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(54) **Title:** RADIANT BURNER

(57) **Abstract:** A gas-fired burner unit for providing combustion and infrared radiation includes at least one plenum for receiving at least the gas, and at least one perforated metal plate mounted for receiving at least the gas from the plenum and supplying at least the gas to the combustion so that the combustion is proximate the perforated metal plate.

RADIANT BURNER

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application claims the benefit of both U.S. Provisional Application No. 60/582,276, filed June 23, 2004, and U.S. Provisional Application No. 60/591,215, filed July 26, 2004. Each of the above-referenced provisional applications is incorporated herein by reference, in its entirety. Also incorporated herein by reference, in its entirety, is the U.S. utility patent application that is entitled "Infrared Emitting Element", names Willie H. Best as the inventor, and has been filed on the same day as the present application.

TECHNICAL FIELD

The present invention relates to gas-fed infrared burners and, more particularly, to partitions used in gas-fed infrared burners.

BACKGROUND OF THE INVENTION

There are several types of gas-fired infrared burners being used in various manufactured products. These burners usually incorporate one of three design features. The most used and successful burner design employs a ceramic plate that contains apertures to allow the flow of the gas-air mixture to the surface for combustion. Also some types of porous ceramic can be used. The ceramic plate is usually about 0.500 inches thick and possesses relatively low thermal conductivity. The plate can also be manufactured from ceramic fibers such as a product sold under the Fibre Fax brand name. U.S. Patent Nos. 3,277,948 and 3,561,902 to Best describe such a burner. The fuel input to these type burners is usually limited to about 350 BTUH/in^2 of emitting element surface.

The emitting surface of gas-fired radiant burners can also be produced from metal. These types of emitting surfaces have usually been metal form or metal screens. The metal screens are woven from metal strands. Experience with using these types of burners indicates that they have limited life due to failure of the screen. Failure of the screen allows the flame to retrogress into the burner plenum resulting in flashback. Stress developed during the weaving process probably contributes to these failures. Also, since the screen provides for quenching of the flame on its surface, the size of apertures needs to be relatively small. Therefore, the diameter of the wire from which the screen is woven is limited. The small diameter of the wire limits the strength and resistance to thermal fatigue. When these types of burners operate on a generally continuous basis, frequent replacement of failed burners is required.

The other method by which gas-fired radiant burners operate is for the flame and hot combustion gases from a conventional port type burner to be impinged on a surface (usually ceramic) capable of emitting infrared radiant energy. This concept of generating infrared radiant energy is not as efficient as the surface combustion type of infrared burners. There are also other methods of generating infrared radiant energy by which the energy is not directly produced by the burner. U.S. Patent Nos. 4,546,553, 4,785,552, 5,230,161 and 6,114,666 to Best describe this technology. This type of design technology can also be used to convert short wavelengths to longer ones as described in U.S. Patent No. 6,114,666 to Best.

There are some limitations associated with each type of gas-fired radiant burner presently in use. The burner that uses ceramic as an emitter surface is the type most widely used in industrial and commercial applications. However, because the emitter surface is made from ceramic, these types of burners are fragile compared to metal. Also, the ceramic emitter is subject to failure if it is used in applications where it can become wet, such as in outdoor gas grills as described in U.S. Patent No. 4,321,857 to Best. However, this type of burner has been successfully used in outdoor grills when the grill is designed to protect the burner from rain.

The ceramic type of infrared radiant burner is used in many successful products such as disclosed in U.S. Patent Nos. 4,321,857 and 5,676,043 to Best, and in many applications it will continue to be the burner of choice. There are other applications where its limitations prevent its use. As an example, the burner will fail (flashback) if it is fired at an input greater than about 350 BTUH/in^2. A typical burner with a ceramic radiation-emitting surface is disclosed in U.S. Patent No. 3,277,948 to Best. Also, when these types of burners are over fired, incomplete combustion can occur.

Burners that use an emitting surface that employs a woven screen have not been reliable and usually have limited life in most applications of continuous use or where the burner is exposed to thermal shock through cycles of heating and cooling. Both the metal screen burner and ceramic type burners can fail when the input of fuel is increased beyond the ability of the surface to quench the flame, which results in retrogression of the flame into the burner plenum. Foam type of metal emitting surfaces can minimize some of the problems described, but they introduce new problems. Because of the porous nature of the material, it acts as a filter. Over time the surface will become clogged with atmospheric contaminates and the flow area through the surface is decreased resulting in variations in the combustion intensity over the surface. Also this type of material is expensive compared to other types of emitting surfaces. One type of this kind of porous metal is sold under the trade name of Metpore.

Another limitation of existing infrared burners is that when the primary air for combustion is supplied through a venturi as opposed to a pre-mixture of fuel and air supplied through a combustion air blower and mixer, secondary air for combustion is usually required. This phenomenon is notably true if the firing rate exceeds about 350 BTUH/in^2 of burner emitting surface. Typical infrared radiant burners of this type are described in U.S. Patent Nos. 3,277,948 and 3,561,902 to Best. When the input of fuel to infrared burners (described by U.S. Patent Nos. 3,277,948 and 3,561,902) is limited to under about 350 BTUH/in^2 of emitting surface, they can operate with 100% primary air with the use of a venturi. However, it is highly desirable in many applications to increase the energy input per unit area of emitting element surface and to distribute the energy systematically over the combustion surface of the burner. This is not practical to do with prior art type burners described above. Also, when an emitting element of a radiant type burner is placed close (within one inch) to an absorbing body, the emitting element temperature increases, thus increasing the tendency of prior art type burners to flashback. In many of the prior art type burners, secondary air for combustion is required. Some design restrictions are imposed in many applications when secondary air for combustion is required to ensure complete combustion. Also, secondary air for complete combustion is hard to control and usually results in excess air to the combustion process, which lowers the flame temperature and decreases combustion efficiency.

Another limitation of existing burner designs is that the emitting element is usually continuous. That is, the emitting surface area comprises most of the open side of the burner plenum. The emitting surface is usually surrounded by a border of about one half inch. In many applications of infrared type burners, it would be desirable to distribute the energy over larger surfaces than that of the emitting element itself. An example of such an application is the heating of the glass emitter described in U.S. Patent No. 6,114,666 to Best. When it is possible to uniformly distribute the energy over the entire surface of the glass emitter, the burner can be placed very close to the underside of the glass eliminating the need to provide space for concentrated infrared energy to be dispersed over a larger area than its emitting area.

There are many other applications of the use of infrared radiant energy where it would be desirable to distribute the emitted energy over a larger area, such as in the curing of paint. There are other applications where it is desirable to concentrate more energy in a confined area than would be possible with existing technology where the combustion air is supplied through a venturi. Such an example would be to replace the conventional burner of a range top with a radiant type burner. It would provide many benefits if an infrared radiant type burner could have greater latitude in the amount of energy that is emitted over the surface of the burner – that is, for the firing rate to be dramatically increased or decreased per unit of area of the burner surface. Most of the prior art type infrared burners in use that use a venturi for the introduction of combustion air are limited to about 350 BTUH/in^2 of burner surface when operating at high fire and the more normal high fire rating of these types of burners is about 250 BTUH/in^2.

BRIEF SUMMARY OF SOME ASPECTS OF THE INVENTION

In accordance with one aspect of the present invention, a gas-fired burner unit for providing combustion and infrared radiation includes at least one plenum for receiving at least the gas, and at least one perforated metal plate mounted for receiving at least the gas from the plenum and supplying at least the gas to the combustion so that the combustion is proximate the perforated metal plate. Perforations of the perforated metal plate can have a width in a range of about 0.025 inches to about 0.062 inches.

One aspect of the present invention is the provision of an apparatus (e.g., a burner assembly or a baffle assembly) for at least partially defining a flow path in a gas-fired burner unit that generates combustion and infrared radiation. The apparatus can include at least one first metal plate having a plurality of holes that extend therethrough, and one or more second metal plates adjacent the first metal plate and having a multiplicity of holes that extend therethrough. Holes of the multiplicity of holes can have smaller widths than holes of the plurality of holes, and groups of holes of the multiplicity of holes can be respectively aligned with, and respectively in communication with, holes of the plurality of holes.

According to one aspect of the present invention, a gas-fired burner unit for providing combustion and infrared radiation includes at least one plenum, at least one venturi mounted for providing the gas and air to the plenum, and at least one burner assembly mounted for receiving the gas and the air from the plenum and providing the gas and air to the combustion. The burner assembly can be operative so that the combustion is proximate the burner assembly, and so that at least substantially all of the air required for completing the combustion is provided via the venturi while the burner unit's firing rate exceeds about 350 BTUH/in^2 of the burner unit's emitting surface.

In accordance with one aspect of the present invention, an apparatus for providing at least infrared radiant energy includes at least one emitter and at least one gas-fired burner unit. The gas-fired burner unit can be operative for nonuniformly heating the emitter so that the infrared radiant energy over the emitter is substantially equally distributed. For example, gas-fired burner unit can includes at least one burner assembly in opposing face-to-face configuration with respect to the emitter, with the burner assembly including a multiplicity of holes for providing at least the gas to combustion that occurs in a gap between the burner assembly and the emitter, and the multiplicity of holes can be arranged in a predetermined manner so that there is a lesser concentration of the holes proximate the burner assembly's center than there is outwardly from the burner assembly's center.

In accordance with one aspect of the present invention, a gas-fired burner unit for providing combustion and infrared radiation includes at least one plenum for receiving at least the gas, and perforated members (e.g., plates) mounted in series for at least partially obstructing an opening of the plenum and at least partially defining a flow path for providing at least the gas from the plenum to the combustion. Each of the perforated members can be a nonwoven, metallic plate. The perforated members can include an upstream perforated member and a downstream perforated member that is positioned downstream from the upstream perforated member in the flow path (e.g., the upstream perforated member and the downstream perforated member are arranged in series in the flow path). Downstream ends of perforations of the downstream perforated member are for having the combustion proximate thereto, so that the downstream perforated member can become red-hot and emit at least some of the infrared radiation. Multiple at least substantially discrete chambers can be positioned between the upstream perforated member and the downstream perforated member. Upstream ends of perforations of the downstream perforated member can be respectively open to the chambers, and downstream ends of perforations of the upstream perforated member can be respectively open to the chambers.

The upstream perforated member can be replaced with multiple upstream perforated members that are arranged in parallel in the flow path, and likewise the downstream perforated member can be replaced with multiple downstream perforated members that are arranged in parallel in the flow path. The perforated members can be replaced with members having passages that are not in the form of perforations.

In accordance with one aspect of the present invention, there can be multiple mounting members (e.g., plates) that play a role in defining the chambers respectively between the perforated members. Each of the mounting members can have holes that extend therethrough, and the holes of the mounting members can be larger than the perforations of the perforated members. Each of the perforated members can be sandwiched between respective mounting members, with the perforations of the perforated member(s) being respectively aligned with, and in communication with, the holes of the mounting members. Advantageously, these sandwich-like articles can be very sturdy and durable.

Whereas only a single perforated member, or the like, can be used, it can be advantageous to use multiple of them arranged in series in the flow path, in an effort to advantageously restrict flashback and/or advantageously restrict the amount of heat that reaches the plenum. Restricting the heating of the gas-air mixture in the plenum can have significant advantages. For example, keeping the plenum's gas-air mixture cool can play a role in allowing at least substantially all of the oxygen needed for combustion to be provided via a venturi and the plenum. Using thin perforated members can also play a role in allowing at least substantially all of the oxygen needed for combustion to be provided via the venturi and the plenum. When at least substantially all of the oxygen needed for combustion is provided via the plenum, the introduction of excess air to the combustion can be controlled (e.g., substantially eliminated), which can advantageously result in optimal heating of one or more infrared radiant energy emitters that are adjacent the burner unit. The infrared radiant energy emitter can be the element that functions to ultimately emit the radiant energy that is used for heating items such as, but not limited to, food.

As mentioned above, the downstream perforated member(s) emit infrared radiation. In addition, when the downstream perforated member(s) are sandwiched between the mounting members, the downstream-most one of these mounting members can also emit infrared radiation. The infrared radiation emitted form the downstream mounting member can advantageously be at relatively longer wavelengths. This can be advantageous because it is generally desirable to increase the radiant energy output at the longer wavelengths because they are more readily absorbed than short wave lengths by most materials (e.g., food being cooked).

Other aspects and advantages of the present invention will become apparent from the following.

BRIEF DESCRIPTION OF THE DRAWINGS

Having described some aspect of the invention in general terms, reference will now be made to the accompanying drawings, which are not necessarily drawn to scale, and wherein:

Figure 1 is a schematic, end elevation view of a burner unit in a cooking apparatus, in accordance with an exemplary embodiment of the present invention;

Figure 2 is a schematic, top plan view of the burner unit of Figure 1, with the emitter partially cut away;

Figure 3 is a schematic, cross-sectional, enlarged view of a portion of burner and baffle assemblies of the burner unit, taken along line 3-3 of Figure 2;

Figure 4 is a schematic, exploded view of the burner unit of Figure 1;

Figure 5 is an enlarged plan view of a portion of a representative perforated member of the burner unit of Figure 1;

Figure 6 is an isolated pictorial view of a representative mounting member of the burner unit of Figure 1;

Figure 7 is an isolated pictorial view of the plenum, and a portion of an associated passageway, of the burner unit of Figure 1;

Figure 8 is a schematic, cross-sectional view taken along line 8-8 of Figure 2;

Figure 9 is a schematic, pictorial view of a representative mounting member of a burner unit of another embodiment of the present invention;

Figure 10 is a schematic, pictorial view of a representative mounting member of a burner unit of another embodiment of the present invention;

Figure 11 is a schematic, pictorial view of a representative mounting member of a burner unit of another embodiment of the present invention;

Figure 12 is a schematic, pictorial view of a representative mounting member of a burner unit of another embodiment of the present invention;

Figure 13 is a schematic, pictorial view of a representative mounting member of a burner unit of another embodiment of the present invention;

Figure 14 is a schematic, pictorial view of a representative mounting member of a burner unit of another embodiment of the present invention;

Figure 15 is a schematic, pictorial view of a representative mounting member of a burner unit of another embodiment of the present invention;

Figure 16 is a schematic, exploded view of a burner unit in accordance with another embodiment of the present invention;

Figure 17 is a schematic, top plan view of a burner unit in accordance with another embodiment of the present invention;

Figure 18 is a schematic, elevation view of the burner unit of Figure 17;

Figure 19 is a schematic, cross-sectional view of the burner unit take along line 19-19 of Figure 18;

Figure 20 is a chart that schematically illustrates a substantially uniform distribution of infrared radiant energy over an emitter, in accordance with one aspect of the present invention; and

Figure 21 is a chart that schematically illustrates a nonuniform distribution of infrared radiant energy over an emitter.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

Referring now in greater detail to the drawings, in which like numerals refer to like parts throughout the several views, Figures 1-8 illustrate features of an infrared radiant burner unit 20 for generating infrared radiant energy by burning a gaseous fuel, in accordance with an exemplary embodiment of the present invention. Very generally described, and as can be understood from Figures 1-3, the burner unit 20 operates by burning the gaseous fuel so that combustion, which is schematically represented as flames by the series of vertical arrows in Figure 3, emanates from / is proximate an outer surface of a burner element (e.g., burner assembly 22) and is typically at least partially within a gap between the burner assembly and an infrared radiant energy emitter 24. The vertical arrows in Figure 3 are schematic in nature because, for example, the flames of the combustion are typically in a bed-like arrangement that is in close proximity to the outer surface of the burner assembly 22 during normal operation.

The emitter 24 is the part of the burner unit 20 that functions to ultimately emit the radiant energy that is used for heating items such as, but not limited to, food. The emitter 24 is partially cut away in Figure 2 so that part of the burner assembly 22, that would otherwise be hidden from view in Figure 2, is shown. In addition, portions of the burner assembly 22 with holes extending therethrough (e.g., partition(s) with holes, or more specifically perforated members 25 that are parts of the burner assembly) that are hidden from view behind the emitter 24 are illustrated by broken lines. Only a representative few of the perforated members 25 are identified by their reference numerals in Figures 2 and 4 in an effort to clarify those views.

The burner unit 20 can be used in many different applications. As one example that is partially and schematically illustrated in Figure 1, the burner unit 20 can be part of a cooking apparatus that includes a support 21 that is for supporting food 23 and is in sufficiently close proximity to the burner unit 20 so that infrared radiant energy emitted from the emitter 24 cooks the food. Alternatively, the emitter 24 can be omitted from the cooking apparatus and the food 23 can be cooked by infrared radiant energy emitted by the burner assembly 22 as well as by convection associated with the combustion ensuing from the burner assembly. The support 21 for supporting the food 23 can be any conventional mechanism for supporting food that is being cooked, such as a conventional open grating or a skewer-like device associated with a rotisserie. The cooking apparatus can further include an open-top housing (not shown) for containing the burner unit 20 and carrying the support 21. More specifically, the cooking apparatus that includes the burner unit 20 and support 21 can be an outdoor grill generally like that disclosed in U.S. Patent No. 6,114,666, which is incorporated herein by reference, in its entirety. Indeed, the burner unit 20 includes features that can make it very well suited for an outdoor grill, as well as many other types of cooking apparatus.

In accordance with the exemplary embodiment of the present invention, the support 21 can be a cooking grid having bottom surfaces that are in contact with (e.g., rest upon) the upper surface of the infrared radiant energy emitter 24, or the cooking grid 26 can be positioned slightly above the upper surface of the emitter 24. Such arrangements can be optional, but when employed they can at least play a role in: overcoming problems associated with flare-up and/or provide substantially uniform energy distribution over the upper surfaces of the cooking grid. These features are further described in the U.S. utility patent application that is entitled “Infrared Emitting Element”, names Willie H. Best as the inventor, has been filed on the same day as the present application, and is incorporated herein by reference, in its entirety.

Referring in more detail to Figures 3 and 4, one or more baffle assemblies 26 can be positioned in series with the burner assembly 22 to enhance the operation of the burner unit 20, as will be discussed in greater detail below. Whereas there can be more than one baffle assembly 26 positioned in series with the burner assembly 22, only a single baffle assembly 26 is illustrated in series with the burner assembly 22 in the accompanying figures, and primarily only a single baffle assembly is described in the following for purposes of readability rather than for the purpose of narrowing the scope of the present invention.

In accordance with the exemplary embodiment of the present invention, each of the burner and baffle assemblies 22, 26 includes one or more perforated members 25 (e.g., partitions with holes) and one or more mounting members 30 for mounting the perforated members. Each of Figures 2 and 4 are schematic because, for example, the perforated members 25 are illustrated schematically therein. The perforated members 25 can be best seen in Figures 3 and 5, which are enlarged views that are discussed in greater detail below. As illustrated in Figure 4, each of the burner and baffle assemblies 22, 26 includes multiple perforated members 25; however, for each of the burner and baffle assemblies, the multiple perforated members can be replaced with a single, broader perforated member (e.g., see perforated member 25j in Figure 16, which is discussed below).

