A direct smelting plant for producing molten metal from metalliferous feed material in a direct smelting process is disclosed. The plant includes a process controller for adjusting the volumetric flow rate of fuel gas supplied to a burner unit of at least one of the unit operations of the plant so as to at least meet selected requirements of the plant to operate the direct smelting process.
DIRECT SMELTING PLANT WITH WASTE HEAT RECOVERY UNIT

[0001] The present invention relates to a molten bath-based direct smelting plant and process for producing molten metal in a direct smelting vessel.

[0002] In particular, the present invention relates to recovering energy from off-gas released from a direct smelting vessel.

[0003] The present invention relates particularly, although by no means exclusively, to molten bath-based direct smelting processes for producing molten iron from iron-containing metalliferous feed material, such as iron ores, partly reduced iron ores and iron-containing waste streams (for example, from steelmaking plants).

[0004] A known molten bath-based direct smelting process is generally referred to as the Hmsmelt process. In the context of producing molten iron, the Hmsmelt process includes the steps of:

[0005] (a) forming a bath of molten iron and slag in a direct smelting vessel;
[0006] (b) injecting into the bath: (i) a metalliferous feed material, typically iron ore in the form of fines; and (ii) a solid carbonaceous material, typically coal, which acts as a reductant of the metalliferous feed material and a source of energy; and
[0007] (c) smelting metalliferous feed material to iron in the bath.

[0008] The term “smelting” is herein understood to mean thermal processing wherein chemical reactions that reduce metal oxides take place to produce molten metal.

[0009] In the Hmsmelt process, metalliferous feed material and solid carbonaceous material are injected into the molten bath through a number of lances/tuyeres which are inclined to the vertical so as to extend downwardly and inwardly through the side wall of the direct smelting vessel and into a lower region of the vessel so as to deliver at least part of the solids material into the metal layer in the bottom of the vessel. A blast of hot oxygen-containing gas, typically air or oxygen-enriched air, is injected into an upper region of the vessel through a downwardly extending lance to cause post-combustion of reaction gases released from the molten bath in the upper region of the vessel. Typically, in the case of producing molten iron, the hot air or oxygen-enriched air is at a temperature of the order of 1200°C and is generated in hot blast stoves. Off-gases resulting from the post-combustion of reaction gases in the vessel are taken away from the upper region of the vessel through an off-gas duct. The vessel includes refractory-lined water cooled panels in the side wall and the roof of the vessel, and water is circulated continuously through the panels in a continuous circuit.

[0010] The Hmsmelt process enables large quantities of molten iron, typically at least 0.5 Mt/a, to be produced by direct smelting in a single compact vessel.

[0011] However, in order to achieve high molten iron production rates in the Hmsmelt process it is necessary to (a) generate and transport large quantities of hot air or oxygen-enriched air and carrier gas (for solids injection) to the direct smelting vessel, (b) transport large quantities of the metalliferous feed material, such as iron-containing feed materials, to the vessel, including generating and transporting large quantities of carrier gas to the vessel (c) transport large quantities of hot off-gas from the vessel, (d) transport large quantities of molten iron and slag produced in the process away from the vessel, and (e) circulate large quantities of water through the water cooled panels—all within a relatively confined area.

[0012] In view of the above, high molten iron production rates require a Hmsmelt plant that includes (a) a pressurised direct smelting vessel and ancillary equipment such as lock hoppers for supplying solid feed materials to the vessel and pressure control equipment on the off-gas duct of the vessel, (b) stoves that produce the high flowrate of hot air or oxygen-enriched air for the vessel, and (c) off-gas treatment equipment that is capable of processing large quantities of off-gas discharged from the vessel.

[0013] It has been proposed to use at least part of the off-gas from a direct smelting vessel during a smelting campaign as a fuel gas in off-gas treatment equipment that includes a waste heat recovery unit and, more particularly, as a fuel gas in a burner unit of a waste heat recovery furnace of the waste heat recovery unit that produces steam for (a) generating electricity and (b) operating the Hmsmelt process.

[0014] The term “smelting campaign” is understood herein to mean operation of a molten bath-based direct smelting process, such as the Hmsmelt process, without a total shutdown of the process involving end tapping of molten metal and slag from a direct smelting vessel.

[0015] It has also been proposed to use at least part of the off-gas from a direct smelting vessel during a smelting campaign as a fuel gas in burner units of stoves that produce air or oxygen-enriched air for operating the Hmsmelt process.

[0016] The possible uses of off-gas from a direct smelting vessel during a smelting campaign are not confined to the above unit operations of waste heat recovery unit and stoves, and the off-gas can be used as a fuel gas in burner units of other unit operations that are part of the plant and/or are external to the plant.

[0017] One Hmsmelt process flowsheet currently proposed is designed to operate in a number of “states” that have different operating conditions during a smelting campaign, including by way of example the following process states:

[0018] (a) start-up;
[0019] (b) hot metal production, i.e. supplying pretreated metalliferous feed material such as hot ore, solid carbonaceous material such as coal, and hot blast air;
[0020] (c) hold—i.e. no pretreated metalliferous feed material, supplying solid carbonaceous material and hot blast air;
[0021] (d) idle—i.e. no pretreated metalliferous feed material and no solid carbonaceous material, supplying hot blast air; and
[0022] (e) off-wind—i.e. no pretreated metalliferous feed material, no solid carbonaceous material, and no hot blast air.

[0023] Typically, the volumetric flow rates of off-gas produced in the direct smelting vessel in the above process states are different. For example, typically, the flow rate of off-gas is relatively high during a hot metal production state and relatively low during an idle state. By way of further example, typically, there is no off-gas during an off-wind state and typically there is no calorific value in off-gas during an idle state.

[0024] The volumetric flow rates and calorific values of off-gas produced in the direct smelting vessel during the course of a given process state may also be different as a consequence of variations in operating conditions during the process state. For example, there may be variations in oper-
ating conditions during the metal production state that would result in different flow rates and calorific values of off-gas being produced.

[0025] Consequently, the applicant has realised that during at least some states of the HSmelt process there are needs for natural gas (or other fuel gas other than off-gas) to be supplied to burner units (or other types of combustion units) of different unit operations that form part of a particular HSmelt plant and/or that may be external to the plant in order to meet the operating requirements of the plant or the external operations.

