Office de la Propriété Intellectuelle du Canada
Un organisme d'Industrie Canada

Canadian Intellectual Property Office
An agency of Industry Canada

CA 2320654 C 2010/05/11

(11)(21) 2 320 654

(12) BREVET CANADIEN
CANADIAN PATENT

(13) C

(22) Date de dépôt/Filing Date: 2000/09/26

(41) Mise à la disp. pub./Open to Public Insp.: 2001/03/27

(45) Date de délivrance/Issue Date: 2010/05/11

(30) Priorité/Priority: 1999/09/27 (AU PQ3087)

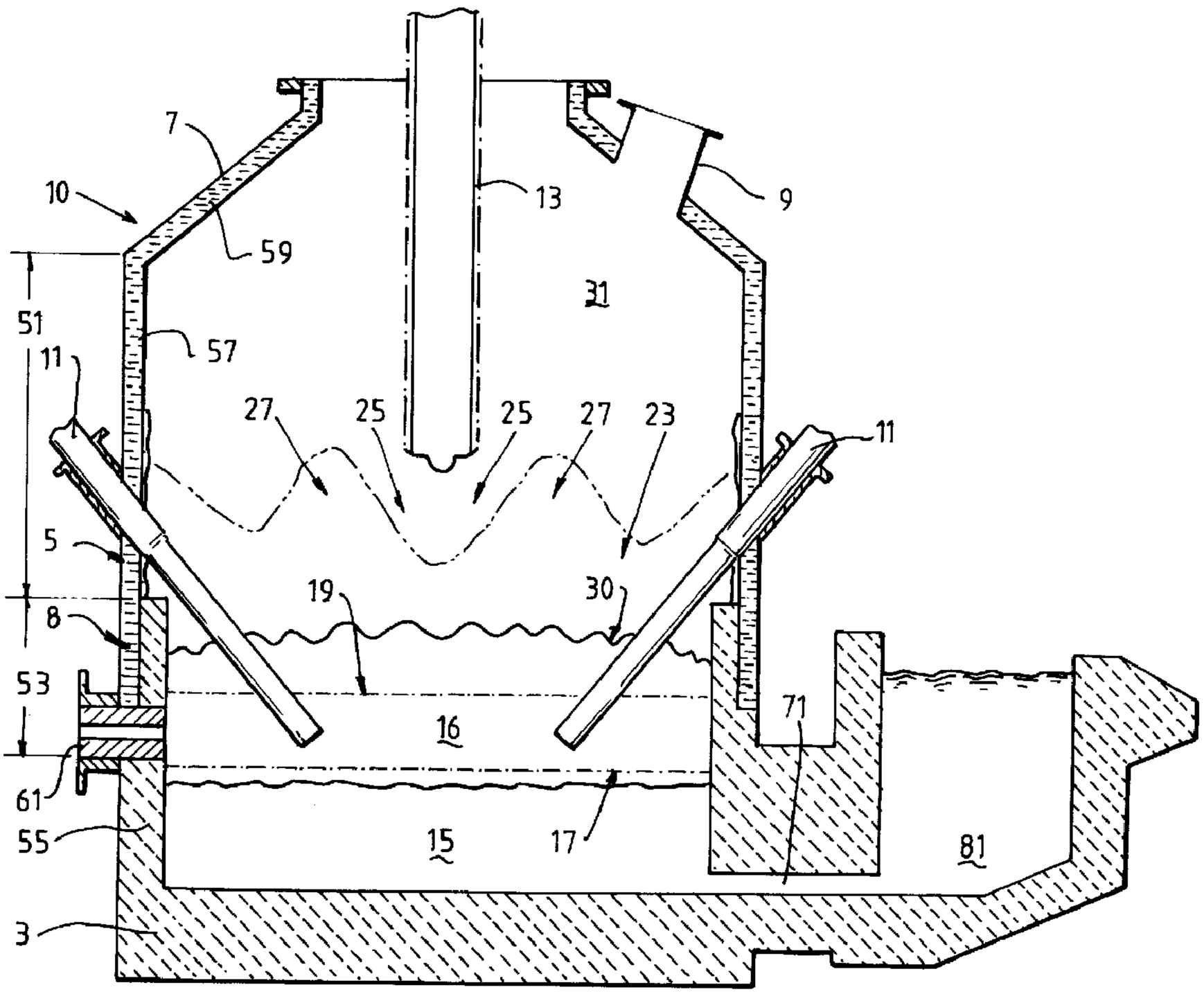
(51) Cl.Int./Int.Cl. *C21B 11/00* (2006.01), *C21B 13/00* (2006.01), *C21C 5/56* (2006.01), *C22B 9/00* (2006.01), *F27B 1/16* (2006.01), *C22B 7/02* (2006.01)

(72) Inventeur/Inventor:
BATTERHAM, ROBIN JOHN, AU

(73) Propriétaire/Owner:
TECHNOLOGICAL RESOURCES PTY. LTD., AU

(74) Agent: OGILVY RENAULT LLP/S.E.N.C.R.L.,S.R.L.

(54) Titre : PROCEDE DE FUSION DIRECTE
(54) Title: A DIRECT SMELTING PROCESS



(57) Abrégé/Abstract:
A direct smelting process and a fixed, ie non-rotatable, metallurgical vessel for producing metal from a metalliferous feed material is disclosed. The process is a molten bath-based process which includes injecting solid feed materials with a carrier gas into the

CA 2320654 C 2010/05/11

(11)(21) 2 320 654

(13) C

(57) Abrégé(suite)/Abstract(continued):
molten bath via one or more downwardly extending lance/tuyere (11) and causing gas flow from the molten bath at a flow rate of at least 0.30 $Nm^3/s/m^2$ at the interface between the metal layer (15) and the slag layer (16) of the molten bath (under quiescent conditions).

A B S T R A C T

A direct smelting process and a fixed, ie non-rotatable, metallurgical vessel for producing metal from a metalliferous feed material is disclosed. The process is a molten bath-based process which includes injecting solid feed materials with a carrier gas into the molten bath via one or more downwardly extending lance/tuyere (11) and causing gas flow from the molten bath at a flow rate of at least 0.30 $Nm^3/s/m^2$ at the interface between the metal layer (15) and the slag layer (16) of the molten bath (under quiescent conditions).

A DIRECT SMELTING PROCESS

The present invention relates to a process for producing molten metal (which term includes metal alloys), in particular although by no means exclusively iron, from metalliferous feed material, such as ores, partially reduced ores and metal-containing waste streams, in a metallurgical vessel containing a molten bath.

The present invention relates particularly to a molten metal bath-based direct smelting process for producing molten metal from a metalliferous feed material.