Very generally described, for each of the burner and baffle assemblies 22, 26, the perforated members 25 and mounting members 30 can, alone or in combination, be broadly characterized as partitions because, for example, they have the effect of at least partially defining the flow path of the gaseous fuel through the burner unit 20. Accordingly, and for purposes of explanation rather than for the purpose of narrowing the scope of the present invention, the arrangement of components of the burner unit 20 is at times referred to in the following with reference to the flow path of the gaseous fuel, namely by using the terms "upstream" and "downstream".

The one or more baffle assemblies 26 that are positioned in series with the burner assembly 22 are positioned upstream from the burner assembly. The burner and baffle assemblies 22, 26 are arranged so that there is a series of the perforated members 25 that are respectively spaced apart from one another along the flow path and are attached to the open side of a plenum 32 so that a seal is formed around the perimeter of the open side of the plenum.

In accordance with an alternative embodiment of the present invention, perforated members 25 are not arranged in series, so that there is only a single layer of perforated members 25. The single layer can be the result of, for example, omitting the baffle assembly 26. On the other hand, the embodiment that includes only the single layer of the perforated members 25 can also be described in the context of omitting the so-called burner assembly 22, and then referring to the so-called baffle assembly 26 as the burner assembly.

The burner assembly 22 and the baffle assembly 26 can be constructed similarly or identically, although varied constructions are also within the scope of the present invention. In accordance with the exemplary embodiment of the present invention, the perforated members of the burner and baffle assemblies 22, 26 are sufficiently alike so that all of the perforated members are identified by the reference numeral 25, and the mounting members of the burner and baffle assemblies 22, 26 are sufficiently alike so that all of the mounting members are identified by the reference numeral 30. Nonetheless, in accordance with the exemplary embodiment of the present invention, the upstream-most mounting member 30 is formed so as to include an upright flange 34 that extends around and upwardly from the entire periphery of the upstream-most mounting member 30; in contrast the other mounting members 30 do not include such a flange.

The upright flange 34 extends a sufficient distance from the upstream-most mounting member 30 such that the upright flange encircles, is in face-to-face relation with edges of the burner assembly 22, and extends past / upwardly from the burner assembly 22. As will become apparent from the following, the upright flange 34 can, for example, help to facilitate stacking and stabilization of components of the burner and baffle assemblies 22, 26 by restricting relative movement therebetween, and it can also help to restrict the introduction of secondary air to the combustion. The combustion is schematically represented by the series of vertical arrows in Figure 3, and Figure 3 is illustrative of partial, cross-sectional views taken across each of the perforated members 25. In accordance with an alternative embodiment of the present invention, the upright flange 34 is omitted from the upstream-most mounting member 30, or the upright flange

34 can be a component of another one of the mounting members 30, or the upright flange 34 can be a separate component that is mounted to, or otherwise proximate, the burner assembly 22 and/or baffle assembly 26.

Each of the mounting members 30 can be characterized, for purposes of explanation rather than for purposes of narrowing the scope of the present invention, as a generally mask-like, nonwoven plate of sheet metal. Nonetheless, the mounting members 30 can be other mechanisms (e.g., mounting and/or spacing mechanisms) that can be used to mount and appropriately space the perforated members 25. Figure 6 is a schematic, isolated pictorial view of a mounting member 30 that is representative of all of the mounting members of the burner and baffles assemblies 22, 26, except that the mounting member illustrated in Figure 6 does not include the upright flange 34 that optionally extends around and upwardly from the entire periphery of the upstream-most mounting member 30. With continued reference to Figure 6, the mounting member 30 includes multiple mounting holes 36 that extend through the marginal portion of the mounting member. Each of the mounting members 30 also defines other holes that extend completely therethrough, and these other holes can be referred to as mask holes 38 for purposes of explanation rather than for purposes of narrowing the scope of the present invention. The size and arrangement of the mask holes 38 defines a pattern of heat distribution over the downstream surface of the burner assembly 22. That is, the combustion (e.g., represented by the series of vertical arrows in Figure 3) emanate from the downstream openings of the mask holes 38 of the downstream-most mounting member 30.

As illustrated in Figures 3 and 4, the mask holes 38 of the burner assembly 22 are respectively sized the same as, and aligned with, the mask holes of the baffle assembly 26. The mask holes 38 of the adjacent mounting members 30 of the burner assembly 22 are respectively aligned with one another, and these aligned mask holes respectively have the perforated members 25 of the burner assembly interposed therebetween. Similarly, the mask holes 38 of the adjacent mounting members 30 of the baffle assembly 26 are respectively aligned with one another, and these aligned mask holes respectively have the perforated members 25 of the baffle assembly interposed therebetween. Other arrangements are also within the scope of the present invention.

More specifically, the perforated members 25 can be laminated (sandwiched) between the respective mounting members 30. Even more specifically described, the burner assembly 22 of the exemplary embodiment of the present invention can be characterized as being the unit consisting primarily of, or substantially solely of, the downstream-most mounting member 30, the mounting member that is adjacent the downstream-most mounting member, and the perforated members 25 sandwiched between these two mounting members; and these two mounting members can be optionally connected together by welding, or more specifically spot welding, or the like. Similarly, the baffle assembly 26 of the exemplary embodiment of the present invention can be characterized as being the unit consisting primarily of, or substantially solely of, the upstream-most mounting member 30, the mounting member that is adjacent the upstream-most mounting member, and the perforated members 25 sandwiched between these two mounting members; and these two mounting members can be optionally connected together by welding, or more specifically spot welding, or the like. Alternatively, the spot welds can be omitted, and other means for mounting are also within the scope of the present invention.

In accordance with the exemplary embodiment of the present invention, marginal portions of the burner assembly 22 and the baffle assembly 26 are mounted to a peripheral flange 40 of the plenum 32 to form a gas-tight seal around the perimeter of the plenum. As best understood with reference to Figure 7, the plenum's flange 40 includes mounting holes 42 for facilitating mounting of the burner assembly 22 and the baffle assembly 26. The burner assembly 22 and the baffle assembly 26 can be mounted to the peripheral flange 40 of the plenum 32 by respectively aligning the mounting holes 36 of the burner and baffle assemblies with the mounting holes 42 of the of the plenum's flange 40, then passing male fasteners 44 (e.g., bolts, or the like) through these holes and optionally respectively attaching female fasteners 46 (e.g., nuts, or the like) to the male fasteners. Other methods and apparatus for mounting or otherwise associating the burner assembly 22 and the baffle assembly 26 to the plenum 32 are also within the scope of the present invention. In addition, whereas the burner assembly 22 and the baffle assembly 26 are often referred to herein as different components for the purpose of clarifying this disclosure, they can also be referred to together / collectively as a burner assembly.

Referring to the housing / plenum 32 more specifically, and as best understood with reference to Figure 7, the plenum 32 is formed with an outlet opening 48 that is partially closed as a result of the burner assembly 22 and the baffle assembly 26 being mounted to the plenum's flange 40. A gas-air mixture is supplied to the plenum 32 through a conventional venturi 50 (Figures 2 and 4). Alternatively the gas-air mixture can be supplied by way of any other conventional means, or the like, such as by way of a connection for a pre-mixture of gas and air, such as a pre-mixture provided by a combustion air blower and mixer (not shown). When the venturi 50 is used, the gas is supplied through a conventional orifice 52 (Figures 2 and 4) to which a gas supply line is connected (not shown). From the venturi 50, the gas-air mixture flows through a feed pipe 54 that extends through a side wall of the plenum 32 and has an outlet end that is open in the interior of the plenum 32, so that the gas-air mixture flows into the interior of the plenum. A portion of the feed pipe 54, the venturi 50 and the orifice 52 are cut away in, and thereby not shown in, Figure 7.

Referring in greater detail to the perforated members 25 (e.g., partitions with holes), a portion of a representative perforated member is shown on an enlarged scale in Figure 5, and a pair of serially arranged perforated members, and respective portions of the burner and baffle assemblies 22, 26, are shown on an enlarged scale in Figure 3. In accordance with the exemplary embodiment of the present invention, each of the perforated members 25 is fabricated from a nonwoven plate of high temperature metal alloy so that it defines a multiplicity of holes or perforations 56 that extend completely therethrough. The combustion air mixture flows from the plenum 32, to and through the perforations 56 that are respectively open to the mask holes 38 of the mounting members 30, and the combustion is closely associated with the downstream openings of the perforations 56 of the burner assembly 22 (i.e., the perforations 56 that are open to the mask holes 38 of the burner assembly 22). In accordance with the exemplary embodiment of the present invention, the perforations 56 that are not open to the mask holes 38 of the mounting members 30 are closed by the mounting members, and the combustion air mixture does not flow through those perforations 56 that are respectively closed by the mounting members 30.

The perforations 56 in the perforated members 25 can be formed by perforating (e.g., boring or punching), but they can also be formed by means other than perforating, such that the perforated members 25 can be more generally referred to as partitions with holes, or the like. The perforated members 25 contiguous with the mask holes 38 in the burner assembly 22 are small enough to be capable of quenching the combustion / flame, which is schematically represented by the series of vertical arrows in Figure 3, at the downstream surface of the burner assembly 22 so that flashback does not occur. In accordance with the exemplary embodiment, the diameter of each of the perforations 56 contained in the perforated members 25 does not exceed about 0.062 inches, and more specifically the diameter of each of the perforations 56 contained in the perforated members 25 is in a range of about 0.025 inches to about 0.062 inches. More precisely, the diameter of each of the perforations 56 contained in the perforated members 25 does not exceed 0.062 inches, and the diameter of each of the perforations 56 contained in the perforated members 25 can be in a range of 0.025 inches to 0.062 inches. More specifically, the diameter of each of the perforations 56 contained in the perforated members 25 can be in a range of about 0.030 inches, or about 0.033 inches, to about 0.060 inches. More precisely, the diameter of each of the perforations 56 contained in the perforated members 25 can be in a range of 0.030 inches, or 0.033 inches, to 0.060 inches. In one specific example, the diameter of each of the perforations 56 contained in the perforated members 25 is about 0.03125 inches. More precisely, the diameter of each of the perforations 56 contained in the perforated members 25 can be 0.03125 inches. Alternatively, the width of the perforations 56 contained in the perforated members 25 do not exceed about 0.045 inches if the perforations are rectangular. Perforations 56 of other shapes are also within the scope of the present invention. The above-described diameters can be more generally referred to as widths.

In addition, the perforated members 25 of the exemplary embodiment are relatively thin, such as by being less than about 0.125 inches thick, to minimize the pressure drop resulting from the combustion air mixture flowing through the perforations 56 of the perforated members 25. More precisely, the perforated members 25 can be less than 0.125 inches thick. More specifically, the thickness of the perforated members 25 can be within a range of about 0.0156 inches to about 0.0625 inches, and even more specifically the thickness of the perforated members 25 can be about 0.0312 inches. More precisely, the thickness of the perforated members 25 can be within a range of 0.0156 inches to 0.0625 inches, and even more specifically the thickness of the perforated members 25 can be 0.0312 inches.

More specifically, it can be advantageous in a perforated member 25 with a thickness of less than about 0.125 inches, such as a thickness of about 0.0312 inches, for the diameter of each perforation 56 to be about 0.033 inches, with the perforations 56 placed on about 0.055 inch straight centers (i.e., so that centers of adjacent perforations 56 are about 0.055 inches apart). More generally, the distance between centers of adjacent perforations 56 can be within a range of about 0.040 inches to about 0.080 inches. More precisely, the perforations 56 can be placed on 0.055 inch straight centers. Also, the distance between centers of adjacent perforations 56 can be within a range of 0.040 inches to 0.080 inches.

It is also advantageous for the flames of the combustion to remain in close contact with the downstream side of the perforated members 25 of the burner assembly 22 in order to transfer the maximum amount of the energy of combustion into the perforated members of the burner assembly, in order to maximize the radiant output from the burner assembly. With the combustion remaining in close contact with the downstream side of the perforated members 25 of the burner assembly 22, the flames of the combustion can be characterized as at least generally projecting from the downstream ends of the perforations of the perforated members 25 of the burner assembly 22.

If there is any tendency for the combustion / flames to lift and develop a boundary layer between the combustion/flames and the perforated members 25 of the burner assembly 22, the heat transfer from the combustion/flames to the burner assembly will be greatly diminished. Therefore and in accordance with the exemplary embodiment of the present invention, in order to maintain good combustion/flame stability and to avoid any lifting of the combustion/flame, the mixture velocity through the perforations 56 of the perforated members 25 is no more than about 80% of the flame speed which is 2.2 ft/sec for methane and 2.7 ft/sec.

As best understood with reference to Figure 3, each of the mounting members 30 and perforated members 25 can be substantially planar, so that the laminating or other mounting of them results in the formation of voids, spaces, or chambers 58. In addition, the perforated members 25 can be of sufficient width and length that marginal portions of the perforated members extends beyond the mask holes 38 of the mounting members 30 to effectively form seals proximate the peripheries of the mask holes 38. Also, it is advantageous for the perforated members 25 to be flat so that the seals proximate the peripheries of the mask holes 38 can be readily formed. It would be more difficult to achieve such a gas-tight seal if the perforated members 25 were replaced with woven screens. Nonetheless, in accordance with alternative embodiments of the present invention the perforated members 25 can optionally be replaced with woven screens, sintered elements with passageways therethrough, ceramic elements with passageways therethrough, or the like.

As illustrated in Figure 3, the perforated members 25 are arranged in series so that the gas-air mixture flows through at least two layers of the perforated members 25. This serial arrangement decreases the temperature of the gas-air mixture in the plenum 32 because the upstream perforated members 25 block infrared radiation from the underside of the downstream perforated members 25 that are included in the burner assembly 22, and the chambers 58 act as thermal barriers to convective heat transfer. The multiple layers of perforated members 25, through which the gas-air mixture must flow, also substantially eliminate any tendency for the burner unit 20 flashback, as mentioned above. A single perforated member 25 or a single layer of perforated members 25 that are coplanar can be used to quench the combustion/flame. On the other hand, it is advantageous to use the serial arrangement of the perforated members 25 because the operation of the burner unit 20 becomes more stable and dependable when two or more perforated members 25 are used in series.

While the primary source of infrared radiant energy is the downstream-most perforated members 25 (i.e., the one or more perforated members 25 of the burner assembly 22), the portions of downstream-most mounting member 30 that are between and around the downstream perforated members 25 also radiate radiant energy, but at a temperature lower than the temperature of the downstream-most perforated members 25. This feature advantageously increases the levels of emitted energy at the longer wavelengths. It is generally desirable to increase the radiant energy output at the longer wavelengths because they are more readily absorbed than short wave lengths by most materials. For example, and not for the purpose of limiting the scope of the present invention, it is noted that it has been demonstrated that when infrared radiant energy is used for grilling food (specifically meat) that there are beneficial results when most of the energy is emitted at wavelengths greater than 3 microns.

As mentioned above, in one alternative embodiment, the burner assembly 22 can be omitted, and then the so-called baffle assembly 26 can be referred to as the burner assembly. That alternative embodiment is just one example of the various possible arrangements that are within the scope of the present invention. For example, and as best understood with general reference to Figure 6, in one version, the so-called burner assembly 22 is mounted beneath the so-called baffle assembly 26, such that the so-called baffle assembly 26 functions as (and can be referred to as) the burner assembly, and the so-called burner assembly 22 functions as (and can be referred to as) the baffle assembly.

Also in accordance with this version, and as best understood with general reference to Figure 3, one of the mounting members 30 can be omitted, so that in a cross-sectional view similar to that of Figure 3, the two layers of perforated members 25 are separated by only a single mounting member 30.

In accordance with the exemplary embodiment of the present invention, the infrared radiant energy emitter 24 is held by mounting clips 60 that retain the emitter within about an inch or less of the downstream surface of the burner assembly 22, and so that a peripheral exhaust opening 62 is defined between the periphery of the burner assembly 22 and the emitter 24. Each mounting clip 60 includes a lower horizontal flange that is in opposing face-to-face engagement with the downstream surface of the burner assembly 22 and held thereto by a respective one of the male fasteners 44. Each mounting clip 60 also includes an upper horizontal flange that is in opposing face-to-face engagement with the bottom surface of the emitter 24. A tab extends upwardly from each upper horizontal flange of the clips 60 and engages the outer edge of the emitter 24. Alternatively, the emitter 24 can be mounted by other means or even be omitted.

The material used in the construction of the burner unit 20 is selected to be capable of withstanding the operating temperatures of the burner unit for long periods. For example, the perforated members 25 can be fabricated from a high temperature stainless steel, such as, but not limited to, 310 stainless steel, and the mounting members 30 and plenum 32 can be constructed from 304 stainless steel. More specifically, suitable perforated members 25 can obtained from Ferguson Perforating, which is located at 30-140 Ernest Street, Providence, RI 02905-0038. The emitter 24 can be made of metal or from another high temperature material. More specifically, the emitter 24 can be constructed from 310 stainless steel and/or nichrome, and the emitter can also be glass as described by U.S. Patent No. 6,114,666 to Best. U.S. Patent No. 6,114,666 is incorporated herein by reference, in its entirety. Other emitters 24 are within the scope of the present invention. For example, whereas the emitter 24 of the exemplary embodiment of the present invention is solid, it could alternatively be perforated, such as a perforated plate, or a screen. In any event, it is preferred, but not necessarily required, for the emissivity of the emitter 24 to be at least 0.7 or greater after it is oxidized, with this oxidizing being carried out before the burner unit 20 is assembled or from the operation of the burner unit 20. For a thorough discussion of emissivity, see NASA S-31 "Measurement of Thermal Radiation Properties of Solids" 1963 (585 pages) and

"Thermal Radiation Properties Survey," G.G. Gubaneff, J.E. Janssen and R.H Torberg, J.E. Janssen and H.R. Torberg, Honeywell Research Center, Minneapolis, MN, 1960. The above references are cited by CRC Handbook of Tables for Applied Engineering Science, page 163.

The emitter 24 is heated by infrared radiation from the burner assembly 22 and from the hot products of combustion (i.e., the hot products resulting from the combustion/flames that emanate from the downstream surface of the burner assembly 22 and are schematically represented by the series of vertical arrows in Figure 3). When the emitter 24 is replaced with a woven screen or a perforated plate, the usable infrared radiation emitted from the burner unit 20 is emitted from both the burner assembly 22 and the woven screen or perforated plate. In contrast, when the solid emitter 24 is used, then substantially all of the usable infrared radiant energy emitted from the burner unit 20 is emitted or transmitted from the emitter 24.