[0026] For example, in the context of the HSmelt plant described above, there is a need for natural gas (or other fuel gas other than off-gas) to be supplied to a burner unit of a waste heat recovery unit to meet the steam requirements of the plant during a smelting campaign.

[0027] In addition, in the context of the HSmelt plant described above, the applicant has realised that there is a need to supply natural gas (or other fuel gas other than off-gas) to burner units of stoves to compensate for varying flow rates and calorific values of off-gas from the direct smelting vessel.

[0028] In addition, in the context of the HSmelt plant described above, the applicant has realised that there is a need for varying flow rates of natural gas (or other fuel gas other than off-gas) to the burner unit of the waste heat recovery unit and the burner units of stoves during a given process state to compensate for varying flow rates and calorific values of off-gas from the direct smelting vessel during the process state to meet the operating requirements of the plant.

[0029] In addition, the applicant has realised that there is likely to be considerably greater rates of change of the calorific value of off-gas produced in a HSmelt process than occurs in blast furnaces and, hence, there is a need to closely monitor the calorific value of off-gas.

[0030] In broad terms the present invention provides a direct smelting plant for producing molten metal from metalliferous feed material in a direct smelting process that includes:

[0031] (a) a direct smelting vessel for producing molten metal, molten slag, and an off-gas by way of a process for direct smelting metalliferous feed material in the vessel;

[0032] (b) a first fuel gas supply apparatus for supplying off-gas from the direct smelting vessel for use as a fuel gas in burner units of two or more unit operations of the plant and/or external to the plant;

[0033] (d) a second fuel gas supply apparatus for supplying another fuel gas, such as natural gas, from another source to a burner unit of at least one of the unit operations; and

[0034] (e) a process controller for adjusting the volumetric flow rate of fuel gas supplied to a burner unit of at least one of the unit operations so as to at least meet selected requirements of the plant to operate the direct smelting process.

[0035] Depending on the circumstances, the term “fuel gas” as used in paragraph (e) above may refer to off-gas and/or another fuel gas, such as natural gas.

[0036] One, although not the only possible, unit operation may be a waste heat recovery unit for producing steam for use in the plant and/or for generating electricity for use in the plant or externally of the plant.

[0037] Another, although not the only other possible, unit operation may be a plurality of stoves for producing a hot blast of air or oxygen-enriched air for use in the direct smelting process.

[0038] The second fuel gas supply apparatus may be adapted to supply fuel gas, such as natural gas, to one or both of the waste heat recovery unit and the stoves.

[0039] The process controller may be adapted to adjust the volumetric flow rate of fuel gas supplied to the burner unit of the waste heat recovery unit.

[0040] In particular, the process controller may be adapted to adjust the volumetric flow rate of fuel gas, such as natural gas, supplied to the burner unit of the waste heat recovery unit via the second fuel gas supply apparatus.

[0041] The process controller may be adapted to adjust the volumetric flow rate of fuel gas supplied to the burner unit of the stoves.

[0042] In particular, the process controller may be adapted to adjust the volumetric flow rate of fuel gas, such as natural gas, supplied to the burner unit of the stoves via the second fuel gas supply apparatus.

[0043] As described above, the HSmelt process currently proposed by the applicant is designed to operate in different “states” and there will be different volumetric flow rates and calorific values of off-gas produced in the direct smelting vessel in the states and during the course of a given state. In addition, the requirements of the plant for steam (via the waste heat recovery unit) and/or hot air or oxygen-enriched air (via the stoves) to operate the HSmelt process may be different in different states and may vary during the course of a given state. Consequently, depending on the available flow rate and calorific value of off-gas at any given point in time, it may be necessary to supply natural gas (and/or other fuel gas) to the burner units of (a) the waste heat recovery unit of the HSmelt plant to generate sufficient steam for the process and/or (b) the stoves of the HSmelt plant to generate sufficient hot air or oxygen-enriched air for the process.

[0044] Preferably the process controller is responsive to the flame temperature of the burner unit of the waste heat recovery unit.

[0045] More preferably the process controller is responsive to the flame temperature of the burner unit of the waste heat recovery unit so as to maintain the flame temperature above a minimum temperature.

[0046] Preferably the process controller is responsive to the steam requirements of the plant by reference to required values of steam flow rate or steam pressure during different operating states of the process, as described above.

[0047] Preferably the process controller is adapted to adjust the volumetric flow rate of fuel gas supplied to the burner unit of the stoves via the second fuel gas supply apparatus so that the combined fuel gas supplied to the stove burner unit is at a predetermined flow rate and/or calorific value.
Preferably the process controller is adapted to adjust the flow rate of fuel gas to the burner unit of the stoves via the second fuel gas supply apparatus so that the stove burner unit operates at a constant calorific value at least at the commencement of a heating phase of the stoves.

Preferably the plant includes an apparatus for monitoring the calorific value of off-gas at different locations of the plant.

The off-gas calorific value monitoring apparatus may be any suitable apparatus such as a mass spectrometer.

Preferably the process controller is responsive to monitored values of calorific values.

Preferably the plant includes a unit operation in the form of a pretreatment unit for pretreating metalliferous feed material.

Preferably the plant includes an apparatus for supplying off-gas from the direct smelting vessel for use as a fluidising gas in the pretreatment unit.

Preferably the plant includes an apparatus for splitting off-gas discharged from the direct smelting vessel into (i) a first stream for the stoves and the waste heat recovery unit and (ii) a second stream for the pretreatment unit.

Preferably the plant includes an apparatus for forming a combined off-gas stream from (i) off-gas in the first stream and (ii) off-gas in the second stream that is discharged from the pretreatment unit.

Preferably the off-gas calorific value monitoring apparatus is adapted to monitor the calorific value of off-gas in the combined off-gas stream.

Preferably the process controller is responsive to the monitored calorific value of off-gas in the combined off-gas stream.

Preferably the process controller is adapted to adjust the volumetric flow rate of fuel gas supplied to the waste heat recovery unit via the second fuel gas supply apparatus in response to the monitored values of calorific value of the combined off-gas stream.

Preferably the off-gas calorific monitoring apparatus is adapted to monitor the calorific value of off-gas in the first and the second streams.