The most widely used process for producing molten iron is based on the use of a blast furnace. Solid material is charged into the top of the furnace and molten iron is tapped from the hearth. The solid material includes iron ore (in sinter, lump or pellet form), coke, and fluxes and forms a permeable burden that moves downwardly. Preheated air, which may be oxygen enriched, is injected into the bottom of the furnace and moves upwardly through the permeable bed and generates carbon monoxide and heat by combustion of coke. The result of these reactions is to produce molten iron and slag.

A process that produces iron by reduction of iron ore below the melting point of the iron produced is generally classified as a "direct reduction process" and the product is referred to as DRI.

The FIOR (Fluid Iron Ore Reduction) process is an example of direct reduction process. The process reduces iron ore fines as the fines are gravity-fed through each reactor in a series of fluid bed reactors. The fines are reduced in solid state by compressed reducing gas that

enters the bottom of the lowest reactor in the series and flows counter-current to the downward movement of fines.

Other direct reduction processes include moving shaft furnace-based processes, static shaft furnace-based processes, rotary hearth-based processes, rotary kiln-based processes, and retort-based processes.

The COREX process includes a direct reduction process as one stage. The COREX process produces molten iron directly from coal without the blast furnace requirement of coke. The COREX process includes 2-stage operation in which:

(a) DRI is produced in a shaft furnace from a permeable bed of iron ore (in lump or pellet form) and fluxes; and

(b) the DRI is then charged without cooling into a connected melter gasifier and melted.

Partial combustion of coal in the fluidised bed of the melter gasifier produces reducing gas for the shaft furnace.

Another known group of processes for producing iron is based on cyclone converters in which iron ore is melted by combustion of oxygen and reducing gas in an upper melting cyclone and is smelted in a lower smelter containing a bath of molten iron. The lower smelter generates the reducing gas for the upper melting cyclone.

A process that produces molten metal directly from ores (and partially reduced ores) is generally referred to as a "direct smelting process".

One known group of direct smelting processes is

based on the use of electric furnaces as the major source of energy for the smelting reactions.

Another known direct smelting process, which is generally referred to as the Romelt process, is based on the use of a large volume, highly agitated slag bath as the medium for smelting top-charged metal oxides to metal and for post-combusting gaseous reaction products and transferring the heat as required to continue smelting metal oxides. The Romelt process includes injection of oxygen enriched air or oxygen into the slag via a lower row of tuyeres to provide slag agitation and injection of oxygen into the slag via an upper row of tuyeres to promote post-combustion. In the Romelt process the metal layer is not an important reaction medium.

Another known group of direct smelting processes that are slag-based is generally described as "deep slag" processes. These processes, such as DIOS and AISI processes, are based on forming a deep layer of slag. As with the Romelt process, the metal layer below the slag layer is not an important reaction medium.

Another known direct smelting process which relies on a molten metal layer as a reaction medium, and is generally referred to as the HIsmelt process, is described in International application PCT/AU96/00197 (WO 96/31627) in the name of the applicant.

The HIsmelt process as described in the International application comprises:

(a) forming a molten bath having a metal layer and a slag layer on the metal layer in a vessel;

(b) injecting into the bath:

(i) a metalliferous feed material, typically metal oxides; and

(ii) a solid carbonaceous material, typically coal, which acts as a reductant of the metal oxides and a source of energy; and

(c) smelting the metalliferous feed material to metal in the metal layer.

The HIsmelt process also comprises post-combusting reaction gases, such as CO and H_2, released from the bath in the space above the bath with oxygen-containing gas and transferring the heat generated by the post-combustion to the bath to contribute to the thermal energy required to smelt the metalliferous feed materials.

The HIsmelt process also comprises forming a transition zone above the nominal quiescent surface of the bath in which there are ascending and thereafter descending droplets or splashes or streams of molten metal and slag which provide an effective medium to transfer to the bath the thermal energy generated by post-combusting reaction gases above the bath.

A preferred form of the HIsmelt process is characterized by forming the transition zone by injecting carrier gas, metalliferous feed material, solid carbonaceous material and optionally fluxes into the bath through lances that extend downwardly and inwardly through side walls of the vessel so that the carrier gas and the solid material penetrate the metal layer and cause molten material to be projected from the bath.

This form of the HIsmelt process is an improvement over earlier forms of the process which form

the transition zone by bottom injection of carrier gas and solid carbonaceous material through tuyeres into the bath which causes droplets, splashes and streams of molten material to be projected from the bath.

The applicant has carried out extensive pilot plant work on the above-described preferred form of the HIsmelt process and has made a series of significant findings in relation to the process.

One of the findings made by the applicant, which forms the basis of the present invention, is that the upward flow rate of bath-derived gas caused by the injection of solid material/carrier gas into the molten bath should be at least 0.30 $Nm^3/s/m^2$ at the location of the interface of the metal layer and the slag layer (under quiescent conditions) to establish the transition zone so that there is heat transfer to the molten bath at an effective rate.

Heat transfer efficiency is a measure of the amount of the available energy generated by post combustion that is transferred to the molten bath. It is also a measure of the amount of the available energy generated by post combustion that is lost from the vessel (via discharge of off-gas above bath temperature and heat transfer via the side walls and roof of the vessel).

The minimum bath-derived gas flow rate of 0.30 $Nm^3/s/m^2$ at the interface of the metal layer and the slag layer (under quiescent conditions) ensures that there is sufficient buoyancy uplift of splashes, droplets and streams of molten material from the molten bath into the transition zone to maximise:

(a) heat transfer to the molten bath via subsequently descending splashes, droplets

and streams of molten material; and

(b) contact of molten material with the side walls of the vessel which forms a protective layer of slag that reduces heat loss from the vessel.

Item (b) above is a particularly important consideration in the context of the preferred vessel construction of the present invention which includes water cooled panels that form the side walls in the upper barrel section and optionally the roof and water-cooled refractory bricks that form the side walls in the lower barrel section of the vessel.

In general terms, the present invention is a direct smelting process for producing metal from a metalliferous feed material in a fixed metallurgical vessel having side walls, which process includes the steps of:

(a) forming a molten bath of molten material, the molten bath having a metal layer and a slag layer on the metal layer in the vessel;

(b) injecting at least one among the metalliferous feed material and a solid carbonaceous material with a carrier gas into the molten bath via one or more than one downwardly extending first lance/tuyere and smelting the metalliferous material in the molten bath, whereby solids and gas injection causes a gas flow from the molten bath at a flow rate of at least 0.50 $Nm^3/s/m^2$ at a location of an interface between the metal layer and the slag layer, which gas flow entrains some of the molten material in the molten bath and carries the entrained molten material upwardly as splashes, droplets and

streams and forms a transition zone in a gas continuous space in the vessel above the slag layer, whereby the splashes, the droplets and the streams of the molten material contact the side walls of the vessel and form a protective layer of slag; and

(c) injecting an oxygen-containing gas into the vessel via one or more than one second lance/tuyere and post-combusting reaction gases released from the molten bath, whereby the splashes, the droplets and the streams ascend and thereafter descend to facilitate heat transfer to the molten bath, and whereby the transition zone minimises radiation heat loss from the vessel via the side walls in contact with the transition zone.

