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(71) Applicant: ASEA Limited
Fanum House 48, Leicester Square
London WC2H 7L2(GB)

(72) Inventor: Reeve, Brian Robert
18, Langbury Lane Ferring
Worthing Sussex(GB)

(74) Representative: Newby, Raymond Laurence et al,
J.Y. & G.W. Johnson Furnival House 14/18 High Holborn
London WC1V 6DE(GB)

(54) **Recovery of energy from waste gas streams.**

(57) In an iron- or steel-making plant comprising a metallurgical processing vessel (1) from which, in operation of the plant, there issues a stream of waste gas at superatmospheric pressure and elevated temperature, there is provided means for recovering energy from the waste gas stream. This energy recovering means comprises means (6, 12) for supplying the gas stream to the inlet of a gas expander (16) which includes a rotor (18) drivable by the gas stream and comprising an output drive shaft (22), an alternating current generator (28) arranged to be driven by the shaft (22), and a voltage and frequency converter (32) having its input side connected to the electrical output of the generator (28) and its output side connected to an electrical power network (5). The converter (32) is of the kind which, over a predetermined range of the speed of rotation of the generator (28), delivers at its output side electric power at a voltage and frequency which at all times conform to the voltage and frequency of the network (5).

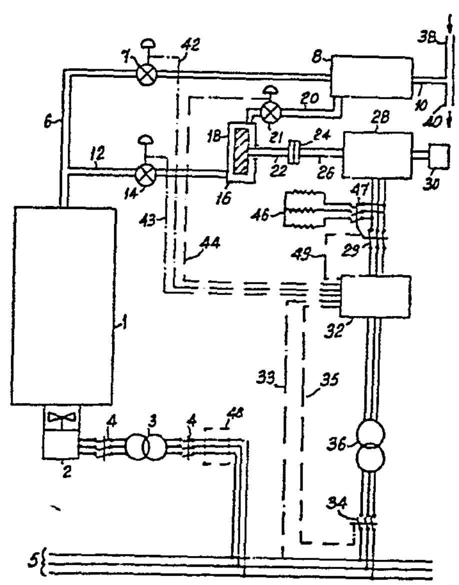

Fig 1

EP 0 056 710 A2

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Recovery of energy from waste gas streams

This invention relates to a method of recovering energy from a waste gas stream issuing from a metallurgical processing vessel in the iron- or steel-making industry, and to an iron- or steel-making plant employing the method.

In the operation of certain iron- and steel-making processes, considerable volumes of waste gas are discharged from metallurgical processing vessels, for example blast furnaces, converters and arc furnaces. It is conventional practice to pass such waste gas streams through cleaning plants, in which solid material and corrosive fluid components are removed, and then to mix the residual gas with gas from coke ovens or the like plant to produce a useful combustible gas. However, the cleaning process results in a considerable decrease in the temperature and pressure of the waste gas stream, and although some energy can be recovered from the gas cleaning plant, there is a considerable nett loss of energy as between the original waste gas stream and the final combustible gas.

The present invention aims to provide an improved method of recovering energy from a waste gas stream issuing from a metallurgical processing vessel, and a plant which utilises the method.

According to one aspect of the invention, a method of recovering energy from a stream of waste gas issuing from a metallurgical processing vessel at superatmospheric pressure and elevated temperature comprises the steps of supplying the gas stream to the inlet of a gas expander in which the gas stream is employed to drive a rotor having an output shaft, employing rotation of the output shaft of the gas expander to drive an alternating current generator, delivering the electrical output of the generator to the input side of a voltage and frequency converter which, within predetermined limits of the speed of rotation of the generator, delivers from its output side an electrical output to an electrical power network at a voltage and a frequency which at all times conform to the voltage and frequency of said network.