In broad terms, according to the present invention there is also provided a molten bath-based direct smelting process for producing molten metal from a metalliferous feed material in a direct smelting plant that includes:

(a) direct smelting metalliferous feed material in a direct smelting vessel containing a molten bath of metal and slag and producing molten metal, molten slag, and off-gas, the process having different process states;

(b) supplying off-gas produced in the vessel during a smelting campaign as a fuel gas to burner units of two or more unit operations of the plant and/or external to the plant, and

(c) supplying another fuel gas, such as natural gas, from another source to the burner unit of at least one of the unit operations,

(d) adjusting the volumetric flow rate of fuel gas supplied to the burner units of the unit operations so as to at least meet requirements of the plant during the course of the process.

Preferably the unit operations include a heat recovery furnace of a waste heat recovery unit for producing steam for use in the plant and/or for generating electricity for use in the plant or externally of the plant.

Preferably the unit operations include a plurality of stoves for producing a hot blast of air or oxygen-enriched air for use in direct smelting metalliferous feed material in the vessel.

Preferably the process also includes adjusting the volumetric flow rate of the other fuel gas supplied to the burner units of the waste heat recovery unit and/or the stoves to maintain a predetermined flow rate and/or calorific value to the burner units.

Preferably the process includes monitoring the calorific value of off-gas at different locations of the plant.

According to the present invention there is also provided a direct smelting plant for producing molten metal from metalliferous feed material in a direct smelting process that includes:

(a) a direct smelting vessel for producing molten metal, molten slag, and an off-gas by way of a process for direct smelting metalliferous feed material in the vessel;

(b) at least two off-gas processing units for receiving andcombusting the off-gas;

(c) a first fuel gas supply apparatus for supplying off-gas from the direct smelting vessel for use in burner units of the off-gas processing units;

(d) a second fuel gas supply apparatus for supplying another fuel gas, such as natural gas, from another source to burner units of said at least two off-gas processing units;

(e) process controller for controlling:

(i) volumetric flow of off-gas to one of the off-gas processing units to meet the requirements of the unit with a balance of off-gas being supplied to a remaining off-gas processing unit or units;

(ii) volumetric flow of the other fuel gas to the off-gas processing units.

Preferably the off-gas processing units comprise stoves for supplying hot blast to the direct smelting vessel and a waste heat recovery unit for generation of steam.

Preferably the process controller is adapted to control supply of off-gas and the other fuel gas to the stoves such that the combined supply of off-gas and the other fuel gas to the stoves has a substantially constant calorific value.

Preferably the process controller is adapted to control supply of the other fuel gas to the waste heat recovery unit in response to variations in the volumetric flow of the off-gas to effect combustion of the off-gas in the waste heat recovery unit.

Preferably said plant comprises one or more than one off-gas supply valve for controlling the volumetric flow rate of off-gas to the stoves and for diverting supply of off-gas to the waste heat recovery unit; off-gas calorific value sensing apparatus for sensing calorific value of off-gas; and the process controller is adapted to monitor off-gas calorific value and to operate the off-gas supply valve or valves to divert off-gas to the waste heat recovery unit in response to the calorific value of the off-gas falling below a predetermined threshold value.

Preferably the pre-determined threshold value is a value at which the off-gas no longer makes a positive contribution to the calorific value of the combined fuel gas stream of the off-gas and the other fuel gas. Preferably the pre-determined threshold value is 1.8 MJ/Nm3 (mega-joules per normal cubic meter).
The present invention is described in more detail hereinafter with reference to the accompanying drawings, of which:

FIG. 1 is a diagrammatic view of one embodiment of a direct smelting plant in accordance with the present invention; and

FIG. 2 is an enlarged view of the wet cone scrubber and off-gas cooler in the off-gas stream that supplies off-gas to the waste heat recovery unit and the stoves shown in FIG. 1.

The following description of the plant shown in the figures is in the context of using the plant to smelt iron-containing feed material to produce molten iron in accordance with the HIsmelt process as described in International application PCT/ AU96/00197 in the name of the applicant. The disclosure in the patent specification lodged with the International application is incorporated herein by cross-reference.

The process is based on the use of a direct smelting vessel 3.

The vessel 3 is of the type described in detail in International applications PCT/AU2004/000472 and PCT/AU2004/000473 in the name of the applicant. The disclosure in the patent specifications lodged with these applications is incorporated herein by cross-reference.

The vessel 3 has a hearth that incudes a base and sides formed from refractory bricks, side walls which form a generally cylindrical barrel extending upwardly from the sides of the hearth and include an upper barrel section and a lower barrel section, a roof, an off-gas duct 9 in an upper section of the vessel 3, a forehearth 67 for discharging molten metal continuously from the vessel 3, and a tap hole for discharging molten slag periodically from the vessel 3.

The vessel 3 is fitted with a downwinding extending water-cooled hot air blast ("HAB") lance 7 extending into a top space of the vessel 3 and eight water-cooled solids injection lances 5 extending downwardly and inwardly through a side wall and into the slag.

In use, the vessel 3 contains a molten iron bath. Iron-containing feed material (such as iron ore fines, iron-bearing steel plant wastes or DR fines), coal and fluxes (lime and dolomite) are directly injected into the bath via the solids injection lances 5.

Specifically, one set of lances 5 is used for injecting iron-containing feed material and fluxes and another set of lances 5 is used for injecting coal and fluxes.

The lances 5 are water cooled to protect them from the high temperatures inside the vessel 3. The lances 5 are typically lined with a high wear resistant material in order to protect them from abrasion by the gas/solids mixture being injected at high velocity.

Iron-containing feed material is pretreated by being preheated to a temperature in the range of 600-700°C and preheated in a fluidised bed preheater 17 before being injected into the bath.

Coal and fluxes are stored in a series of look hoppers 25 before being injected at ambient temperatures into the bath. The coal is supplied to the look hoppers 25 via a coal drying and milling plant 71.

The injected coal de-volatilises in the bath, thereby liberating H₂ and CO. These gases act as reductants and sources of energy. The carbon in the coal is rapidly dissolved in the bath. The dissolved carbon and the solid carbon also act as reductants, producing CO as a product of reduction. The injected iron-containing feed material is smelted to molten iron in the bath and is discharged continuously via the forehearth 67. Molten slag produced in the process is discharged periodically via the slag tap hole (not shown).

