

METHOD AND APPARATUS FOR PRODUCING GLASS SHEET

The present invention relates to a method and an apparatus for producing a glass sheet. Specifically, the present invention relates to a technique for producing
5 a glass sheet by a downdraw process.

The downdraw process is a method for forming a glass ribbon continuously by allowing molten glass flowing over from a trough in an upper part of a wedge-shaped glass sheet forming device to flow downwardly along sidewalls of the
10 glass sheet forming device and fusing it at the lower end (root) of the glass sheet forming device. The glass ribbon passes through a furnace while being supported by rolls disposed below the glass sheet forming device, which is cooled slowly and cut so that a glass sheet of a desired size is obtained.

The downdraw process is suitable for producing a glass sheet having a large
15 area and a small thickness, for example, such as a glass substrate for a flat panel display. For example, JP 2008-133174 A describes a technique for stably producing an extremely thin glass sheet (for example, 0.5 mm or less). Specifically, after reducing the sheet thickness of a glass ribbon to an initial thickness immediately below a forming unit (glass sheet forming device), the glass ribbon is heated by a
20 re-heating means (heater) disposed below a regulating means (cooling rolls) until the temperature reaches its softening point, so that the glass ribbon is softened. Then, the softened glass ribbon is drawn downwardly for a further reduction of the sheet thickness.

Further, in order to form a high-quality glass ribbon, it is important to
25 control the temperature in the width direction of the molten glass on the sidewalls of the glass sheet forming device. For example, JP 2007-112665 A describes a technique for equalizing the temperature distribution in the width direction of molten glass by providing a heater having a rough dense arrangement of heating elements at a position facing the sidewall of a forming unit (glass sheet forming
30 device). JP 2008-69024 A describes a technique for equalizing the temperature distribution in the width direction of molten glass by electrically heating a platinum coating on the surface of a fusion cell (glass sheet forming device).

Normally, the edge portion of a glass ribbon formed by the downdraw
35 process has the shape shown in Fig. 7. However, the edge portion of the glass ribbon does not always have this shape; it may have a two-pronged shape. The edge portion having a two-pronged shape may render the cutting step of the glass

ribbon difficult or cause the glass ribbon to crack. In addition, the edge portion having a two-pronged shape may cause a thickness variation of the center portion (portion to serve as a product), and may cause a decrease in the yields.

5 It is an object of the present invention to prevent the edge portion of a glass ribbon from being formed into a defective shape.

The inventors studied the causes of the shape defects in the edge portions of glass ribbons in detail. As a result, focusing on a point that the viscosity of the glass ribbon immediately after fusion is a main factor that determines the final
10 shape of the edge portions of the glass ribbon, they have accomplished the present invention.

Specifically, the present invention provides a method for producing a glass sheet by a downdraw process. In the downdraw process, molten glass is fused at the lower end of a glass sheet forming device to form a glass ribbon, and the glass
15 ribbon is conveyed downwardly along a plurality of rolls disposed below the glass sheet forming device. The method includes the steps of: providing a heater in a space between the lower end of the glass sheet forming device and the rolls located nearest to the glass sheet forming device; and forming and conveying the glass ribbon while locally heating, by the heater, the edge portion of the glass ribbon
20 immediately after the fusion.

According to another aspect of the present invention, there is provided an apparatus for producing a glass sheet including: a glass sheet forming device having a wedge-shaped cross section; a plurality of rolls that are disposed below the glass sheet forming device and convey, below the glass sheet forming device, a glass
25 ribbon that has been formed by fusing, at the lower end of the glass sheet forming device, molten glass that has flowed over from a trough in an upper part of the glass sheet forming device; and a heater provided in a space between the lower end of the glass sheet forming device and the rolls located nearest to the glass sheet forming device so as to be capable of locally heating the edge portion in the width direction of
30 the glass ribbon immediately after the fusion.

The glass ribbon immediately after fusion is not completely solidified, which is in a viscous fluid state and therefore easily affected by environmental temperature. Generally, the edge portion of the glass ribbon is cooled more rapidly
35 than the center portion of the glass ribbon. If the temperature of the edge portion decreases too rapidly compared to the temperature decrease of the center portion, the viscosity variation in the width direction increases, and thus shape defects of

the edge portion are likely to occur.

