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B01J 3/04

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B1X X34

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US 4269805 A
WPI. A.A.N: 1997-529987 & JP9251981

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INT CL^7 **B01J** 3/02 3/04
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(54) Abstract Title
Autoclave suitable for heat treating parts

(57) Autoclaves of diverse technical features are disclosed in the specification. All feature an internal or load / loadable space and a heating gas circulation means. No reference numerals are used in this abstract as it is not practical given the number of disclosures and the doubt over which combination of features might actually go to make the final invention claimed. The first disclosure features a side wall through which heating gas can circulate, circulation means for circulating the gas within the autoclave, and return flow of gas out of a side wall in the auto clave. A second disclosure features a door to allow the positioning of a load to be treated within the autoclave, gas heating means and gas which impinges non-axially on the load. A third disclosure comprises chamber, door, heating means and a plurality of gas circulation means spaced along the length of the autoclave, each producing an independently controllable zone of circulation of heating gas. A fourth disclosure comprises the features of the third disclosure, further featuring the gas impinging non-axially onto the load. A fifth disclosure comprises an autoclave with a plurality of heat transfer adjustment means. Sixth and seventh disclosures are methods related to the apparatus of the fourth disclosure. The features of the above autoclaves, may in some combination provide for variable heat treatment of parts such as the panels of aircraft.

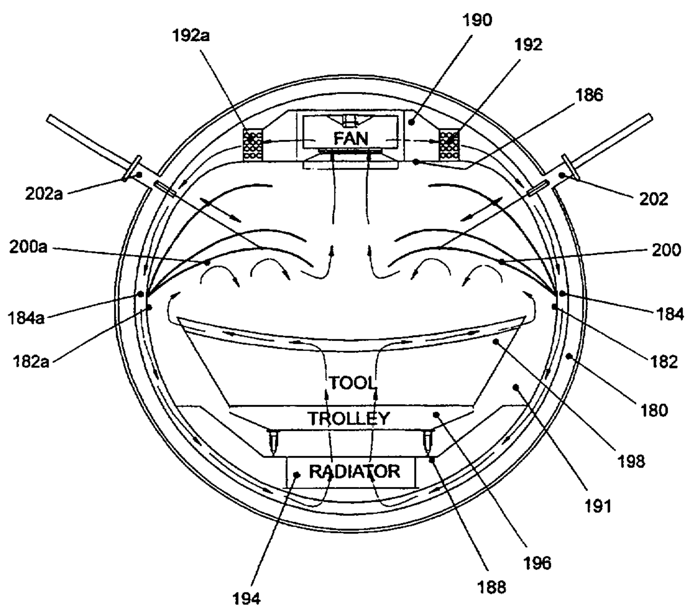

FIGURE 6

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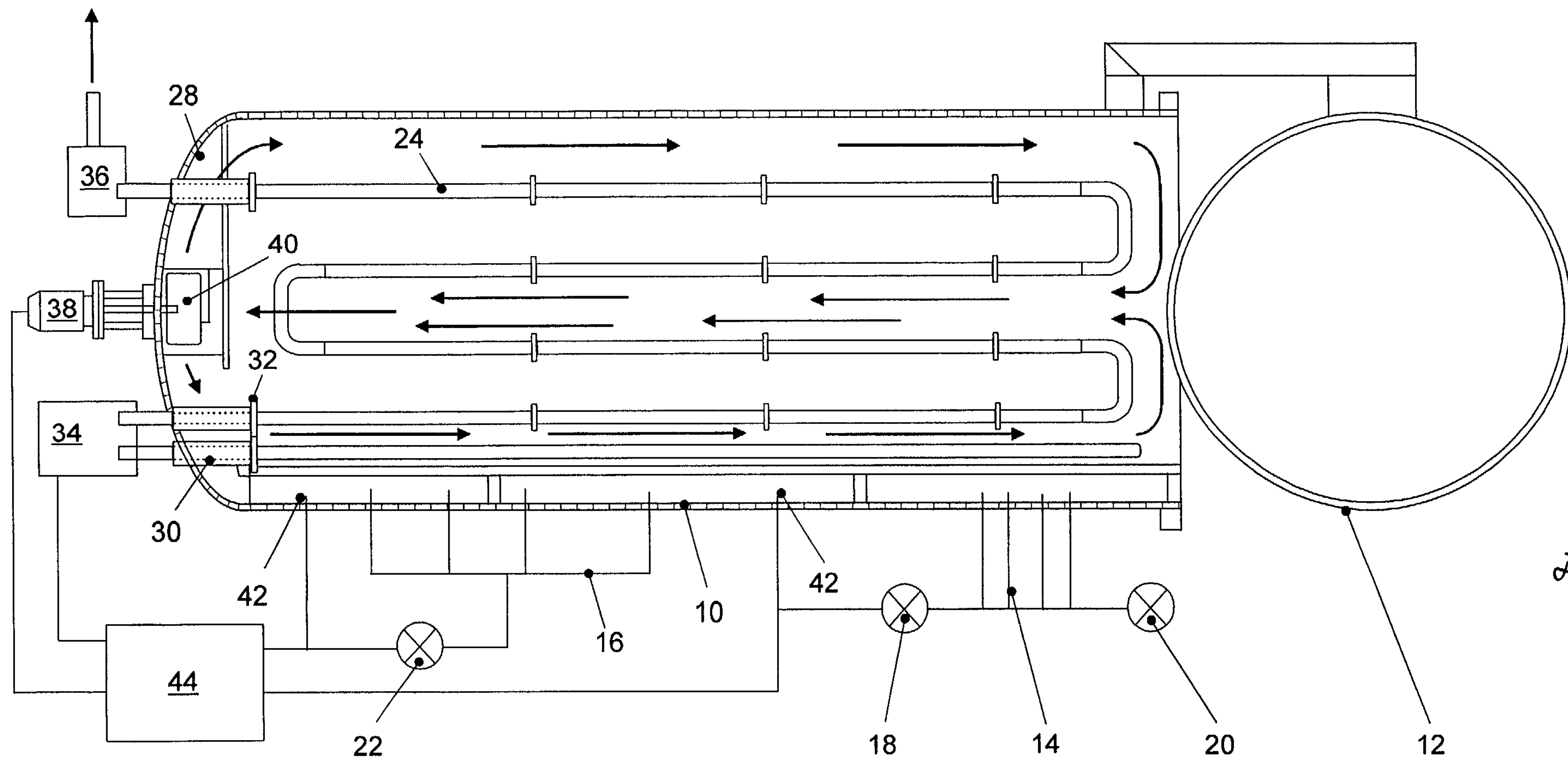

