For example, the second surface portion **603** can form a first angle **609** that may be from about 1 degree to about 3 degrees relative to the first surface portion **601**. In some embodiments, the first angle **609** may be different than about 1 degree to about 3 degrees, for example, wherein the first angle **609** may be from about 0.5 degrees to about 10 degrees. The first angle **609** may be defined between the second surface portion **603** and a plane along which the first surface portion **601** extends. In some embodiments, the third surface portion **605** can form a second angle **611** that may be from about 1 degree to about 3 degrees relative to the first surface portion **601**. In some embodiments, the second angle **611** may be different than about 1 degree to about 3 degrees, for example, wherein the second angle **611** may be from about 0.5 degrees to about 10 degrees. The second angle **611** may be defined between the third surface portion **605** and the plane along which the first surface portion **601** extends. In some embodiments, the first surface portion **601** and the second surface portion **603** may be non-planar relative to one another, and the first surface portion **601** and the third surface portion **605** may be non-planar relative to one another. For example, in some embodiments, the first surface portion **601** may be substantially planar. In some embodiments, the second surface portion **603** may be substantially planar. However, due to the second surface portion **603** forming the first angle **609** relative to the first surface portion **601**, the second surface portion **603** may be non-planar relative to the first surface portion **601**. In some embodiments, the third surface portion **605** may be substantially planar. However, due to the third surface portion **605** forming the second angle **611** relative to the first surface portion **601**, the third surface portion **605** may be non-planar relative to the first surface portion **601**.
(44) In some embodiments, the first surface portion **601** may be in contact with the support surface **347** and may comprise a planar shape such that the first surface portion **601** may extend substantially parallel to the support surface **347**. For example, the first surface portion **601** can rest on the support surface **347** such that the support surface **347** may support the compression block **321**. In some embodiments, due to the second surface portion **603** and the third surface portion **605** being non-planar relative to the first surface portion **601**, the second surface portion **603** and the third surface portion **605** may be non-planar relative to the support surface **347** when the first surface portion **601** is in contact with the support surface **347**. For example, a first distance **615** can separate the second surface portion **603** from the support surface **347** and a second distance **617** can separate the third surface portion **605** from the support surface **347**. In some embodiments, by spacing the second surface portion **603** and the third surface portion **605** apart from the support surface **347**, the support surface **347** can be in contact with a portion of the first surface **331** (e.g., the first surface portion **601**) while not being in contact with other portions of the first surface **331** (e.g., the second surface portion **603** and the third surface portion **605**).
(45) The non-planar shape of the first surface **331** can provide several benefits. For example, less than all of the first surface **331** of the compression block **321** may be in contact with the movement plate **349**, with the first surface portion **601** in contact with the support surface **347**. For example, a central portion (e.g., the first surface portion **601**) may be in contact with the support surface **347**, while lateral portions (e.g., the second surface portion **603** and the third surface portion **605**) located on opposing sides of the central portion may be spaced apart from and not in contact with the support surface **347**. As such, a contact area width **621**, defined by a width of the compression block **321** that is in contact with the movement plate **349** (e.g., comprising a width of the first surface portion **601**), may be less than a block width **623**, defined by a total width of the compression block **321** between opposing sides of the compression block **321** (e.g., comprising a width of the first surface portion **601**, the second surface portion **603**, and the third surface portion