The typical reduction reactions involved in smelting injected iron-containing feed material to molten iron that occur in the bath are endothermic. The energy required to sustain the process and, more particularly these endothermic reactions, is provided by reacting CO and H₂ released from the bath with oxygen-enriched air injected at high temperatures, typically 1200°C, into the vessel 3 via the HAB lance 7.

Energy released from the above-described post combustion reactions in the vessel top space is transferred to the molten iron bath via a "transition zone" in the form of highly turbulent regions above the bath that contain droplets of slag and iron. The droplets are heated in the transition zone by the heat generated from post combustion reactions and return to the slag/iron bath thereby transferring energy to the bath.

The hot, oxygen-enriched air injected into the vessel 3 via the HAB lance 7 is generated in hot blast stoves 11 by passing a stream of oxygen-enriched air (nominal containing 30 to 55% by volume of O₂) through the stoves 11 and heating the air and thereafter transferring the hot oxygen-enriched air to the HAB lance 7 via a hot blast main 41.

The operation of the stoves 11 is coordinated to ensure that there is a continuous, uninterrupted flow of hot, oxygen-enriched air at a constant straight line temperature in the main 41 to the HAB lance 7.

Each stove 11 operates in accordance with a repeating sequence of phases that comprises a heating phase, a bottling phase, and a heat exchange phase that is a longer time period than the heating phase.

The stoves 11 are heated during heating phases of the stoves 11 by combusting (a) a fuel gas in the form of cooled and cleaned off-gas from the vessel 3 and/or (b) optionally another fuel gas such as natural gas (supplied via a line indicated by the numeral 85 in FIG. 1), and (c) combustion air in burner assemblies (not shown) of the stoves 11 and thereafter passing the combustion products through the stoves 11.

During heat exchange phases of the stoves 11, oxygen from an oxygen plant 29 is mixed into streams of pressurised air generated by a blower 31. These oxygen-enriched air streams are passed through the stoves 11 and are heated in the stoves 11 and thereby produce the hot, oxygen-enriched pressurised air streams for the vessel 3. These hot, oxygen-enriched air streams are often referred to as "hot blast" or "hot air blast".

The bottling phases of the stoves 11 are phases in which one of the stoves is essentially closed and is neither heated by combusted off-gas (and other fuel gas, such as natural gas) nor cooled by heat exchange with air streams.

The duration of the bottling phases of a given stove 11 is at least the amount of time required to open and close the valves necessary to change-over off-gas and hot air streams so as to switch over (a) the given stove from a heating phase to a heat exchange phase and (b) the other stove from a heat exchange phase to a heating phase.

Combustion products released from the stoves 11 during heating phases of the stoves 11 are cleaned in a flue gas desulphurisation (FGD) system 13. The FGD removes sulphur, which typically occurs in the form of hydrogen sulphide...
(H₂S) and sulphur dioxide (SO₂), from the combustion products. The off-gas produced in the vessel 3 contains sulphur and the sulphur is not totally removed in the off-gas cleaning that occurs downstream of the vessel 3 before the off-gas reaches the stoves 11, as described hereinafter.

Prior to being passed to the FGD system, combustion products released from the stoves 11 during heating phases of the stoves 11 may pass through heat exchangers (not shown) and preheat cooled and cleaned off-gas from the vessel 3 and combustion air before the heated off-gas and combustion air is supplied as feed materials to the burners of the stoves 11 during heating phases. The vessel off-gas and combustion air may be preheated to a temperature of around 180°C.

Off-gas is released from the vessel 3 via the off-gas duct 9 in the upper section of the vessel 3 and passes initially through a radiation cooler, hereinafter referred to as an “off-gas hood”, 15. Typically, the off-gas leaves the vessel and enters the hood at a temperature of the order of 1450°C.

The off-gas is cooled as it passes through the off-gas hood 15 and thereby results in the generation of steam which accumulates in steam drum 35. The off-gas hood may be of a type described in U.S. Pat. No. 6,585,929 that cools and partially cleans off-gas.

The off-gas stream leaving the off-gas hood 15 is at a temperature of approximately 1000°C and is split into two streams.

With particular reference to FIG. 2, one split off-gas stream leaving the off-gas hood 15, which comprises between 55-65% of the off-gas from the vessel 3, passes first through a wet cone scrubber 21.

The scrubber 21 quenches and removes particulate material and soluble gaseous species and metal vapours from off-gas flowing through the scrubber. The off-gas temperature drop in the scrubber is from approximately 1000°C to below 100°C and typically between 65°C and 90°C.

The scrubber 21 includes an upper chamber 71, a lower chamber 73, and a vertically extending pipe 75 that interconnects the chambers 71, 73. The scrubber 21 includes an off-gas control valve 77 in the lower end of the pipe 75. The control valve 77 includes an hydraulically operated cone element 79 that can move vertically to open or close the lower end of the pipe 75. The scrubber 21 includes water sprays 69 in the upper chamber 71 and further water sprays (not shown) positioned in relation to the pipe 75 and the control element 79. Re-circulating water within the scrubber and make-up water are supplied to the sprays.

The control valve 77 controls the flow rate of off-gas through the scrubber 21. This is the first variable flow rate constraint on off-gas from the vessel 3. Consequently, the control valve 77 controls the pressure in the direct smelting vessel 3, preferably to 0.8 bar gauge while the process is producing molten iron.

The off-gas from the scrubber 21 leaves the scrubber 21 via an outlet 81 in the lower chamber 73 and passes through an off-gas cooler 23 that further cools the off-gas to below 50°C, typically between 30°C and 45°C, to remove sufficient moisture from the off-gas for it to be used as a fuel gas. Typically the off-gas leaving the cooler has 5% or less H₂O and a mist content of less than 10 mg/Nm³ and typically 5.0 mg/Nm³.

Under typical metal production conditions, the resulting off-gas is suitable for use as a fuel gas in (a) the stoves 11 (as described above) and (b) the WHR system 25. In addition, the scrubbed and cooled off-gas is suitable for drying coal in the drying and milling plant 71.