FIGURE 1

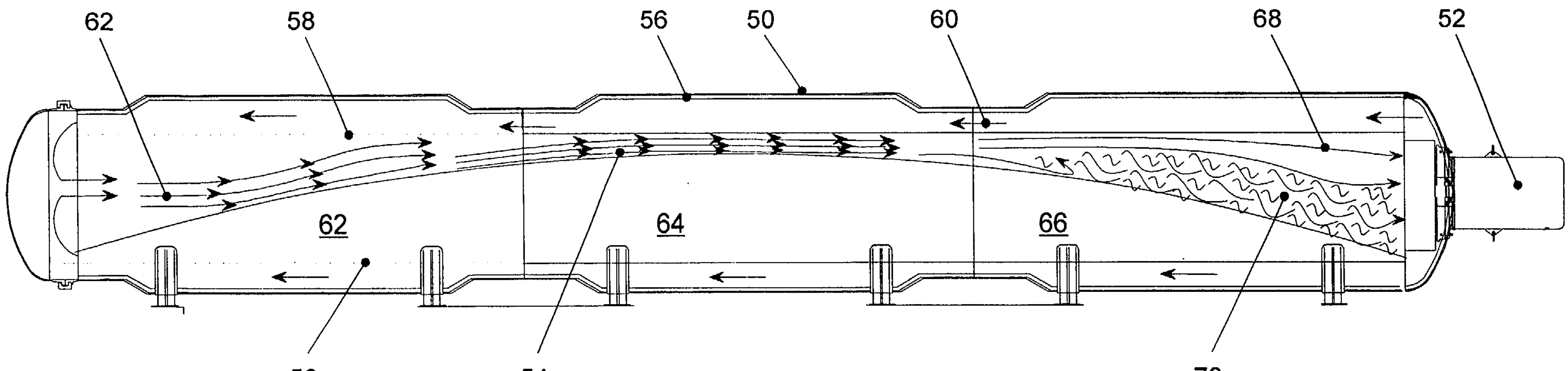

FIGURE 2

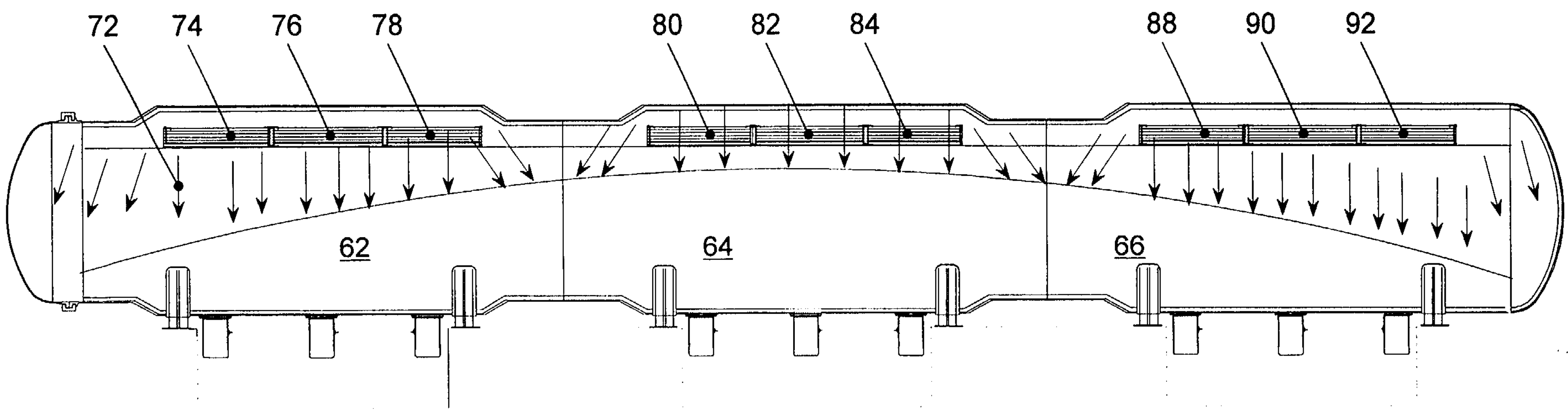

FIGURE 3

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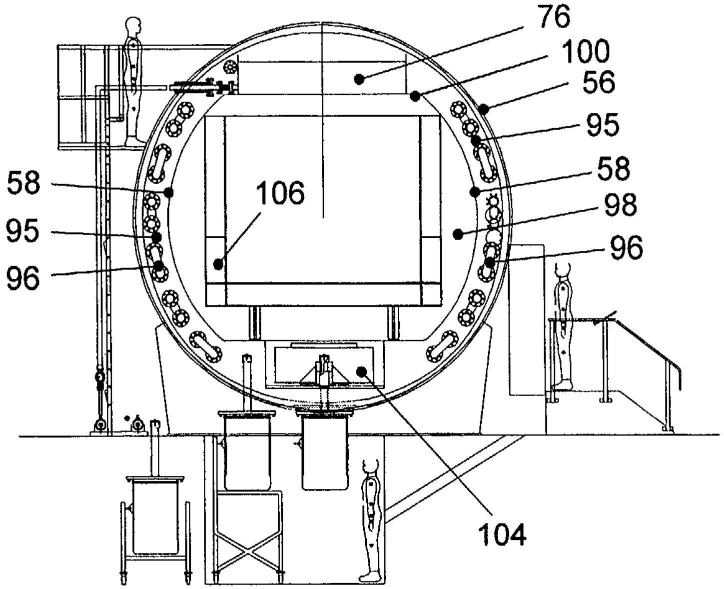