605). The force that may be applied by the compression block **321** to the movement plate **349** may therefore be limited to the contact area width **621**. Due to the contact area width **621** being less than the block width **623**, the force applied by the compression block **321** may be more concentrated at a smaller area of the movement plate **349**, which can reduce a bending moment on the movement plate **349** and, thus, the overall stress on the compression block **321** and the movement plate **349**.
(46) Referring to FIG. **7**, a perspective view of a heating element **701** is illustrated. In some embodiments, the heating element **701** can comprise one or more of a heating portion **702** and/or the insulating block **327** (e.g., illustrated in FIGS. **3-5**). In some embodiments, the heating portion **702** of the heating element **701** can comprise an electrically conductive material **703** configured to increase a temperature of a portion of the forming vessel **140**. For example, the heating portion **702** can comprise a resistive heating element comprising a metal material through which electrons can flow to generate an electric current which can produce heat. In some embodiments, the portion of the forming vessel **140** that may be heated by the heating portion **702** are the edge directors **163**, **164** (e.g., illustrated in FIG. **2**). For example, the electrically conductive material **703** can comprise a wire that can be positioned on a first surface **705** of the heating portion **702**, with the first surface **705** facing the forming vessel **140**. The electrically conductive material **703** can be arranged to wind along the first surface **705**. In some embodiments, the heat generated by the electrically conductive material **703** can facilitate control of a temperature of the forming vessel **140**. For example, with the heating portion **702** positioned in proximity to the forming vessel **140**, the electrically conductive material **703** can generate heat, wherein the heat can increase a temperature of the portion of the forming vessel **140**, for example, the edge directors **163**, **164**.
(47) In some embodiments, the heating element **701** can comprise an insulating block **707** that can thermally insulate the support apparatus **325** (e.g., illustrated in FIG. **3**) from the heating portion **702**. For example, the insulating block **707** can comprise an identical material as the insulating block **327** illustrated in FIG. **3**. In some embodiments, the insulating block **707** can comprise a unitary, one-piece structure that can be attached to the first surface **705**. The insulating block **707** can comprise a dimension (e.g., length and width) that can substantially match a dimension of the first surface **705**, such that the support apparatus **325** can be thermally insulated and shielded from the heat generated by the heating portion **702**. In some embodiments, the heating element **602** (e.g., illustrated in FIG. **6**) and the heating element **701** (e.g., illustrated in FIG. **7**) can be operated independently of one another. For example, the heating element **602** (e.g., for the compression block **321**) and the heating element **701** (e.g., for the heating portion **702** of the insulating block **327**) can operate independently, such that the compression block **321** can be separately heated from the heating portion **702** of the insulating block **327**. By operating independently, several benefits can be achieved. For example, if one of the heating elements **602**, **701** is turned off, then the other of the heating elements **602**, **701** may remain on. The heating element **602** can therefore operate at a temperature that may be different from a temperature of the heating element **701**. As such, a desired and/or more finely tuned thermal profile can be achieved by heating the edge director **163** at a different temperature than the forming vessel **140**.
(48) Referring to FIG. **8**, a rear perspective view of the insulating block **707** of the heating element **701** is illustrated. In some embodiments, the insulating block **707** can comprise one or more openings (e.g., grooves, channels, etc.) that can facilitate attachment of the heating element **701** to the support apparatus **325**. For example, the insulating block **707** can extend between a first end **801** and a second end **803**. In some embodiments, the heating element **701** can comprise a first opening **805** and a second opening **807**. The first opening **805** can be located at the first end **801** and the second opening **807** can be located at the second end **803**. The first opening **805** can be bordered by a first wall **809** while the second opening **807** can be bordered by a second wall **811**. In some embodiments, a first distance **813** can separate the first opening **805** and the second opening **807**. In some embodiments, a second distance **815** can separate an end of the first wall **809** and the second wall **811**. The first distance **813** may be less than the second distance **815**. In some

embodiments, the insulating block **707** can comprise a third opening **821** that can extend through a center of the insulating block **707**. For example, the third opening **821** can extend along an axis **823** that is perpendicular to an axis along which the first distance **813** and the second distance **815** are measured.