For the above purposes, the off-gas from the off-gas cooler 23 is split into three streams and supplied to downstream unit operations, specifically the stoves 11, the WHR system 25, and the drying and milling plant 71, via an apparatus that is collectively described as a “first fuel gas supply apparatus”. Specifically, one stream is passed to the stoves 11, another stream is passed to the WHR system 25, and a third stream being passed to the drying and milling plant 71. The flow rate of off-gas in the streams is controlled via off-gas supply valves (not shown).

The off-gas stream from off-gas cooler 23 is a relatively rich off-gas. The stream that is passed to the WHR system 25 is mixed with cooled and cleaned off-gas that has passed through the preheater 17 as described hereinafter, which is a relatively lean off-gas, due to some pre-reduction of the iron-containing feed material in the pre-heater by CO and H₂ in the off-gas.

As detailed above, under typical metal production conditions, the combined off-gas stream has a calorific value that makes it suitable for combustion as a fuel gas.

The combined off-gas stream, an additional source of fuel gas in the form of natural gas (supplied via a line indicated by the numeral 83 in FIG. 1), and air are supplied to and combusted in the WHR system 25.

It is noted that the line 83 mentioned in the preceding paragraph and the line 85 mentioned earlier in the context of supplying natural gas to the WHR system 25 are part of a fuel gas supply apparatus that is collectively described as a “second fuel gas supply apparatus”.

The combined off-gas stream is combusted within the WHR system 25 in a manner that maximises CO destruction, while minimising NOx formation.

The off-gas released from the WHR system 25 is combined with off-gas from the stoves 11 and then passes to the FGD system 13. SO₂ is removed in the FGD system 23 and the exhaust gas is released to the atmosphere via a stack 45.

The other split stream, which contains approximately 35-45% by volume of the off-gas stream, is passed through the humidified bed preheater 17 for iron-containing feed material. The preheater 17 removes moisture from and preheats and prereduces the iron-containing feed material. The off-gas is a source of energy and a fluidising gas in the preheater 17.

A process controller of the plant controls the off-gas flow to the preheater 17 (a) to be above a minimum flow rate to maintain fluidising conditions in the preheater 17 and (b) to preheat iron-containing feed material to a substantially constant temperature, in the range of 600-700°C while the process is producing molten metal.

The off-gas released from the preheater 17 is passed through a cyclone 61 and entrained dust is separated from the off-gas.

The off-gas then passes through a wet cone scrubber 63 that removes particulate material and soluble gaseous species and metal vapours from the off-gas and cools the off-gas from between 500°C and 200°C to below 100°C and typically between 65°C and 90°C.

The scrubber 63 is the same basic construction as the wet cone scrubber 21 described above. In particular, the scrubber 63 quenches and removes particulate material and soluble gaseous species and metal vapours from off-gas flow-
ing through the scrubber. Moreover, as is the case with scrubber 21, the scrubber 63 includes an off-gas flow control valve that has an hydraulically operated cone element that can move vertically to open or close the valve and thereby control flow of off-gas through the scrubber.

[0129] The off-gas from the scrubber 63 then passes through an off-gas cooler 65 that further cools the off-gas to below 50°C, typically between 30°C and 45°C, to remove sufficient moisture from the off-gas for it to be used as a fuel gas. Typically the off-gas leaving the cooler has 5% or less H₂O and a mist content of less than 10 mg/Nm³ and typically 5.0 mg/Nm³.

[0130] As is described above, the cooled and cleaned off-gas is then combined with a stream of off-gas from cooler 23 and used as a fuel gas in a waste heat recovery (WHR) system 25.

[0131] The WHR system 25 includes:

[0132] a thermal oxidiser, ie burner assembly, 37, and associated combustion chamber;

[0133] a WHR unit, ie boiler, 39;

[0134] a steam drum; and

[0135] heat exchange equipment, such as superheat coils and a demineralised water economiser.

[0136] The WHR system 25 produces saturated steam. The saturated steam is combined with the saturated steam from the steam drum 35 of the off-gas hood 15 and the superheat coils of the WHR system 25 generates superheated steam from the saturated steam.

[0137] The steam raising equipment of the WHR system 25 comprises:

[0138] a radiant screen to protect the downstream coils;

[0139] a two-stage superheater section with desuperheater controls (where the quantity of superheat is controlled by injecting demineralised water as required to maintain the superheated steam at a temperature of 420°C);

[0140] a main evaporator section, consisting of three modules of convective coils;

[0141] an economiser section; and

[0142] a steam drum with three element demineralised water control.

[0143] The steam raised in the WHR system 25 and the off-gas hood 15 is used to drive the HAB blower 31 and the main air compressor (not shown) of oxygen plant 29, with the remainder being passed through a turbo-alternator that generates electrical power required to operate the plant.

[0144] The turbo-generator system includes a condensing turbine designed to receive superheated steam. The discharge from the turbine passes through a surface condenser operating at vacuum with the resultant condensate being pumped to the de-aerator via condensate pumps.

[0145] The use of the off-gas as a fuel gas within a plant offsets an amount of electrical power that would otherwise need to be obtained from an external electricity supply grid, which makes the plant generally self sufficient in terms of electrical power.

[0146] Typically, the burner assembly 37 of the WHR system 25 is a cylindrical carbon steel shell, with internal refractory and insulation.

[0147] In use, the burner assembly 37 of the WHR system operates with varying combined off-gas flow rates from the above-described split streams of off-gas, due to a number of factors including (a) variations in off-gas that is produced during operation of the process and therefore discharged from the vessel 3, (b) variations in the steam requirements of the plant, (c) variations in off-gas available for the burner assembly 37 of the WHR system 25 because of competing calls on off-gas for the stoves 11, and (d) variations in off-gas requirements for the stoves 11. In other words, the burner assembly 37 of the WHR system is supplied with and controlled so as to combust the balance of off-gas after competing calls from the stoves 11 and other units that utilise off-gas have been satisfied. As detailed further below, these calls may vary with the calorific value of the off-gas.

[0148] The process is designed to operate in a number of "states" that have different operating conditions during a smelting campaign, including by way of example the following process states:

[0149] (a) start-up;

[0150] (b) hot metal production—supply hot ore, coal, fluxes, and hot blast;

[0151] (c) hold—ie no hot ore, supply coal and hot blast;

[0152] (d) idle—ie no ore and no coal, supply hot blast; and

[0153] (e) off-wind—ie no ore, no coal, and no hot blast and in some instances a fuel gas such as natural gas.