According to a further aspect of the invention, an iron- or steel-making plant comprises a metallurgical processing vessel from which, in operation of the plant, there issues a stream of waste gas at superatmospheric pressure and elevated temperature, means for supplying said gas stream to the inlet of a gas expander which includes a rotor drivable by the gas stream, said rotor comprising an output drive shaft, an alternating current generator arranged to be driven by said output drive shaft, and a voltage and frequency converter having its input side connected to the electrical output of the generator and its output side connected to an electrical power network, said converter being of the kind which, over a predetermined range of the speed of rotation of the generator, delivers at is output side electric power at a voltage and frequency which at all times conform to the voltage and frequency of said network.

When using the method in accordance with the invention, it is anticipated that it will be possible to lead the waste gas stream directly from the metallurgical processing vessel, for example a blast furnace, to the inlet side of the gas expander. Due to the hostile environment represented by the waste gas stream, rapid wear of the rotor of the gas expander may occur, leading to the need to replace the rotor at fairly frequent intervals, for example every 8,000 to 15,000 hours in the case of employing the method with a large blast furnace. The cost of such rotor replacement is, however, insignificant compared with the energy saving that may be achieved by the method in accordance with the invention. For example, in the operation of a large blast furnace, energy may be recovered from the waste gas by the method of the invention at a rate of up to 15 MW (megawatts). Assuming that the furnace is in operation for 8,000 hours per annum, the energy recovered per annum thus amounts to 120,000 MWh. Since the present day cost of purchasing this amount of electrical energy is of the order of £3.5 millions, the need to replace the rotor of the gas expander once every one to two years (at a present day cost of about £0.2 million) still leads to a vast saving of money.

However, if it is found in practice that wear of the rotor of the gas expander is too excessive, due to the abrasive nature of the high solids content of the waste gas stream, it is possible to pass the waste gas stream through a device, for example a cyclone type separator, for separating a proportion of the solid matter from the gas prior to supplying it to the inlet of the gas expander. A very considerable recovery of energy can still be achieved in this way.

The method and plant of the invention may be operated in conjunction with a conventional gas cleaning plant of the kind described above. In this case, the waste gas stream from the metallurgical processing vessel is directable, via suitable valve means, either to the gas cleaning plant or to the gas expander. The residual gas passing from the gas expander would pass to the gas cleaning plant for subsequent use in the manufacture of useful combustible gas as previously described. In the event of failure of the means used to recover energy from the waste gas stream by the method in accordance with the invention, the waste gas stream can be diverted by said valve means to the gas cleaning plant without passing through the gas expander.

Known gas expanders of a kind suitable for use in the method and plant in accordance with the invention have an operating speed of rotation of up to 6,500 r.p.m. On the other hand, known generators of a kind suitable for use in the method and plant in accordance with the invention are designed to rotate at a considerably lower speed, for example about 3,000 r.p.m. If, therefore, a gas expander having an operating speed range of from 5,000 to 6,500 r.p.m. is used, a reducing gear must be provided between the output drive shaft of the gas expander and the generator. On the other hand, if a gas expander with a lower operating speed range is chosen, for example 2,800 to 4,200 r.p.m., its output drive shaft may be coupled directly to the generator.

In operation of the method in accordance with the invention, the mechanical and electrical inertia of the system comprising the generator, the converter and the electrical power network can ensure that the rotor of the gas expander does not exceed a safe speed. However, in the event of an electrical failure in the aforesaid system, it is possible that owing to the consequent reduced inertia of the system, the speed of rotation of the rotor of the gas expander may build up to a dangerous level. To guard against this possibility, the aforesaid valve means may be linked to the control system of the converter so that immediately an electrical fault is detected, said valve means is actuated to divert the waste gas stream from the gas expander to the gas cleaning plant. The control system of the converter may comprise means which enables the converter to maintain connection between the generator and the power network for a short time, for example up to 4 seconds after the occurrence of an electrical fault in the system, so that at least commencement of the actuation of the valve means to divert the waste gas stream to the gas cleaning plant has commenced prior to the disconnection of the generator from the power network. In the event of a through fault developing in the converter, a short time-rated resistance load bank may be switched across the generator terminals to prevent breakaway of the gas expander/generator system