In accordance with an alternative embodiment of the present invention, the emitter 24 is omitted. Tests have demonstrated that the radiant energy output of the burner unit 20 decreases by more than 25% when the emitter 24 is removed. This is the result of the emitter 24, when present as in the exemplary embodiment of the present invention, absorbing or transmitting the radiant energy from the burner assembly 22 and being heated from the products of combustion emerging from the burner assembly 22. Also, the temperature of the burner assembly 22 is increased when cooling of the surface of the burner assembly by free convection is eliminated by covering the burner assembly with the emitter 24 and limiting the size of the peripheral exhaust opening 62. In addition, the solid emitter 24 can protect the burner assembly 22 from moisture to help render the burner unit 20 water-resistant. This can be an important benefit in many applications where the burner unit 20 is used in a drying or curing process that takes place in a wet or damp atmosphere. Also, in some process applications, the outer emitter 24 will protect the burner assembly 22 from splatter or contamination from the process. An example or such a process would be the drying of coated paper. Even when the emitter 24 is replaced with a woven screen or a perforated plate, some protection of the burner assembly 22 is provided.

With the solid emitter 24, the slot-like exhaust opening 62 between the upper surface of the burner assembly 22 and the lower surface of the emitter 24 not only allows for the products of combustion to be discharged, but it is also sufficiently narrow so that it seeks to prevent secondary air from reaching the burner assembly 22 (i.e., reaching the combustion/flames that emanate from the downstream surface of the burner assembly 22 and are schematically represented by the series of vertical arrows in Figure 3). As illustrated in Figures 1 and 8, the upright flange 34, which extends around and upwardly from the baffle assembly 26, extends to a position above the downstream surface of the burner assembly 22, so that the exhaust opening 62 is defined between the upper edge of the upright flange 34 and the bottom surface of the emitter 24. Figure 8 is schematic, for example, because its scale is not sufficiently large to individually crosshatch the respective parts of the burner and baffle assemblies 22, 26; therefore, the burner and baffle assemblies are schematically illustrated together / crosshatched together as a single component. In accordance with the exemplary embodiment of the present invention, the distance between the upper edge of the upright flange 34 and the bottom surface of the emitter 24 is about 0.500 inches in the vertical direction. The exhaust opening 62 for discharging the products of combustion can be omitted when the emitter 24 includes a sufficient number of apertures therethrough or is replaced with a screen-like emitter.

The performance of the burner unit 20 is dictated, in part, by the emissivity of the emitter 24. Emissivity is a factor that indicates the ability of a surface to absorb or radiate infrared energy at the same temperature. A perfect emitter (black body) or absorber would have an emissivity of one. All other emissivities are a fraction of one. It has been widely accepted that, in general, metal has low emissivity and other material, such as ceramic, has emissivities of about 0.9. Therefore, metal generally would not be considered a good emitting surface for a radiant type burner. However, certain alloys of metal, when oxidized, become very good emitters and possess the strength and durability not found in most ceramic type materials. As an example, oxidized nichrome wire heated to about 500°C (932°F) can possess an emissivity above 0.95.

Since, in accordance with the exemplary embodiment, the emitter 24 is in close proximity to the burner assembly 22 (e.g., within less than 1 inch), the emissivity of the burner assembly 22 is not as important to the operation of the burner unit 20 as is the emissivity of the emitter 24. This configuration of the burner unit 20 can be characterized as there being two parallel planes, one radiating to the other in close proximity. Since the exhaust opening 62 between the perimeters of the burner assembly 22 and the emitter 24 is narrow (e.g., less than one inch), the majority of the energy will be absorbed by the emitter even if the energy is reflected from the emitter back to the burner assembly. The amount of energy lost through the exhaust opening 62 around the perimeter will be negligible because the intensity of the emitted energy decreases as the angle between the normal and that of the emission increases. In other words, the maximum energy is emitted normal to the surface of the emitting element and decreases to zero at zero angle to the surface.

The burner unit 20 of the exemplary embodiment of the present invention has many advantages and associated features, and some of them have been described above, and some of them will be described in the following, but they are not being described herein for the purpose of narrowing the scope of the present invention. As one example of an advantage, the burner unit 20 can eliminate the fragility of existing type ceramic burner emitting elements since the burner and baffle assemblies 22, 26 can be completely constructed of metal.

Additionally, the burner unit 20 is also highly resistant to flashbacking and can be fired at rates more than triple that of at least some conventional infrared burners based on BTUH/in^2 of surface area of the emitter 24. In this regard, traditional studies of the concept of critical boundary velocity gradient as a rational means of correlating flame flashback and blow off stability limits do not completely apply to the burner unit 20. As an example, in a study of Structure and Propagation of Laminar Flames by Thomas and Wilhelm (U.S. Air Force Contract No. A.F. 33(038140976)) it was shown that the quenching distance for methane-air flames are 0.32 cm (0.126 inches) for a tubular orifice and 0.250 cm (0.098 inches) for a rectangular orifice. In the burner unit 20 of the exemplary embodiment, these determined quenching distances would result in flashback and burner failure. The difference is that in the burner unit 20 of the exemplary embodiment, there is little or no thermal quenching and the quenching of the flame is more by material diffusion.

When the gas-air mixture passes through the multiple layers of the perforated members 25 in the burner unit 20, a secondary method of quenching the flame is introduced. When multiple layers of perforated members 25 are used, the chambers 58 (e.g., air gaps) illustrated in Figure 3 are formed between the layers of perforated members. Advantageously, these chambers 58 can function to lower the temperature of the gas-air mixture in the plenum 32 and thereby increase the ability to inject combustion air into the plenum 32 by the venturi 50. Since metal (which is what the perforated members 25 are constructed from in accordance with the first exemplary embodiment) has almost infinite thermal conductivity, both the upper and lower surfaces of the perforated members of the burner assembly 22 are at about the same temperature. The perforated members 25 of the baffle assembly 26 block the radiation from the underside of the perforated members 25 of the burner assembly 22. The perforated members 25 of the baffle assembly 26 also form a thermal boundary layer between the perforated members 25 of the burner assembly 22 and the plenum 32. It is not necessary that the perforated members 25 of the baffle assembly 26 be made of the same materials as the perforated members 25 of the burner assembly 22 or that they have the same dimensions. However, to provide for the maximum protection against any type of flashback, at least the perforated members 25 in the baffle assembly 26 should be capable of quenching the flame even if they are fabricated of a relatively less expensive alloy such as 304 stainless steel.

In some embodiments of the present invention, only a single layer of one or more perforated members 25 is used and is sufficient; however, the performance of the burner unit 20 is improved (lower gas-air mixture temperatures in the plenum 32 and increased resistance to flashback) when multiple layers of the perforated members 25 are employed and spaced in series and relatively close to each other (e.g., adjacent perforated members 25 that are in series with respect to one another are spaced apart by less than about 0.250 inches).

Advantageously, the burner unit 20 of the exemplary embodiment can operate on 100% primary air (i.e., air provided by way of the venturi 50) for complete combustion using the venturi 50. That is, the air for providing complete combustion is 100% primary air that is air mixed with the supplied gas and provided by way of the venturi 50 at normal operating gas pressures. It is possible for the burner unit 20 to operate with 100% primary air for combustion using the venturi 50 because, for example, of the low pressure drop across the thin perforated members 25. Because the burner unit 20 does not require secondary air for combustion, the burner assembly 22 can be positioned in close proximity to the object to be heated (e.g., less than about one inch), namely the emitter 24 that absorbs the infrared radiation and energy from the products of combustion to re-radiate infrared energy to the object (e.g., food) to be heated (e.g., cooked). In accordance with an alternative embodiment of the present invention, the burner unit 20 does not necessarily operate on 100% primary air.

In accordance with the exemplary embodiment of the present invention, the burner unit 20 is operative so that all of the air required for completing the combustion is provided via the conventional venturi 50 throughout the operating range of the burner unit 20, with the operating range including, for example and not for purposes of limitation, all firing rates between and including 350 BTUH/in^2 of the burner unit's emitting surface and about 1,000 BTUH/in^2 of the burner unit's emitting surface. In the immediately foregoing, for the purposes of providing specific examples, the burner unit 20 has been described as operating with 100% primary air for combustion using the conventional venturi 50. However and more generally, it is also within the scope of the present invention for the burner unit 20 to be operative for so that substantially all of the air required for completing the combustion is provided via the conventional venturi 50 throughout the operating range of the burner unit 20, with the operating range including, for example and not for purposes of limitation, all firing rates between and including 350 BTUH/in^2 of the burner unit's emitting surface and about 1,000 BTUH/in^2 of the burner unit's emitting surface.

In accordance with the exemplary embodiment, it is advantageous to the efficiency of the burner unit 20 that the burner unit can and does operate on 100% primary air. As a result, the combustion gases emanating from combustion/flames that emanate from the burner assembly 22 are not cooled or diluted by any secondary air until after these combustion gases are discharged from the burner unit 20 by way of the peripheral exhaust opening 62. At least partially as a result, the burner unit 20 can operate up to about 1,000 BTUH/in^2 without flashbacking. Since the emitted radiant energy is a function of the temperature of the emitter 24 (in R°) to the fourth power, it is important to maintain the highest temperature possible of the emitting surface for a fixed input of energy. The high inputs per unit area of burner assembly 22 is possible, in part, because of the burner assembly's ability to optimally quench the flame and thereby restrict flashback. The flame can be quenched by the use of one or more perforated members 25 in a single layer, but when two layers of the perforated members are used in series and are spaced apart by less than about 0.250 inches it becomes almost impossible to flashback the burner unit 20 due to over-firing. Perforated members 25 of adjacent layers can be spaced apart by a distance that is in the range of about 0.050 inches to about 0.250 inches, and in one specific example, they are spaced apart by about 0.0625 inches. That is, and as best understood with reference to Figure 3, each of the chambers 58 provides a gap (e.g., thermal boundary layer) between perforated members 25, with the gap being a less than about 0.250 inches, or more specifically the gap being in the range of about 0.050 inches to about 0.250 inches, or even more specifically the gap being about .0625 inches. Even when a perforation 56 of one of the perforated members 25 of the burner assembly 22 is damaged so that it is enlarged to a diameter that will allow retrogression of the flame, flashbacking into the plenum 32 does not occur because the perforated member that is in series with / upstream from the damaged perforated member will quench the flame and thereby prevent any flashback.

The configuration of the mask holes 38 in the burner assembly 22 (e.g., the size, shape and arrangement of the exposed portions of the perforated members 25 in the burner assembly) can at least partially control the radiant output of the burner assembly, including the pattern in which the infrared energy is emitted from the burner assembly. The perforated members 25 can comprise most of the surface of the burner assembly 22 or only a small percentage of it. Accordingly, the energy emitted from the surface of the burner unit 20 can be adjusted to the requirements of the heat transfer process. That is, the mask holes 38 / pattern of perforations 56 can be varied in size, geometric shape, and location based on the desired distribution and intensity of the emitted energy.

In accordance with the exemplary embodiment of the present invention, each of the burner and baffle assemblies 22, 26 has an open area (i.e., the flow area which is the sum of the areas of the exposed / open perforations 56 of the assembly) that does not exceed more than about 60% of the total area of the assembly in a plan view of the assembly. In accordance with a more specific example, each of the burner and baffle assemblies 22, 26 has an open area that does not exceed more than about 50% of the total area of the assembly in a plan view of the assembly. In one specific example, each of the burner and baffle assemblies 22, 26 has an open area that does not exceed more than about 33% of the total area of the assembly in a plan view of the assembly.

The perforated members 25 / perforations 56 can be dispersed over the surface of the burner and baffle assemblies 22, 26 so that they only occupy, or are only exposed at, a portion of the surface of the burner and baffle assemblies. The perforated members 25 can be arranged and/or exposed / masked in a manner that will allow the radiant energy to be varied in its intensity over the surface of the burner assembly 22. As a contrasting example, in a typical prior art radiant burner, the maximum energy is usually emitted from the center of the burner. In contrast, in the burner unit 20, the perforated members 25 of the burner assembly 22 can be concentrated toward / around the perimeter of the burner assembly so that there is a relative decrease in the radiant energy emitted from the center, so that a very uniform distribution of the energy can be provided. That is, the perforated members 25 / perforations 56 in the burner assembly can be systematically located over the surface of the burner assembly 22 (e.g., due to the configuration of the mask holes 38) to influence the intensity and distribution of the radiant energy.

In accordance with one aspect of the present invention, the perforated members 25 are arranged and/or exposed / masked in a predetermined manner so that the emitter 24 is nonuniformly heated in a predetermined manner, so that the infrared radiant energy over the emitter is substantially equally distributed. As one example of this aspect, the perforated members 25 can be exposed / masked in a predetermined manner so that the burner unit 20 provides more heating proximate its perimeter, as a result of the mask holes being arranged, for example and not limitation, as at least generally illustrated in Figure 2, 4, 6, 10, or 12, or the like. This aspect of the present invention is schematically illustrated by Figure 20. Figure 20 is a chart that includes an upright arrow 80 and a horizontal line 82. The upright arrow 80 provides a frame of reference about the intensity of infrared radiant energy over the emitter 24 in BTUH/in^2. The horizontal line 82 illustrates how the intensity of infrared radiant energy varies, if at all, over the surface of the emitter 24. That is, the substantially straight line 80 in Figure 20 indicates that there is a substantially uniform level of radiation intensity over the emitter 24, and this is the result of the burner unit 20 nonuniformly heating the emitter 24 in the predetermined manner. In accordance with one example, the infrared radiant energy over the emitter 24 is substantially equally distributed over at least about a square foot. In accordance with this and other aspects, the predetermined arrangement of open perforations 56 (e.g., holes) can be achieved, for example, without the mounting members and their mask holes, such as, in one example, by arranging the perforations in the predetermined manner.

In contrast to Figure 20, Figure 21 is a chart that schematically illustrates the uneven distribution of infrared radiant energy over an emitter 124 positioned over a burner unit 120 that uniformly heats the emitter 124. The chart of Figure 21 includes an upright arrow 180 and a horizontal line 182. The upright arrow 180 provides a frame of reference about the intensity of infrared radiant energy over the emitter 124 in BTUH/in^2. The horizontal line 182 illustrates how the intensity of infrared radiant energy varies significantly over the surface of the emitter 124, with the greatest intensity being in the middle.

The mask holes 38 of the burner assembly 22 and baffle assembly 26 can be located in various spaced relationships and the geometry of the mask holes 38 can vary widely to accommodate different radiant heat transfer requirements. When the burner unit 20 is put to a use that requires high levels of infrared radiation energy, the areas in which the perforated members 25 (i.e., the size of the mask holes 38) are increased to provide for sufficient flux density of infrared radiation energy based on the applications. At one extreme, the exposed area of the one or more perforated members 25 of the burner assembly 22 can essentially equal the entire area of the outlet opening 48 of the plenum 32, except for the relatively small peripheral frame-like outer mounting member (e.g., see the frames 70 and 72 in Figure 16) that would likely be provided to support the perimeter of the associated perforated member. For example, Figure 15 illustrates a mounting member 38g with a single, relatively large mask hole 38g such that the exposed area of the associated perforated member(s) 25 would be relatively large. On the other hand, the one or more perforated members 25 of the burner assembly 22 can be only a small percentage of the emitting surface of the burner assembly.

Some of the possible variations in the shapes and arrangements of the mask holes 38 are illustrated in Figures 9-15, which respectively are schematic, isolated pictorial views of representative mounting members 30a, 30b, 30c, 30d, 30e, 30f, 30g of burner units of other embodiments of the present invention. The other embodiments of the present invention that are respectively partially illustrated by Figures 9-15 are each like the exemplary embodiment of the present invention illustrated in Figures 1-8, or alternatively like the embodiment of Figure 16, except for variations noted and variations that will be apparent to those of ordinary skill in the art. For example, the mask holes 38a, 38b, 38c, 38d, 38e, 38f, 38g of the mounting members 30a, 30b, 30c, 30d, 30e, 30f, 30g differ in location and/or geometry from the mask holes 38 of the mounting members 30 of the exemplary embodiment. Nonetheless there are some similarities. For example, in the embodiments of Figures 9-15, perforated members like the perforated members 25j of the embodiment of Figure 16 can be used; and/or perforated members like the perforated members 25 of the exemplary embodiment can be used, although the overall size and/or shape of the perforated members may need to be changed to generally respectively conform to the configurations of the mask holes. Only a representative few of the mask holes 38f are identified by their reference numeral in Figure 14 in an effort to clarify the view; nonetheless, it should be apparent that the mask holes 38f are arranged in a generally continuous and repeating pattern.

As one example of the similarities, for each of the burner and baffle assemblies (e.g., partitions) constructed according to the embodiments respectively partially illustrated by Figures 6, 9, 10, 11, 12 and 13, the perforations 56 (e.g., holes) respectively open to the mask holes 38, 38a, 38b, 38c, 38d, 38e are arranged in a predetermined manner so that there are less of the perforations per unit area in a central portion of the assembly than there are in an intermediate portion of the assembly, with the intermediate portion of the assembly being between the central portion of the assembly and a marginal portion of the assembly. This aspect can be more generally described in the context of a partition for at least partially defining a flow path in a gas-fired burner that generates combustion (e.g., flames) and infrared radiation, with the partition including a multiplicity of holes extending through the partition for at least partially defining a flow path for providing at least the gas to the combustion, wherein the multiplicity of holes are arranged in a predetermined manner so that there are less of the holes per unit area in a central portion of the partition than there are in an intermediate portion of the partition, with the intermediate portion of the partition being between the central portion of the partition and a marginal portion of the partition. More specifically, one or more edges of the partition extends around the marginal portion, the marginal portion extends around the intermediate portion, and the intermediate portion extends around the central portion. In accordance with alternative embodiments of the present invention, these same arrangements of open perforations 56 (e.g., holes) are achieved without the mounting members and their mask holes, such as, in one example, by replacing each of the burner and baffle assemblies with a single perforated plate with the perforations thereof arranged in the predetermined manner.