In contrast, according to the above-mentioned present invention, the edge portion of the glass ribbon immediately after fusion is heated locally by a heater. That is, it is prevented that only the edge portion of the glass ribbon immediately after separation from the glass sheet forming device is cooled rapidly. Thus, the temperature distribution in the width direction of the glass ribbon, that is, the viscosity distribution is equalized, so that shape defects of the edge portion are unlikely to occur. An existing apparatus can be diverted for carrying out the present invention, and thus the present invention is excellent also in terms of cost performance.

For achieving effects similar to those of the present invention, it also is conceivable to increase the temperature of the atmosphere inside the furnace in the vicinity of the lower end of the glass sheet forming device. This may make it possible to achieve effects similar to those of the present invention. However, the present invention is considerably advantageous in terms of power consumption because the present invention requires only the edge portion of the glass ribbon to be heated locally. Further, if the temperature of the atmosphere inside the furnace is increased, various components are degraded rapidly and the life span of the apparatus is shortened, unpreferably.

It should be noted that "the edge portion of the glass ribbon" means, for example, a part of a glass ribbon of about 50 mm inside from each side surface of the glass ribbon.

Fig. 1 is a schematic front view showing a glass sheet producing apparatus according to one embodiment of the present invention.

Fig. 2 is a schematic vertical sectional view taken along the line II-II of the glass sheet producing apparatus indicated in Fig. 1.

Fig. 3 is a partial enlarged view showing a detailed position of a heater.

Fig. 4 is a schematic view showing a dimensional relationship between a guide and the heater.

Fig. 5 is a schematic view showing a modified embodiment of the heater.

Fig. 6 is a schematic view showing a positional relationship between a glass ribbon and rolls.

Fig. 7 is a sectional view showing a shape of an edge portion of the glass ribbon.

Hereinafter, one embodiment of the present invention is described with reference to the attached drawings.

As shown in Fig. 1 and Fig. 2, a glass sheet producing apparatus 100 according to this embodiment includes a furnace 2, a glass sheet forming device 4 disposed in an upper part inside the furnace 2, a plurality of rolls 6 disposed below the glass sheet forming device 4, and heaters 8 disposed close to a lower end 4e (root) of the glass sheet forming device 4. According to the apparatus 100, it is possible to produce a glass sheet by a downdraw process in which a glass ribbon 9 is formed by fusing, at a lower end 4e, molten glass flowing over from the glass sheet forming device 4.

The furnace 2 is generally made of firebrick. A plurality of heaters 10 are disposed along a vertical direction on the inner wall of the furnace 2. The heaters 10 each have an elongated shape extending in parallel with a longitudinal direction of the glass sheet forming device 4, which are suitable for heating over a comparatively wide range. It is possible to adjust the temperature inside the furnace 2 by controlling the heaters 10. Specifically, a temperature gradient is formed along the vertical direction so that the glass ribbon 9 is cooled slowly while passing through the inside of the furnace 2 downwardly.

The glass sheet forming device 4 is generally made of firebrick. As shown in Fig. 2, the glass sheet forming device 4 has a wedge shape in a cross section orthogonal to the longitudinal direction LD of the glass sheet forming device 4. The longitudinal direction LD of the glass sheet forming device 4 is the same direction as the width direction of the glass ribbon 9. In an upper part of the glass sheet forming device 4, a trough 4k for retaining molten glass is formed in such a manner that the trough 4k extends in the longitudinal direction LD. As shown in Fig. 1, a supply tube 11 is connected to the trough 4k so that molten glass can be supplied continuously to one side in the longitudinal direction LD of the trough 4k.

As shown in Fig. 2, the glass sheet forming device 4 has a pair of sidewalls 4j in a direction orthogonal to both of the longitudinal direction LD and the vertical direction. The sidewalls 4j form flow paths for molten glass that has flowed over from the trough 4k. The sidewalls 4j form a ridge line at the lower end 4e so that the molten glass that has flowed along each sidewall 4j is fused at the lower end 4e. As shown in Fig. 1, a guide 7 that prevents the molten glass from flowing over from the sidewalls 4j is attached to each of both ends in the longitudinal direction LD of the glass sheet forming device 4. As shown in Fig. 4, the guide 7 has a wedge shape in a planar view and is made of a sheet material of a size capable of covering the entire end surface of the glass sheet forming device 4. In the vertical direction, the tip of the guide 7 is located coincident with the lower end 4e of the glass sheet forming device 4. Owing to the function of the guides 7, all of the molten glass can

flow along the sidewalls 4j.