(49) Referring to FIG. **9**, a front perspective view of the support plate **351** is illustrated. In some embodiments, the support plate **351** of the support apparatus **325** can comprise an attachment apparatus **901** comprising a plurality of attachment brackets extending from the second surface **363** toward the forming vessel **140**. For example, the plurality of attachment brackets can comprise a first attachment bracket **903** and a second attachment bracket **905** that can extend from the second surface **363** toward the forming vessel **140**. The attachment apparatus **901** can attach the heating portion **702** to the support plate **351**. For example, the first attachment bracket **903** can comprise a first wall **907** and a second wall **909**. The first wall **907** can extend from the second surface **363**, for example, by extending substantially perpendicularly from the second surface **363**. The first wall **907** can be attached to the second surface **363** in several ways. For example, in some embodiments, the first wall **907** can be formed with (e.g., as a one-piece structure) with the second surface **363**, while in other embodiments, the first wall **907** can be separately attached to the second surface **363** (e.g., with mechanical fasteners, adhesives, etc.). In some embodiments, the second wall **909** can be attached to the first wall **907** opposite the second surface **363**. For example, the first wall **907** can be attached at one end to the second surface **363** and at an opposing end to the second wall **909**. In some embodiments, the second wall **909** can extend substantially perpendicularly from the first wall **907**. For example, the second wall **909** can project from the first wall **907** toward the second attachment bracket **905**. The second wall **909** can be attached to the first wall **907** in several ways. For example, in some embodiments, the second wall **909** can be formed with (e.g., as a one-piece structure) with the first wall **907**, while in other embodiments, the second wall **909** can be separately attached to the first wall **907** (e.g., with mechanical fasteners, adhesives, etc.). In some embodiments, the second wall **909** can form a first opening **911** between the second wall **909** and the second surface **363**. For example, the first opening **911** may be bordered by the second surface **363**, the first wall **907**, and the second wall **909**.

(50) The second attachment bracket **905** can be substantially identical to the first attachment bracket **903**, with the second attachment bracket **905** spaced a distance apart from the first attachment bracket **903**. For example, the second attachment bracket **905** can comprise a third wall **917** and a fourth wall **919**. The third wall **917** can extend from the second surface **363**, for example, by extending substantially perpendicularly from the second surface **363**. In some embodiments, the third wall **917** can extend substantially parallel to the first wall **907**. The third wall **917** can be attached to the second surface **363** in several ways. For example, in some embodiments, the third wall **917** can be formed with (e.g., as a one-piece structure) with the second surface **363**, while in other embodiments, the third wall **917** can be separately attached to the second surface **363** (e.g., with mechanical fasteners, adhesives, etc.). In some embodiments, the fourth wall **919** can be attached to the third wall **917** opposite the second surface **363**. For example, the third wall **917** can be attached at one end to the second surface **363** and at an opposing end to the fourth wall **919**. In some embodiments, the fourth wall **919** can extend substantially perpendicularly from the third wall **917**. For example, the fourth wall **919** can project from the third wall **917** toward the first attachment bracket **903**. The fourth wall **919** can be attached to the third wall **917** in several ways. For example, in some embodiments, the fourth wall **919** can be formed with (e.g., as a one-piece structure) with the third wall **917**, while in other embodiments, the fourth wall **919** can be separately attached to the third wall **917** (e.g., with mechanical fasteners, adhesives, etc.). In some embodiments, the fourth wall **919** can form a second opening **921** between the fourth wall **919** and the second surface **363**. For example, the second opening **921** may be bordered by the second surface **363**, the third wall **917**, and the fourth wall **919**.

(51) In some embodiments, the attachment apparatus **901** can comprise a ledge **923**. The ledge **923**

can extend from the second surface **363** toward the forming vessel **140**. In some embodiments, the ledge **923** can extend partially between the first attachment bracket **903** and the second attachment bracket **905**. For example, the first attachment bracket **903** can extend between a first end **925** and a second end **927** while the second attachment bracket **905** can extend between a first end **929** and a second end **931**. In some embodiments, the ledge **923** can be attached to the second end **927** of the first attachment bracket **903** and the second end **931** of the second attachment bracket **905**. In some embodiments, the first end **925** of the first attachment bracket **903** and the first end **929** of the second attachment bracket **905** may be unbounded. In some embodiments, the heating element **701** may be configured to be received within the attachment apparatus **901**, for example, through the first end **925** of the first attachment bracket **903** and the first end **929** of the second attachment bracket **905**, whereupon the heating element **701** can rest on and/or be supported by the ledge **923** located at the second end **927** of the first attachment bracket **903** and the second end **931** of the second attachment bracket **905**. For example, as illustrated in FIG. **10**, one of the plurality of attachment brackets (e.g., the second attachment bracket **905**) can be received within the first opening **805** of the heating element **701**, and another of the plurality of attachment brackets (e.g., the first attachment bracket **903**) can be received within the second opening **807** when the heating element **701** is attached to the second surface **363**.