Known gas expanders of a kind suitable for use in the method and plant in accordance with the present invention are not designed to be self-starting and the preferred method of starting is to set the rotor of the gas expander in rotation prior to introduction of the gas stream. It is, of course, a simple matter to provide auxiliary means for effecting this initial rotation of the rotor of the gas expander, but a particularly convenient way of doing this is to employ the alternating generator as a motor for driving the rotor. To this end, the control system of the converter comprises means enabling the converter to supply power (approximately 10 per cent of the rated load) from the electrical power network to the generator at a voltage and frequency which result in the generator acting temporarily as a motor and driving the rotor of the gas expander.

If a plurality of similar metallurgical processing vessels, for example two or more blast furnaces, are operating close to one another, it may be convenient to lead the waste gas stream from each vessel to a common gas expander.

The invention will now be described in greater detail, by way of example, with reference to the accompanying drawing, the single Figure of which is a schematic diagram of a blast furnace plant in accordance with the invention.

The drawing shows a blast furnace plant comprising a furnace vessel 1 having a conventional blower 2 supplied, via a transformer 3 and circuit breakers 4, from a 3-phase electrical power supply network 5, which may be the network supplying the entire works in which the blast furnace plant is operating. In operation of the plant, waste gas from the vessel 1 can be led via a pipe 6 and a valve 7 to a conventional gas cleaning plant 8, in which the waste gas is de-pressurised, cooled and cleaned. The plant 8 has an outlet pipe 10 for cleaned and cooled gas.

A branch pipe 12 from the pipe 6 leads via a valve 14 to the inlet of a gas expander 16. The latter comprises a rotor 18 which can be driven by waste gas from the furnace vessel 1. After passing through the gas expander 16 and imparting most of its energy content to the rotor 18, the exhaust gas from the expander 16 is led via a pipe 20, including a valve 21, to the gas cleaning plant 8.

The rotor 18 has an output shaft 22 connected via a coupling 24 to the drive shaft 26 of a 3-phase alternating current generator 28 with a field exciter 30. The electrical output of the generator 28 is supplied via a circuit breaker 29, to the input side of a frequency converter 32, the output side of which is connected, via a circuit breaker 34, to the 3-phase supply network 5. A transformer 36 may be required between the converter 32 and the supply network 5, depending on the voltage of the network.

The converter 32 is controlled, in known manner, by signals transmitted to it from the network 5 via a line 33, so that its output voltage and frequency at all times match the voltage and frequency of the network 5 (or of the transformer 36 when provided) independent of the speed of rotation of the generator 28 within a wide range of speed of rotation of the latter. For example, if the generator 28 is a 2-pole machine having a synchronous speed of 3,000 r.p.m., the converter 32 should be capable of providing a substantially constant output voltage at a substantially constant frequency within a range of speeds of rotation of the generator 28 matching the operational speed range of the rotor 18 which, in the case of some commercially available gas expanders, may be from 2,000 to 6,500 r.p.m.

In operation of the above-described plant, with the blower 2 in operation, the valves 14 and 21 are first closed, the valve 7 is opened and the circuit breaker 34 is opened. Waste gas at high pressure and high temperature leaving the vessel 1 then flows via the pipe 6 to the gas cleaning plant 8. The clean, cooled gas leaving the plant 8 via the pipe 10 is mixed with coke oven gas introduced via a pipe 38 to form a combustible gas which is led away via a pipe 40.