The rolls 6 function to convey the glass ribbon 9 below the glass sheet forming device 4. The rotation speed of the rolls 6 is adjusted so that the glass ribbon 9 of a desired thickness is formed. As shown in Fig. 2, the rolls 6 are
5 disposed symmetrically with respect to a vertical plane including the lower end 4e of the glass sheet forming device 4 so as to be capable of nipping the glass ribbon 9 in the thickness direction. Further, the rolls 6 are disposed at predetermined intervals in the vertical direction. The glass ribbon 9 is conveyed downwardly while being nipped by the rolls 6.

10 As shown in Fig. 1, the heaters 8 each are provided on one side and the other side in the longitudinal direction LD of the glass sheet forming device 4. Specifically, each heater 8 is provided in a space between the lower end 4e of the glass sheet forming device 4 and the roll 6a located nearest to the glass sheet forming device 4 in the vertical direction. The heaters 8 locally heat the edge
15 portions in the width direction of the glass ribbon 9 immediately after fusion, thereby preventing the viscosity of the edge portions of the glass ribbon 9 immediately after fusion from being too high compared to the viscosity of the center portion. In other words, the viscosity variation in the width direction of the glass ribbon 9 reduces. As a result, the edge portions of the glass ribbon 9 are prevented
20 from being formed into a defective shape. In addition, glass devitrification also can be prevented.

As is well known, devitrification is a phenomenon in which crystal grains are formed in glass, and thus the transparency of glass decreases. In the case of producing a glass sheet by the downdraw process, devitrification is likely to occur at
25 the edge portions of the glass ribbon 9. Although the reasons are not entirely clear, the following seems to be one of the causes: the flow velocity of molten glass decreases in the vicinity of the guides 7, so that the molten glass is long maintained in a temperature range in which devitrification is likely to occur.

The heaters 8 disposed in the vicinity of the guides 7 heat not only the edge
30 portions of the glass ribbon 9 but also the guides 7. Since the heat of the guides 7 is conducted to the molten glass in the vicinity of the guides 7, it can be prevented that only the molten glass in the vicinity of the guides 7 is long maintained in the temperature range in which devitrification is likely to occur. Particularly, in the case where the molten glass contains tin as a clarifier, tin oxide crystallizes in glass,
35 which is likely to cause devitrification. Therefore, in the case where the molten glass contains tin, the present invention is recommended especially.

In this embodiment, the heaters 8 do not contact any of the glass sheet

forming device 4, the guides 7 and the furnace 2. The position of the heaters 8 is adjusted so that the edge portions of the glass ribbon 9 immediately after fusion can be heated effectively. With reference to Fig. 3, the position of the heaters 8 will be described in detail. Each heater 8 is provided in a space that is located more
5 laterally than the guide 7 attached to each of both ends in the longitudinal direction LD of the glass sheet forming device 4 and the side surface 9p of the glass ribbon 9 faces the space. More specifically, the heater 8 is provided in a space between the lower end 4e of the glass sheet forming device 4 and a point P₁ at which the width of the glass ribbon 9 becomes constant after being reduced gradually, in the vertical
10 direction.

As shown in Fig. 3, the width of the glass ribbon 9 is gradually reduced during the formation of the glass ribbon 9 from the lower end 4e of the glass sheet forming device 4 to the point P₁. That is, the side surface 9p curves gently. The heater 8 faces the curved portion of the side surface 9p. By providing each heater 8
15 in such a position, the edge portions of the glass ribbon 9 immediately after fusion can be heated efficiently. It should be noted that, although it depends on the output, size or the like of the heater 8, the distance H₁ in the vertical direction from the lower end 4e of the glass sheet forming device 4 (the lower end of the guide 7) to the heater 8 is, for example, 0 to 500 mm, preferably 0 to 100 mm. The distance L₁
20 in the horizontal direction from the inner wall of 7g of the guide 7 to the heater 8 is, for example, -10 to 100 mm, preferably 0 to 100 mm, further preferably 0 to 30 mm. However, attention should be paid so that the heater 8 does not contact the glass ribbon 9. In the case of the distance L₁ of -10 mm or more but less than 0 mm, a part or all of the heater 8 is present on the side of the glass ribbon 9, taking the
25 inner wall of 7g of the guide 7 as a reference.