(52) In some embodiments, the attachment apparatus **901** can comprise a third attachment bracket **935**. The third attachment bracket **935** can extend from the second surface **363** toward the forming vessel **140**. In some embodiments, the third attachment bracket **935** can extend substantially parallel to the first attachment bracket **903** and the second attachment bracket **905**, with the third attachment bracket **935** positioned between the first attachment bracket **903** and the second attachment bracket **905**. The third attachment bracket **935** can comprise an outcropping, a protuberance, an extension, etc. that projects from the second surface **363**. In some embodiments, the third attachment bracket **935** can be attached to the ledge **923**, wherein one end of the third attachment bracket **935** can be attached to the ledge **923** while an opposing end of the third attachment bracket **935** can be unbounded. In this way, the third attachment bracket **935** can extend along an axis that can intersect the ledge **923**.

(53) FIG. **10** illustrates a top-down view of the heating element **701** and the attachment apparatus **901** as viewed along line **10-10** of FIG. **9**, wherein the heating element is attached to the support plate **351** by the attachment apparatus **901**. For example, in some embodiments, the first attachment bracket **903** may be sized and shaped to be received within the second opening **807** at the second end **803** of the insulating block **707**. The second attachment bracket **905** may be sized and shaped to be received within the first opening **805** at the first end **801** of the insulating block **707**. The heating element **701** can rest on the ledge **923** and, due to the force of gravity, can remain in contact with the ledge **923**. In some embodiments, the third attachment bracket **935** can be received within the third opening **821**. The heating element **701** may therefore be supported between the first attachment bracket **903** and the second attachment bracket **905**, with the third attachment bracket **935** centering the heating element **701**. In some embodiments, the first distance **813** (e.g., separating the first opening **805** and the second opening **807**) may be less than a distance separating the second wall **909** of the first attachment bracket **903** and the fourth wall **919** of the second attachment bracket **905**. The fourth wall **919** can therefore be received within the first opening **805** and the second wall **909** can be received within the second opening **807**.

(54) Due to the second distance **815** (e.g., separating the first wall **809** and the second wall **811**) being larger than the first distance **813**, the first wall **809** and the second wall **811** can maintain the heating element **701** in attachment with the attachment apparatus **901**. For example, the first wall **809** may be supported between the support plate **351** and the fourth wall **919** such that the fourth wall **919** can limit the first wall **809** from inadvertently detaching from the second attachment bracket **905**. Similarly, the second wall **811** may be supported between the support plate **351** and the second wall **909** such that the second wall **909** can limit the second wall **811** from inadvertently

detaching from the first attachment bracket **903**. In some embodiments, the first attachment bracket **903** and the second attachment bracket **905** can be spaced a distance apart to facilitate thermal expansion of the heating element **701**, wherein the heating element **701** may expand and/or contract due to temperature variations during the glass manufacturing process. In some embodiments, during this thermal expansion, the third attachment bracket **935**, which may be received within the third opening **821**, can maintain the heating element **701** in a centered position relative to the first attachment bracket **903** and the second attachment bracket **905**.