The above-described gas flow rate of at least 0.30 $Nm^3/s/m^2$ at the location of the interface of the metal layer and the slag layer (under quiescent conditions) is a substantially higher bath-derived gas flow rate than the Romelt process and the deep-slag process such as the DIOS and AISI processes described above and is a significant difference between the process of the present invention and these known direct smelting processes.

By way of particular comparison, US patent 5,078,785 of Ibaraki et al (assigned to Nippon Steel Corporation) discloses a particular form of a deep-slag process using a rotatable vessel and discloses bottom injection of gas into a metal layer for the purpose of metal bath agitation. The paragraph commencing at line 17 of column 14 discloses that it is preferred that the "metal bath agitation force" generated by the bottom gas injection be no more than 6kW/t. The US patent discloses that at

higher levels of agitation there may be undesirably high levels of iron dust generation. On the basis of the information provided in the paragraph commencing at line 21 of column 14, a maximum metal bath agitation force of 6kW/t corresponds to a maximum bath-derived gas flow rate of 0.12 $Nm^3/s/m^2$ at the interface between the metal layer and the slag layer. This maximum gas flow rate is considerably below the minimum flow rate of 0.30 $Nm^3/s/m^2$ of the present invention.

Preferably the process includes smelting metalliferous material to metal mainly in the metal layer.

Preferably the solids and gas injection in step (b) causes gas flow from the molten bath substantially across the interface between the metal layer and the metal slag layer (under quiescent conditions).

Preferably the gas flow rate is at least 0.35 $Nm^3/s/m^2$, more preferably at least 0.50 $Nm^3/s/m^2$, at the location of the interface between the metal layer and the slag layer (under quiescent conditions).

Preferably the gas flow rate is less than 0.90 $Nm^3/s/m^2$ at the location of the interface between the metal layer and the slag layer (under quiescent conditions).

Typically, the splashes, droplets and streams of molten material entrain further molten material (particularly slag) as they move upwardly.

Typically, slag is a major part and molten metal is the remaining part of the molten material in the splashes, droplets and streams of molten material.

The term "smelting" is understood herein to mean thermal processing wherein chemical reactions that reduce

metal oxides take place to produce liquid metal.

The term "metal layer" is understood herein to mean that region of the bath that is predominantly metal. Specifically, the term covers a region or zone that includes a dispersion of molten slag in a metal continuous volume.

The term "slag layer" is understood herein to mean that region of the bath that is predominantly slag. Specifically, the term covers a region or zone that includes a dispersion of molten metal in a slag continuous volume.

Preferably the transition zone extends above the slag layer.

It is preferred that the level of dissolved carbon in metal be greater than 4 wt%.

It is preferred that the concentration of FeO in the slag layer be below 5 wt%.

It is preferred that the process further comprises selecting the amount of the solid carbonaceous material injected into the molten bath to be greater than that required for smelting the metalliferous feed and for generating heat to maintain reaction rates such that dust entrained in off-gas leaving the vessel contains at least some excess carbon.

It is preferred that the concentration of solid carbon in dust in off-gas from the vessel be in the range of 5 to 90 wt% (more preferably 20 to 50 wt%) of the weight of dust in the off-gas at a rate of dust generation of 10-50g/Nm^3 in the off-gas.

The injection of metalliferous material and carbonaceous material may be through the same lance/tuyere or separate lances/tuyeres.

The transition zone is quite different to the slag layer. By way of explanation, under stable operating conditions of the process the slag layer comprises gas bubbles in a liquid continuous volume whereas the transition zone comprises splashes, droplets, and streams of molten material, predominantly slag, in a gas continuous volume.

Preferably step (c) of the process post-combusts reaction gases, such as carbon monoxide and hydrogen, generated in the molten bath, in a top space (including the transition zone) above the surface of the molten bath and transfers the heat generated by the post-combustion to the molten bath to maintain the temperature of the molten bath - as is essential in view of endothermic reactions in the molten bath.

Preferably the one or more than one oxygen-containing gas injection lance/tuyere is positioned to inject the oxygen-containing gas into a central region of the vessel.

The oxygen-containing gas may be oxygen, air or oxygen enriched air containing up to 40% oxygen by volume.

Preferably the oxygen-containing gas is air.

More preferably the air is pre-heated.

Typically, the air is preheated to 1200°C.

The air may be oxygen enriched.

Preferably step (c) of the process operates at high levels, ie at least 40%, of post-combustion, where post-combustion is defined as:

$$\frac{[CO_2] + [H_2O]}{[CO_2] + [H_2O] + [CO] + [H_2]}$$

where:

$[CO_2]$ = volume % of CO_2 in off-gas;
$[H_2O]$ = volume % of H_2O in off-gas;
$[CO]$ = volume % of CO in off-gas; and
$[H_2]$ = volume % of H_2 in off-gas.

In some instances a supplementary source of solid or gaseous carbonaceous material (such as coal or natural gas) may be injected into the off-gas from the vessel in order to capture thermal energy in the form of chemical energy.

An example of such supplementary injection of carbonaceous material is injection of natural gas which cracks and reforms, and thus cools, the off-gas whilst enriching its fuel value.

The supplementary carbonaceous material may be added in the upper reaches of the vessel or in the off-gas duct after the off-gas has left the vessel.

Preferably the process operates at a post-combustion greater than 50%, more preferably greater than 60%.

Preferably, the one or more than one lance/tuyere extend through the side walls of the vessel and are angled downwardly and inwardly towards the metal layer.

Preferably the location and operating parameters of the one or more than one lance/tuyere that injects the oxygen-containing gas and the operating parameters that control the transition zone are selected so that:

(a) the oxygen-containing gas is injected towards and penetrates the transition zone;

(b) the transition zone extends upwardly around the lower section of the or each lance/tuyere and thereby shields to some degree the side walls of the vessel from the combustion zone generated at the end of the or each lance/tuyere; and

(c) there is gas continuous space described as a "free space" which contains practically no metal and slag around the end of the or each lance/tuyere.

Item (c) above is an important feature because it makes it possible for reaction gases in the top space of the vessel to be drawn into the region at the end of the or each lance/tuyere and be post-combusted in the region.