As shown in Fig. 2, the heater 8 extends in the horizontal direction orthogonal to both of the longitudinal direction LD of the glass sheet forming device 4 and the vertical direction, that is, the thickness direction of the glass ribbon 9. As shown in Fig. 4, the dimension W₁ of the heater 8 in the thickness direction of
30 the glass ribbon 9 is larger than the dimension W₂ of the glass sheet forming device 4 or the dimension W₃ of the guide 7 in the same direction. With such a configuration, the edge portions of the glass ribbon 9 can be heated uniformly from both sides of the front surface side and the back surface side of the glass ribbon 9, which can prevent shape defects more effectively. Further, since the dimension W₁
35 of the heater 8 is large enough to heat the lower part of the guide 7 sufficiently, effect on prevention of devitrification also are enhanced.

The power supply (set temperature) to the heaters 8 is controlled

appropriately, considering the glass composition, the distance from the heater 8 to the glass ribbon 9 and the like. For example, in the case of the composition of a glass sheet for a flat panel display, the set temperature of the heaters 8 can be adjusted arbitrarily within the range of 800 to 1300°C.

5 Further, as shown in Fig. 4, a temperature sensor 12 that detects the temperature of molten glass on the sidewall 4j of the glass sheet forming device 4 and a controller 14 that receives signals from the temperature sensor 12 may be provided. The temperature sensor 12 is attached to, for example, a lower part of the guide 7, and detects the temperature of molten glass indirectly. Examples of
10 the temperature sensor 12 to be used include a thermocouple. The controller 14 controls the power supply to the heaters 8 based on detection results of the temperature sensor 12. For example, the set temperature of the heaters 8 is equalized to the temperature detected by the temperature sensor 12. In this way, it is possible to control the heaters 8 appropriately regardless of the glass
15 composition, so as to surely prevent shape defects of the edge portions of the glass ribbon 9.

In this regard, the output of the heaters 8 may be adjusted manually based on the detection results of the temperature sensor 12. Further, in order to detect the temperature of the center portion in the width direction of the molten glass at
20 the lower end 4e of the glass sheet forming device 4, a non-contact infrared radiation sensor can be used as the temperature sensor 12.

The heater 8 is not specifically limited, as long as it can be used in an atmosphere at a temperature exceeding 1000°C. Specifically, a wire heating element or a wire heating element in coil form can be used as the heater 8.
25 Further, radiation heaters, such as a ceramic heater, a halogen heater, and a silicon carbide heating element, can be used. The shape of the heater 8 also is not specifically limited, which may be a rod shape as shown in Figs. 1 to 4, or a U shape as shown in Fig. 5. As above described, the width of each edge portion of the glass ribbon 9 is about 50 mm, and therefore the heater 8 having the shape shown in Figs.
30 1 to 4 is necessary and sufficient for local heating of the edge portion. Further, it is not necessary to bother to ensure exclusive space for the heater 8. Meanwhile, according to the U-shaped heater 18 shown in Fig. 5, the edge portion 9t of the glass ribbon 9 can be heated from three directions while being surrounded by the heater 18.

35 According to this embodiment, the heaters 8 heat the edge portions of the glass ribbon 9, and therefore the edge portions of the glass ribbon 9 more strongly maintain properties of a viscous fluid until reaching the rolls 6a. Therefore, as

shown in Fig. 6, it is possible to convey the glass ribbon 9 with the edge portions 9t being nipped by the rolls 6a. In other words, the rolls 6a are disposed so as to nip the edge portions 9t. Each roll 6a extends over the edge line of the glass ribbon 9. On the other hand, the other rolls 6 located below the rolls 6a do not nip the edge portions 9t, but nip more internal portions than the edge portions 9t.

For example, as indicated in Fig. 2 of JP 2008-133174 A, it also is possible to determine the position of the rolls so that all the rolls do not nip the edge portions of the glass ribbon. In the case of edge portions with a high viscosity, it is advisable to avoid nipping edge portions with rolls from the viewpoint of stable conveyance or the viewpoint of crack prevention of the glass ribbon.