As another example of the similarities, for each of the burner and baffle assemblies (e.g., partitions) constructed according to the embodiments respectively partially illustrated by Figures 6, 9, 10, 11, 12, 13 and 14, the adjacent mask holes 38, 38a, 38b, 38c, 38f are substantially farther apart than adjacent perforations 56 (e.g., holes) open to the same mask hole. This aspect can be more generally described in the context of a partition for at least partially defining a flow path in a gas-fired burner that generates combustion and infrared radiation, with the partition including a multiplicity of holes extending through the partition for at least partially defining a flow path for providing at least the gas to the combustion, wherein pluralities of first and second areas of the partition are arranged in an alternating series, with the holes being respectively arranged in the first areas, the first areas each including a multiplicity of the holes, the second areas being absent of the holes, and adjacent pairs of the second areas being substantially farther apart than adjacent pairs of the holes in a first area of the first areas. In accordance with alternative embodiments of the present invention, these same arrangements of open perforations 56 (e.g., holes) are achieved without the mounting members and their mask holes, such as, for example, by replacing each of the burner and baffle assemblies with a single perforated plate with the perforations thereof arranged in a predetermined manner.

In accordance with another aspect illustrated in Figures 6, 10, 12 and 13, at least some of the mask holes 38, 38b, 38d, 38e include an inner portion and an outer portion, with the outer portion being closer to the mounting member's marginal portion (e.g., the partition's marginal portion) than the inner portion, and the outer portion being wider than the inner portion. This aspect can be more generally described in the context of a partition for at least partially defining a flow path in a gas-fired burner that generates combustion and infrared radiation, with the partition including a multiplicity of holes extending through the partition for at least partially defining a flow path for providing at least the gas to the combustion, wherein pluralities of first and second areas of the partition are arranged in an alternating series, with the holes being respectively arranged in the first areas, the first areas each including a multiplicity of the holes, the second areas being absent of the holes, and at least one of the first areas includes an inner portion and an outer portion, with the outer portion being closer to the partition's marginal portion than the inner portion, and the outer portion being wider than the inner portion. In accordance with alternative embodiments of the present invention, these same arrangements of open perforations 56 (e.g., holes), and other arrangements of open perforations 56 (e.g., holes), can be achieved without the mounting members and their mask holes, such as, for example, by replacing each of the burner and baffle assemblies with a single perforated plate with the perforations thereof arranged in a predetermined manner.

Figure 16 is a schematic exploded view of the burner unit 20j in accordance with another embodiment of the present invention. The burner unit 20j of Figure 16 is like the burner unit 20 of the exemplary embodiment of the present invention except for variations noted and variations that will be apparent to those of ordinary skill in the art. For the burner unit 20j, the emitter 24j is in the form of a nichrome woven screen, or the like, that is retained by frames 70 and 72. The woven screen emitter 24j by definition has a multiplicity of open areas extending therethrough; therefore, the exhaust opening 62 of the exemplary embodiment is omitted from the embodiment of Figure 16, because the exhaust gases (products of combustion) can be discharged through the woven screen emitter 24j.

Another difference between the embodiment of Figure 16 and the exemplary embodiment is that each of the burner and baffle assemblies 22j, 26j includes only a single perforated member 25j that is broad enough to cover all of the respective mask holes 38j of the mounting members 30j. The perforated members 25j can be like the perforated members 25 of the exemplary embodiment, except for the overall size of the perforated members 25j being larger than the overall size of the perforated members 25 of the exemplary embodiment. Another difference between the embodiment of Figure 16 and the exemplary embodiment is the size and shape of the mask holes 38j. This difference provides an example of how the radiant energy output of a burner of this invention can be controlled as to intensity and location over the burner surface.

Figures 17-19 schematically illustrate a burner unit 20m in accordance with another embodiment of the present invention, and the embodiment of Figures 17-19 is generally like the exemplary embodiment of the present invention except for variations noted and variations that will be apparent to those of ordinary skill in the art. The burner unit 20m includes two of each of burner assemblies 22m, emitters 24m and baffle assemblies 26m, and these burner assemblies, emitters, baffle assemblies and associated components are angled relative to the plenum 32m and the horizon. Triangular end panels 76 and additional sealing structures, or other means, can be used so that the only flow path out of the plenum 32m is through the perforated members 25m of the burner assemblies 22m. Figure 19 is schematic, for example, because its scale is not sufficiently large to individually crosshatch the respective parts of the burner and baffle assemblies 22m, 26m; therefore, the burner and baffle assemblies are schematically illustrated together / crosshatched together as a single component.

As described above, the burner unit 20 can be used for cooking. Nonetheless, the burner unit 20 can have a wide variety of applications. For example and not for the purpose of narrowing the scope of the present invention, the burner unit 20, with or without the emitter 24, can be incorporated into water heater, and it can also be used to dry coatings, such as, but not limited to, paint. As one example, it may be desirable to replace the emitter 24 with a woven screen or a perforated plate when the burner of the present invention is used for drying coatings. As also described above, the burner unit 20 can provide a substantially uniform energy distribution. However, in some applications, a substantially uniform energy distribution is not required, and the present invention is not limited to a substantially uniform energy distribution.

It will be understood by those skilled in the art that while the present invention has been discussed above with reference to several embodiments, various additions, modifications and changes can be made thereto without departing from the spirit and scope of the invention as set forth in the following claims.

WHAT IS CLAIMED IS:

1. A gas-fired burner unit for providing combustion and infrared radiation, the gas-fired burner comprising:

at least one plenum for receiving at least the gas; and

at least one perforated metal plate mounted for receiving at least the gas from the plenum and supplying at least the gas to the combustion so that the combustion is proximate the perforated metal plate.

2. The gas-fired burner unit according to claim 1, wherein flames of the combustion at least generally project from perforations of the perforated metal plate.

3. The gas-fired burner unit according to claim 1, wherein perforations of said perforated metal plate have a width in a range of 0.025 inches to 0.062 inches.

4. The gas-fired burner unit according to claim 1, wherein perforations of said perforated metal plate have a width in a range of about 0.025 inches to about 0.062 inches.

5. The gas-fired burner unit according to claim 1, wherein perforations of said perforated metal plate have a width in a range of about 0.030 inches to about 0.060 inches.

6. The gas-fired burner unit according to claim 1, wherein said perforated metal plate has a thickness within a range of about 0.0156 inches to about 0.0625 inches

7. The gas-fired burner unit according to claim 1, wherein perforations of said perforated metal plate are placed on straight centers within a range of about 0.040 inches to about 0.080 inches.

8. The gas-fired burner unit according to claim 1, wherein said perforated metal plate comprises high temperature stainless steel.

9. The gas-fired burner unit according to claim 1, further comprising means for providing at least the gas to the plenum.

10. The gas-fired burner unit according to claim 1 in combination with other components of a cooking apparatus for cooking food, the combination comprising:

at least one support for supporting the food being cooked, and

at least one infrared energy emitter positioned between said burner unit and said support, for absorbing at least some of the infrared radiation emitted from said burner unit and at least emitting infrared radiation toward said support.

11. The gas-fired burner unit according to claim 1, wherein:

perforations of said perforated metal plate are for at least partially defining a flow path for providing at least the gas to the combustion, and

said perforations are arranged in a predetermined manner so that there is a lesser concentration of said perforations proximate the burner unit's center than there is outwardly from the burner unit's center.

12. The gas-fired burner unit according to claim 1, wherein said perforated metal plate is less than about 0.125 inches thick.

13. The gas-fired burner unit according to claim 12, wherein perforations of said perforated metal plate have a width in a range of about 0.025 inches to about 0.062 inches.

14. The gas-fired burner unit according to claim 1 in combination with at least one infrared energy emitter, wherein the infrared energy emitter is mounted proximate said perforated metal plate for absorbing at least some of the infrared radiation emitted from said perforated metal plate.

15. The combination according to claim 14, wherein said gas-fired burner unit is operative for nonuniformly heating said infrared energy emitter so that energy is substantially uniformly emitted over said infrared energy emitter.

16. The gas-fired burner unit according to claim 1, further comprising at least one second plate, wherein:

said second plate has at least one hole that extends therethrough,

said perforated metal plate is adjacent to the hole,

perforations of said perforated metal plate have smaller widths than said hole of said second plate, and

said hole of said second plate is at least generally aligned with, and in fluid communication with, multiple of said perforations of said perforated metal plate.

17. The gas-fired burner unit according to claim 16, wherein said second plate and said perforated metal plate are in opposing face-to-face contact with one another.

18. An apparatus for at least partially defining a flow path in a gas-fired burner unit that generates combustion and infrared radiation, the apparatus comprising:

at least one first metal plate having a plurality of holes that extend therethrough; and

one or more second metal plates adjacent said first metal plate and having a multiplicity of holes that extend therethrough, wherein

holes of said multiplicity of holes have smaller widths than holes of said plurality of holes, and

groups of holes of said multiplicity of holes are respectively aligned with, and respectively in communication with, said holes of said plurality of holes.

19. The apparatus according to claim 18, wherein at least some of said holes of said plurality of holes are elongate.

20. The apparatus according to claim 18, wherein said holes of said multiplicity of holes were formed by punching.

21. The apparatus according to claim 18, wherein said multiplicity of holes comprises a multiplicity of perforations.

22. The apparatus according to claim 18, wherein said holes of said plurality of holes each have a width in a range of about 0.025 inches to about 0.062 inches.

23. The apparatus according to claim 18, wherein said first metal plate is in opposing face-to-face contact with said one or more second metal plates.

24. The apparatus according to claim 18, wherein the apparatus is a burner assembly so that said holes of said multiplicity of holes are for having the combustion proximate thereto at a downstream side of said burner assembly.

25. The burner assembly according to claim 24, in combination with other components of a burner unit, the combination comprising:

at least one plenum for receiving at least the gas, wherein the burner assembly is mounted for at least partially obstructing an opening of the plenum.

26. The combination according to claim 25, further in combination with other components of a cooking apparatus for cooking food, the combination comprising:

at least one support for supporting the food being cooked, wherein said support is proximate said burner assembly for at least indirectly receiving some infrared radiation emitted from said burner assembly.

27. The combination according to claim 26, further comprising at least one infrared energy emitter positioned between said burner assembly and said support, for absorbing at least some of the infrared radiation emitted from said burner assembly and at least emitting infrared radiation toward said support.

28. A gas-fired burner unit for providing combustion and infrared radiation, the gas-fired burner comprising:

at least one plenum;

at least one venturi mounted for providing the gas and air to the plenum; and

at least one burner assembly mounted for receiving the gas and the air from the plenum and providing the gas and air to the combustion so that the combustion is proximate the burner assembly, wherein the burner unit is operative so that at least substantially all of the air required for completing the combustion is provided via said venturi while the burner unit's firing rate exceeds about 350 BTUH/in^2 of the burner unit's emitting surface.

29. A gas-fired burner unit according to claim 28, wherein the combustion is in substantially close proximity to the burner assembly.

30. A gas-fired burner unit according to claim 28, wherein 100% of the air required for completing the combustion is provided via said venturi while the burner unit's firing rate exceeds about 350 BTUH/in^2 of the burner unit's emitting surface.

31. A gas-fired burner unit according to claim 28, wherein at least substantially all of the air required for completing the combustion is provided via said venturi while the burner unit's firing rate exceeds about 400 BTUH/in^2 of the burner unit's emitting surface.

32. A gas-fired burner unit according to claim 28, wherein at least substantially all of the air required for completing the combustion is provided via said venturi while the burner unit's firing rate exceeds about 500 BTUH/in^2 of the burner unit's emitting surface.

33. The gas-fired burner unit according to claim 28, in combination with at least one infrared energy emitter, wherein said infrared energy emitter is adjacent said gas-fired burner unit for absorbing at least some of the infrared radiation emitted from said gas-fired burner unit.

34. A gas-fired burner unit according to claim 33, wherein said infrared energy emitter is within about an inch from said gas-fired burner unit.

35. An apparatus for providing at least infrared radiant energy, comprising:

at least one emitter; and

at least one gas-fired burner unit operative for nonuniformly heating said emitter so that the infrared radiant energy over said emitter is substantially equally distributed.

36. The apparatus according to claim 35, wherein the infrared radiant energy over said emitter is substantially equally distributed over at least about a square foot.

37. The apparatus according to claim 35, wherein:

said gas-fired burner unit includes at least one burner assembly in opposing face-to-face configuration with respect to said emitter,

said burner assembly includes a multiplicity of holes for providing at least the gas to combustion that occurs in a gap between said burner assembly and said emitter, and

the multiplicity of holes are arranged in a predetermined manner so that there is a lesser concentration of said holes proximate the burner assembly's center than there is outwardly from the burner assembly's center.

38. The apparatus according to claim 35, further comprising at least one support for supporting food, wherein:

said emitter includes opposite first and second sides,

said burner assembly in opposing face-to-face configuration with said first side of said emitter, and

said support is in opposing face-to-face configuration with said second side of said emitter.

39. A partition for at least partially defining a flow path in a gas-fired burner unit that generates combustion and infrared radiation, the partition comprising:

a multiplicity of holes extending through said partition for at least partially defining a flow path for providing at least the gas to the combustion, wherein the multiplicity of holes are arranged in a predetermined manner so that there is a lesser concentration of said holes proximate the partition's center than there is outwardly from the partition's center.

40. The partition according to claim 39, wherein there are less of said holes per unit area in a central portion of the partition than there are in an intermediate portion of the partition, with said intermediate portion of said partition being between said central portion of the partition and a marginal portion of the partition.

41. The partition according to claim 40, wherein one or more edges of said partition extends around said marginal portion, said marginal portion extends around said intermediate portion, and said intermediate portion extends around said central portion.

42. The partition according to claim 39, wherein said holes extending through said partition, for at least partially defining the flow path, do not occupy more than about 60% of the partition in a plan view of the partition.

43. The partition according to claim 39, wherein the partition is a baffle so that said holes are for

(a) receiving at least the gas at an upstream side of said baffle, and

(b) discharging at least the gas at a downstream side of said baffle.

44. The partition according to claim 39, wherein the partition is a burner assembly so that said holes are for

(a) receiving at least the gas at an upstream side of said burner assembly, and

(b) having the combustion proximate thereto at a downstream side of said burner assembly.

45. The partition according to claim 44, wherein energy is substantially uniformly emitted over said downstream side of said burner.

46. The burner assembly according to claim 44 in combination with other components of the burner unit, the combination comprising:

at least one plenum for receiving at least the gas, wherein the burner assembly is mounted for at least partially obstructing an outlet opening of the plenum.

47. The combination according to claim 46, further in combination with other components of a cooking apparatus for cooking food, the combination comprising:

at least one support for supporting the food being cooked, wherein said support is adjacent said burner assembly for at least indirectly receiving some infrared radiation emitted from said burner assembly.

48. The combination according to claim 47, further comprising at least one infrared energy emitter positioned between said burner assembly and said support, for absorbing at least some of the infrared radiation emitted from said burner assembly and at least emitting infrared radiation toward said support.

49. A gas-fired burner unit for providing combustion and infrared radiation, the gas-fired burner comprising:

at least one plenum for receiving at least the gas;

at least a plurality of perforated plates mounted in series for at least partially obstructing an opening of the plenum and at least partially defining a flow path for providing at least the gas from the plenum to the combustion, wherein

each perforated plate of said plurality of perforated plates is nonwoven and metallic,

said plurality of perforated plates includes one or more upstream perforated plates and one or more downstream perforated plates that are positioned downstream from said one or more upstream perforated plates in said flow path,

downstream ends of perforations of said one or more downstream perforated plates are for having the combustion proximate thereto, whereby at least said one or more downstream perforated plates are for emitting at least some of the infrared radiation,

a plurality of chambers are positioned between said one or more upstream perforated plates and said one or more downstream perforated plates,

upstream ends of perforations of said one or more downstream perforated plates are respectively open to said chambers, and

downstream ends of perforations of said one or more upstream perforated plates are respectively open to said chambers.

50. The gas-fired burner unit according to claim 49, wherein chambers of said plurality of chambers are at least substantially discrete with respect to one another.

51. A gas-fired burner unit for providing combustion and infrared radiation, the gas-fired burner comprising:

at least one plenum for receiving at least the gas;

at least a plurality of perforated plates mounted in series for at least partially obstructing an opening of the plenum and at least partially defining a flow path for providing at least the gas from the plenum to the combustion, wherein

each perforated plate of said plurality of perforated plates is nonwoven and metallic,

said plurality of perforated plates includes one or more upstream perforated plates and one or more downstream perforated plates that are positioned downstream from said one or more upstream perforated plates in said flow path,

downstream ends of perforations of said one or more downstream perforated plates are for having the combustion proximate thereto, whereby at least said one or more downstream perforated plates are for emitting at least some of the infrared radiation,

a plurality chambers are positioned between said one or more upstream perforated plates and said one or more downstream perforated plates,

upstream ends of perforations of said one or more downstream perforated plates are respectively open to said chambers, and

downstream ends of perforations of said one or more upstream perforated plates are respectively open to said chambers.

52. The gas-fired burner unit according to claim 51, wherein said one or more upstream perforated plates are spaced apart from said one or more downstream perforated plates by at least about 0.25 inches.

53. The gas-fired burner unit according to claim 51, wherein said one or more upstream perforated plates are less than about 0.125 inches thick.

54. The gas-fired burner unit according to claim 51, further comprising a plurality of mounting members, wherein:

each said mounting member has a plurality of holes that extend therethrough,

said one or more upstream perforated plates are sandwiched between said mounting members, said perforations of said one or more upstream perforated plates have smaller widths than said holes of said plurality of holes,

said holes of said plurality of holes of a first of said mounting members are respectively at least generally aligned with, and in fluid communication with, said holes of said plurality of holes of a second of said mounting members, and

groups of said perforations of said one or more upstream perforated plates are respectively between, and in communication with, said holes of said plurality of holes of said first and second mounting members.

55. The gas-fired burner unit according to claim 51, wherein downstream surfaces of said one or more upstream perforated plates are in opposing face-to-face relation with upstream surfaces of said one or more downstream perforated plates, so that said downstream surfaces and said upstream surfaces respectively cooperate to at least partially define said chambers.

56. The gas-fired burner unit according to claim 51, wherein chambers of said plurality of chambers are at least substantially discrete with respect to one another.

57. The gas-fired burner unit according to claim 51, further comprising one or more spacers positioned between said one or more upstream perforated plates and said one or more downstream perforated plates, said one or more spacers having a plurality of circumferential walls that respectively extend at least partially around, and thereby at least partially define, said chambers.

58. The gas-fired burner unit according to claim 57, wherein said one or more spacers includes at least one metallic, nonwoven plate having a plurality of holes that extend therethrough and respectively correspond, at least partially, to said chambers.

59. The gas-fired burner unit according to claim 57, wherein:

at least one upstream surface of said one or more spacers is in opposing face-to-face contact with at least one downstream surface of said one or more upstream perforated plates, and at least one downstream surface of said one or more spacers is in opposing face-to-face contact with at least one upstream surface of said one or more downstream perforated plates.