Preferably the process maintains a relatively high (but not too high) slag inventory and uses the amount of slag as a means of controlling the process.

The term "relatively high slag inventory" may be understood in the context of the amount of slag compared to the amount of metal in the vessel.

Preferably, when the process is operating under stable conditions, the weight ratio of metal:slag is between 4:1 and 1:2.

More preferably the weight ratio of metal:slag is between 3:1 and 1:1.

It is preferred particularly that the metal:slag weight ratio be between 2:1 and 1:1.

The term relatively high slag inventory may also be understood in the context of the depth of slag in the vessel.

Preferably the process includes maintaining the high slag inventory by controlling the slag layer to be 0.5 to 4 metres deep under stable operating conditions.

More preferably the process includes maintaining the high slag inventory by controlling the slag layer to be 1.5 to 2.5 metres deep under stable operating conditions.

It is preferred particularly that the process includes maintaining the high slag inventory by controlling the slag layer to be at least 1.5 metres deep under stable operating conditions.

The amount of slag in the slag layer of the molten bath has a direct impact on the amount of slag that is in the slag-rich transition zone.

The slag is important in the context of minimising heat loss via radiation from the transition zone to the side walls of the vessel.

If the slag inventory is too low there will be increased exposure of metal in the slag-rich transition zone and therefore increased oxidation of metal and the potential for reduced post-combustion.

If the slag inventory is too high then the one or

more than one oxygen-containing gas injection lance/tuyere become buried in the transition zone and this minimises movement of top space reaction gases to the end of the or each lance/tuyere and, as a consequence, reduces potential for post-combustion.

According to the present invention there is provided a fixed, ie non-rotatable, vessel which produces metal from a metalliferous feed material by a direct smelting process, which vessel contains a molten bath having a metal layer and a slag layer on the metal layer and has a gas continuous space above the slag layer, which vessel includes:

(a) a shell;

(b) a hearth formed of refractory material having a base and sides in contact with the molten bath;

(c) side walls which extend upwardly from the sides of the hearth and are in contact with the slag layer and the gas continuous space, wherein the side walls that contact the gas continuous space include water cooled panels and a layer of slag on the panels;

(d) one or more than one lance/tuyere extending downwardly into the vessel and injecting an oxygen-containing gas into the vessel above the metal layer;

(e) one or more than one downwardly and inwardly extending lance/tuyere injecting at least part of the metalliferous feed material and/or a carbonaceous material with a carrier gas into the molten bath so as to

generate bath-derived gas flow at a rate of at least 0.30 $Nm^3/s/m^2$ at the location of the interface between the metal layer and the slag layer (under quiescent conditions) and resultant buoyancy uplift of molten material from the metal layer and the slag layer;

(f) a transition zone formed by ascending and thereafter descending splashes, droplets and streams of molten material in the gas continuous space above the slag layer with some of these splashes, droplets and streams contacting the side walls of the vessel and forming a layer of molten material on the side walls; and

(g) a means for tapping molten metal and slag from the vessel.

Preferably the solids and gas injection via the lance/tuyere or lances/tuyeres generates gas flow from the molten bath substantially across the interface between the metal layer and the slag layer (under quiescent conditions).

Preferably the vessel includes a cylindrical hearth and side walls which form a cylindrical barrel extending from the hearth.

The metalliferous feed material may be any suitable material and in any suitable form. A preferred metalliferous feed material is an iron containing material. The iron-containing material may be in the form of ores, partially reduced ores, DRI (direct reduced iron), iron carbide, millscale, blast furnace dust, sinter fines, BOF dust or a mixture of such materials.

In the case of partially reduced ores, the degree of pre-reduction may range from relatively low levels (eg to FeO) to relatively high levels (eg 70 to 95% metallisation).

In this connection, the process further includes partially reducing metalliferous ores and thereafter injecting the partially reduced ores into the molten bath.

The metalliferous feed material may be pre-heated.

The carrier gas may be any suitable carrier gas.

It is preferred that the carrier gas be an oxygen-deficient gas.

It is preferred that the carrier gas comprise nitrogen.

The present invention is described further by way of example with reference to the accompanying drawings of which:

Figure 1 is a vertical section through a metallurgical vessel illustrating in schematic form a preferred embodiment of the process of the present invention;

Figure 2 is a graph of heat transfer efficiency vs flow rate of bath derived gases for campaign 8.1 of the pilot plant work carried out by the applicant; and

Figure 3 is a graph of heat transfer efficiency vs flow rate of bath derived gases for campaign 8.2 of the pilot plant.

The following description is in the context of smelting iron ore to produce molten iron and it is understood that the present invention is not limited to this application and is applicable to any suitable metallic ores and/or concentrates - including partially reduced metallic ores and waste revert materials.

The vessel 10 shown in Figure 1 is a fixed, is non-rotatable, vessel that has a cylindrical hearth that includes a base 3 and sides 55 formed from refractory bricks; side walls 5 which form a generally cylindrical barrel extending upwardly from the sides 55 of the hearth and which include an upper barrel section 51 and a lower barrel section 53; a roof 7; an outlet 9 for off-gases; a forehearth 81 which can discharge molten iron continuously; a forehearth connection 71 that interconnects the hearth and the forehearth 81; and a tap-hole 61 for discharging molten slag.

In use, the vessel 10 contains a molten bath of iron and slag which includes a layer 15 of molten iron and a layer 16 of molten slag on the metal layer 15. The arrow marked by the numeral 17 indicates the position of the nominal quiescent surface of the metal layer 15 and the arrow marked by the numeral 19 indicates the position of nominal quiescent surface of the slag layer 16. The term "quiescent surface" is understood to mean the surface when there is no injection of gas and solids into the vessel 10.

The vessel 10 also includes 2 solids injection lances/tuyeres 11 extending downwardly and inwardly at an angle of 30-60° to the vertical through the side walls 5 and into the slag layer 16. The position of the lances/tuyeres 11 is selected so that the lower ends are above the quiescent surface 17 of the iron layer 15 under steady-state process conditions.

In use, iron ore, solid carbonaceous material (typically coal), and fluxes (typically lime and magnesia) entrained in a carrier gas (typically N_2) are injected into the metal layer 15 via the lances/tuyeres 11. The momentum of the solid material/carrier gas causes the solid material and gas to penetrate the metal layer 15. The coal is devolatilised and thereby produces gas in the metal layer 15. Carbon partially dissolves into the metal and partially remains as solid carbon. The iron ore is smelted to metal and the smelting reaction generates carbon monoxide gas. The gases transported into the metal layer 15 and generated via devolatilisation and smelting produce significant buoyancy uplift of molten metal, solid carbon, and slag (drawn into the metal layer 15 as a consequence of solid/gas/injection) from the metal layer 15 which generates an upward movement of splashes, droplets and streams of molten material, and these splashes, and droplets, and streams entrain slag as they move through the slag layer 16.