The circuit breaker 34 is then closed and the control system of the converter 32 is adjusted so that power is supplied to the generator 28 from the network 5 for the purpose of driving the generator 28 as a motor and setting the rotor 18 of the gas expander in rotation. When the base speed of the gas expaander is reached (e.g. 2,000 r.p.m.), the valve 7 is closed and simultaneously the valves 14 and 21 are opened, so that the waste gas from the vessel 1 flows via the pipes 6 and 12 to the gas expander 16. After a short period (for example several minutes) the rotor 18 of the gas expander 16 produces a torque in excess of the torque provided by the synchronous drive system. When this torque is established, a signal is sent to the control system of the converter 32 to reverse the power flow of the converter, and power generation is established.

The exhaust gas which leaves the gas expander 16 at a considerably lower pressure and temperature compared with the gas fed to the gas expander, is led via the pipe 20 to the gas cleaning plant 8 to a region of the latter downstream of the de-pressurising unit of the plant. After cleaning, this exhaust gas passes from the plant 8 via the pipe 10, is mixed with coke oven gas introduced via pipe 38 to produce a combustible gas and is led away via the pipe 40.

In normal use of the plant, the electrical and mechanical inertia of the system formed by the generator 28, the converter 32, the transformer 36 and the power supply network 5 is sufficient to prevent over-speeding of the rotor 18 of the gas expander 16. However, in the event of an electrical failure developing in this system, there is a danger that opening of the circuit breaker 34 may lead to over-speeding of the rotor 18. To prevent this, the control system of the converter 32 is designed to delay opening of the circuit breaker 34, in the event of a fault arising, for a short period, for example 3 seconds, and at the same time to send electrical signals via lines 42, 43 and 44 to the valves 7, 14 and 21, respectively, to initiate opening of valve 7 and closing of valves 14 and 21. Immediately the valve 7 is cracked open there will be a considerably reduced torque applied to the rotor 18 by the gas stream. When the valves 14 and 21 are finally closed and the valve 7 is opened, waste gas is diverted from the gas expander 16 directly to the gas cleaning plant 8. In the event of a through fault occurring in the converter 32, a resistive short time-rated load 46 is immediately switched across the generator output terminals by a circuit breaker 47. The circuit breaker 47 is coupled with the circuit breaker 29 so that when the latter is closed, the circuit breaker 47 is simultaneously opened, and vice versa. Closing of the circuit breaker 47 and simultaneous opening of the circuit breaker 29 are initiated by a signal over a line 49 from the control system of the converter 32. Upon operation of the circuit breakers 29 and 47 in this manner, the control system of the converter 32 initiates closing of the valves 14 and 21 and opening of the valve 7 as described above. In the event of a failure of the network 5, a signal is sent via a line 35 from the network 5 to the control system of the converter 32 to initiate operation of the circuit breakers 29 and 47 as described above.

If the blower 2 operates at variable capacity during the metallurgical process carried out in the vessel 1, it may be economically worthwhile employing a converter, similar to the converter 32, but of lower power rating, to supply the blower 2. Such a converter is indicated by the chain lines 48.

In one embodiment of the plant shown in the drawing, the gas expander 16 was a two-stage gas expander, made by Ingersoll-Rand, capable of delivering an output of 17 MW at a speed of rotation of the shaft 22 of about 3,600 r.p.m. The generator 28 was a 2-pole, turbo designed synchronous machine, type GTL 1050CP made by ASEA AB. of Västerås, Sweden and described in ASEA's pamphlet No. OK 13-104E. This generator has an output of 21250 kVA at a voltage of 15 kV ± 5% and a frquency of from 47 to 60 Hz (corresponding to speeds of rotation of from 2,800 to 3,600 r.p.m.). The exciter 30 was an asynchronous generator, type MDE 500C made by ASEA AB. having an output of 210 kW, the excitation of this asynchronous generator being controlled by a 3-phase a.c. thyristor converter, type YQND made by ASEA AB. and described in ASEA's pamphlet No. YT 374-001E. The converter 32 consisted of a thyristor rectifier/inverter equipment comprising a d.c. thyristor rectifier connected by a d.c. link to an a.c. thyristor inverter, the rectifier and inverter each being a six-pulse bridge unit of the type YRTC 16-1450-3 made by ASEA AB. and described in ASEA's pamphlet No. YT 272-101E. This converter had an output power of 17 MW, an input voltage of 15 kV, and an output voltage to match the voltage of the power network 5 (or the transformer 36 when provided) at a frequency which automatically followed the network frequency. Using this equipment it is estimated that up to 72 per cent of the heat and pressure energy of the waste gas stream can be usefully recovered as electrical energy delivered to the network 5.