FIGURE 4A

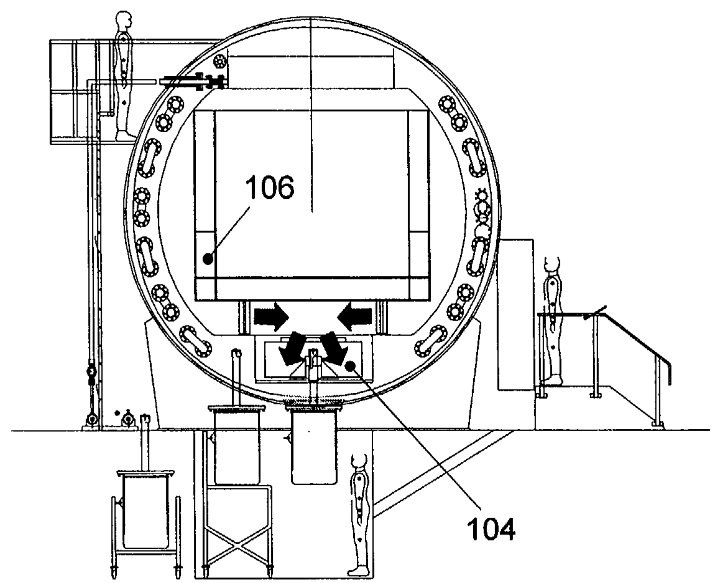


FIGURE 4B

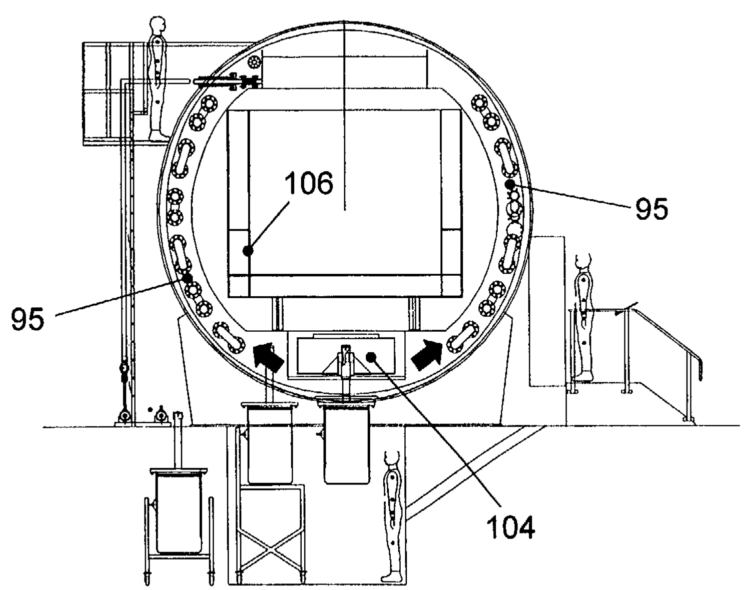


FIGURE 4C

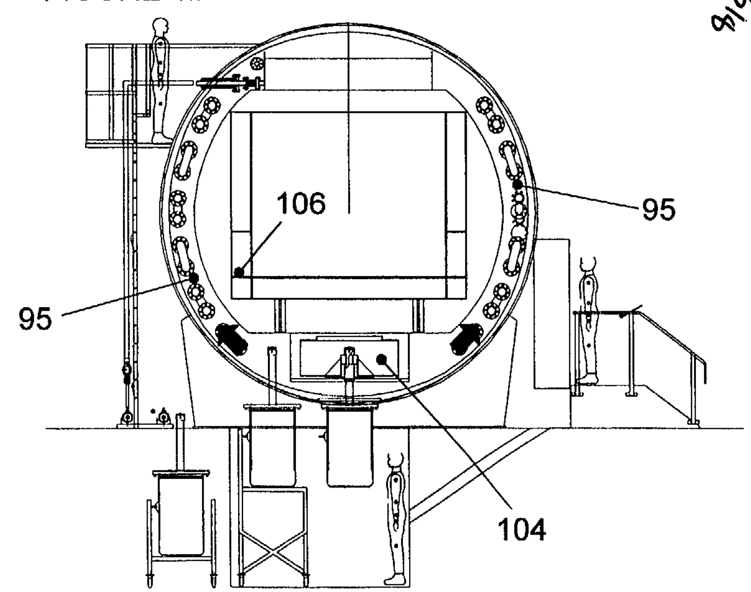


FIGURE 4D

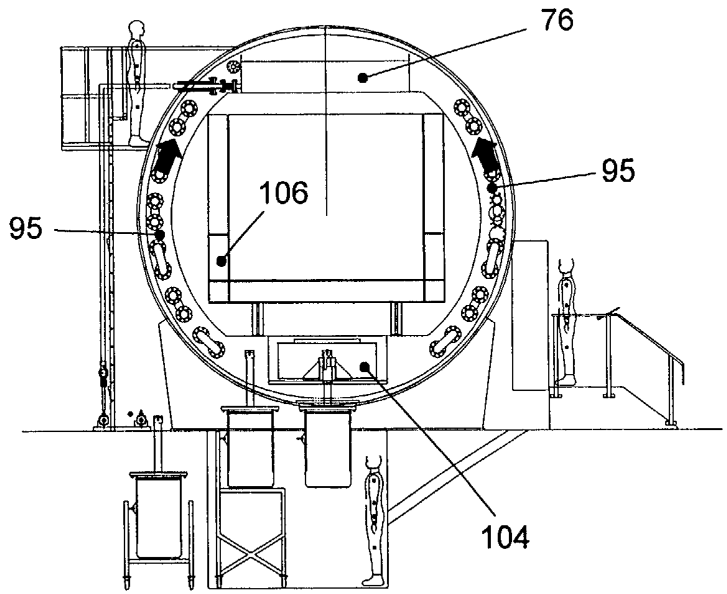


FIGURE 4E

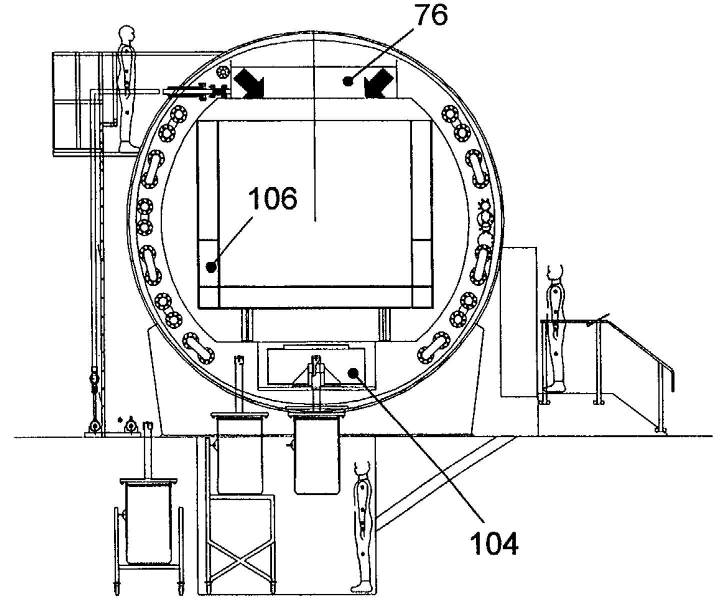


FIGURE 4F

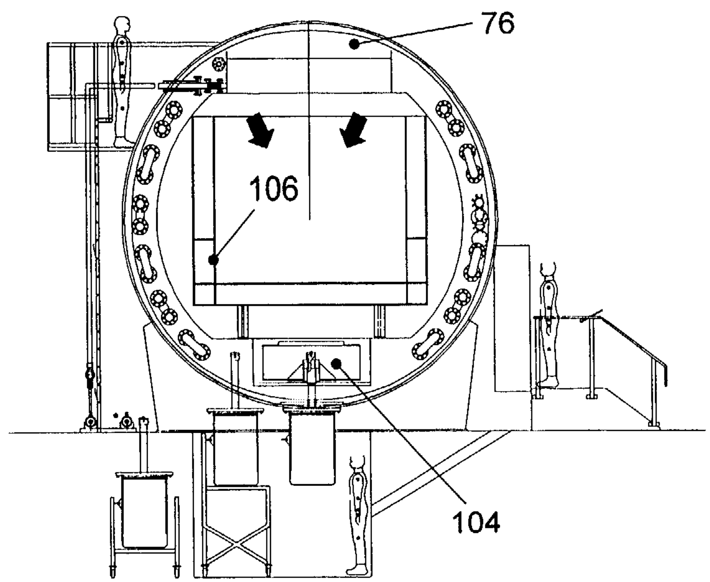


FIGURE 4G

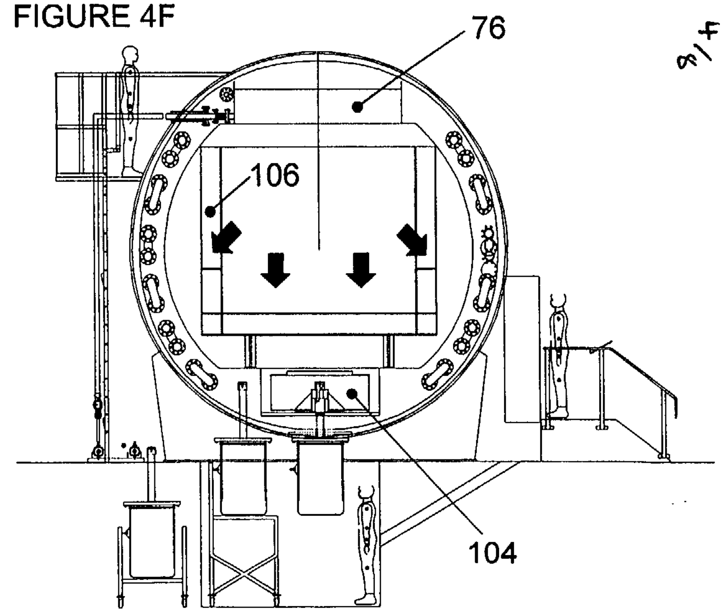
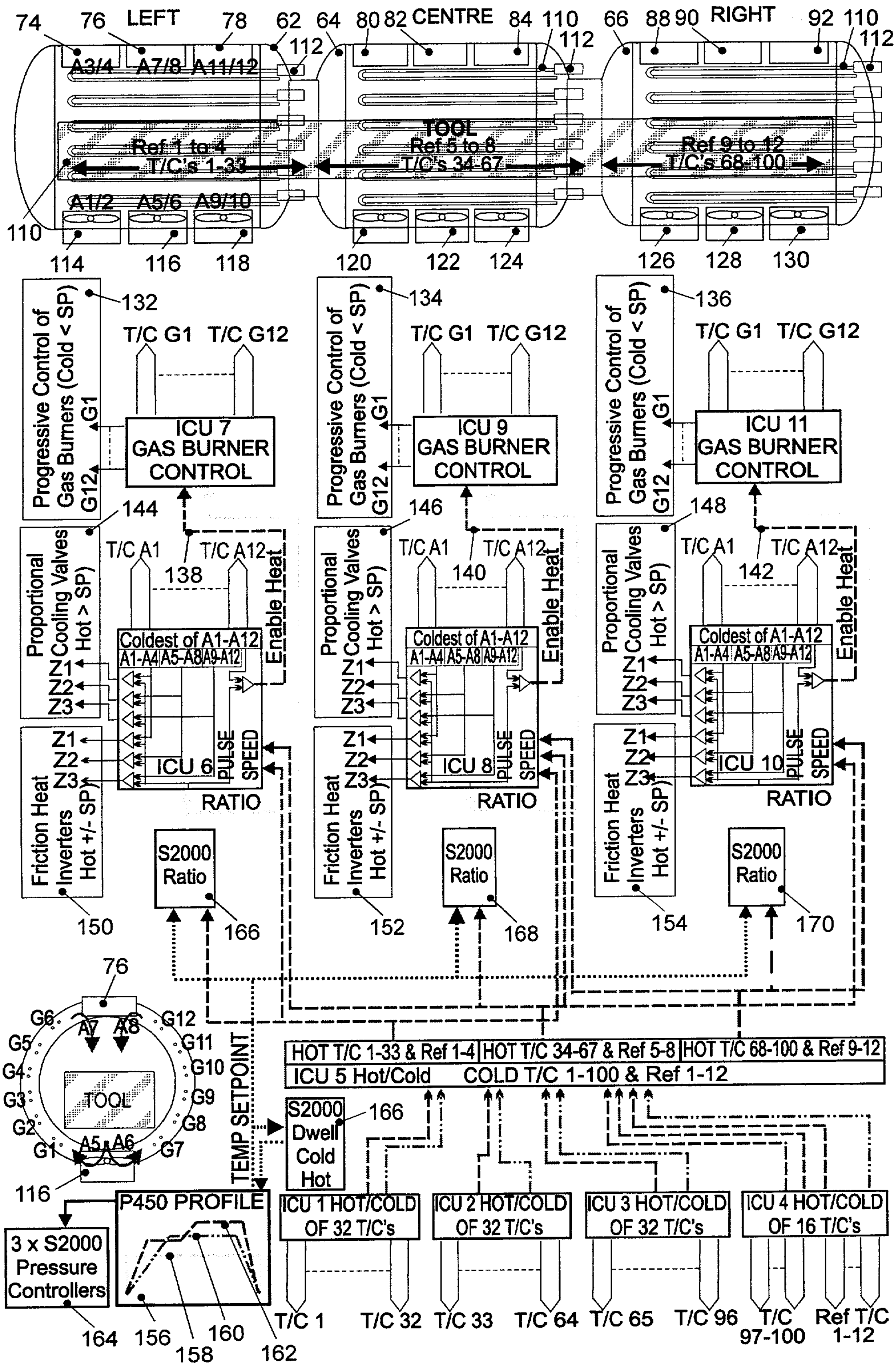


FIGURE 4H


LEFT
CENTRE
RIGHT
A3/4
A7/8
A11/12
A1/2
A5/6
A9/10
TOOL
Ref 1 to 4
T/C's 1-33
Ref 5 to 8
T/C's 34-67
Ref 9 to 12
T/C's 68-100
74
76
78
62
64
80
82
84
110
112
66
88
90
92
114
116
118
120
122
124
126
128
130
Progressive Control of Gas Burners (Cold < SP)
G1
G12
132
134
136
T/C G1
T/C G12
ICU 7 GAS BURNER CONTROL
ICU 9 GAS BURNER CONTROL
ICU 11 GAS BURNER CONTROL
Proportional Cooling Valves Hot > SP)
Z1
Z2
Z3
144
146
148
T/C A1
T/C A12
138
140
142
Enable Heat
Coldest of A1-A12
A1-A4
A5-A8
A9-A12
ICU 6
ICU 8
ICU 10
PULSE
SPEED
RATIO
Friction Heat Inverters Hot +/- SP)
150
152
154
S2000 Ratio
166
168
170
G1
G2
G3
G4
G5
G6
G7
G8
G9
G10
G11
G12
A5
A6
A7
A8
TOOL
TEMP SETPOINT
HOT T/C 1-33 & Ref 1-4
HOT T/C 34-67 & Ref 5-8
HOT T/C 68-100 & Ref 9-12
ICU 5 Hot/Cold
COLD T/C 1-100 & Ref 1-12
S2000 Dwell Cold Hot
P450 PROFILE
3 x S2000 Pressure Controllers
ICU 1 HOT/COLD OF 32 T/C's
ICU 2 HOT/COLD OF 32 T/C's
ICU 3 HOT/COLD OF 32 T/C's
ICU 4 HOT/COLD OF 16 T/C's
T/C 1
T/C 32
T/C 33
T/C 64
T/C 65
T/C 96
T/C 97-100
Ref T/C 1-12
164
156
158
160
162