60. The gas-fired burner unit according to claim 51 in combination with other components of a cooking apparatus for cooking food, the combination comprising:

at least one support for supporting the food being cooked, wherein said support is proximate said one or more downstream perforated plates for at least indirectly receiving some of the infrared radiation emitted from said one or more downstream perforated plates.

61. The combination according to claim 60, further comprising at least one infrared energy emitter positioned between said one or more downstream perforated plates and said support, for absorbing at least some of the infrared radiation emitted from said one or more downstream perforated plates and at least emitting infrared radiation toward said support.

62. An apparatus for at least partially defining a flow path in a gas-fired burner unit that generates combustion and infrared radiation, the apparatus comprising:

at least two mounting members, with each said mounting member having a plurality of holes that extend therethrough; and

one or more inner members sandwiched between said mounting members, with said one or more inner members having a multiplicity of holes that extend therethrough, wherein

(1) holes of said multiplicity of holes have smaller widths than holes of said plurality of holes,

(2) said holes of said plurality of holes of a first of said mounting members are respectively at least generally aligned with, and in fluid communication with, said holes of said plurality of holes of a second of said mounting members, and

(3) groups of holes of said multiplicity of holes are respectively between, and in communication with, said holes of said plurality of holes of said first and second mounting members.

63. The apparatus according to claim 62, wherein each of said one or more inner members comprises a metallic nonwoven plate.

64. The apparatus according to claim 62, wherein the apparatus is a baffle so that said holes of said mounting members respectively are for

(a) receiving at least the gas at an upstream side of said baffle, and

(b) discharging at least the gas at a downstream side of said baffle.

65. The apparatus according to claim 62, wherein:

a surface of said first mounting member is in opposing face-to-face contact with a first surface of said one or more inner members,

a surface of said second mounting member is in opposing face-to-face contact with a second surface of said one or more inner members, and

said first surface and said second surface of said one or more inner members are respectively at opposite sides of said one or more inner members.

66. The apparatus according to claim 65, wherein:

each said mounting member comprises a metallic nonwoven plate;

said multiplicity of holes comprises a multiplicity of perforations; and

said one or more inner members comprises one or more metallic, nonwoven plates, and said multiplicity of perforations extend through said one or more metallic, nonwoven plates.

67. The apparatus according to claim 62, wherein said multiplicity of holes comprises a multiplicity of perforations.

68. The apparatus according to claim 67, wherein said one or more inner members comprises one or more metallic, nonwoven plates, and said multiplicity of perforations extend through said one or more metallic, nonwoven plates.

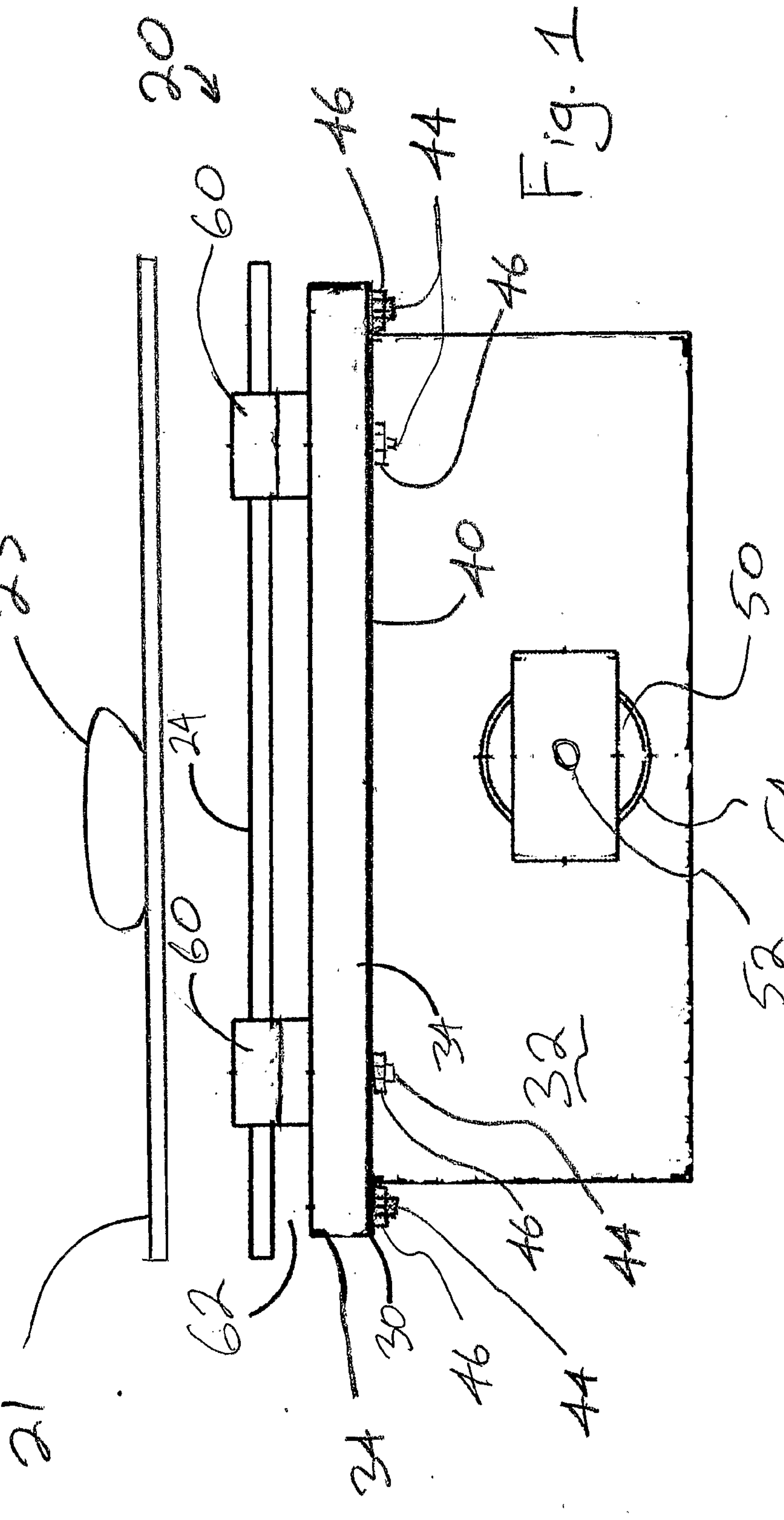

Fig. 1

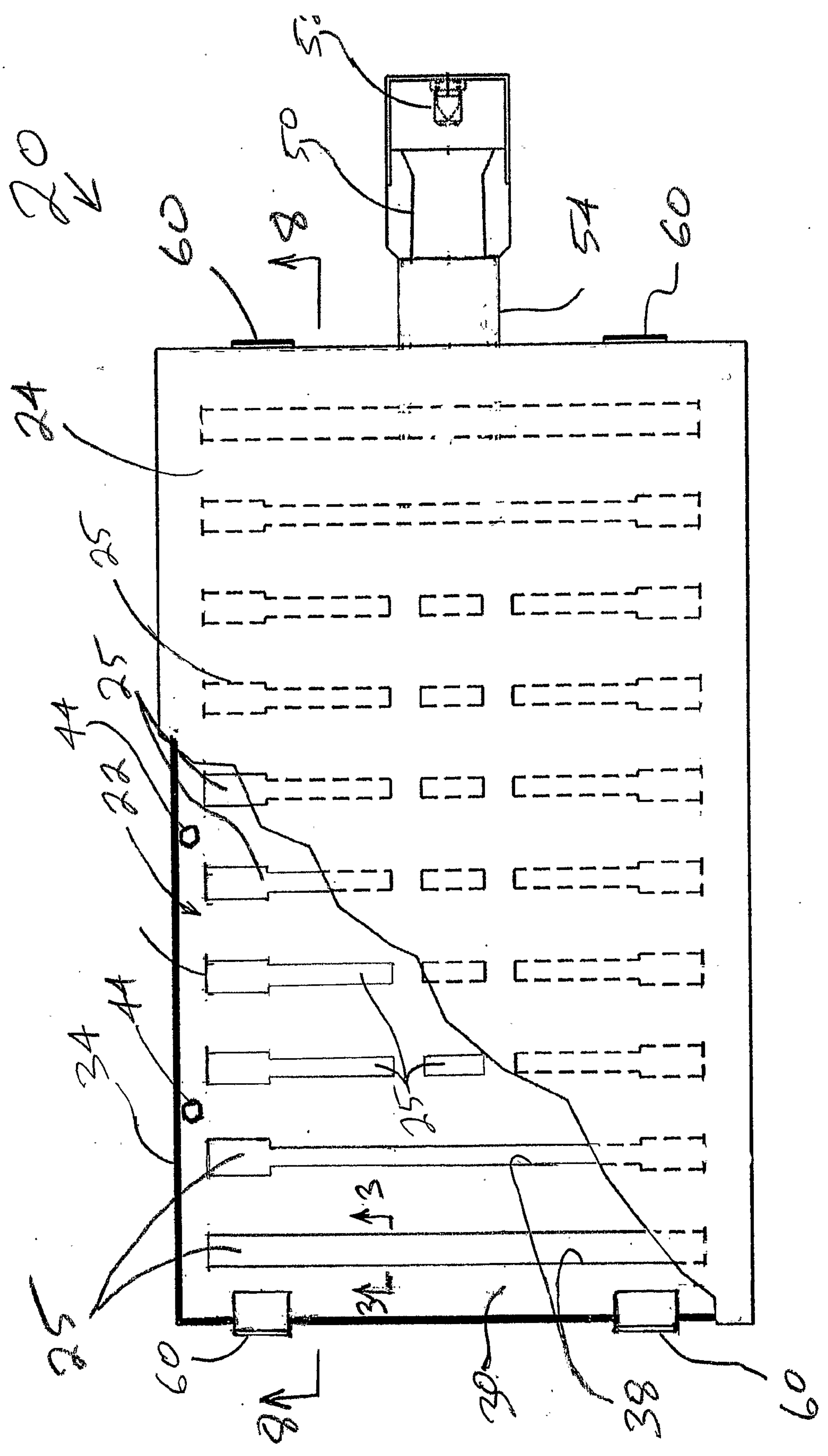

Fig. 2

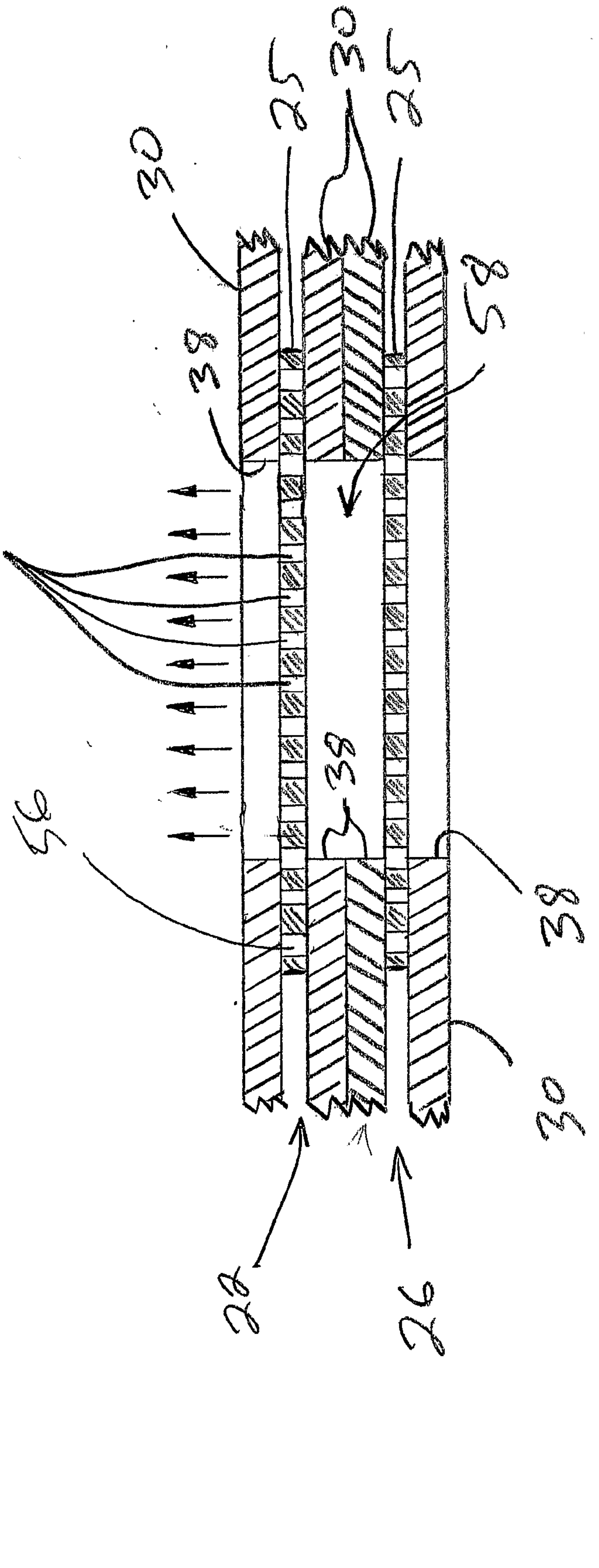

Fig. 3

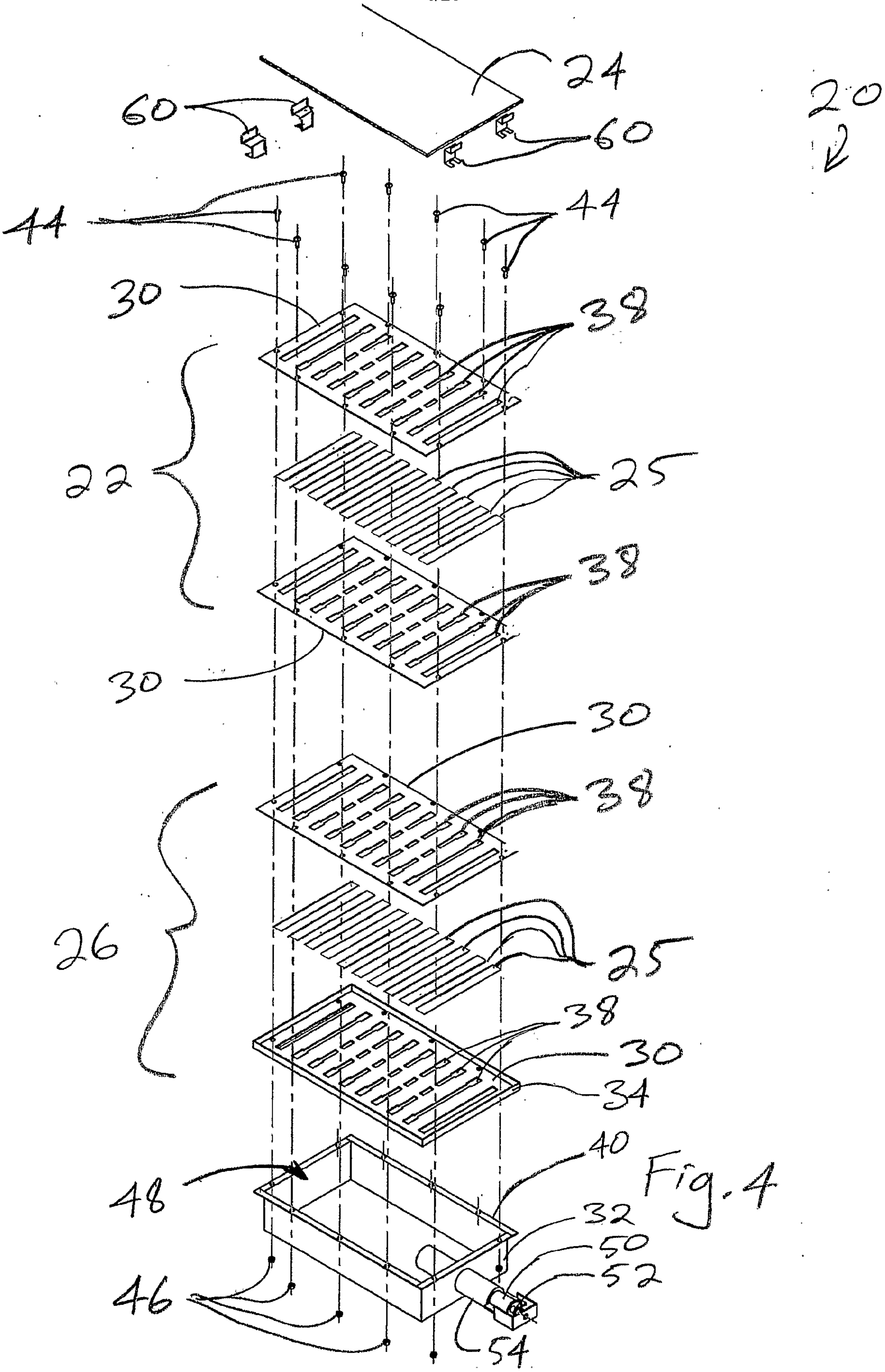
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Fig. 4