[0154] During a hold state the calorific value of the off-gas can vary between being relatively lean and being relatively rich. The calorific value depends on the feed rate of coal into the bath and the feed rate of hot air blast into the vessel 3. These parameters affect the level of carbon in the off-gas and the levels of CO and CO₂ in the off-gas.

[0155] The calorific value of the off-gas during an idle state is relatively low. Typically only hot air blast is supplied to the vessel 3 (along with nitrogen purge gas supplied through the solids injection lance 5) and so the off-gas has a composition similar to air.

[0156] During an idle state the hot metal temperature is monitored and, if necessary, a fuel gas, such as natural gas, is supplied into the top space above the molten bath. This fuel gas is combusted in the hot air blast. This assists with heating the vessel 3 and the molten bath.

[0157] Combustion of fuel gas in this manner is typically complete and so the calorific value of the off-gas does not increase compared to the situation of an idle state where only hot air blast is supplied to the vessel 3.

[0158] Prior to combusting fuel gas in the vessel 3 when the process is in an idle state, the operators of the vessel must either top slag to a minimum level or may even perform a slag drain. A slag tap leaves a certain minimum level of slag in the vessel 3 whereas a slag drain removes substantially all of the slag from the vessel. Reducing the level of slag in the vessel 3 allows the metal to be heated directly by the combustion. Slag acts as an insulator in these circumstances and reduces the amount of heat seen by the metal.

[0159] The volumetric flow rates and calorific values of off-gas produced in the vessel 3 in the above process states are different. For example, the flow rate and calorific value of off-gas are relatively high during a hot metal production state and relatively low during an idle state.

[0160] In addition, the volumetric flow rates and calorific values of off-gas produced in the vessel 3 during the course of a given process state are also different as a consequence of variations in operating conditions. For example, there may be variations in operating conditions during a hot metal production state that would result in different amounts and calorific values of off-gas being produced. For example, the off-gas calorific value can fall below 1.8 MJ/Nm³ (mega-joules per
In addition, the volumetric flow rate of fuel gas that is available for the WHR system 25 varies with the phases of the stoves 11. Specifically, the split off-gas stream to the WHR system 25 has a substantially higher flow rate when the stoves 11 are operating in the bottling phases of the stoves. As is described above, substantially lower amounts of off-gas are required by the stoves 11 during bottling phases of the stoves 11 than is required during heating phases of the stoves 11.

In addition, the steam (and electricity) requirements of the plant, and therefore the required volumetric flow rates and calorific values of fuel gas for the WHR system 25, are different in different states of the process. For example, the steam (and electric) requirements of the plant are typically of the order of 40-60% higher during a hot metal production state than during a start-up state.

In addition, the fuel gas requirements of the stoves 11 are different in different states of the process. For example, larger amounts of fuel gas are required during a hot metal production state than during an idle state.

In view of the above, during at least some states of the process there is a need for an alternative fuel gas, such as natural gas (or other fuel gas other than off-gas), to be supplied to the burner assembly 37 of the WHR system 25 in order to compensate for varying flow rates and calorific values of off-gas from the vessel 3 during a given state of the smelting campaign to meet the steam requirements of the plant.

In addition, in view of the above, during at least some of the states of the process, there is a need for an alternative fuel gas, such as natural gas (or other fuel gas), to be supplied to the burner assemblies of the stoves 11 to compensate for variations in flow rates and calorific values of off-gas to thereby maintain target flow rates and target calorific values of fuel gas for the burner assemblies. For example, during a hot metal production state, the flow of combined fuel gas to the stoves, being the combined off-gas and alternative fuel gas, is controlled to have a constant calorific value. As the calorific value of the off-gas varies with process conditions, so does the required flow rate of off-gas to the stoves. If the calorific value of the off-gas falls below 1.8 MJ/Nm³ all of the off-gas is diverted to the WHR system because the calorific value of the off-gas is too low to make a useful contribution to heating the stoves 11, at any flow rate. It is the calorific value of the off-gas that, at least in part, determines the call for off-gas made by the stoves. The balance of off-gas is supplied to and combusted by the WHR system.

Supply of an alternative fuel gas, such as natural gas, is particularly necessary when the process is operating in the off-wind, hold and idle states. During these states, off-gas flow to the stoves 11 is shut off altogether or at least is substantially reduced and, therefore, another fuel gas, such as natural gas is required to maintain operation of the stoves 11 at a required level during these process states.

Consequently, the process controller of the plant operates the burner assembly 37 of the WHR system 25 with varying flow rates of natural gas as an additional fuel gas to provide required flow rates and calorific values of fuel gas at any point in the process.

In addition, consequently, the process controller of the plant operates the burner assembly 37 of the WHR system 25 with varying flow rates of air to combat the varying flow rates of off-gas and natural gas to ensure optimum combustion.

In addition, consequently, the process controller of the plant operates the burner assemblies of the stoves 11 with varying flow rates of natural gas as an additional fuel gas to provide required flow rates and calorific values of fuel gas at any point in the process.

In addition, consequently, the process controller of the plant operates the burner assemblies of the stoves 11 with varying flow rates of air to combat the varying flow rates of off-gas and natural gas to ensure optimum combustion.

In addition, the process controller of the plant commences ramping up the air flow rate to the burner assembly 37 of the WHR system 25 a predetermined time period, typically 30 seconds, before there is an increase in off-gas to the burner assembly 37 due to a decrease in demand for off-gas in the stoves 11.

Similarly, the process controller of the plant commences ramping down the air flow rate to the burner assembly 37 of the WHR system 25 a predetermined time period, typically 30 seconds, before there is a decrease in off-gas to the burner assembly 37 due to an increase in demand for off-gas in the stoves 11.

In one particular example of the operation of the above-described plant, the process controller controls:

(a) the volumetric flow rate of natural gas to burner units of the stoves 11 so that the combined flow rate of off-gas and natural gas has a substantially constant calorific value during the heating phases of the stoves; and

(b) the volumetric flow rate of natural gas to the WHR system 25 in response to variations in the volumetric flow rate of off-gas to the WHR system to effect combustion of the off-gas in the WHR system.