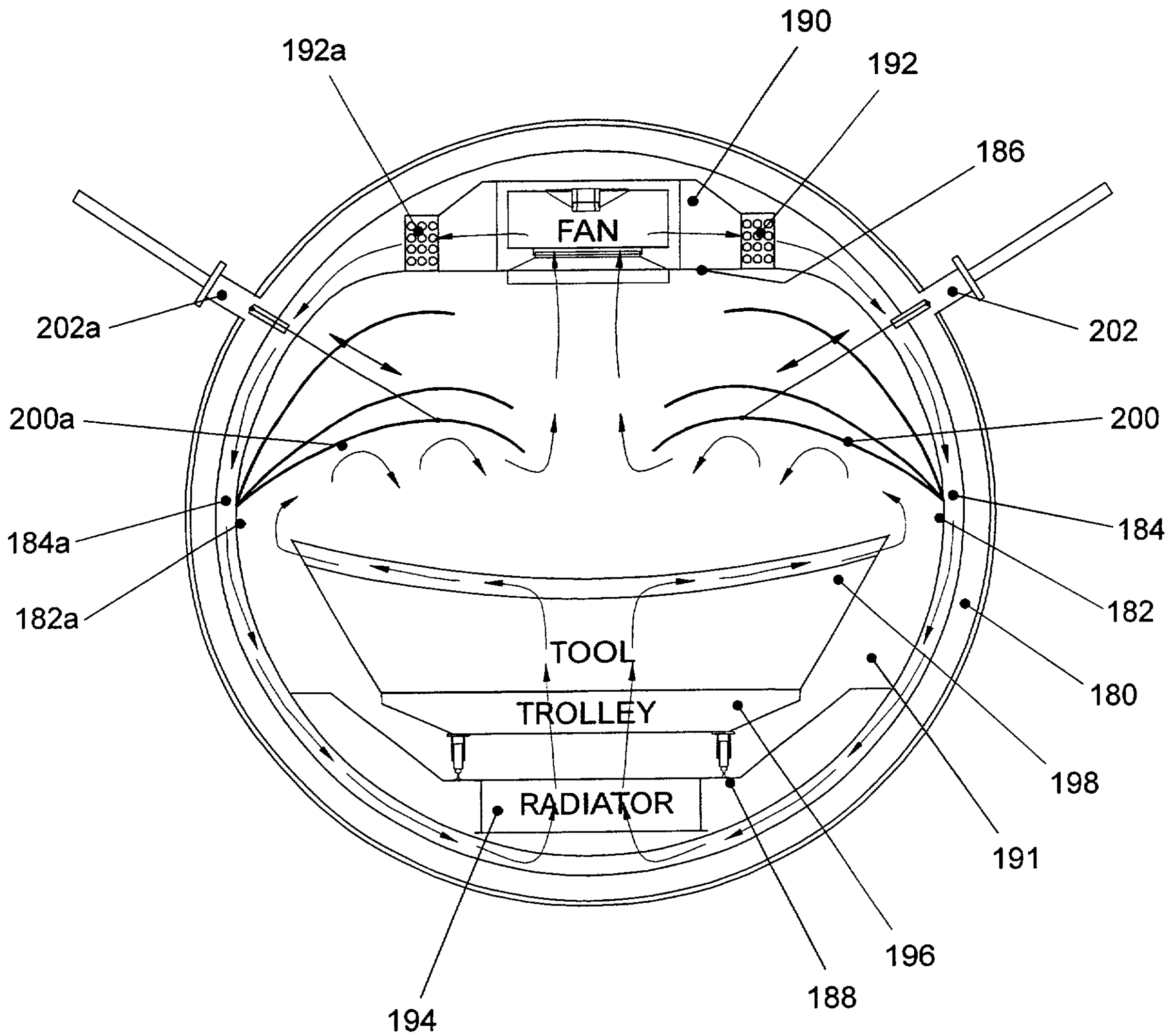

190
192a
192
186
FAN
202a
202
200a
200
184a
184
182a
182
180
TOOL
TROLLEY
198
RADIATOR
191
196
188
194

FIGURE 6

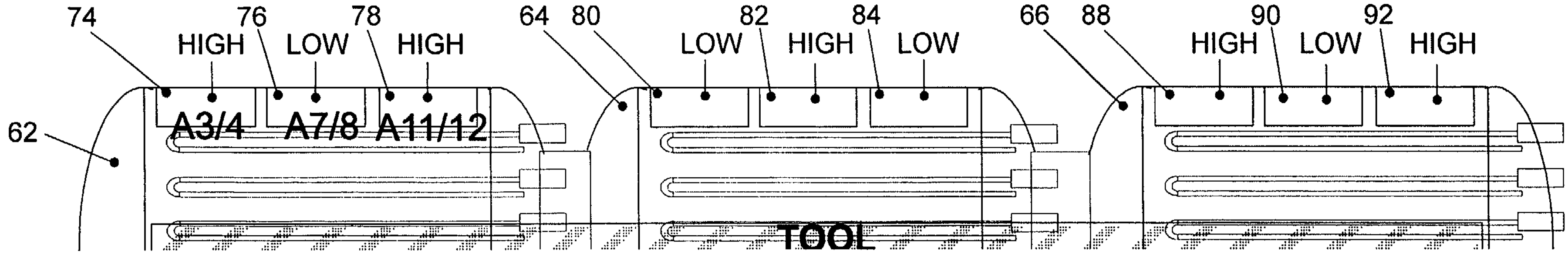


FIGURE 7A

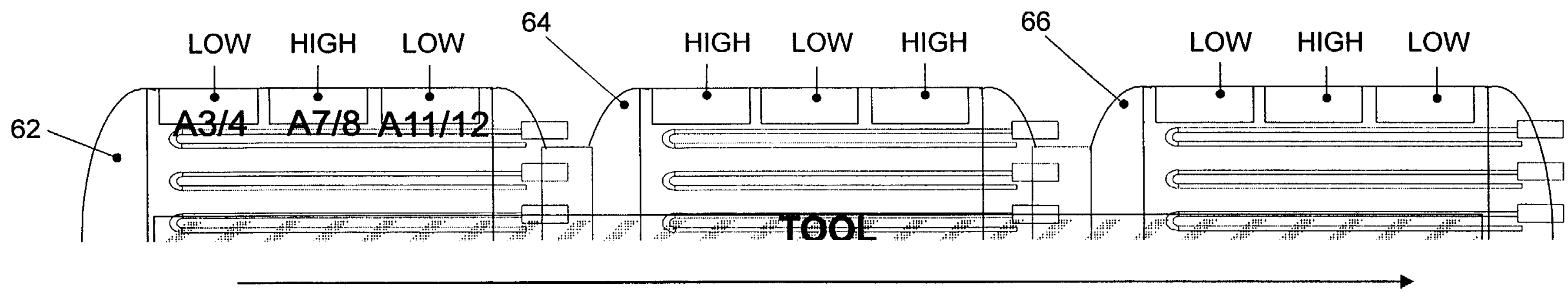


FIGURE 7B

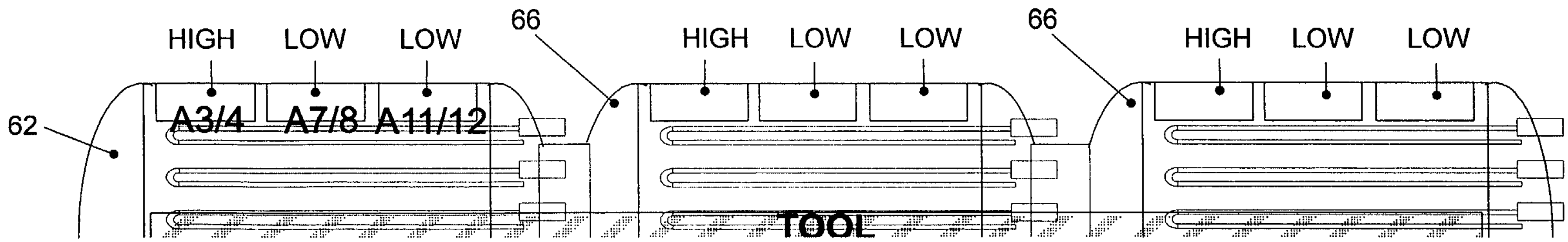


FIGURE 8A

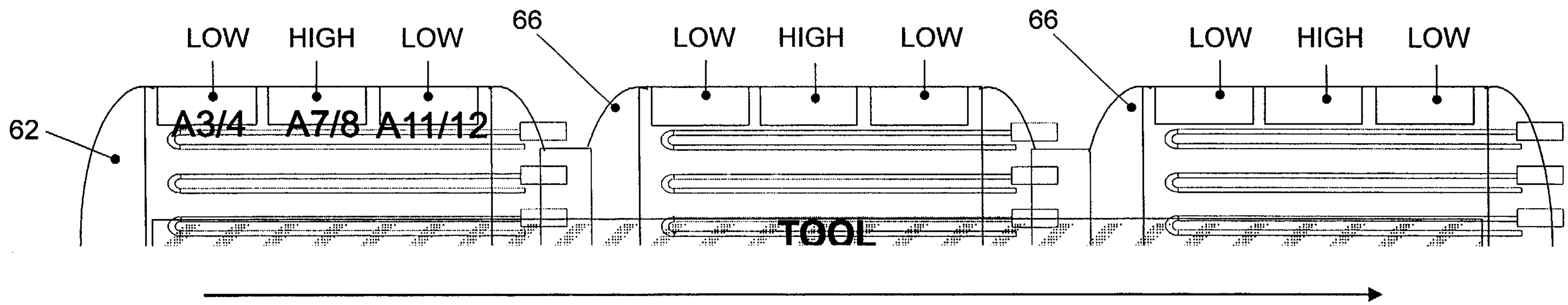


FIGURE 8B

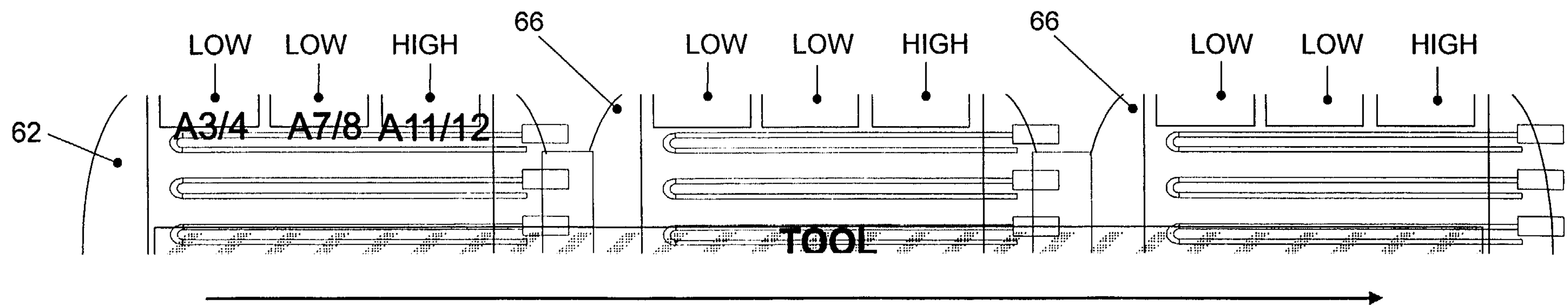


FIGURE 8C

MULTIPLE ZONE AUTOCLAVES

FIELD OF THE INVENTION

The present invention relates to autoclaves and to their use in the heat treatment of workpieces.

BACKGROUND TO THE INVENTION

EP-B-0176508 discloses a design for a gas-fired autoclave which is useful e.g. in the production of articles from fiber/resin mixtures and which nowadays typically have working temperatures of up to 450°C and working pressures of up to 68 Bar. As shown in Fig. 1, the autoclave is based on a pressure vessel that may typically have a length of about 3.7 meters (12 feet) and a diameter of about 1.5 meters (5 feet), the vessel having a body 10 and a loading door 12. Vacuum lines14 are provided for connection to the mold side of a mold tool (not shown) that is covered by a flexible diaphragm with a workpiece to be molded located between the tool and the diaphragm. The tool is connectable through valve 18 to vacuum and through valve 20 to air. Valve 22 can be operated to admit air through pressure lines 16 to the interior of the pressure vessel. Heating is by exposed radiant tubes 24 that run up and down the length of the pressure vessel. The entry to each tube is provided with a gas-fired heater 34 and the discharge end of each tube is provided with an impeller 36 by which a negative pressure is produced towards the discharge end and a flow of flue gas is maintained through the tube. A motor 38 mounted on the tank end wall drives a radial flow impeller 40 to produce a re-circulating flow of the gas within the pressure vessel. Thermocouples 42 through the tank wall 10 responsive to gas temperature are connected to a control unit 44 that is operatively connected to the various heaters to turn them off or on and maintain the gaseous atmosphere within the autoclave at ±1° of an intended value. The use of a variable speed impeller to enable the same tubes to be used for heating and for return to room temperature during the cooling part of the operating cycle is disclosed in EP-A-0333389.

Autoclaves of other design are electrically heated, steam heated, oil-heated, hot air heated or gas radiant-heated, but in the relatively large sizes contemplated in this application up to now they all rely on an impeller in the end wall to produce a single generally axial pattern of re-circulating gas flow as indicated by the arrows in Fig. 1.

US6240333 (Lockheed-Martin) concerns the fabrication of composite parts in an autoclave. Lockheed-Martin explain that the F22 Raptor is an example of an aircraft made largely from composite materials formed with flexible graphite fibres, called a ply, that are impregnated with epoxy or BMI resins which harden when subjected to the application of heat. The uncured plies are placed on tools, each tool corresponding to a composite part of the Raptor. Thus, when the graphite resin mixture hardens over the tool, the composite part is formed with the proper shape. Lockheed-Martin go on to explain that a number of production techniques are available for forming composite parts. Again, using the Raptor as an example, once the plies are placed over the tool, a vacuum bag is used to hold the plies securely to the tool during curing of the resin. The vacuum bag forces the material to the tool and prevents the formation of bubbles and other material deformities. The tools are then placed in an autoclave for heating according to a schedule, adherence to which may be essential in order to avoid the production of defective parts. Lockheed-Martin further explains that an autoclave operator must carefully distribute tools in the heating chamber of the autoclave to ensure that heating rate specifications are met, a typical autoclave being 15 metres (50 feet) long but nevertheless still being heated by blowing air with a large fan located at one end of the heating chamber. They identify a number of difficulties that this method of heating introduces into the production process, amongst others that if an autoclave operator adjusts heating rates to a lower level in order to avoid over-heating of a part, the autoclave will require a greater time to cure other parts, increasing the time required for the entire production run, and that if the parts are distributed improperly, the autoclave operator may have to violate the heating rate specifications for some of the tools, thus wasting the parts on those tools, in order to obtain useful parts from other tools. The solution suggested by Lockheed-Martin is to provide load distribution software for appropriate positioning of workpieces within a load to be introduced into the autoclave. The software includes a layout engine for determining the best layout of selected tools in an autoclave heating container depending upon (a) the particular tools selected, (b) the thermal performance of the tools and (c) the thermal characteristics of the autoclave, the layout engine generating the resulting pattern on a graphical user interface. The layout pattern is determined depending on:

- Thermal response of the tools stored in a database.
- Radial and axial variance in autoclave heating, the slow responding tools being laid out in regions of high heating and the fast responding tools being located in regions of low heating.
- Uniform airflow around the load.
- Feasibility of loading in the indicated pattern.

However, Lockheed-Martin give no detailed directions about how a layout engine should be written and what calculations it should perform, particularly as regards uniformity of airflow.

SUMMARY OF THE INVENTION

The present invention is based on the premise that in order to be in a position to treat loads that differ in mass, shape and cross-section along their length and to improve the chance that the whole load can receive the intended heat treatment, it is inherently better to modify the characteristics of the autoclave to take account of the characteristics of the load rather than to accept whatever characteristics the autoclave happens to have and modify the characteristics of the load.

One problem that arises when complex loads are heat treated in autoclaves is that at different positions along the autoclave there may be differences in the relative position or the cross-section of the load, said differences in an autoclave with axial gas circulation changing the speed of the circulating gas and hence of heat transfer to the load.

That problem is solved according to the invention by a method of heat treating a load as aforesaid in an autoclave, which method includes circulating heated gas within the load space by a plurality of gas circulation means spaced along its length and each causing the heated gas to circulate generally non-axially of the load space and/or to impinge non-axially onto the load.

The invention further comprises an autoclave for heat treatment of a load whose position relative to the autoclave and/or whose cross-section may vary along the load, said autoclave comprising:

a chamber for receiving the load, said chamber having first and second ends and an axis that passes through said first and second ends, the wall of said chamber providing the first end;

a door providing the second end of the chamber and giving access for insertion and removal of the load;

means for heating gas in said chamber; and

heated gas circulation means arranged to produce a pattern of circulation in which heating gas circulates generally non-axially of the load space and/or impinges non-axially onto the load.

Another problem that arises when complex loads are heat treated in autoclaves is that at different positions along the autoclave there may be differences in the thermal characteristics of the load, which in an autoclave with axial gas circulation may be difficult to overcome merely by adjusting the distribution of the load to take account of known or forecast differences in heat transfer rate with position.

That problem is solved according to the invention by a method of heat treating a load whose thermal characteristics vary with position along the load, which method comprises heating the load in an autoclave having a plurality of gas circulation means spaced its length and each producing a zone for circulation of heating gas, the gas circulation in said zones being independently controllable. With this method, a load of variable geometry and mass can be heated at different temperatures along its length in order to raise the temperature of the mass as a whole at a uniform rate.

The invention further provides an autoclave for heat treatment of a load whose thermal characteristics may vary along its length, said autoclave comprising:

a chamber for receiving the load, said chamber having first and second ends, the wall of said chamber providing the first end;

a door providing the second end of the chamber and giving access for insertion and removal of the load;

means for heating gas in said chamber; and

a plurality of gas circulation means spaced along the length of the autoclave and each producing a zone for circulation of heating gas, the gas circulation in said zones being independently controllable.