In contrast, this embodiment makes it possible to convey the glass ribbon 9 with the edge portions 9t being nipped by the rolls 6a, because the viscosity of the edge portions 9t immediately after fusion is prevented from increasing. In addition, before the glass ribbon 9 sufficiently solidifies, it also is possible to apply a pressure to the edge portions 9t by the rolls 6a so as to render the edge portions 9t flat to some extent, as shown in Fig. 6. The flat shaped edge portions 9t facilitate the cutting step of the glass ribbon 9. It also is possible to nip the edge portions 9t by the other rolls 6 located below the rolls 6a. However, effect on flattening of the edge portions 9t are greatest when the edge portions 9t are nipped by the rolls 6a that are located nearest to the glass sheet forming device 4. Then, by nipping more internal portions than the edge portions 9t in the glass ribbon 9 by the other rolls 6, it is possible to convey the glass ribbon 9 stably without causing any defects such as crack. In this way, this embodiment can provide both of effect on adjustment of the shape of the edge portions 9t and effect on stable conveyance of the glass ribbon 9.

The operation of the glass sheet producing apparatus 100 is described briefly. When the molten glass supplied to the trough 4k of the glass sheet forming device 4 exceeds a predetermined amount, the molten glass flows over from the trough 4k and flows downwardly along the sidewalls 4j. The molten glass flowing on the sidewalls 4j is heated by the heaters 10 disposed circumferentially around the glass sheet forming device 4 so as to maintain the viscosity. The molten glass that has flowed on each of the sidewalls 4j is fused at the lower end 4e, thereby forming the glass ribbon 9. The glass ribbon 9 is lead between one of the rolls 6 and another of the rolls 6 that face each other and conveyed downwardly while being cooled slowly. The temperature of the glass ribbon 9 decreases, as the glass ribbon 9 proceeds downwardly. Accompanying this, the solidification of the glass ribbon 9 proceeds. The glass ribbon 9 conveyed to the outside of the furnace 2 is cut into a desired size. Thus, a glass sheet can be obtained.

According to this embodiment, since the heaters 8 heat the edge portions 9t of the glass ribbon 9, it is possible to prevent the viscosity of the edge portions 9t of the glass ribbon 9 in the vicinity of the rolls 6a from being too high compared to the viscosity of the center portion. For example, the glass ribbon 9 is cooled, until the temperature range of the glass transition point, to be solidified around the middle of the furnace 2.

The viscosity of the molten glass at the lower end 4e of the glass sheet forming device 4 varies depending on the glass composition and production conditions. For example, in the case of producing a glass sheet for a flat panel display, the viscosity of the molten glass at the lower end 4e is adjusted in the range of 10000 to 60000 Pa·s. The viscosity of the molten glass is controlled by controlling the temperature of the molten glass. By adjusting the temperature of the molten glass in the range of 800 to 1000°C, the viscosity of the molten glass falls within the above-mentioned range. Specifically, the atmosphere temperature inside the furnace 2 is adjusted by controlling the heaters 10 so that the temperature of the molten glass at the lower end 4e is 800 to 1000°C.

Particularly in recent years, there is a growing demand for a large-area glass sheet. For example, a glass substrate for a liquid crystal display of the tenth generation has dimensions of 2850 mm × 3050 mm. The more the width of the glass ribbon increases, the more likely the viscosity variation in the width direction is to occur. Therefore, the effects to be obtained by applying the present invention are enhanced. In the following, a typical glass composition of a glass substrate for a flat panel display is indicated.

SiO₂: 57 to 70 mass%
Al₂O₃: 13 to 19 mass%
B₂O₃: 8 to 13 mass%
MgO: 0 to 2 mass%
CaO: 4 to 6 mass%
SrO: 2 to 4 mass%
BaO: 0 to 2 mass%
Na₂O: 0 to 1 mass%
K₂O: 0 to 1 mass%
As₂O₃: 0 to 1 mass%
Sb₂O₃: 0 to 1 mass%
SnO₂: 0 to 1 mass%
Fe₂O₃: 0 to 1 mass%
ZrO₂: 0 to 1 mass%

Example

Using a continuous melter provided with a melting tank made of firebrick and a regulating tank made of platinum (in which a clarification step is performed),
5 a glass raw material that had been prepared so as to have the below-described composition was melted at 1550°C, clarified at 1600°C, and stirred at 1550°C. Thus, molten glass was obtained. It should be noted that the total mass exceeds 100% because it includes rounding errors.