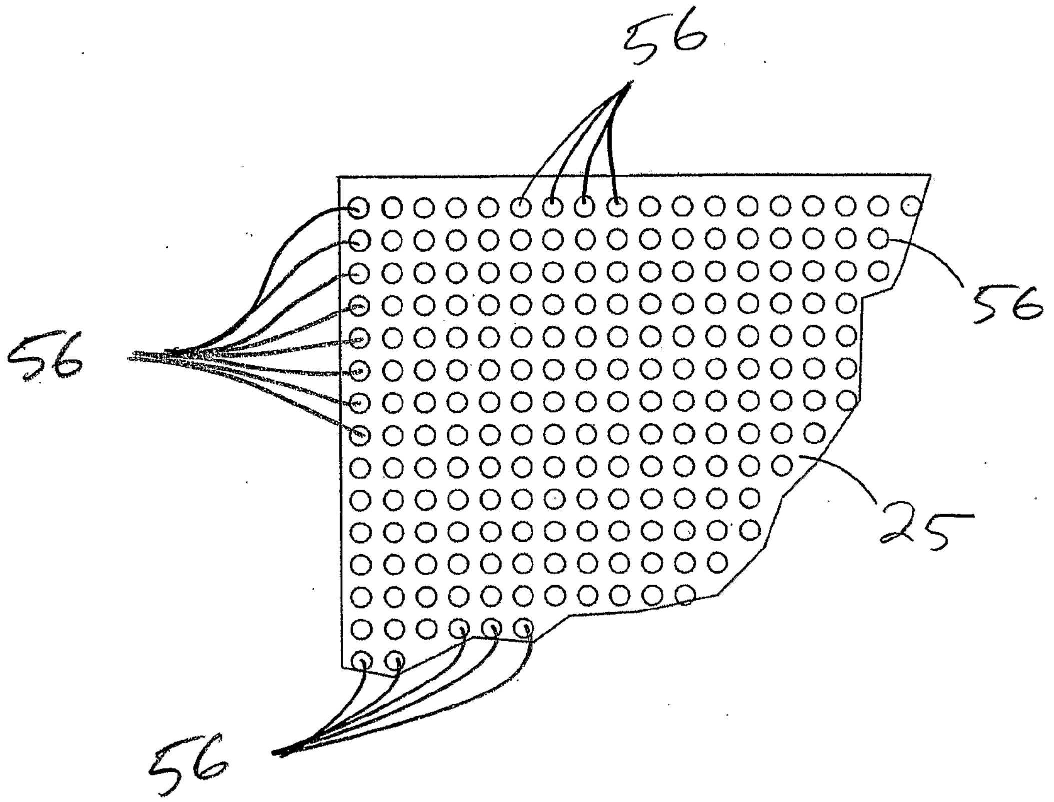

Fig. 5

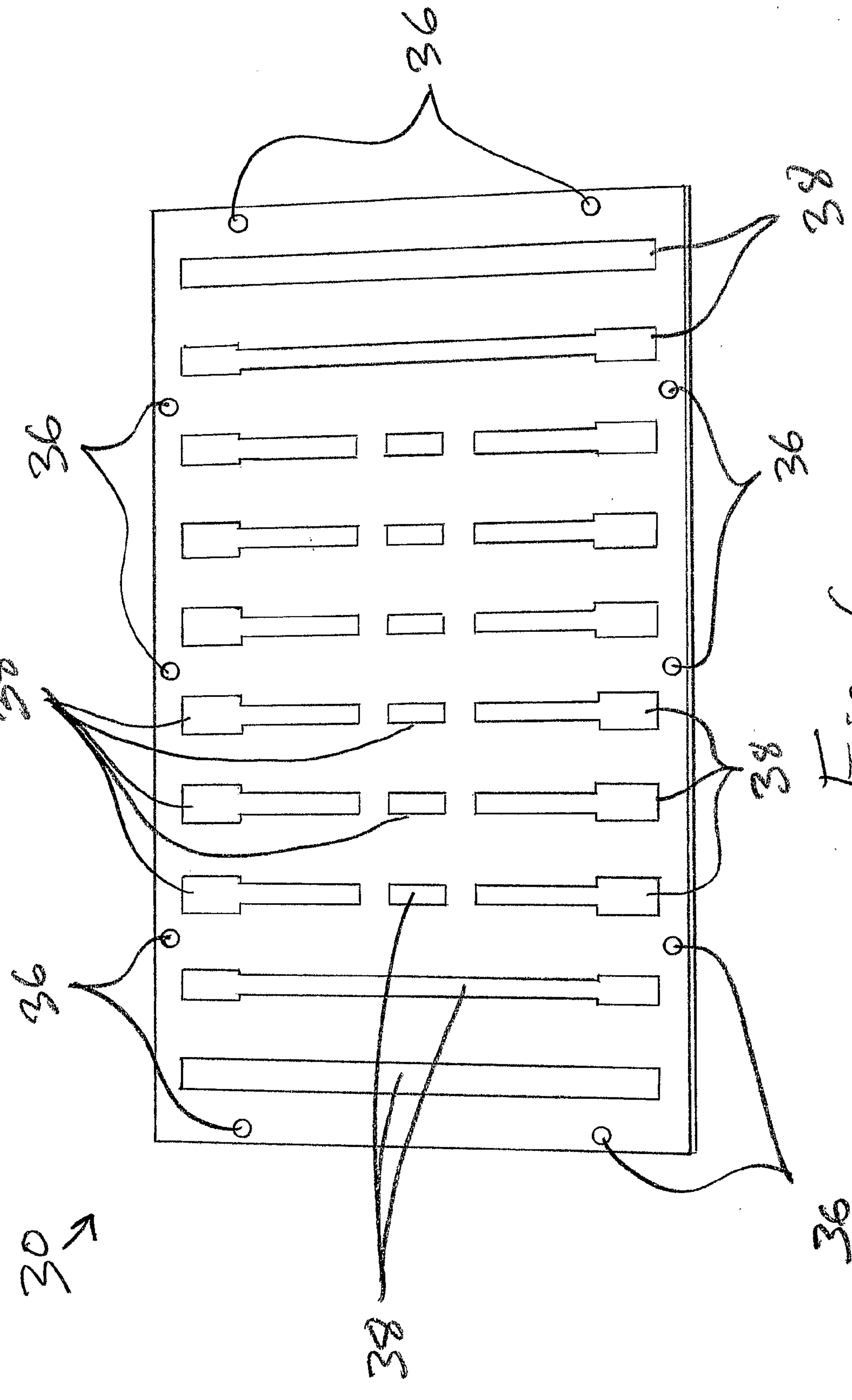

Fig. 6

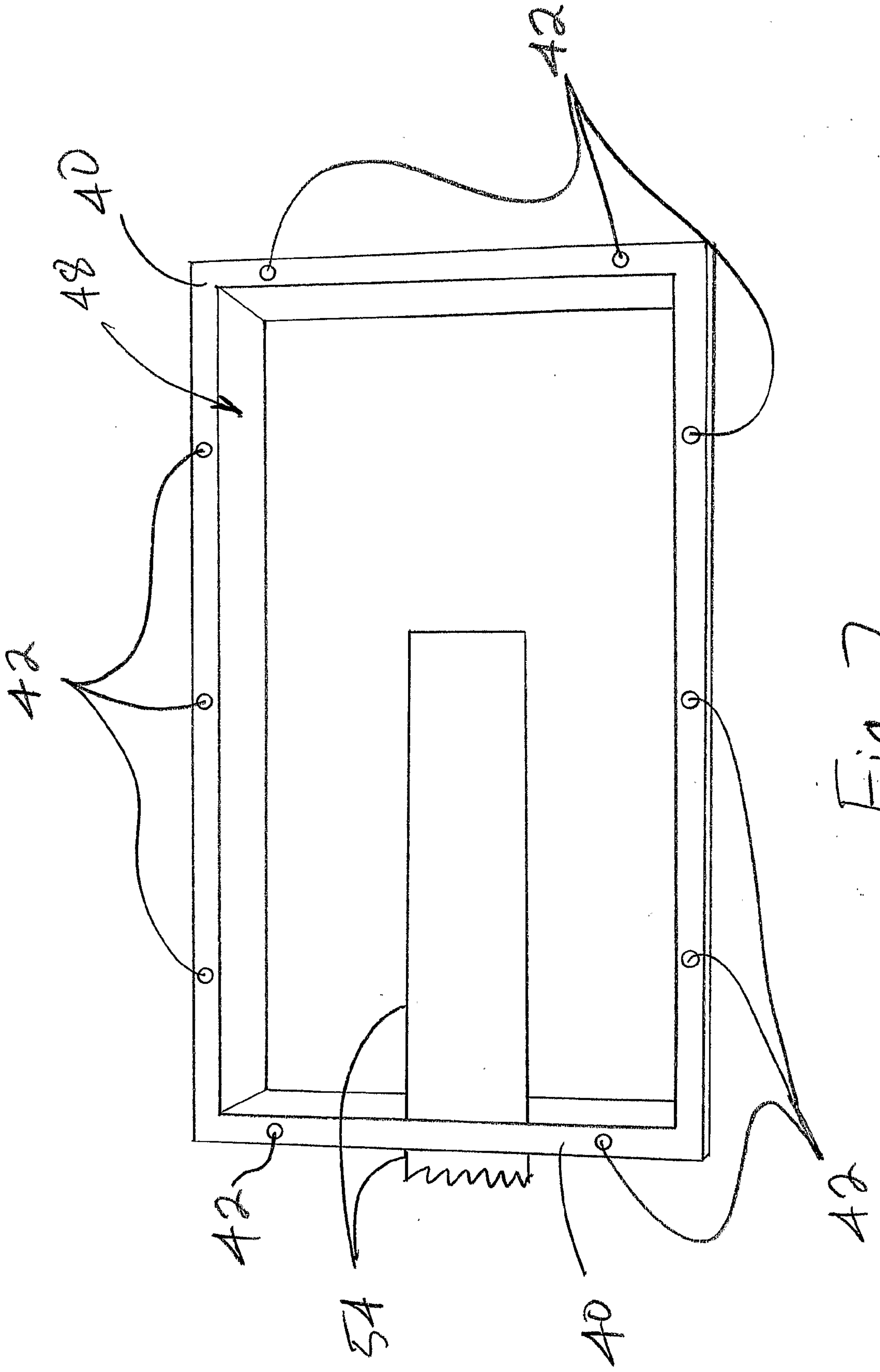

Fig. 7

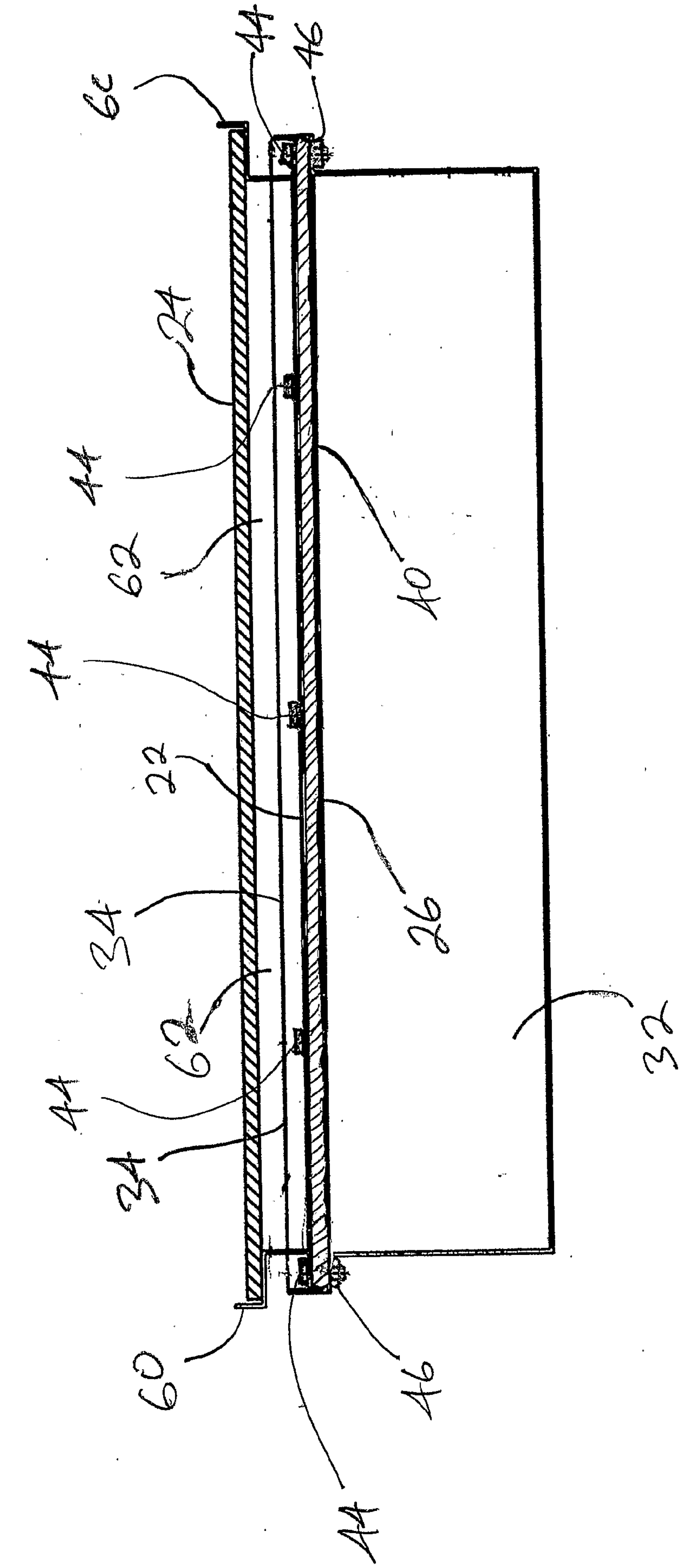

Fig. 8

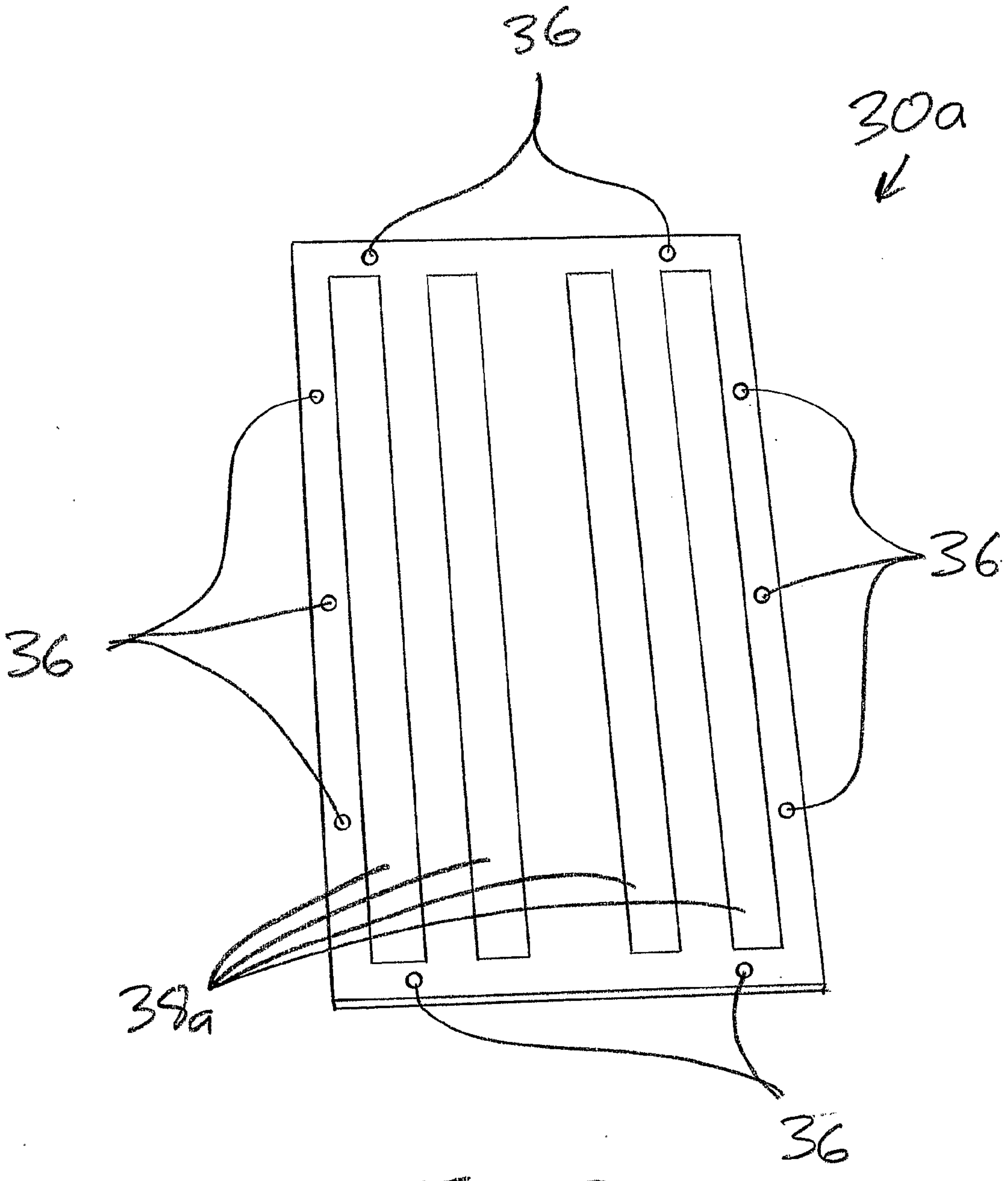

Fig. 9

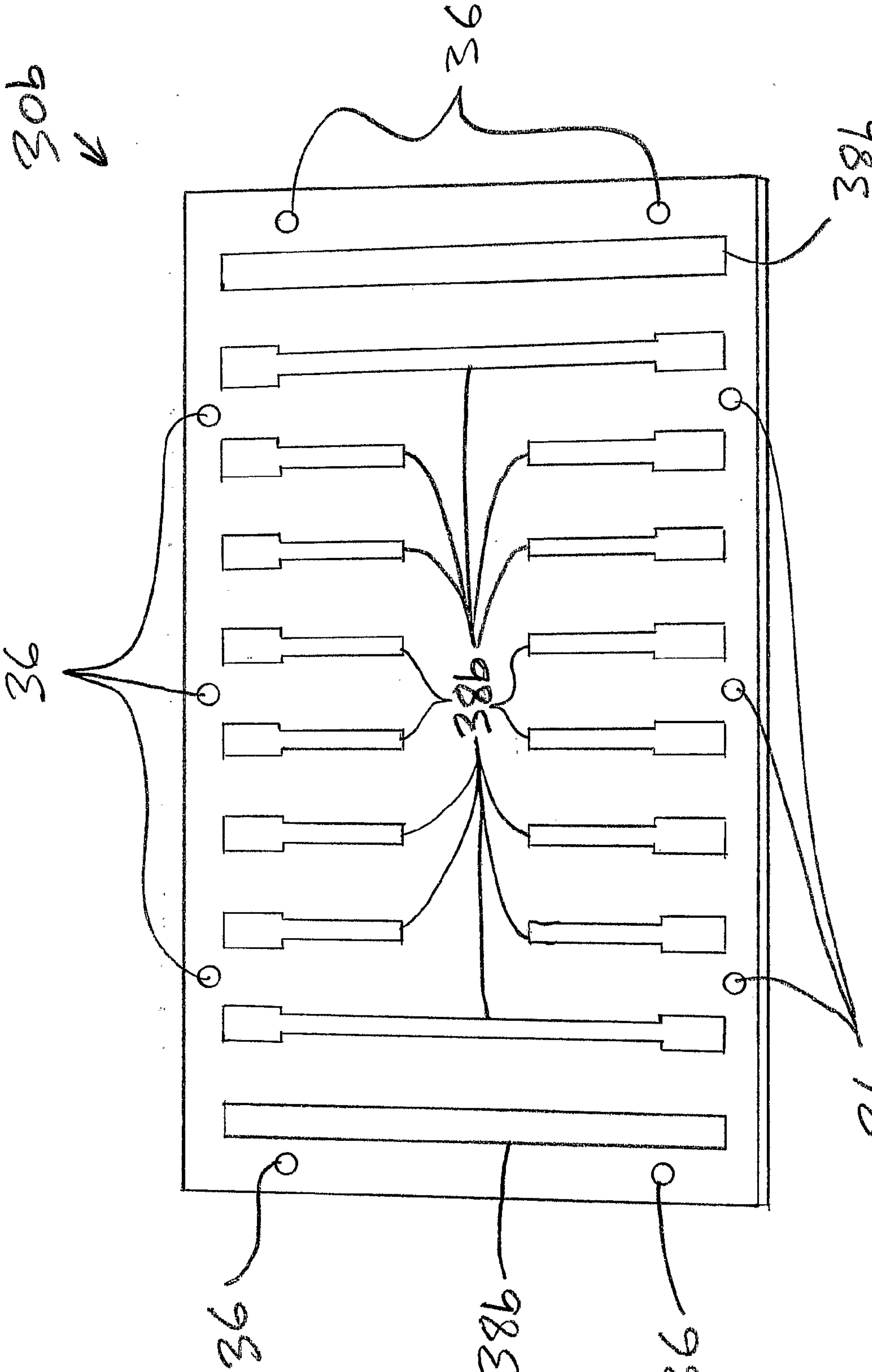

Fig. 10

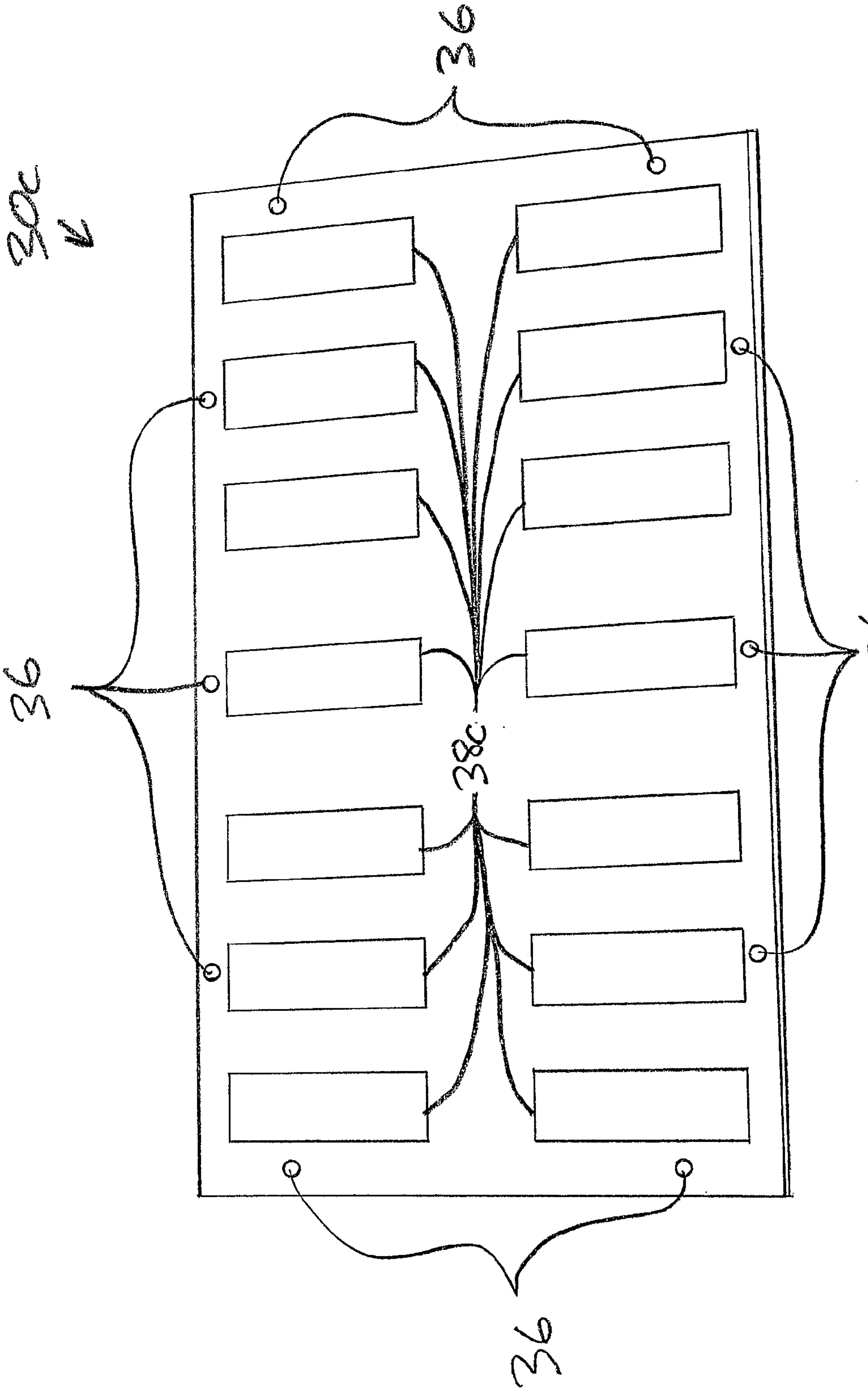