With regard to item (b) above, in context of the particular example the WHR system 25 requires an amount of fuel gas, which may be provided by off-gas and/or natural gas to provide at least a minimum threshold calorific value.

The calorific value of off-gas at different points in the plant is an important parameter in determining the flow rates of natural gas required for the burner assembly 37 of the WHR system 25 and the burner assemblies of the stoves 11 at any point in time.

The plant includes mass spectrometers CV1, CV2, and CV3 at selected locations of the plant to determine the calorific values of the off-gas at these locations. The measured values of calorific values are processed by the process control for the plant as part of the process of determining required flow rates of off-gas and natural gas.

The selected locations are in the off-gas hood 15 (CV1), downstream of the off-gas cooler 23 and upstream of the split of the off-gas to the stoves 11 and the WHR system 25 (CV2), and downstream of the pre-heater 61 (CV3).

Operating the above-described process with a range of different states also has an impact on pressure control in the vessel 3 during the different states.
[0182] In addition, the preheater 17 has certain minimum flow gas requirements in order to maintain the iron-containing feed material in a fluidised state. Gas flow through the preheater 17 is controlled by the control valve in the wet cone scrubber 63 that is downstream of the preheater 17.  

[0183] The above description indicates that vessel pressure control is via the control valve 77 of the wet cone scrubber 21 when the process is producing molten iron, i.e. when operating in a hot metal production state.  

[0184] More particularly, the plant includes a pressure sensor 15 in the off-gas hood 15 that monitors the pressure in off-gas flowing through the hood on a continuous basis. The process controller of the plant is responsive to the monitored pressure and operates the control valve 77 of the wet cone scrubber 21 to adjust the pressure as required, preferably to maintain a constant vessel pressure. When the process is operating in a hot metal production state. The time constant of the control circuit of the control valve 77 is considerably faster than the time constant of the control circuit of the control valve in the scrubber 63 downstream of the preheater 17. Hence, as between the control of pressure in the vessel 3 and the control of gas flow rate through the preheater 17, during the metal production state, the control of vessel pressure dominates.  

[0185] It is still necessary to maintain control of pressure in the vessel 3 during other states, particularly the hold and idle states of the process. Such pressure control is achieved during these states via the above-described control valve in the wet cone scrubber 63 downstream of the preheater 17 rather than via the control valve 77 of the wet cone scrubber 21.  

[0186] More particularly, when the process is operating in these states, the control valve 77 of the wet cone scrubber 21 is at least substantially closed so that there is no or at most a minimal flow of off-gas through the scrubber 21 and thereafter to the stove 11. The pressure set point of the vessel may also be reduced. Typically the set point is reduced from 0.8 bar gauge to 0.4 bar gauge.  

[0187] During hold and idle states, a portion of the off-gas that has passed through the preheater 17 is recycled and combined with the off-gas from the vessel 3 so as to assist with maintaining fluidising conditions within the preheater 17.  

[0189] At off-wind state, no hot air blast is supplied to the vessel. The scrubber 63 downstream of the preheater 17 is closed and all of the off-gas within the preheater 17 is recycled so as to operate as fluidising gas.  

[0190] During hold and idle states the stoves 11 produce a reduced amount of hot air blast. In order to ensure that the stoves 11 do not exceed a maximum temperature, the total energy of the fuel gas supplied to the stoves 11 is reduced compared with the total energy of the fuel gas supplied to the stoves during hot metal production. In this way, the energy input to the stoves 11 is reduced during hold and idle states so as to match the reduced energy requirements of the reduced hot air blast flow.

[0191] Many modifications may be made to the embodiment of the present invention described above without departing from the spirit and scope of the invention.

1-35. (canceled)  
36. A direct smelting plant for producing molten metal from metalliferous feed material in a direct smelting process that includes:  
(a) a direct smelting vessel for producing molten metal, molten slag, and an off-gas by way of a process for direct smelting metalliferous feed material in the vessel;  
(b) a first fuel gas supply apparatus for supplying off-gas from the direct smelting vessel for use as a fuel gas in burner units of two or more unit operations of the plant and/or external to the plant;  
(c) a second fuel gas supply apparatus for supplying another fuel gas, such as natural gas, from another source to the burner unit of at least one of the unit operations, and  
(d) a process controller for adjusting the volumetric flow rate of fuel gas supplied to a burner unit of at least one of the unit operations so as to at least meet selected requirements of the plant to operate the direct smelting process.  
37. The plant defined in claim 36 wherein the unit operations include one or both of (i) a waste heat recovery unit for producing steam for use in the plant and/or for generating electricity for use in the plant or externally of the plant and (ii) a plurality of stoves for producing a hot blast of air or oxygen-enriched air for use in the direct smelting process.  
38. The plant defined in claim 37 wherein the second fuel gas supply apparatus is adapted to supply fuel gas, such as natural gas, to one or both of the waste heat recovery unit and the stoves.  
39. The plant defined in claim 37 or claim 38 wherein the process controller is adapted to adjust the volumetric flow rate of fuel gas supplied to the burner unit of the waste heat recovery unit.  
40. The plant defined in claim 39 wherein the process controller is adapted to adjust the volumetric flow rate of fuel gas, such as natural gas, supplied to the burner unit of the waste heat recovery unit via the second fuel gas supply apparatus.  
41. The plant defined in claim 37 wherein the process controller is adapted to adjust the volumetric flow rate of fuel gas supplied to the burner unit of the stoves.  
42. The plant defined in claim 41 wherein the process controller is adapted to adjust the volumetric flow rate of fuel gas, such as natural gas, supplied to the burner unit of the stoves via the second fuel gas supply apparatus.  
43. The plant defined in claim 37 wherein the process controller is responsive to the flow rate and/or the calorific value of off-gas and to the steam requirements of the plant and/or to the hot air or oxygen-enriched air requirements of the process and determines the volumetric flow rate of fuel gas, such as natural gas, required for the burner units of the waste heat recovery unit and/or the stoves via the second fuel gas supply apparatus having regard to the flow rate and/or calorific value of off-gas and the requirements of the plant and/or the process at any point in time.  
44. The plant defined in claim 43 wherein the process controller is responsive to the flame temperature of the burner unit of the waste heat recovery unit.  
45. The plant defined in claim 44 wherein the process controller is responsive to the flame temperature of the burner
unit of the waste heat recovery unit so as to maintain the flame temperature above a minimum temperature.