The applicant has found in the pilot plant work that generating gas flow from the molten bath at a rate of at least 0.30 $Nm^3/s/m^2$ of the area of the metal layer 15 at the quiescent metal level 17 (ie at the interface of the metal layer 15 and the slag layer 16 under quiescent conditions), preferably substantially across the area, causes substantial agitation in the metal layer 15 and the slag layer 16, with the result that:

(a) the slag layer 16 expands in volume and has a surface indicated by the arrow 30; and

(b) the metal layer 15 and the slag layer 16 are each substantially homogenous in that there are reasonably uniform temperatures throughout each layer, typically, 1450-

1550°C and reasonably uniform compositions throughout each layer.

In addition, the applicant has found in the pilot plant work that the above-described gas flow rate and resultant buoyancy uplift of molten material and solid carbon produces:

(a) forms a transition zone 23; and

(b) projects some molten material (predominantly slag) beyond the transition zone and onto the part of the upper barrel section 51 of the side walls 5 that is above the transition zone 23 and onto the roof 7.

In general terms, the slag layer 16 is a liquid continuous volume, with gas bubbles therein, and the transition zone 23 is a gas continuous volume with splashes, droplets, and streams of molten metal and slag.

The vessel further includes a lance 13 for injecting an oxygen-containing gas (typically pre-heated oxygen enriched air) which is centrally located and extends vertically downwardly into the vessel. The position of the lance 13 and the gas flow rate through the lance 13 are selected so that under steady-state process conditions the oxygen-containing gas penetrates the central region of the transition zone 23 and maintains an essentially metal/slag free space 25 around the end of the lance 13.

In use, the injection of the oxygen-containing gas via the lance 13 post-combusts reaction gases CO and H_2 in the transition zone 23 and in the free space 25 around the end of the lance 13 and generates high temperatures of the order of 2000°C or higher in the gas space. The heat is transferred to the ascending and descending splashes

droplets, and streams, of molten material in the region of gas injection and the heat is then partially transferred to the iron layer 15 when the metal/slag returns to the iron layer 15.

The free space 25 is important to achieving high levels of post combustion, ie more than 40%, because it enables entrainment of gases in the space above the transition zone 23 into the end region of the lance 13 and thereby increases exposure of available reaction gases to post combustion.

The combined effect of the position of the lance 13, gas flow rate through the lance 13, and upward movement of splashes, droplets and streams of molten material is to shape the transition zone 23 around the lower region of the lance 13 - generally identified by the numerals 27. This shaped region provides a partial barrier to heat transfer by radiation to the side walls 5.

Moreover, the ascending and descending droplets, splashes and streams of molten material is an effective means of transferring heat from the transition zone 23 to the molten bath with the result that the temperature of the transition zone 23 in the region of the side walls 5 is of the order of 1450°C-1550°C.

The vessel is constructed with reference to the levels of the metal layer 15, the slag layer 16, and the transition zone 23 in the vessel when the process is operating under steady-state process conditions and with reference to splashes, droplets and streams of molten material that are projected into the top space 31 above the transition zone 23 when the process is operating under steady-state operating conditions, so that:

(a) the hearth and the lower barrel section 53

of the side walls 5 that contact the metal/slag layers 15/16 are formed from bricks of refractory material (indicated by the cross-hatching in the figure);

(b) at least part of the lower barrel section 53 of the side walls 5 is backed by water cooled panels 8; and

(c) the upper barrel section 51 of the side walls 5 and the roof 7 that contact the transition zone 23 and the top space 31 are formed from water cooled panels 57, 59.

Each of the water cooled panels 8, 57, 59 has parallel upper and lower edges and parallel side edges and is curved so as to define a section of the cylindrical barrel. Each panel includes an inner water cooling pipe and an outer water cooling pipe. The pipes are formed into a serpentine configuration with horizontal sections interconnected by curved sections. Each pipe further includes a water inlet and a water outlet. The pipes are displaced vertically so that the horizontal sections of the outer pipe are not immediately behind the horizontal sections of the inner pipe when viewed from an exposed face of the panel, ie the face that is exposed to the interior of the vessel. Each panel further includes a rammed refractory material which fills the spaces between the adjacent straight sections of each pipe and between the pipes.

The water inlets and the water outlets of the pipes are connected to a water supply circuit (not shown) which circulates water at high flow rate through the pipes.

The pilot plant work referred to above was carried out as a series of extended campaigns by the

applicant at its pilot plant at Kwinana, Western Australia.

The pilot plant work was carried out with the vessel shown in Figure 1 and described above and in accordance with the process conditions described above. In particular, the process operated with continuous discharge of molten iron via the forehearth 81 and periodic tapping of molten slag via the tap-hole 61. In the context of the present invention it is relevant to note that the hearth diameter was 2.74 m.

The pilot plant work evaluated the vessel and investigated the process under a wide range of different:

(a) feed materials;

(b) solids and gas injection rates;

(c) slag inventories - measured in terms of the depth of the slag layer and the slag:metal ratios;

(d) operating temperatures; and

(e) apparatus set-ups.

Figures 2 and 3 are graphs which plot the relationship between heat transfer efficiency (HTE-TS) and the flow rate of bath derived gases (expressed as kNm^3/h) for two of the pilot plant campaigns.

The heat transfer efficiency is the amount of energy generated by post combustion that is transferred to the molten bath divided by the total amount of energy generated by post combustion, expressed as a percentage. If the off-gas is substantially at bath temperature, it is fair to say that high heat transfer efficiencies are an indication of

low heat loss from the vessel (which occurs principally via the side walls).

It is evident from Figures 2 and 3 that there were sharp increases in heat transfer efficiency at bath-derived gas flow rates of approximately 7.5 kNm^3/h. This amount corresponds to 0.32 $Nm^3/s/m^2$ at the interface between the metal layer 15 and the slag layer 16 of the vessel under quiescent conditions.

Many modifications may be made to the preferred embodiment of the present invention described without departing from the spirit and scope theory.

Whilst the preferred embodiment of the present invention generates bath-derived gas flow from the metal layer due to solid material/carrier gas injection through the lances/tuyeres 11, the present invention extends to arrangements in which there is a minor contribution to bath-derived gas flow by bottom/side injection of gas.