CLAIMS

1. A method of recovering energy from a stream of waste gas issuing from a metallurgical processing vessel (1) at superatmospheric pressure and elevated temperature, characterised by the steps of supplying the gas stream to the inlet of a gas expander (16) in which the gas stream is employed to drive a rotor (18) having an output shaft (22), employing rotation of the output shaft (22) of the gas expander (16) to drive an alternating current generator (28), and delivering the electrical output of the generator (28) to the input side of a voltage and frequency converter (32) which, within predetermined limits of the speed of rotation of the generator (28), delivers from its output side an electrical output to an electrical power network (5) at a voltage and a frequency which at all times conform to the voltage and frequency of said network (5).

2. An iron- or steel-making plant comprising a metallurgical processing vessel from which, in operation of the plant, there issues a stream of waste gas at superatmospheric pressure and elevated temperature, characterised in that it comprises means (6, 12) for supplying said gas stream to the inlet of a gas expander (16) which includes a rotor (18) drivable by the gas stream, said rotor (18) comprising an output drive shaft (22), an alternating current generator (28) arranged to be driven by said output drive shaft (22), and a voltage and frequency converter (32) having its input side connected to the electrical output of the generator (28) and its output side connected to an electrical power network (5), said converter (32) being of the kind which, over a predetermined range of the speed of rotation of the generator (28), delivers at its output side electric power at a voltage and frequency which at all times conform to the voltage and frequency of said network (5).

3. A plant according to claim 2, characterised in that it comprises valve means (7, 14) for directing said

waste gas stream from said processing vessel (1) either to said gas expander (16) or to a gas cleaning plant (8).

4. A plant according to claim 3, characterised in that said converter (32) is connected to said network (5) via a circuit breaker (34), and the control system of the converter (32) comprises means for initiating opening of said circuit breaker (34) in the event of an electrical fault developing in said generator (28), said converter (32) or said network (5).

5. A plant according to claim 4, characterised in that the control system of the converter (32) comprises means for initiating actuation of said valve means (7, 14), to divert said waste gas stream from said gas expander (16) to said gas cleaning plant (8), in the event of an electrical fault developing in said generator (28), said converter (32) or said network (5).

6. A plant according to claim 5, characterised in that the control system of the converter (32) comprises means enabling it to maintain said circuit breaker (34) closed for a short time after the occurrence of said electrical fault, whereby commencement of the actuation of said valve means (7, 14) to divert said waste gas stream to said gas cleaning plant (8) has commenced prior to opening of said circuit breaker (34).

7. A plant according to any of claims 2 to 6, characterised in that said converter (32) is a thyristor rectifier/inverter equipment comprising a d.c. thyristor rectifier connected by a d.c.link to an a.c. thyristor inverter.

8. A plant according to any of claims 2 to 7, characterised in that said generator (28) is drivable as a motor with current supplied from said network (5) via said converter (32), whereby said gas expander (16) can be set in rotation prior to being driven by said waste gas

stream.

9. A plant according to any of claims 2 to 8, characterised in that it comprises a device for separating solid matter from said waste gas stream prior to supplying it to the inlet of said gas expander (16).

10. A plant according to any of claims 2 to 9, characterised in that it comprises a resistance load bank (46) connectible across the terminals of said generator (28) in the event of a through fault developing in said converter (32).