Fig. 11

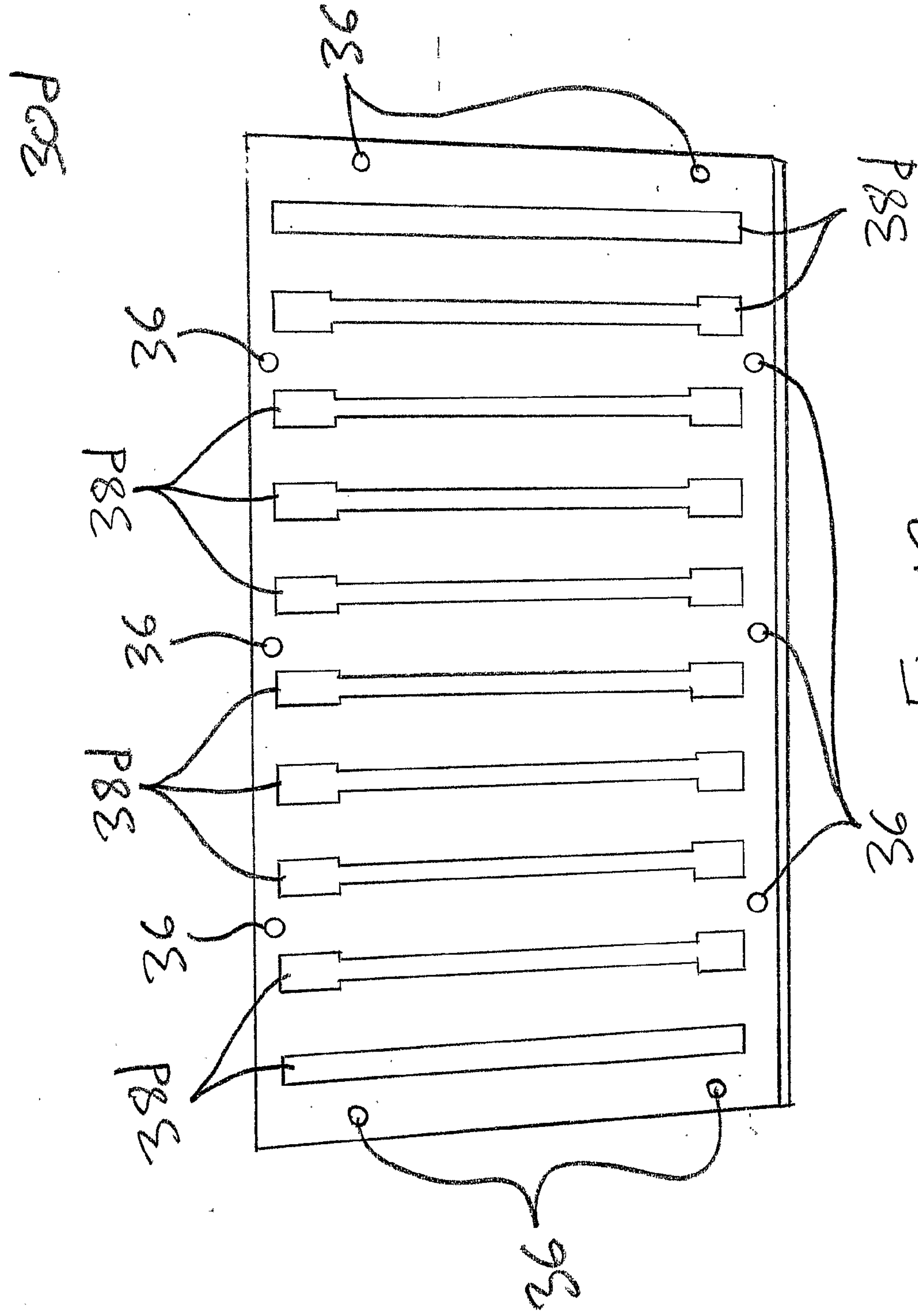

Fig. 12

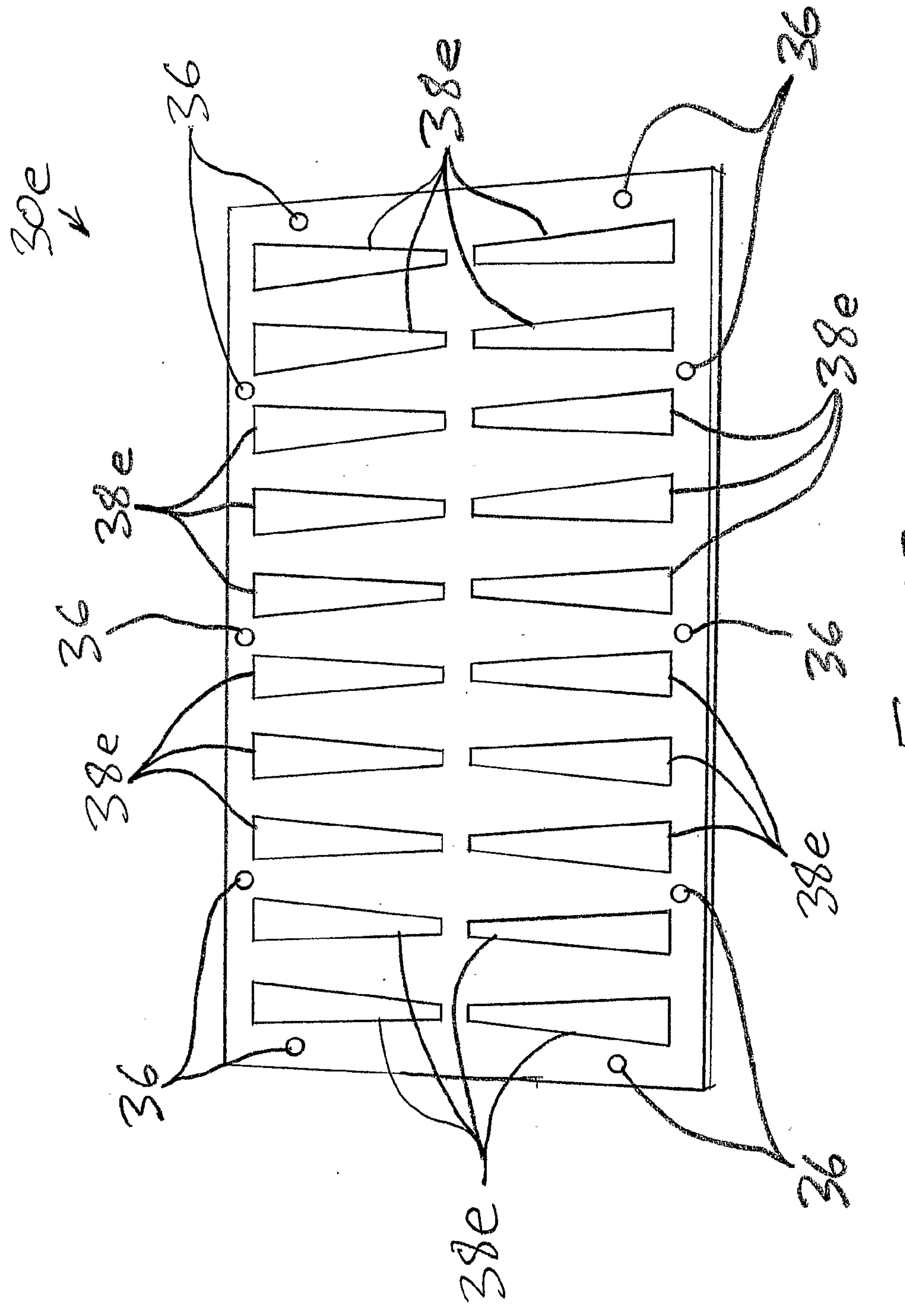

Fig. 13

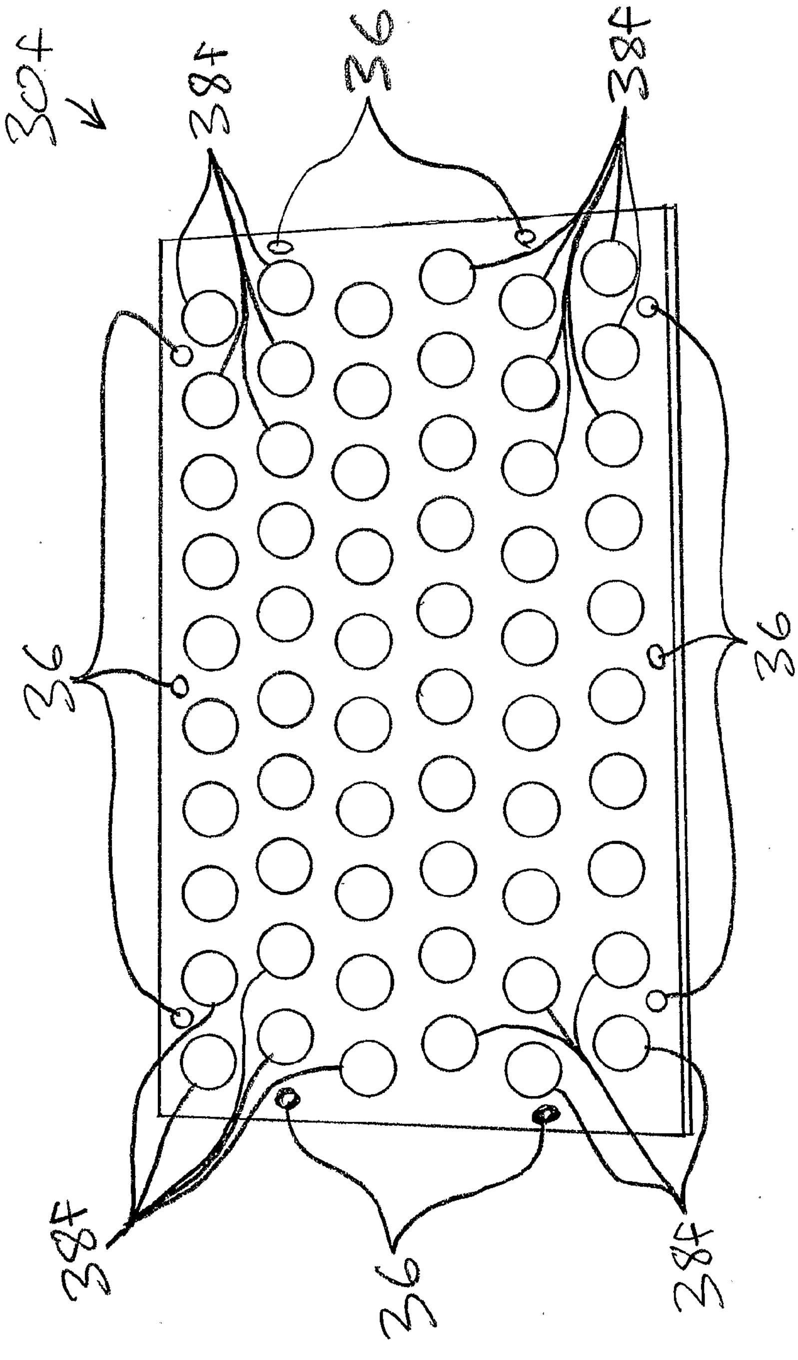

Fig. 14

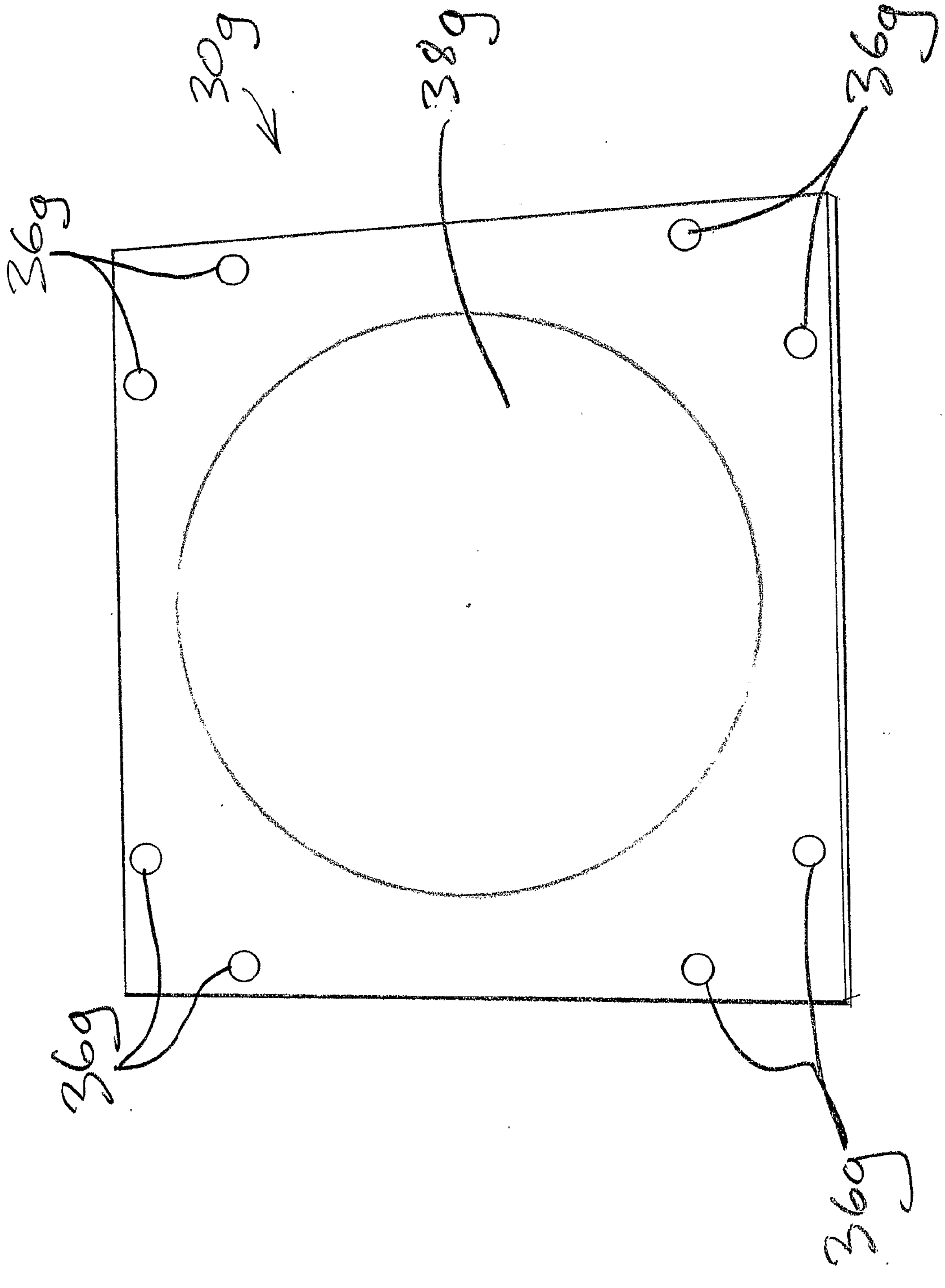

Fig. 15

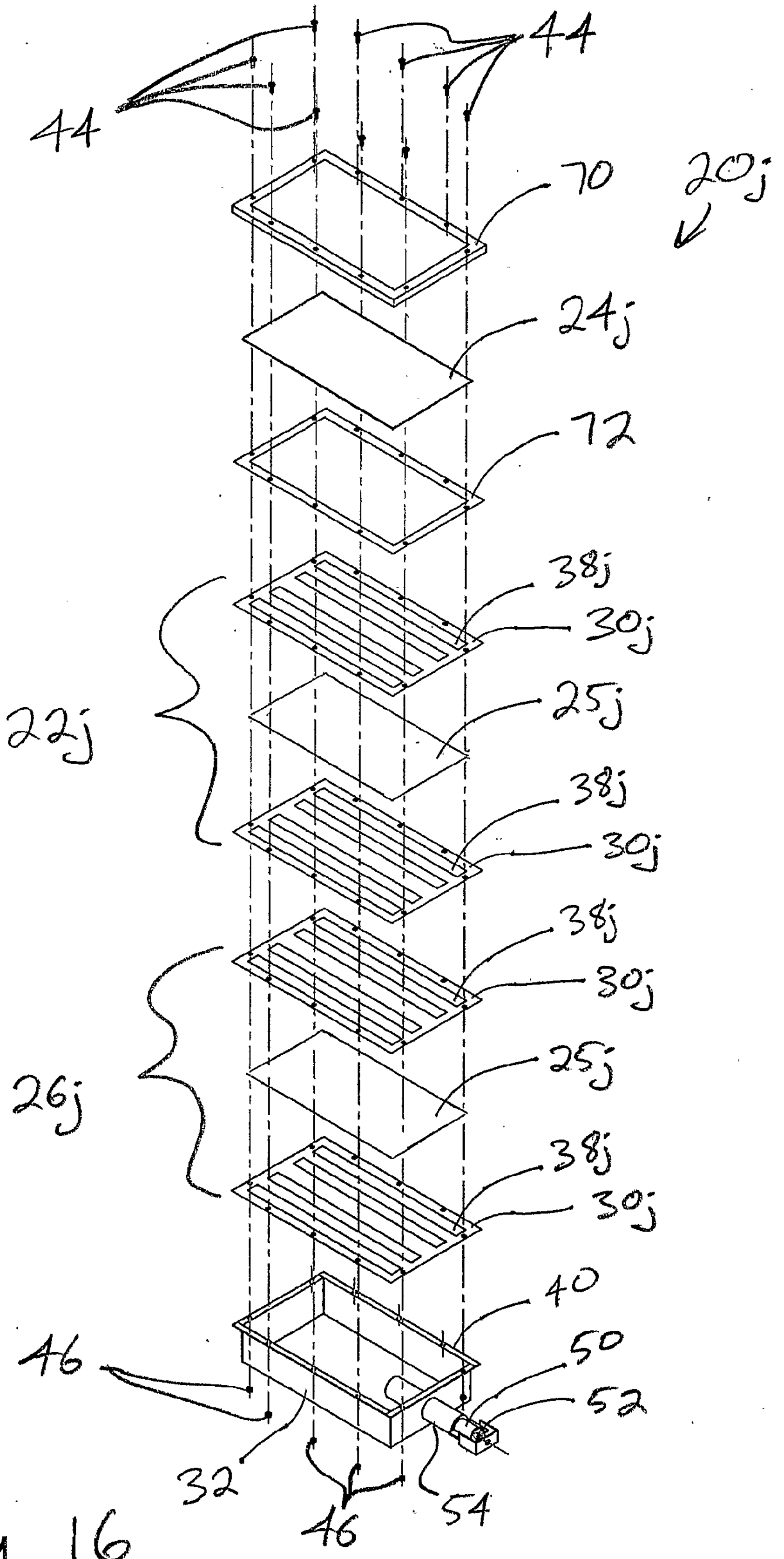
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Fig. 16