CLAIMS:

1. A direct smelting process for producing metal from a metalliferous feed material in a fixed metallurgical vessel having side walls, which process includes the steps of:

(a) forming a molten bath of molten material, the molten bath having a metal layer and a slag layer on the metal layer in the vessel;

(b) injecting at least one among the metalliferous feed material and a solid carbonaceous material with a carrier gas into the molten bath via one or more than one downwardly extending first lance/tuyere and smelting the metalliferous material in the molten bath, whereby solids and gas injection causes a gas flow from the molten bath at a flow rate of at least 0.50 $Nm^3/s/m^2$ at a location of an interface between the metal layer and the slag layer, which gas flow entrains some of the molten material in the molten bath and carries the entrained molten material upwardly as splashes, droplets and streams and forms a transition zone in a gas continuous space in the vessel above the slag layer, whereby the splashes, the droplets and the streams of the molten material contact the side walls of the vessel and form a protective layer of slag; and

(c) injecting an oxygen-containing gas into the vessel via one or more than one second lance/tuyere and post-combusting reaction gases released from the molten bath, whereby the

splashes, the droplets and the streams ascend and thereafter descend to facilitate heat transfer to the molten bath, and whereby the transition zone minimises radiation heat loss from the vessel via the side walls in contact with the transition zone.

2. The process defined in claim 1 wherein the metalliferous material is smelted to metal mainly in the metal layer.

3. The process defined in claim 1 or 2 wherein the solids and gas injection in step (b) causes the gas flow from the molten bath substantially across the interface between the metal layer sad the metal slag layer.

4. The process defined in any one of claims 1 to 3 wherein the transition zone extends above the slag layer.

5. The process defined in any one of claims 1 to 4 wherein metal dissolved carbon is at a level that is greater than 4 wt%.

6. The process defined in any one of claims 1 to 5 wherein a concentration of FeO in the slag layer is below 5 wt%.

7. The process defined in any one of claims 1 to 6 wherein the process further includes selecting an amount of the solid carbonaceous material injected into the molten bath to be greater than that required for smelting the metalliferous feed material and for generating heat to maintain reaction rates such that dust entrained in off-gas leaving the vessel contains at least some excess solid carbon.

8. The process defined in claim 7 wherein a concentration of the solid carbon in the dust in the off-gas from the vessel is in a range of 5 to 90 wt% of the weight of the dust in the off-gas at a rate of generation of the dust of 10-50 g/Nm^3 in the off-gas.

9. The process defined in claim 8 wherein the concentration of the solid carbon in the dust in the off-gas from the vessel is between 20 and 50 wt%.

10. The process defined in any one of claims 1 to 9 wherein the injection of the metalliferous material and the carbonaceous material in step (b) is through the same first lance/tuyere or through separate ones of the first lances/tuyeres.

11. The process defined in any one of claims 1 to 10 wherein the oxygen-containing gas is oxygen, air or oxygen enriched air containing up to 40% oxygen by volume.

12. The process defined in any one of claims 7 to 9 wherein step (c) operates at at least 40% of post-combustion, where the post-combustion is defined as:

$$\frac{[CO_2]+[H_2O]}{[CO_2]+[H_2O]+[CO]+[H_2]}$$

where:

$[CO_2]$ = volume % of CO_2 in the off-gas;

$[H_2O]$ = volume % of H_2O in the off-gas;

[CO] = volume % of CO in the off-gas; and

$[H_2]$ = volume % of H_2 in the off-gas.

13. The process defined in any one of claims 1 to 12 wherein step (b) includes injecting the solids and gas into the molten bath via said one or more than one first

lance/tuyere that is extending through the side walls of the vessel and angled downwardly and inwardly towards the metal layer.

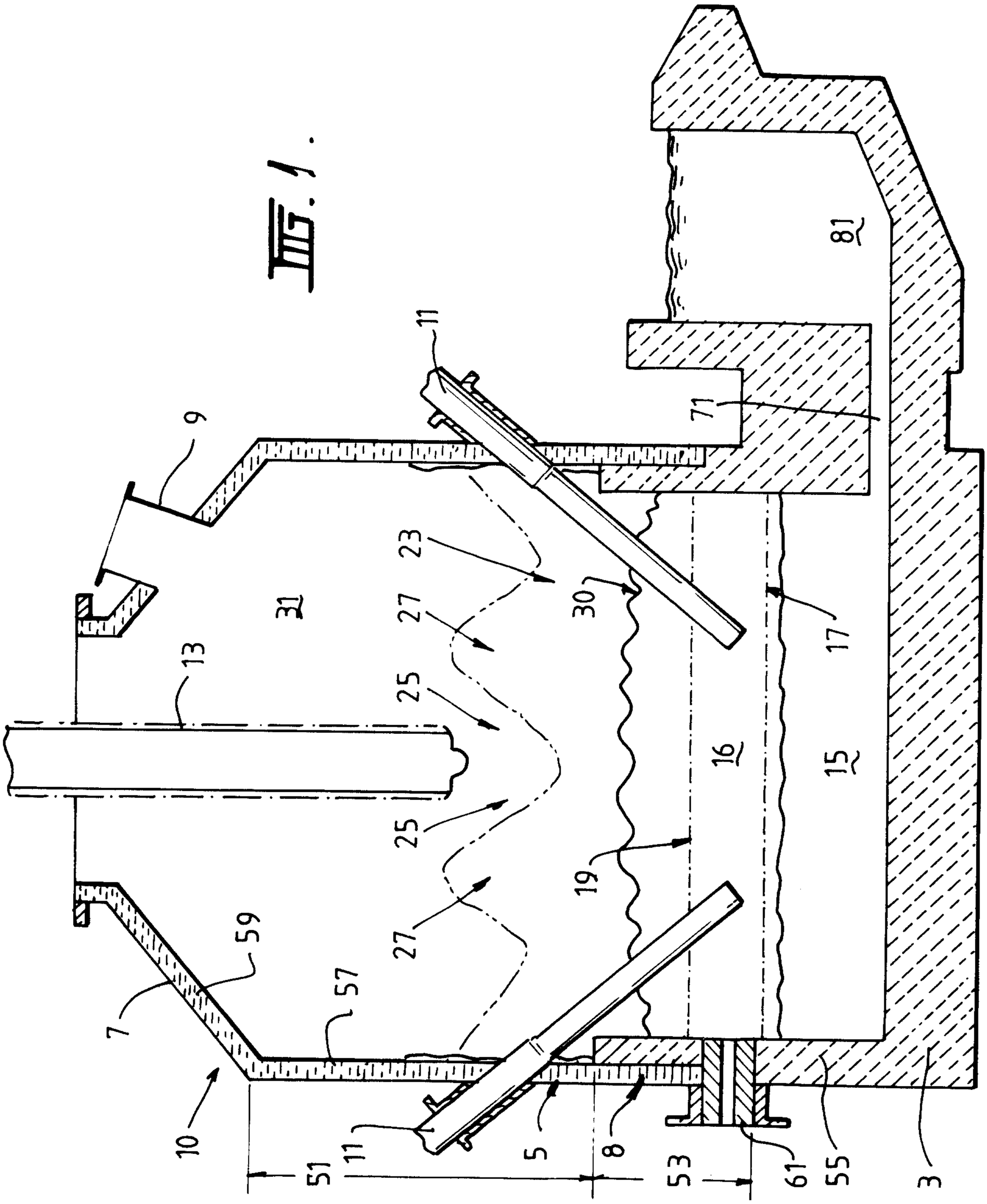
14. The process defined in any one of claims 1 to 13 wherein step (c) includes injecting the oxygen containing gas into the vessel via said one or more than one second lance/tuyere so that:

(a) the oxygen-containing gas is injected towards and penetrates the transition zone;

(b) the transition zone extends upwardly around a lower section of the or each second lance/tuyere and thereby shields to some degree the side walls of the vessel from a combustion zone generated at an end of the or each second lance/tuyere; and

(c) the gas continuous space described contains practically no metal and slag around the end of the or each second lance/tuyere.

FIG. 1


81
11
71
9
23
27
30
17
31
13
25
25
16
15
19
27
59
57
7
10
11
5
8
51
53
61
55
3

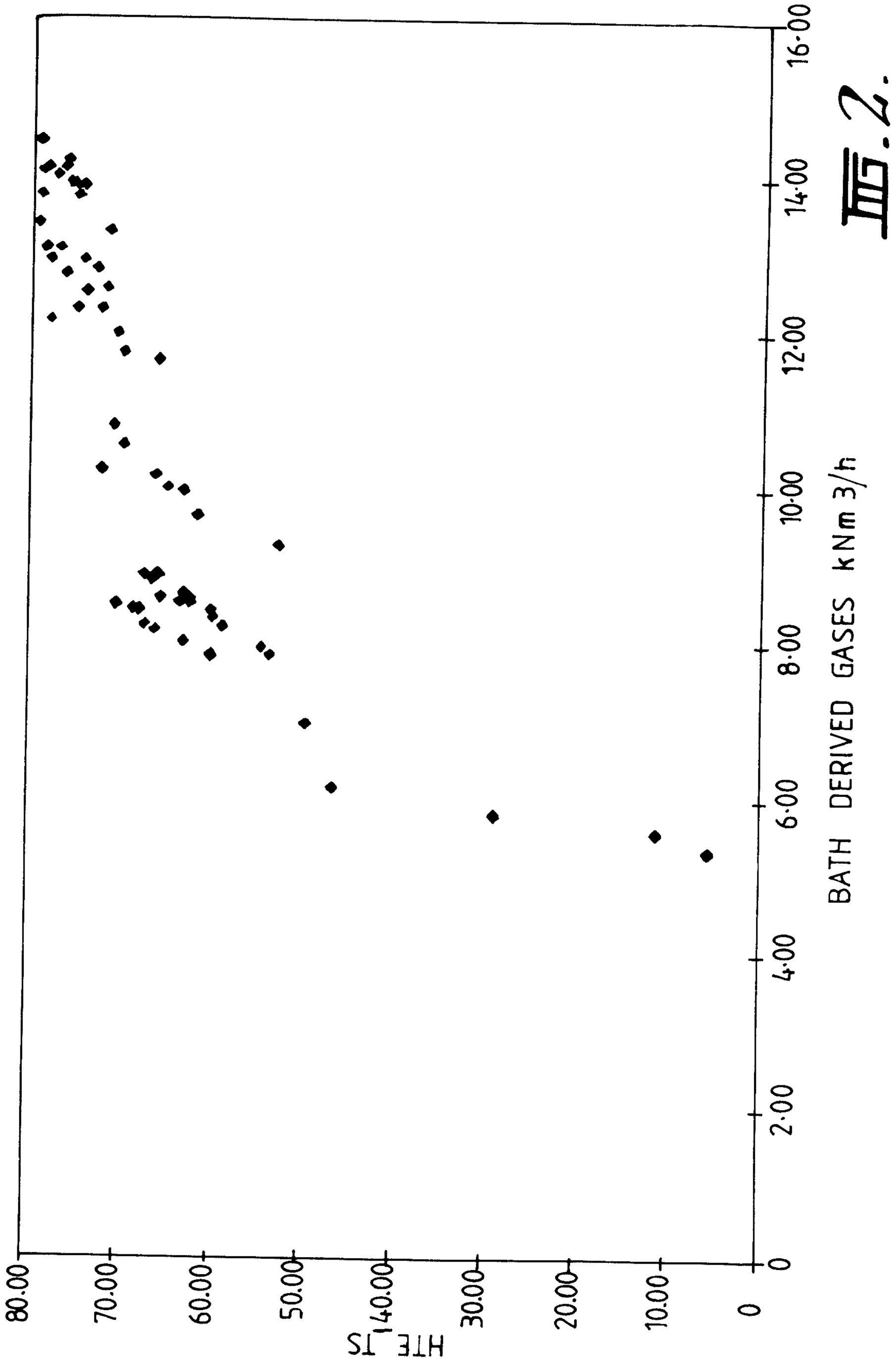
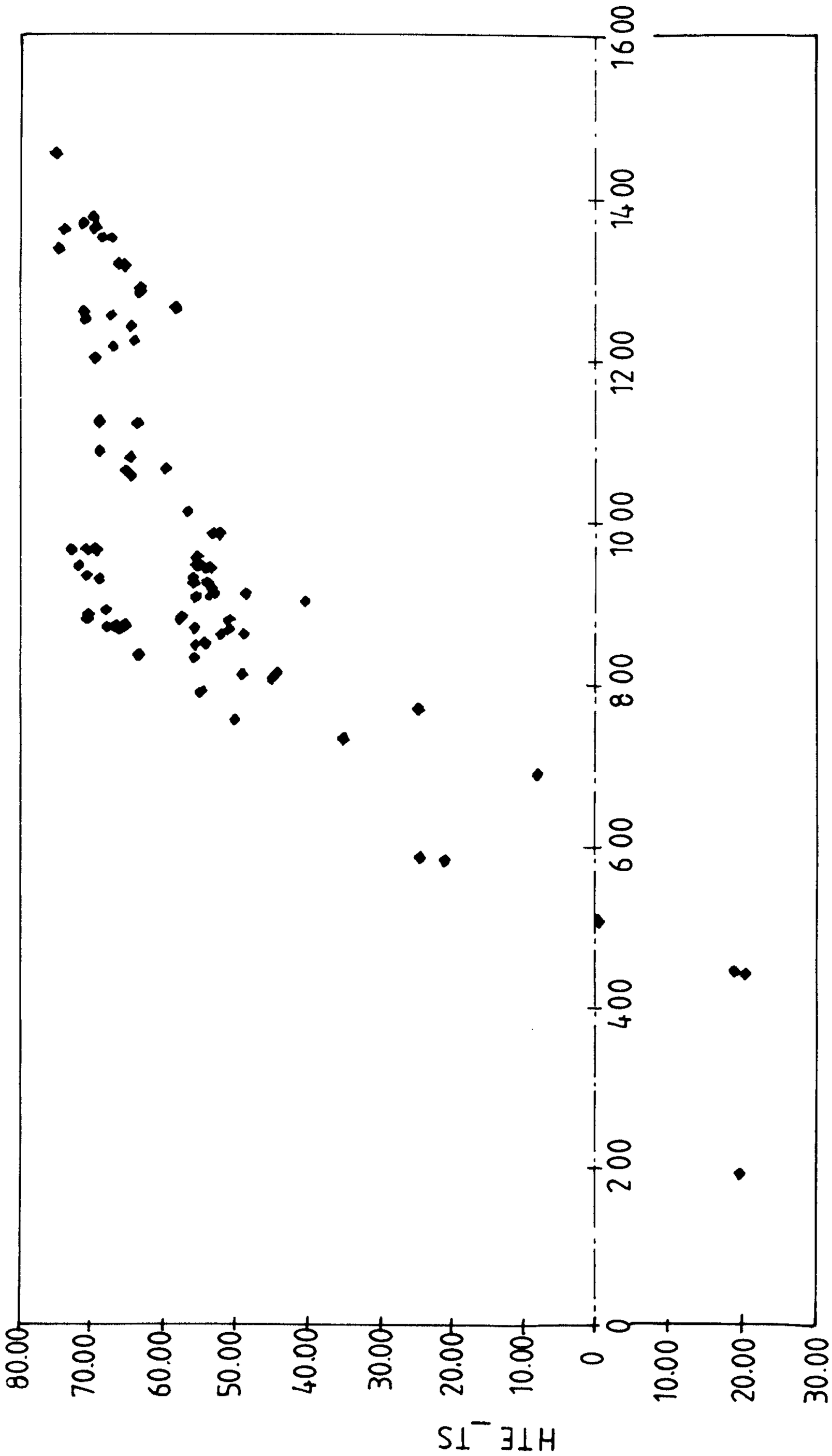
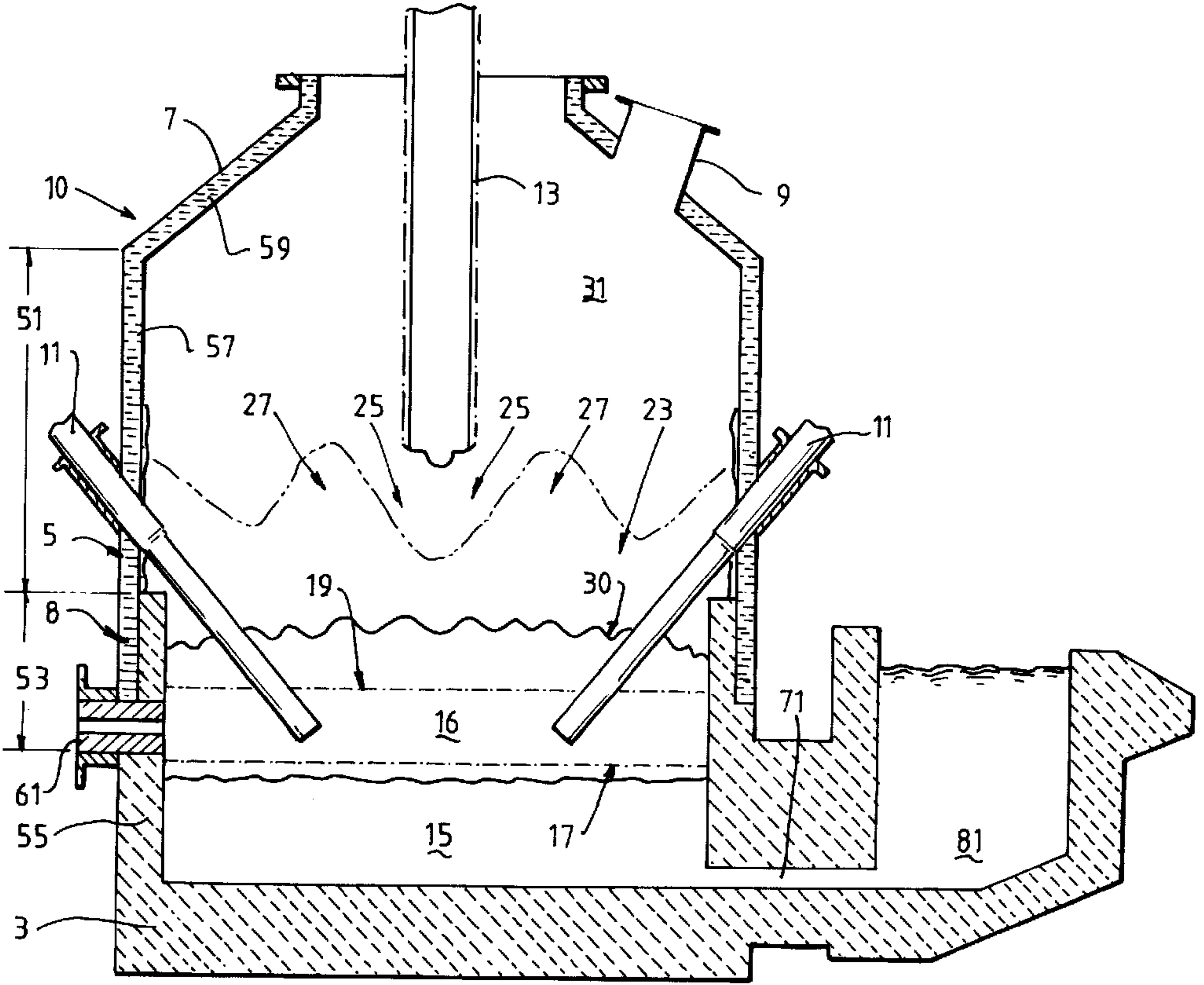

CAMPAIGN 8.1
BATH DERIVED GASES kNm 3/h
HTE TS
0
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00

FIG. 2.

3/3


FIG. 3.
CAMPAIGN 8-2
BATH DERIVED GASES kNm3/h
HTE_TS
1600
1400
1200
1000
800
600
400
200
0
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0
10.00
20.00
30.00


7
10
59
13
9
31
51
57
11
27
25
25
27
23
11
5
19
30
8
53
16
71
61
55
15
17
81
3