The aforesaid problems are not mutually exclusive, and indeed will commonly occur together.

Thus in a further aspect the invention provides an autoclave for heat treatment of a load whose position relative to the autoclave, whose cross-section and/or whose thermal characteristics may vary along the load, said autoclave comprising:

a chamber for receiving the load, said chamber having first and second ends and an axis that passes through said first and second ends, the wall of said chamber providing the first end;

a door providing the second end of the chamber and giving access for insertion and removal of the load;

means for heating gas in said chamber; and a plurality of gas circulation means spaced along the length of the autoclave and each producing a zone for circulation of heating gas, the gas circulation in said zones being independently controllable and said gas circulation means being arranged to produce a pattern of circulation in which heating gas impinges non-axially onto the load.

DESCRIPTION OF PREFERRED FEATURES

The above autoclave is divided longitudinally into a sequence of treatment zones, and preferably the means for controlling the rate of heat transfer between the heating gas and the load in each zone comprises an impeller. It has been found that the impeller can provide a dual function: firstly adjusting the speed of the circulating gas and hence the coefficient of heat transfer to the load and secondly because of the high power input which is required in practice to produce gas circulation at the required velocity acting as a source of heat for the heating gas, means preferably being provided for independently adjusting the friction heat generated in said heating gas by the impeller. It has been found in practice that providing one or more thermocouples in the autoclave measuring gas temperature and load temperature and using a difference between measured and required temperatures to generate a difference signals to adjust the impeller speeds and hence the amount of friction heat that the impellers generate provides fine temperature control and can enable load temperatures of ±1°C to be achieved during the load heating phase of the autoclave processing cycle. The means for controlling the rate of heat transfer between the heating gas and the load in each zone preferably also comprises cooling means for cooling gas circulating in said zone.

As regards heating the circulating gas, electricity is one possible heat source, in which case it is convenient to provide an independent heater for heating gas circulating in each zone. In the case of gas, steam or oil heating e.g. using radiant tubes, the heating means may comprise at least a first heater that is common to a group of zones and typically at least first and second heaters for first and second groups of zones. Control means may be adapted to create differential conditions in at least one zone in a time-varying pattern, thereby to transfer gas axially between zones.

The pattern of gas circulation is non-axial, with means preferably being provided in each zone for establishing a circumferential bilobal circulation of gas, the plane of said circumferential bilobal circulation being generally at right angles to said axis. In order to achieve such a circulation pattern, the autoclave may further comprise spaced oppositely facing inner wall portions defining with a side wall of the chamber spaces for flow of gas along the circumference of said chamber, a first aperture defined between said inner wall portions for entry of gas into said flow spaces, and a second aperture defined between said inner wall portions opposite the first ap[erture for gas leaving the flow spaces and flowing through said chamber towards the first slot. In order to increase the mass flow of heated gas traveling over the load and hence the coefficient of heat transfer, it is preferred to provide means for reducing the volume of gas above the load and hence increasing the speed of the gas. For this purpose at least one gas deflection means is preferably provided in said autoclave for varying the velocity of gas adjacent to the load, and actuator means is preferably connected to the gas deflection means for adjustment of the position thereof from the exterior of said chamber.

The above autoclave may be used for heat treating an elongated article with its longest dimension directed generally parallel to the axis of the autoclave, and the heat treatment is carried out so as to heat the article according to a predetermined pattern, usually so that it rises in temperature evenly along its length. The article is non-linear in its longitudinal direction e.g. a panel for an aircraft wing having both longitudinal and transverse curvature.

Typically the load comprises one or more articles each consisting of a workpiece in contact with a tool, the workpiece being heat treated and being shaped by contact with the tool as in the forming of composites by a combination of evacuation of the interface between the composite and the forming tool and application of pressure of the hot gaseous atmosphere within the autoclave. Use of an autoclave to make shaped parts is not limited to the production of parts in curable plastics or composite materials, but also includes parts made in metal that are required to undergo a heat treatment to change their shape or improve their properties. Age creep forming is a process that can be used for forming metallic plates into a desired contoured shape, for example to give an aluminium wing panel its aerofoil shape. The practical steps involved in age creep forming are closely analogous to those involved in moulding a curable composition. Following machining, a metal panel is placed onto a mould and covered with a sheet of a plastics material that resists high temperatures. The assembly is placed in an autoclave, the air beneath the sheet is evacuated and the interior of the autoclave is pressurised, forcing the panel tightly onto the mould, and the autoclave is heated. After a period of e.g. 24 hours the panel is cooled to room temperature and removed from the autoclave. US-A-4188811 (Chem-tronics) discloses a process for shaping a metallic workpiece that uses a single-faced die and the use of heat and pressure to conform the workpiece to the shape of the die surface by creep forming. In particular, the patent discloses a process for altering the shape of a metallic workpiece which comprises the steps of: placing the workpiece on the face of a die which face has a configuration wanted in the workpiece and concurrently heating said workpiece and applying pressure thereto via a compliant body composed of discrete pieces of a heat resistant, pressure transmitting material and located on that side of the workpiece opposite the die, the temperature to which the workpiece is heated and the pressure applied thereto being so correlated as to cause the workpiece metal to flow plastically at a stress below its yield strength into contact with the face of said die to thereby impart the wanted configuration to the workpiece. More recent references to creep forming occur in US-A-5345799 (Aliteco AG) and 6264771 (Bornschlegel).

The preferred gas circulation pattern within the zones of the autoclave is bilobal with a plane of bilobal circulation in each zone directed transversely of the axis of the autoclave, and wherein gas at a central region of said bilobal circulation passes through the tool. The tool advantageously has a gas-receiving opening that faces a location where gas that has been traveling along a circumferential part of its circulation path enters a central part of its circulation path in which the gas travels across the load space.

BRIEF DESCRIPTION OF THE DRAWINGS

How the invention may be put into effect will now be described, by way of example only, with reference to the accompanying drawings, in which:

Fig. 1 is a view in longitudinal vertical section of a known autoclave;

Fig 2 is diagrammatic view in vertical section of an autoclave with air circulation from one end and with an elongated workpiece that is curved at least along its longitudinal direction;

Fig 3 is a diagrammatic view of an autoclave and workpiece similar to that in Fig. 2 except that an air circulation at least part of which is radial is produced by means of a series of impellers located at intervals along the autoclave;

Figs 4a-4h are views of the autoclave in transverse section showing the pattern of air circulation;

Fig. 5 is a diagram of the autoclave and its associated control systems;

Fig 6 is a view of another autoclave according to the invention in transverse section; and

Figs 7a-7b and 8a-8c are views of the autoclave of Figs 3 and 4a-4h showing schemes for the creation of pressure waves for bringing about movement of air axially from one zone to another.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The present invention is particularly, though not exclusively applicable to autoclaves of high aspect ratio, high volume or both high volume and high aspect ratio. An autoclave of relatively small size but high aspect ratio might be used, for example, in the heat treatment or shaping of yacht masts and could have a length of e.g. 20 meters and a diameter of 1 meter, with an internal volume of about $12m^3$. In the case of both high volume and high aspect ratio, the autoclave may be 15 meters in length and in a typical installation may be about 35 meters in length, there being no specific upper limit in length because of the non-axial flow pattern that has been selected. The volume of the autoclave may be more than 250 cubic meters, often more than 500 cubic meters and in a typical installation more than 750 cubic meters. The aspect ratio of the load space within the autoclave (length to diameter or maximum transverse dimension) may be more than three, usually more than 5 and in a typical installation about 7.

The problems that arise when a component such as a panel for a large aircraft wing, said panel arising from where the wing joins the fuselage of the aircraft, is to be heat treated in a conventional autoclave 50 with axial air circulation via fan 52 are shown in Fig. 2. The wing panel 54 may be, for example, of aluminum alloy of section typically 40mm towards its base and 4mm towards its tip with curvature both transversely and longitudinally and with change of section gradually all along its length. Tooling of steel plate that is typically about 10 mm thick supports the panel 54 that is to be creep formed and the panel or workpiece is to be pulled down onto a datum surface defined by screw jacks distributed along and across the tool. The panel is covered by a rubber sheet and is pulled down onto the datum surface by vacuum and by the pressure of the gas within the autoclave, which will typically be at a pressure of up to 20 bar and up to 200°C.

For creep forming, the specification for the thermal regime to be undergone by the panel 54 is that it should be heated to ±2°C of its target temperature and that the thickest part of the panel should achieve its target temperature within one hour of the thinnest part. Heat reaches the panel mainly by impingement of the heating gas on the rubber cover sheet, so that it is necessary to model convection in air, conduction through the rubber cover sheet and the thermal capacity of the aluminum panel.