(55) In this way, in some embodiments, the heating element **701** can be attached to the second surface **363** and may be positioned within the support opening **365** (e.g., illustrated in FIG. **3**) between the support apparatus **325** (e.g., illustrated in FIG. **3**) and the vessel surface **307**. Referring briefly to FIG. **3**, wherein the heating element **701** can replace a location of the insulating block **327**, the heating element **701** can be positioned on the second side **359** of the support plane **355** and spaced apart from the compression block **321**. In some embodiments, a first length **1001** of the heating element **701** can substantially match a second length **1003** of the compression block **321**. For example, the heating element **701** can extend the first length **1001** between the first end **801** and the second end **803** along a first axis **1005** that may be parallel to the second surface **363**. In some embodiments, the compression block **321** can extend the second length **1003** along a second axis **1007** that may be parallel to the first axis **1005**. In some embodiments, the first length **1001** of the heating element **701** can be substantially equal to the second length **1003** of the compression block **321**.

(56) Referring to FIGS. **11-13**, embodiments of the support plate **351** and the edge director **163** (e.g., illustrated in FIGS. **1-2**) are illustrated, wherein different shadings can represent different temperatures of the support plate **351** and the edge director **163**. For example, FIG. **11** illustrates embodiments in which neither the insulating block **327** nor the heating element **701** are provided within the support opening **365** attached to the second surface **363** such that the support opening **365** is void of any structures between the second surface **363** and the forming vessel **140**. FIG. **12** illustrates embodiments in which the insulating block **327** is provided within the support opening **365** attached to the second surface **363** such that the support plate **351** is shielded from the forming vessel **140** by the insulating block **327**. FIG. **13** illustrates embodiments in which the heating element **701** is provided within the support opening **365** attached to the second surface **363** such that the support plate **351** is shielded from the forming vessel **140** by the heating element **701** and the heating element **701** provides heat to the forming vessel **140** and the edge director **163**.

(57) In FIG. **11**, the support plate **351** can reach a maximum temperature at a first region **1101**, wherein the maximum temperature may be about 1040° C. The edge director **163** can reach a minimum temperature at a second region **1103**, wherein the minimum temperature may be about 1100° C. An average temperature of the edge director **163** at a lower region **1105** may be about 1150° C. In FIG. **12**, the support plate **351** can reach a maximum temperature at the first region **1101**, wherein the maximum temperature may be about 1000° C. The edge director **163** can reach a minimum temperature at the second region **1103**, wherein the minimum temperature may be about 1100° C. An average temperature of the edge director **163** at the lower region **1105** may be about 1150° C. In FIG. **13**, the support plate **351** can reach a maximum temperature at the first region **1101**, wherein the maximum temperature may be about 1000° C. The edge director **163** can reach a minimum temperature at the second region **1103**, wherein the minimum temperature may be about 1120° C. An average temperature of the edge director **163** at the lower region **1105** may be about 1160° C. As such, the absence of the insulating block **327** and the heating element **701** (e.g., as illustrated in FIG. **11**) can generate the highest maximum temperature of the support plate **351** at the first region **1101** (e.g., about 1040° C.), the lowest minimum temperature of the edge director **163** at the second region **1103** (e.g., about 1100° C.), and the lowest average temperature at the lower region **1105** (e.g., about 1150° C.). In contrast, as compared to the embodiments of FIG. **11**, providing the insulating block **327** (e.g., as illustrated in FIG. **12**) or the heating element **701** (e.g.,