46. The plant defined in claim 43 wherein the process controller is responsive to the steam requirements of the plant by reference to required values of steam flow rate or steam pressure during different operating states of the process, as defined herein.

47. The plant defined in claim 43 wherein the process controller is adapted to adjust the volumetric flow rate of fuel gas supplied to the burner unit of the stoves via the second fuel gas supply apparatus so that the combined fuel gas supplied to the stove burner unit is a predetermined flow rate and/or calorific value.

48. The plant defined in claim 43 wherein the process controller is adapted to adjust the flow rate of fuel gas supplied to the burner unit of the stoves via the second fuel gas supply apparatus so that the stove burner unit operates at a constant calorific value at least at the commencement of a heating phase of the stoves.

49. The plant defined in claim 43 includes an apparatus for monitoring the calorific value of off-gas at different locations of the plant.

50. The plant defined in claim 49 wherein the off-gas calorific value monitoring apparatus is a mass spectrometer.

51. The plant defined in claim 49 or claim 50 wherein the process controller is responsive to monitored values of calorific values.

52. The plant defined in claim 56 includes a unit operation in the form of a pretreatment unit for pretreating metalliferous feed material.

53. The plant defined in claim 52 includes an apparatus for supplying off-gas from the direct smelting vessel for use as a fluidising gas in the pretreatment unit.

54. The plant defined in claim 53 includes an apparatus for splitting off-gas discharged from the direct smelting vessel into (i) a first stream for the stoves and the waste heat recovery unit and (ii) a second stream for the pretreatment unit.

55. The plant defined in claim 54 includes an apparatus for forming a combined off-gas stream from (i) off-gas in the first stream and (ii) off-gas in the second stream that is discharged from the pretreatment unit.

56. The plant defined in claim 55 wherein the off-gas calorific value monitoring apparatus is adapted to monitor the calorific value of off-gas in the combined off-gas stream.

57. The plant defined in claim 56 wherein the process controller is responsive to the monitored calorific value of off-gas in the combined off-gas stream.

58. The plant defined in claim 57 wherein the process controller is adapted to adjust the volumetric flow rate of fuel gas supplied to the waste heat recovery unit via the second fuel gas supply apparatus in response to the monitored values of calorific value of the combined off-gas stream.

59. The plant defined in claim 56 wherein the off-gas calorific monitoring means is adapted to monitor the calorific value of off-gas in the first and the second streams.

60. A molten bath-based direct smelting process for producing molten metal from a metalliferous feed material in a direct smelting plant that includes:
   (a) direct smelting metalliferous feed material in a direct smelting vessel containing a molten bath of metal and slag and producing molten metal, molten slag, and an off-gas, the process having different process states;
   (b) supplying off-gas produced in the vessel during a smelting campaign as a fuel gas to burner units of two or more unit operations of the plant and/or external to the plant, and
   (c) supplying another fuel gas, such as natural gas, from another source to the burner unit of at least one of the unit operations,
   (d) adjusting the volumetric flow rate of fuel gas supplied to the burner units of the unit operations so as to at least meet requirements of the plant during the course of the process.

61. The process defined in claim 60 wherein the unit operations include one or both of (i) a heat recovery furnace of a waste heat recovery unit for producing steam for use in the plant and/or for generating electricity for use in the plant or externally of the plant and (ii) a plurality of stoves for producing a hot blast of air or oxygen-enriched air for use in direct smelting metalliferous feed material in the vessel.

62. The process defined in claim 61 includes adjusting the volumetric flow rate of the other fuel gas supplied to the burner units of the waste heat recovery unit and/or the stoves to maintain a predetermined flow rate and/or calorific value to the burner units.

63. The process defined in claim 62 includes monitoring the calorific value of off-gas at different locations of the plant.

64. A direct smelting plant for producing molten metal from metalliferous feed material in a direct smelting process that includes:
   (a) a direct smelting vessel for producing molten metal, molten slag, and an off-gas by way of a process for direct smelting metalliferous feed material in the vessel;
   (b) at least two off-gas processing units for receiving and combusting the off-gas;
   (c) a first fuel gas supply apparatus for supplying off-gas from the direct smelting vessel for use in burner units of the off-gas processing units;
   (d) a second fuel gas supply apparatus for supplying another fuel gas, such as natural gas, from another source to burner units of said at least two off-gas processing units;
   (e) process controller for controlling:
      i) volumetric flow of off-gas to one of the off-gas processing units to meet the requirements of the unit with a balance of off-gas being supplied to a remaining off-gas processing unit or units;
      ii) volumetric flow of the other fuel gas to the off-gas processing units.

65. The plant defined in claim 64 wherein the off-gas processing units comprise stoves for supplying hot blast to the direct smelting vessel and a waste heat recovery unit for generation of steam.

66. The plant defined in claim 65 wherein the process controller is adapted to control supply off-gas and the other fuel gas to the stoves such that the combined supply of off-gas and the other fuel gas to the stoves has a substantially constant calorific value.

67. The plant defined in claim 65 or claim 66 wherein the process controller is adapted to control supply of the other fuel gas to the waste heat recovery unit in response to variations in the volumetric flow of the off-gas to effect combustion of the off-gas in the waste heat recovery unit.

68. The plant defined in claim 65 comprises one or more than one off-gas supply valve for controlling the volumetric flow rate of off-gas to the stoves and for diverting supply of
off-gas to the waste heat recovery unit, and off-gas calorific value sensing apparatus for sensing calorific value of off-gas, and wherein the process controller is adapted to monitor off-gas calorific value and to operate the off-gas supply valve or valves to divert off-gas to the waste heat recovery unit in response to the calorific value of the off-gas falling below a pre-determined threshold value.

69. The plant defined in claim 68 wherein the pre-determined threshold value is a value at which the off-gas no longer makes a positive contribution to the calorific value of the combined fuel gas steam of the off-gas and the other fuel gas.

70. The plant defined in claim 68 wherein the pre-determined threshold value is 1.8 MJ/Nm³ (mega-joules per normal cubic meter).