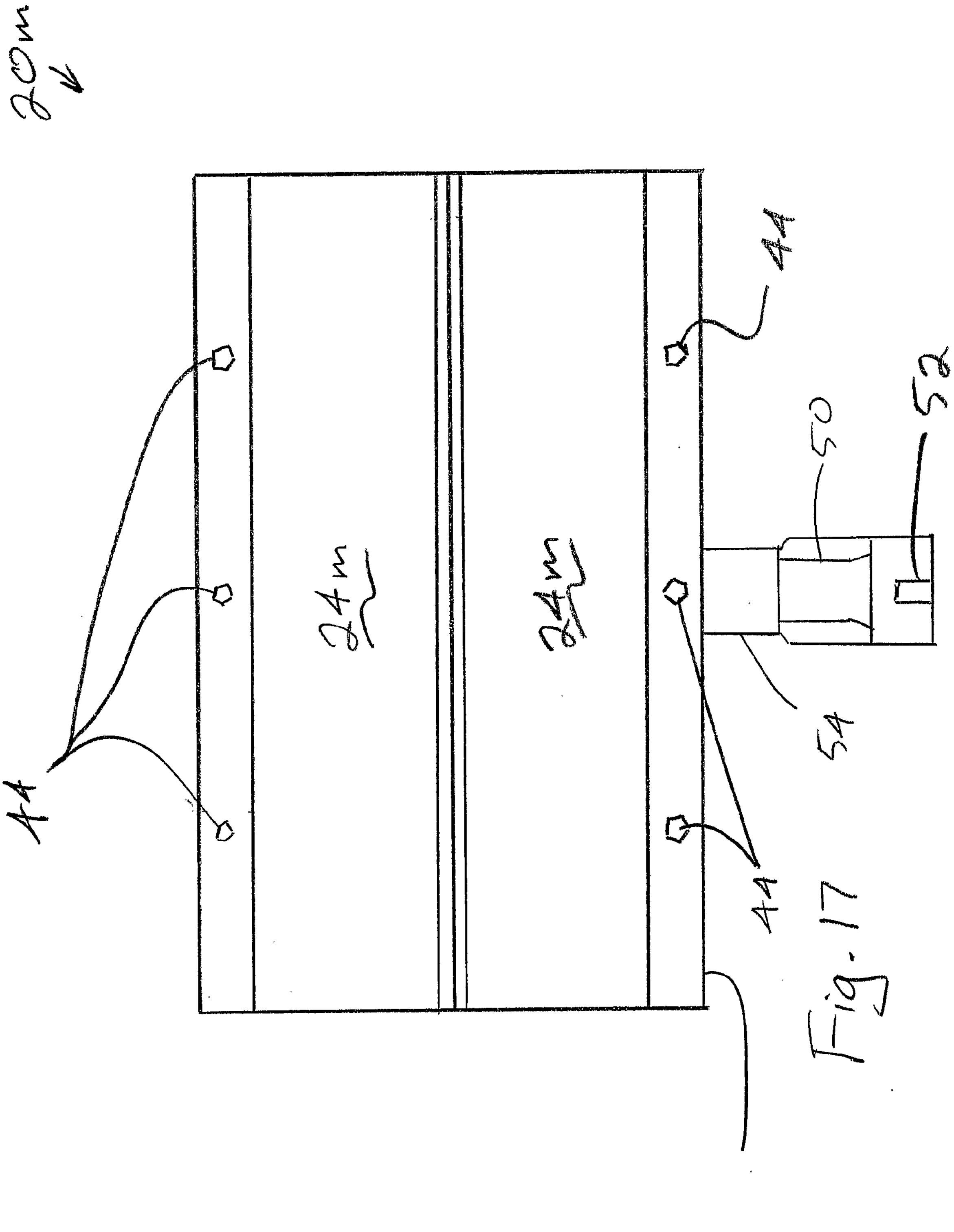

Fig. 17

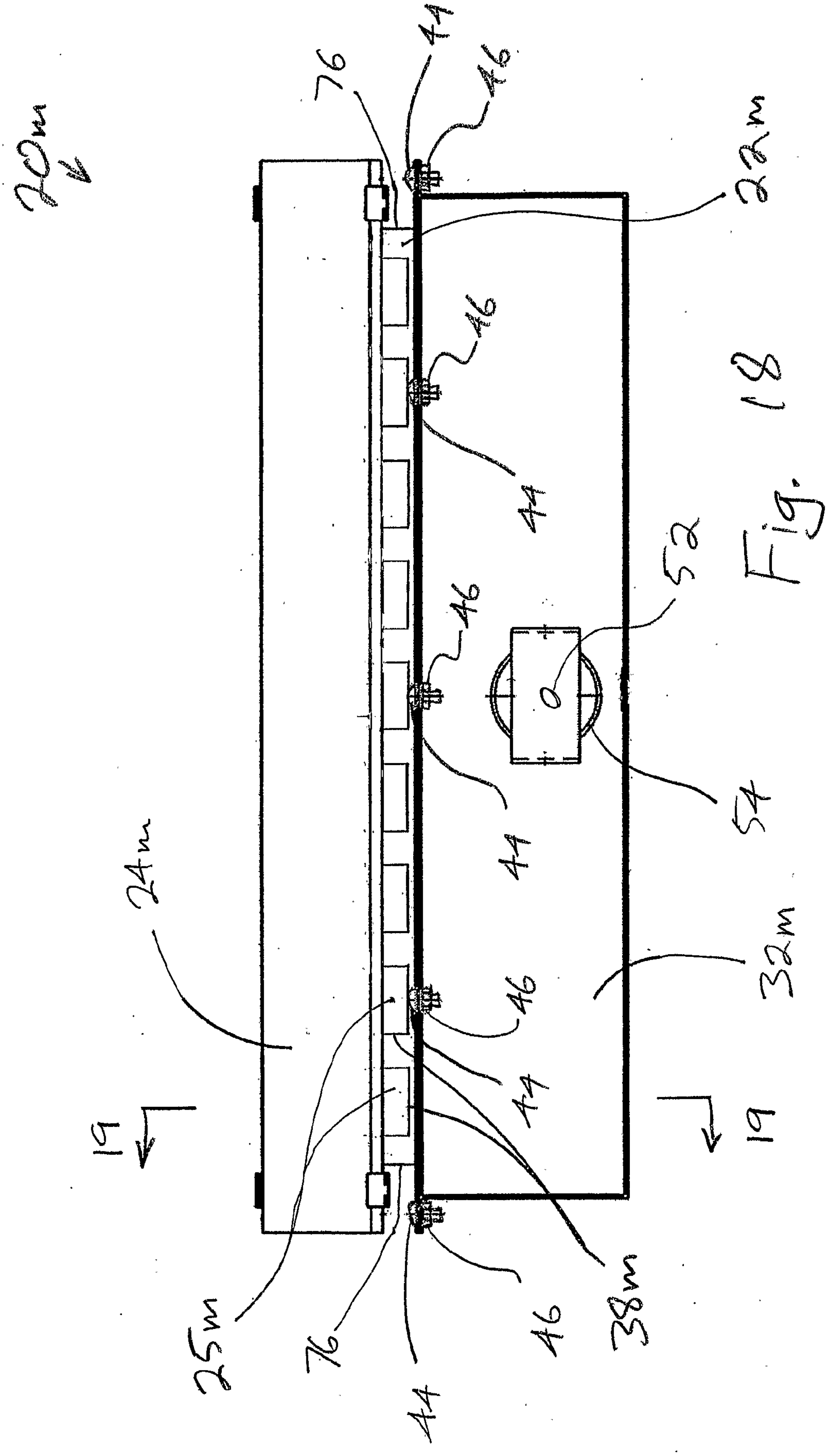
20m
76
44
46
22m
46
44
52
46
44
54
24m
32m
46
44
19
19
25m
76
44
46
38m

Fig. 18

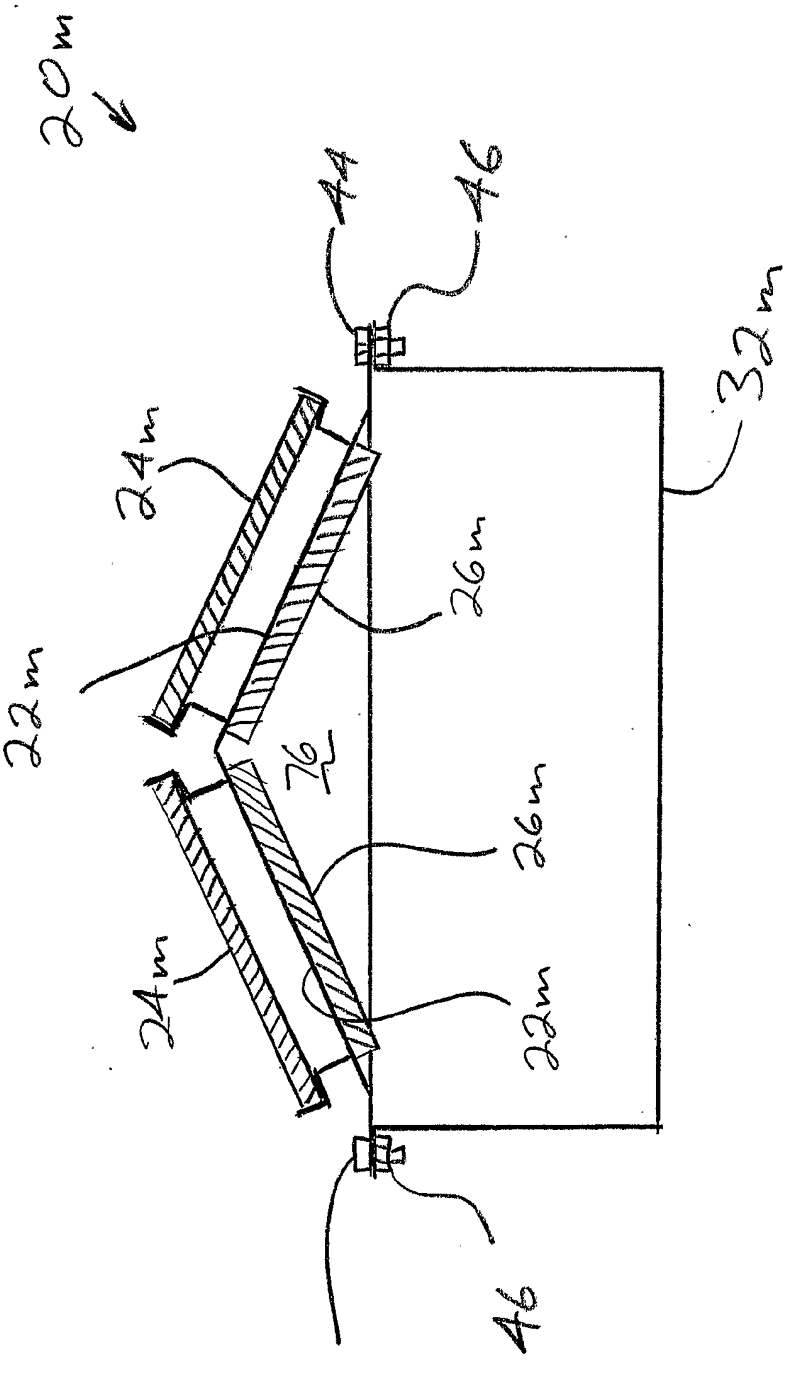

Fig. 19

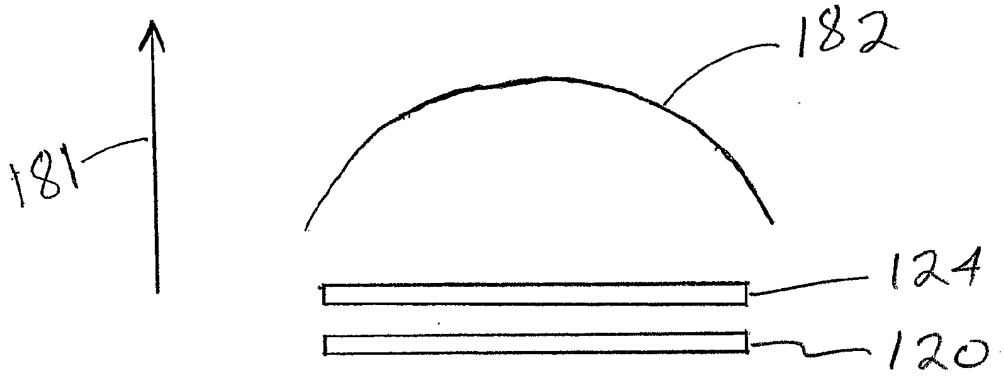

Fig 21

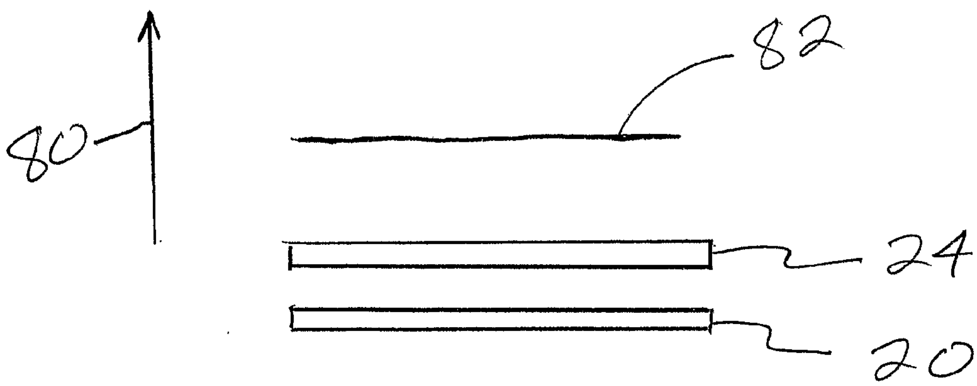

Fig. 20