as illustrated in FIG. **13**) can produce lower maximum temperatures at the first region **1101**, higher minimum temperatures at the second region **1103**, and higher average temperatures at the lower region **1105**. Thus, the insulating block **327** and the heating element **701** can reduce the maximum temperature that the support plate **351** is subjected to and/or can increase the minimum temperature that the edge director **163** can be subjected to.
(58) The compression apparatus **305** provides several benefits that can prolong the lifespan of the compression apparatus **305** and/or the forming vessel **140**. For example, due to the insulating block **327** and/or the heating element **701** being attached to the support plate **351** and separated from (e.g., not attached to) the compression block **321**, the compression block **321** can move freely and independently of the insulating block **327** and/or the heating element **701**. As such, inadvertent detachment of the insulating block **327** and/or the heating element **701** from the support plate **351** may be avoided. By avoiding detachment of the insulating block **327** and/or the heating element **701** from the support plate **351**, the insulating block **327** and/or the heating element **701** may remain in place and can thermally insulate the support plate **351** and/or provide heat to the edge director **163**. In addition, the support plate **351** can support one or more of the insulating block **327** or the heating element **701**, such that thermal insulation of the support plate **351** and an increase in temperature of the edge director **163** can be achieved. In some embodiments, a portion of the compression block **321** may be in contact with the movement plate **349**, for example, the first surface portion **601** of the compression block **321**, due to a beveled shape of the first surface **331** of the compression block **321** (e.g., wherein the second surface portion **603** and the third surface portion **605** are non-planar relative to the first surface portion **601**). As such, a bending moment applied by the compression block **321** to the movement plate **349** can be reduced. In some embodiments, the reduction in the bending moment can reduce a bending stress of the compression block **321** that can result from sagging of the support plate **351**. As such, the overall stress on the compression block **321** can be reduced. Further stress reduction on the compression block **321** can also be achieved due to the radius of curvature of the edge surface **337**, in which the radius of curvature can be within a range from about 6 mm to about 10 mm, or about 8 mm.
(59) In some embodiments, the movement plate **349** can comprise the friction-reducing material, which can facilitate movement of the compression block **321** relative to the movement plate **349**. The friction-reducing material, for example, a copper-oxide based thermal paste, can act as a lubricant between the compression block **321** and the movement plate **349**, and may function up to temperatures of about 1500° C.
(60) It should be understood that while various embodiments have been described in detail relative to certain illustrative and specific examples thereof, the present disclosure should not be considered limited to such, as numerous modifications and combinations of the disclosed features are possible without departing from the scope of the following claims.

Claims

1. A glass manufacturing apparatus comprising: a forming vessel comprising a first end and a second end, the first end comprising a vessel surface defining a recess; a compression block positioned within the recess and comprising a first surface and a contact surface that contacts the vessel surface, the compression block configured to apply a force to the forming vessel, the first surface comprising a non-planar shape; and a support apparatus comprising a support surface supporting the compression block, the support surface in contact with a portion of the first surface, wherein the first surface comprises a first surface portion, a second surface portion, and a third surface portion, the first surface portion in contact with the support surface and comprising a planar shape, and the second surface portion and the third surface portion are positioned on opposite sides of the first surface portion, the second surface portion forming a first angle that is from about 1 degree to about 3 degrees relative to the first surface portion, the third surface portion forming a