SiO₂: 60.9 mass%,

10 Al₂O₃: 16.9 mass%

B₂O₃: 11.6 mass%

MgO: 1.7 mass%

CaO: 5.1 mass%

SrO: 2.6 mass%

15 BaO: 0.7 mass%

K₂O: 0.25 mass%

Fe₂O₃: 0.15 mass%

SnO₂: 0.13 mass%

Next, the molten glass was supplied to the glass sheet producing apparatus
20 100, which has been described referring to Fig. 1. The temperature of the heaters 8 was set to 1110°C. It is inferable that the viscosity of the molten glass poured into the glass sheet forming device 4 was equivalent to about 5000 Pa·s, since the temperature of the molten glass was 1200°C.

The molten glass was continuously supplied and was allowed to flow over
25 from the glass sheet forming device 4, thereby forming a glass ribbon. The glass ribbon was cut into a predetermined size and a number of glass sheets were thus obtained. These glass sheets were studied on the shape of the edge portions. As a result, no edge portions were two-pronged. Further, there was no apparent devitrification found in these glass sheets. It should be noted that another glass
30 ribbon was formed by the same procedure, using molten glass having another composition that tends to allow a high viscosity at the time of the above-mentioned formation. As a result, glass sheets with edge portions having a favorable shape were obtained.

CLAIMS

1. A method for producing a glass sheet by a downdraw process in which molten glass is fused at a lower end of a glass sheet forming device to form a glass ribbon, and the glass ribbon is conveyed downwardly along a plurality of rolls disposed below the glass sheet forming device, the method comprising the steps of:
5 providing a heater in a space between the lower end of the glass sheet forming device and one of the rolls located nearest to the glass sheet forming device;
and
10 forming and conveying the glass ribbon while locally heating, by the heater, an edge portion of the glass ribbon immediately after the fusion.
2. The method for producing a glass sheet according to claim 1, wherein the space is located more laterally than a guide attached to each of both
15 ends in a longitudinal direction of the glass sheet forming device, and the glass ribbon has a side surface facing the space.
3. The method for producing a glass sheet according to claim 1, wherein the space is located between the lower end of the glass sheet forming device
20 and a point at which a width of the glass ribbon becomes constant after being reduced gradually.
4. The method for producing a glass sheet according to claim 1, wherein the edge portion of the glass ribbon is nipped by the rolls located nearest to
25 the glass sheet forming device.
5. The method for producing a glass sheet according to claim 1, wherein the molten glass contains tin.
- 30 6. An apparatus for producing a glass sheet comprising:
a glass sheet forming device having a wedge-shaped cross section;
a plurality of rolls that are disposed below the glass sheet forming device
and convey, below the glass sheet forming device, a glass ribbon that has been
formed by fusing, at a lower end of the glass sheet forming device, molten glass that
35 has flowed over from a trough in an upper part of the glass sheet forming device;
and
a heater provided in a space between the lower end of the glass sheet

forming device and one of the rolls located nearest to the glass sheet forming device so as to be capable of locally heating an edge portion in a width direction of the glass ribbon immediately after the fusion.

- 5 7. The apparatus for producing a glass sheet according to claim 6, wherein
 the glass sheet forming device includes a guide that is attached to an end in
 a longitudinal direction of the glass sheet forming device and that prevents the
 molten glass from flowing over from a sidewall of the glass sheet forming device,
 the space is located more laterally than the guide, and
10 the glass ribbon has a side surface facing the space.
8. The apparatus for producing a glass sheet according to claim 6, wherein
 the heater has a larger dimension in a direction orthogonal to a longitudinal
 direction of the glass sheet forming device and a vertical direction than that of the
15 glass sheet forming device in the same direction.
9. The apparatus for producing a glass sheet according to claim 6, wherein
 the rolls located nearest to the glass sheet forming device are disposed so as
 to nip the edge portion of the glass ribbon.
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10. The apparatus for producing a glass sheet according to claim 6, further
 comprising:
 a temperature sensor that detects a temperature of the molten glass on a
 sidewall of the glass sheet forming device; and
25 a controller that controls power supply to the heater based on detection
 results of the temperature sensor.