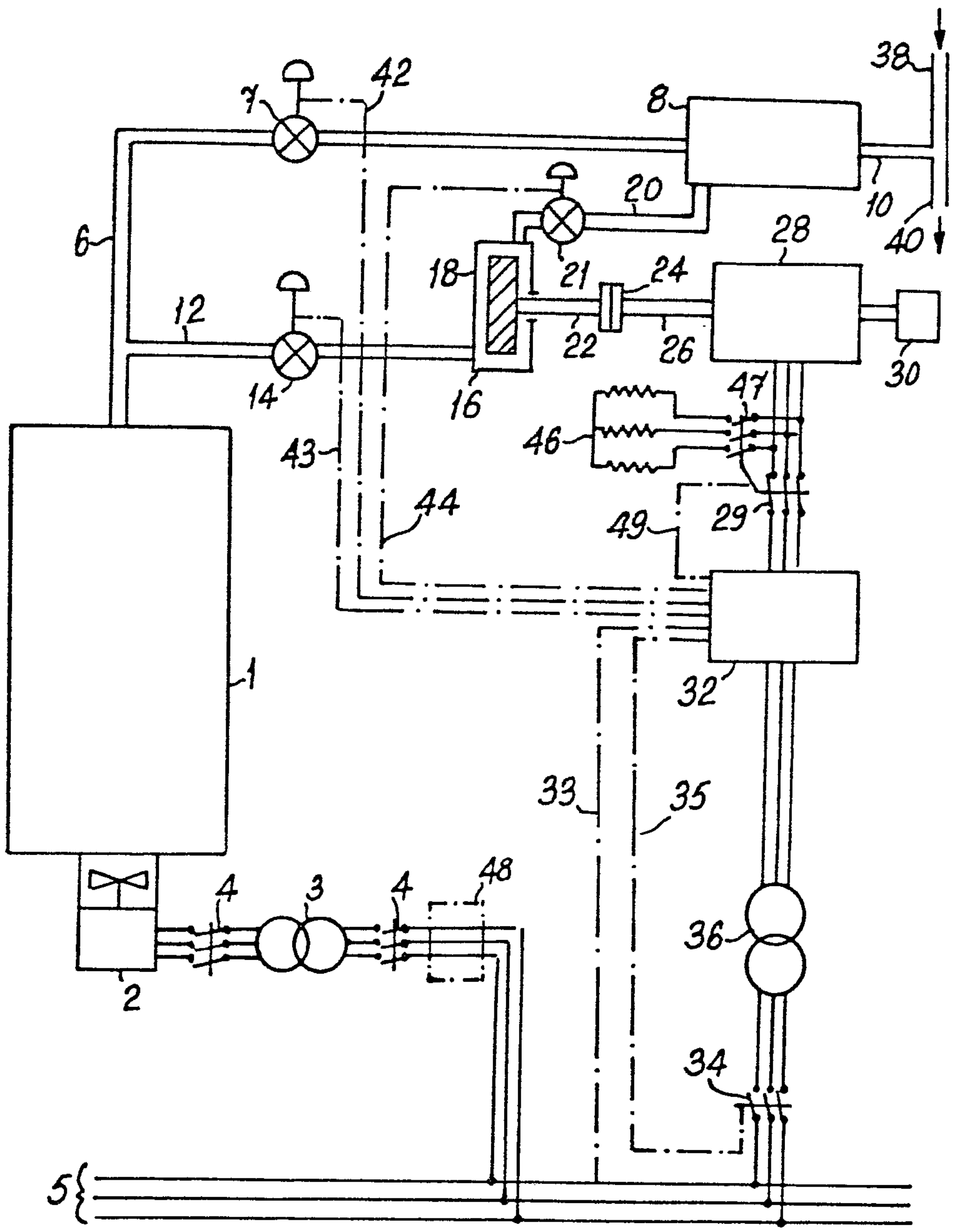

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Fig. 1