In Fig. 2 the tooling is omitted for the sake of clarity. As apparent, gas flows axially away from fan 52 between the sidewall 56 of the autoclave and inner wall 58 as indicated by arrows 60 and returns inward to provide an axial return flow 62. Radiant tube heating elements (not shown) are provided between walls 56 and 58. The autoclave is formed in three segments, with a segment 62 furthest from the fan, a central segment 64 and a segment 66 nearest to the fan. In the segment 62 furthest from fan 52 the panel 54 is at a relatively wide spacing from inner wall 58 and gas flow is relatively slow. In the middle segment 64 the gap between panel 54 and inner wall 58 has narrowed and gas flow has accelerated with a corresponding increase in heat transfer coefficient. In the segment 66 nearest the fan 52 because of the reverse curvature of the panel 54, the heating gas no longer impinges directly on the rubber over-layer and instead part of it by-passes it to return directly to the fan as indicated by arrow 68, while the remainder becomes turbulent as indicated by arrows 70. In order to overcome the problems imposed by the differing gas flow regimes and consequential differences in load (workpiece and/or tool) heat transfer coefficient, the fan 52 has to produce a very high gas flow which is against a high static head resulting from the length of the flow paths and obstruction provided by the heaters in the outflow part of the path and the load in the return part of the path. Gas flow through the tooling does not contribute significantly to processing because the predominant gas flow is over the surface of the panel 54 as shown. Inevitably one end of the load is cooler than the other. MW of fan power is required, with high capital cost, and there is a zero diversity factor.

The invention overcomes these problems, as shown in Fig. 3 by providing a generally non-axial flow pattern of heating gas with gas circulating circumferentially between inner and outer walls of the autoclave and traveling across the load space so that the flow impinges onto the load, as indicated by arrows 72. The pattern of gas circulation in planes directed generally at right angles to the axis of the autoclave provides the opportunity to divide the load space into a multiplicity of processing zones in which gas flow (speed and temperature) is independently controllable to maintain uniform temperature of the load with diversity factors. Circumferential flow for each segment is directed through and then downwardly from cooling units mounted at and spaced axially along the uppermost region of the autoclave, with cooling units 74, 76 and 78 being provided in the segment 62, cooling units 80, 82 and 84 being provided in the segment 64 and cooling units 88, 90 and 92 being provided in the segment 66. The circumferential flow enters the cooling units and is then directed downwardly towards the load as shown. For the return part of the travel of the gas, impellers in matching units under the floor of the autoclave return gas from the load space for flow circumferentially between the walls 56, 58. Use of a multiplicity of impellers located at intervals along the autoclave in addition to sharing the load gives rise to a reduced static head at each impeller, so that smaller motors can be used without compromising the air movement requirements of the autoclave.

A cross-section of the autoclave of Fig 3 is shown in Figs. 4a-4h in which it is apparent that the autoclave has a side wall 56 and oppositely facing arcuate side walls 58, 58a defining with the wall 56 circumferential gas circulation spaces 95 containing gas-fired radiant heater tubes 96. As is apparent from Fig. 4a, each segment has six radiant tubes per side fired by six gas burners giving twelve radiant tubes and gas burners per segment. It will be appreciated that gas fired radiant tubes are only an example and that other forms of heating may be employed. A load space 98 is defined between the inner walls 58,58a, ceiling 100 and floor 102, the cooling units, in this case the unit 76 being ceiling-mounted and the impellers 104 being floor-mounted. Load 106 is present in the load space and takes the form of a panel to be formed and a forming tool with a blanket of deformable material or a rigid second part of the tool covering the panel and with means (not shown) for applying a vacuum under the panel to assist the forming operation. As shown by the arrows in successive figures, heating gas from the underside of the load 106 passes into the impeller or fan 104 (Fig 5b), from which it is discharged towards gas circulation spaces 95 through which it flows circumferentially (Figs.4d, 4e), until it reaches the cooling unit 76. The gas leaving the cooling unit passes downwardly into and then through a forming tool that forms part of the load 106 (Figs 4f, 4g, 4h) before returning to the underside of the load (Fig. 4b). Accordingly there is established in each zone a circumferential bilobal circulation pattern, with the load being in a central region or load space where the gas flow from the two lobes becomes combined and where the gas travels transversely of the load space, in this case downwards.

The layout of the autoclavee of Fig 3 is diagrammatically shown in Fig. 5, which is a schematic view of the autoclave and an associated control system. The segments 62, 64, 66 are heated by radiant tubes and fired by gas burners 112. The radiant tubes are represented in the diagrammatic section that forms part of Fig. 5 as G1-G12, and are directed axially and each passing through three heating zones each defined by independently controllable coolers 74-92 and by independently controllable impellers 114-130.The gas burners for each segment have associated thermocouples T/C G1 – T/C G12 which measure the temperature of the circumferential air and pass signals to a respective one of segment heater logic units ICU 7, ICU 9 and ICU 11 that in turn pass command signals to progressive gas burner controllers 132, 134, 136 associated with the respective segments (cold < SP). The three heater logic units receive heat enable commands 138, 140, 142 from fan and cooler logic units ICU 6, ICU8 and ICU 10 for the three segments.

In the first zone, thermocouples A1 and A2 measure the temperature of the flow exiting impeller 114, and thermocouples A3 and A3 measure the flow entering cooler unit 74 the difference providing a measure of the heat taken up by the load, the thermocouples occurring in pairs because of the bilobal flow pattern. In the second zone thermocouples A5 and A6 measure the temperature of air exiting impeller 116 and thermocouples A7 and A8 monitor the temperature of air entering cooler unit 76. In the third zone, thermocouples A9 and A10 monitor the temperature of air leaving impeller 118 and thermocouples A11 and A12 monitor the temperature of air entering cooler unit 78. Signals from the twelve thermocouples are supplied to the unit IC6, IC7 or IC8 which in addition to providing gas burner command signals also provides command signals Z1, Z2, Z3 to proportional cooling valves 144, 146 and 148 (Hot > SP) and similar signals to friction heat inverters 150, 152, 154 (Hot ± SP) for the impellers of each zone. Accordingly if the gas in any zone is sufficiently below the set point, then the gas burners of the radiant tubes can be switched on. If the temperature of the gas in any zone is above the set point, cooling can be initiated, and adjusting inverter power for each zone can compensate fine deviations in gas temperature.

The operation of the autoclave depends not only on measurements of gas temperature but also on measurement of load (tool or workpiece) temperature. For that purpose, load sensor thermocouples 1-33 and reference thermocouples 1-4 are allocated to segment 62, load sensor thermocouples 34-67 and reference thermocouples 5-8 are allocated to segment 64 and load sensor thermocouples 68-100 and reference thermocouples 9-12 are allocated to segment 66. Logic units ICU 1 – ICU 4 feed signals for the hottest and the coldest of groups of thermocouples that they monitor to temperature control logic ICU 5.

As shown at 156, the processing cycle to be carried out by the autoclave which is stored at device 156 will normally include a relatively simple pressure cycle 158, a workpiece processing cycle with a predetermined rate of temperature rise, dwell time at the intended processing temperature and rate of temperature return to ambient. The cycle of processing gas temperature 162 is usually more complex, with the gas temperature leading the workpiece temperature, and with a ratio between those temperatures being a factor that determines the coefficient of heat transfer. From device 156, information is supplied to pressure controllers 164 for the three segments, and temperature set points are supplied to air/load temperature ratio controllers 166, 168, 170.

If any of the workpiece or control thermocouples indicate too low a temperature, then logic ICU5 supplies information to dwell/cold/hold logic which is also supplied with the temperature set-point and which may return a signal to device 156 to vary e.g. the air temperature set point. Device ICU 5 is also concerned with spread control. If one of the thermocouples in the group is at or near the required temperature while others are at too low a temperature, then the logic causes supply of additional heat to be reduced (Hold) until the temperature of the cold areas has caught up. If a thermocouple in any of the segments is hot, then a signal is sent to the ratio controller 166, 168 or 170 to reduce heating in the segment where the thermocouple in question is sited. The signal is passed both to the segment heater logic unit ICU 7, 9 or 11 and also to the fan and cooler logic units for the adjoining segments. Thus if one of the thermocouples 1-33 or one of the reference thermocouples 1-4 gives a HOT signal, then a signal is passed to the ratio controller 166 for segment 62 for reduction of gas burner heat and/or impeller friction heat and to pulse speed input of fan and cooler logic ICU 8 for adjoining segment 64 to adjust the friction heat developed any or all of the zones in that segment. Similarly, if one of the thermocouples 34-67 or one of the reference thermocouples 5-8 gives a HOT signal, then a signal is passed to the ratio controller 168 for segment 64 for reduction of gas burner heat and/or impeller friction heat and to pulse speed input of fan and cooler logic units ICU 6 and ICU 10 for adjoining segments 62 and 66 to adjust the friction heat developed any or all of the zones in those segments. Again, if one of the thermocouples 68-100 or one of the reference thermocouples 9-12 gives a HOT signal, then a signal is passed to the ratio controller 170 for segment 66 for reduction of gas burner heat and/or impeller friction heat and to pulse speed input of fan and cooler logic ICU 8 for adjoining segment 64 to adjust the friction heat developed any or all of the zones in that segment. The control circuit therefore enables a relatively coarse response to be carried out segment-wise to major low or high deviations of gas, tool or workpiece temperature, and more finely tuned zone-wise responses to smaller temperature fluctuations from the intended heat treatment cycle using zone-wise cooling and zone-wise friction heat generation.