second angle that is from about 1 degree to about 3 degrees relative to the first surface portion.
2. The glass manufacturing apparatus of claim 1, wherein the forming vessel is configured to receive a molten material along a flow direction that is parallel to a longitudinal direction of the forming vessel, the compression block configured to apply the force along a force direction that is parallel to the flow direction and the longitudinal direction.
3. The glass manufacturing apparatus of claim 1, wherein the compression block comprises an edge surface that connects the contact surface and the first surface, the edge surface comprising a rounded shape.
4. The glass manufacturing apparatus of claim 1, wherein the support surface extends along a support plane and the compression block is on a first side of the support plane.
5. The glass manufacturing apparatus of claim 1, wherein the support apparatus comprises a second surface spaced apart from the vessel surface to define a support opening, and one or more of: an insulating block attached to the second surface and positioned within the support opening between the support apparatus and the vessel surface, the insulating block comprising a thermally insulating material configured to thermally insulate the support apparatus from the forming vessel; or a heating element attached to the second surface and positioned within the support opening between the support apparatus and the vessel surface, the heating element comprising an electrically conductive material configured to increase a temperature of a portion of the forming vessel.
6. The glass manufacturing apparatus of claim 5, wherein the insulating block comprises a first block portion attached to a second block portion, the first block portion comprising a first protrusion and a first cavity, the second block portion comprising a second protrusion and a second cavity, the first protrusion configured to be received within the second cavity and the second protrusion configured to be received within the first cavity.
7. The glass manufacturing apparatus of claim 6, wherein the first block portion and the second block portion comprise a first face that faces the forming vessel and a second face that faces the support apparatus, the second face comprising a face opening extending along an axis when the first block portion is attached to the second block portion.
8. The glass manufacturing apparatus of claim 7, wherein the support apparatus comprises a support protrusion extending from the second surface toward the forming vessel, the support protrusion configured to be received within the face opening to attach the first block portion and the second block portion to the support apparatus.
9. A glass manufacturing apparatus comprising: a forming vessel comprising a first end and a second end, the first end comprising a vessel surface defining a recess; a compression block positioned within the recess and comprising a contact surface that contacts the vessel surface, the compression block configured to apply a force to the forming vessel; a support apparatus comprising a support surface supporting the compression block, the support apparatus comprising a second surface spaced apart from the vessel surface to define a support opening; and an insulating block attached to the second surface and positioned within the support opening between the support apparatus and the vessel surface, the insulating block comprising a thermally insulating material configured to thermally insulate the support apparatus from the forming vessel, wherein the insulating block comprises a first block portion attached to a second block portion, the first block portion comprising a first protrusion and a first cavity, the second block portion comprising a second protrusion and a second cavity, the first protrusion configured to be received within the second cavity and the second protrusion configured to be received within the first cavity.
10. The glass manufacturing apparatus of claim 9, wherein the first block portion and the second block portion comprise a first face that faces the forming vessel and a second face that faces the support apparatus, the second face comprising a face opening extending along an axis when the first block portion is attached to the second block portion.
11. The glass manufacturing apparatus of claim 10, wherein the support apparatus comprises a support protrusion extending from the second surface toward the forming vessel, the support

protrusion configured to be received within the face opening to attach the first block portion and the second block portion to the support apparatus.

12. The glass manufacturing apparatus of claim 9, wherein the forming vessel is configured to receive a molten material along a flow direction that is parallel to a longitudinal direction of the forming vessel, the compression block configured to apply the force along a force direction that is parallel to the flow direction and the longitudinal direction.

13. The glass manufacturing apparatus of claim 9, wherein the compression block comprises an edge surface that connects the contact surface and a first surface of the compression block, the edge surface comprising a rounded shape.

14. The glass manufacturing apparatus of claim 9, wherein the contact surface comprises a non-planar shape.

15. A glass manufacturing apparatus comprising: a forming vessel comprising a first end and a second end, the first end comprising a vessel surface defining a recess; a compression block positioned within the recess and comprising a contact surface that contacts the vessel surface, the compression block configured to apply a force to the forming vessel; a support apparatus comprising a support surface supporting the compression block, the support apparatus comprising a second surface spaced apart from the vessel surface to define a support opening; and a heating element attached to the second surface and positioned within the support opening between the support apparatus and the vessel surface, the heating element comprising an electrically conductive material configured to increase a temperature of a portion of the forming vessel.

16. The glass manufacturing apparatus of claim 15, wherein the support apparatus comprises a plurality of attachment brackets extending from the second surface toward the forming vessel.

17. The glass manufacturing apparatus of claim 16, wherein the heating element comprises a first opening and a second opening, one of the plurality of attachment brackets received within the first opening and another of the plurality of attachment brackets received within the second opening when the heating element is attached to the second surface.

18. The glass manufacturing apparatus of claim 15, wherein the heating element extends a first length between a first end and a second end along a first axis parallel to the second surface, the compression block extending a second length along a second axis parallel to the first axis, wherein the first length is substantially equal to the second length.

19. The glass manufacturing apparatus of claim 15, wherein the forming vessel is configured to receive a molten material along a flow direction that is parallel to a longitudinal direction of the forming vessel, the compression block configured to apply the force along a force direction that is parallel to the flow direction and the longitudinal direction.