Fig 6 is a cross-section of an alternative embodiment of an autoclave of the invention in which each zone is electrically heated with an overhead heater and cooled as required by a floor radiator, the flow of gas across the load chamber impinging onto a molding tool from its underside. One possible use of the autoclave is for the molding and curing of large panels of resin reinforced carbon fiber or other composite materials for use in airliners. The autoclave has sidewall 180 and inner walls 182, 182a defining passages 184, 184a for circumferential flow of heating gas together with a ceiling 186 and a floor 188. An impeller 190 brings about flow of gas from load space 191 through electrical heaters 192, 192a and through passages 184, 184a to radiator 194 which contains cooling elements and from which the gas returns to the load space 191. Gas entering the load space passes through trolley 196 and tool 198 so that it impinges on the underside of the molding surface of the tool. The panel to be molded is on the upper surface of the tool and is of negligible thickness, and it has been omitted for the sake of clarity. The upper face of the panel may also need to be molded e.g. because it has one or more upstanding integrally formed ribs, and for that purpose the carbon fiber lay-up may be covered with a second part of the tool, also omitted for clarity. Gas flows along the underside of the tool towards the periphery of the autoclave as shown by the arrows, and is returned towards the tool so as to heat the upper mold part that rests on the carbon fiber lay-up by means of movable baffles 200, 200a whose positions are adjustable from outside the autoclave by actuators 202, 202a. A gap between the baffles 200, 200a permits the gas to return to the impeller 190 as shown. The baffles 200, 200a reduce the volume of gas above the tool 198, with the consequences that the velocity of the gas and hence its coefficient of heat transfer to the tool is increased.

In order to minimize variations in load temperature axially of the autoclave, it may be desirable to provide means for conveying gas axially from one zone to the other. In order to achieve such conveyance, a cyclically varying pattern of circulation conditions may be applied to at least one zone that shifts axially of the autoclave. For example, adjacent zones may vary in temperature individually and cyclically as in Figs 7a and 7b. Alternatively a zone of high temperature may be followed by two zones of lower temperature as in Figs. 8a-8c. The cyclical variation in temperature from zone to zone may conveniently be achieved by adjustment of the friction heat of the impellers 114-130 via logic units ICU 6 – ICU 10 and inverters 150-154.

Various modifications may be made to the illustrated embodiments without departing from the invention. For example, the drawings have illustrated cases where firstly the heater is in the roof and the cooling radiators are in the floor, gas flowing downwardly through the load space, and secondly the cooling radiators are positioned in the roof and the hot air is ducted to rise from under the floor into the load space through which it flows upwardly into the base of the tooling. Although these airflow directions may often be convenient, the direction of air flow is arbitrary and could for example be side to side, the heater and cooling radiator being correspondingly placed.

CLAIMS

1. An autoclave for heat treating a load having a load space, a side wall through which heating gas can circulate, and means for circulating the gas, wherein said gas circulation means is arranged to produce a flow of gas across the load space for heating the load and a return flow through the side wall.

2. The autoclave of claim 1, having an aspect ratio of more than 3.

3. The autoclave of claim 1 or 2, wherein the load space has a volume of more than 250 cubic meters.

4. An autoclave for heat treatment of a load whose position relative to the autoclave and/or whose cross-section may vary along the load, said autoclave comprising:

a chamber for receiving the load, said chamber having first and second ends and an axis that passes through said first and second ends, the wall of said chamber providing the first end;

a door providing the second end of the chamber and giving access for insertion and removal of the load;

means for heating gas in said chamber; and

heated gas circulation means arranged to produce a pattern of circulation in which heating gas impinges non-axially onto the load.

5. An autoclave for heat treatment of a load whose thermal characteristics may vary along its length, said autoclave comprising:

a chamber for receiving the load, said chamber having first and second ends, the wall of said chamber providing the first end;

a door providing the second end of the chamber and giving access for insertion and removal of the load;

means for heating gas in said chamber; and a plurality of gas circulation means spaced along the length of the autoclave and each producing a zone for circulation of heating gas, the rates of heat transfer between the heating gas and the load in said zones being independently controllable

6. An autoclave for heat treatment of a load whose position relative to the autoclave, whose cross-section and/or whose thermal characteristics may vary along the load, said autoclave comprising:

a chamber for receiving the load, said chamber having first and second ends and an axis that passes through said first and second ends, the wall of said chamber providing the first end;

a door providing the second end of the chamber and giving access for insertion and removal of the load;

means for heating gas in said chamber; and

a plurality of gas circulation means spaced along the length of the autoclave and each producing a zone for circulation of heating gas, the rate of heat transfer between the heating gas and the load in said zones being independently controllable and said gas circulation means being arranged to produce a pattern of circulation in which heating gas impinges non-axially onto the load.

7. The autoclave of claim 5 or 6, wherein the means for controlling the rate of heat transfer between the heating gas and the load in each zone comprises an impeller.

8. The autoclave of claim 7, wherein the means for controlling the rate of heat transfer between the heating gas and the load in each zone comprises means for independently adjusting the friction heat generated in the heating gas by the impeller.

9. The autoclave of claim 7 or 8, wherein the means for controlling the rate of heat transfer between the heating gas and the load in each zone comprises cooling means for cooling gas circulating in said zone.

10. The autoclave of any of claims 7-9, wherein the heating means comprises an independent heater for heating gas circulating in each zone.

11. The autoclave of any of claims 5-9, wherein the heating means comprises at least a first heater that is common to a group of zones.

12. The autoclave of claim 11, wherein the heating means comprises at least first and second heaters for first and second groups of zones.

13. The autoclave of claim 11 or 12, wherein the or each heater is a radiant tube heater.

14. The autoclave of any of claims 5-13, further comprising control means adapted to create differential conditions in at least one zone in a time-varying pattern, thereby to transfer gas axially between zones.

15. The autoclave of any of claims 5-14, wherein means is provided in each zone for establishing a circumferential bilobal circulation of gas, the plane of said circumferential bilobal circulation being generally at right angles to said axis.

16. The autoclave of claim 15, further comprising:

spaced oppositely facing inner wall portions defining with a sidewall of the chamber spaces for flow of gas along the circumference of said chamber;

a first aperture defined between said inner wall portions for entry of gas into said flow spaces; and

a second aperture defined between said inner wall portions opposite the first slot for gas leaving the flow spaces and flowing through said chamber towards the first aperture.

17. The autoclave of any preceding claim, further comprising at least one gas deflection means in said autoclave for varying the velocity of gas adjacent to the load.

18. The autoclave of claim 17, further comprising actuator means connected to said gas deflection means for adjustment of the position thereof from the exterior of said chamber.

19. An autoclave comprising:

a chamber for receiving at least one workpiece to be heat treated, said chamber having first and second ends and an axis that passes through said first and second ends, the wall of said chamber providing the first end;

a door providing the second end of the chamber and giving access for insertion and removal of workpieces;

means for heating gas in said chamber;

means for circulating the heated gas; and

a plurality of heat transfer adjustment means disposed between said first and second ends for independently adjusting the rate of transfer of heat to said at least one workpiece in respective zones disposed between said first and second ends.

20. Use of the autoclave of any preceding claim for the heat treatment of a load.

21. Use according to claim 20, wherein the load comprises an elongated article with its longest dimension directed generally parallel to the axis of the autoclave, and the heat treatment is carried out so as to heat the article according to a predetermined pattern.

22. Use according to claim 21, wherein the article is heated so that it rises in temperature evenly along its length.

23. Use according to claim 21 or 22, wherein the article is non-linear in its longitudinal direction.

24. The use of any of claims 20-23, wherein the article comprises a workpiece in contact with a tool, the workpiece being heat-treated and being shaped by contact with the tool.

25. The use of claim 24, wherein the gas circulation in said zones is bilobal with a plane of bilobal circulation in each zone directed transversely of the axis of the autoclave, and wherein gas at a central region of said bilobal circulation passes at least partly through the tool.

26. The use of claim 25, wherein the tool has a gas-receiving opening that faces a location where gas that has been traveling along a circumferential part of its circulation path enters a central part of its circulation path in which the gas travels across the autoclave.

27. The use of any of claims 20-26, wherein the workpiece is a sheet or panel.

28. The use of any of claims 20-27, wherein the workpiece comprises a curable composite material.

29. The use of any of claims 20-27, wherein the workpiece comprises a metal and the heat treatment comprises creep forming.

30. The use of claim 29, wherein the metal is aluminum.

31. A method of heat treating in an autoclave a load that at different positions along the autoclave is subject to differences in the relative position or the cross-section of the load, said method including circulating heating gas within the

autoclave by a plurality of gas circulation means spaced along the length of the autoclave and each causing the heated gas to impinge non-axially onto the load.

32. A method of heat treating a load whose thermal characteristics are subject to variation with position along the load, which method comprises heating the load in an autoclave having a plurality of gas circulation means spaced its length and each producing a zone for circulation of heating gas, the gas circulation in said zones being independently controllable.

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Claims searched:	1-3,17,18,20-30	**Date of search:**	28 March 2002

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Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.T): B1X (X32, X34, X35B, X35D) A5G (GAA)

Int Cl (Ed.7): B01J 3/02, 3/04

Other: ONLINE: WPI, EPODOC, JAPIO

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
X	GB 1034722 (SCOTT) whole document relevant	1,20 at least
X	EP 0830892 A1 (BP) whole document relevant	1,20 at least
X	US 4269805 (SCHOENGEN) whole document relevant	1,20 at least
X	WPI. A.A.N: 1997-529987 & JP9251981 (KAZUAKI) (22/9/97) see translated abstract.	1, 20 at least

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