Title: RECOVERY OF ENERGY FROM BLAST FURNACE GAS IN AN EXPANSION TURBINE

Abstract: A TRT process and system for recovering energy from blast furnace top gas in an expansion turbine are disclosed. The over-pressurized blast furnace top gas stream released by a blast furnace (10) is subsequently passed through a top gas cleaning plant (12), a preheating unit (22) and an expansion turbine (24) coupled to a load (30). The top gas stream is warmed-up in a heat-exchanger (20) located in-between the top gas cleaning plant (12) and the preheating unit (22). The top gas flow, after expansion in the turbine (24), is fed through the heat-giving side of the heat-exchanger (20).
RECOVERY OF ENERGY FROM BLAST FURNACE GAS
IN AN EXPANSION TURBINE

FIELD OF THE INVENTION

The present invention generally relates to the treatment of blast furnace gas and more specifically to the recovery of pneumatic energy from blast furnace top gas pressure in an expansion turbine.

BACKGROUND OF THE INVENTION

As it is well known, blast furnace top gas is a by-product of blast furnaces that is generated when the iron ore is reduced with coke and / or other fuels to metallic iron. Blast furnace top gas is commonly used as a fuel within the steel works, but it can be burnt in boilers and power plants as well. It may also be combined with natural gas or coke oven gas before combustion or a flame support with higher heating value gas or oil is provided to sustain combustion.

As it is also well known, blast furnaces (BF) have been operated since decades with an internal overpressure, which — with a proper dimensioning of the furnace — permits a substantial increase in the conversion of materials and energy and thus in the output of pig iron.

Operation under internal overpressure of course also implies considerable additional costs related to equipment and operation. More particularly, it requires producing pressurized air with convenient supply pressure level in a cold blast compressor, to form the so-called cold blast, which is then heated up in the hot blast stoves (or Cowpers) to high temperature levels and the resulting hot blast is blown into the blast furnace.

Also typical for operation under overpressure is that the gas leaving the blast furnace at the top, known as top gas or blast furnace gas, is at a pressure substantially above atmospheric pressure. This top gas however still contains
combustible components, primarily carbon monoxide, and to a lesser extent hydrogen, and can be used as low heating value combustion gas for producing heat or mechanical and electrical energy.

Top gas exiting the blast furnace carries along important amounts of solid matter, primarily in dust-like form. Before any subsequent use of the top gas, it is required to remove this solid material. This is conventionally achieved in a gas cleaning sub-plant of the blast furnace plant, which typically comprises first dry separation equipment — with a gravity-separator (dust catcher) and/or an axial cyclone—and a subsequent wet, fine cleaning device (wet separator). Due to the wet cleaning, the top gas temperature drops by about 100°C, is saturated with water vapor and includes additional liquid water droplets.

Upon cleaning, it has been known for long, in addition to the use of the thermal energy of the top gas, to recover the pneumatic energy of the pressurized BF top gas in an expansion turbine. In the turbine, the top gas expands to close to atmospheric pressure while producing mechanical work. The turbine rotor can be coupled e.g. to an electric generator, to the cold blast compressor, or to any other load.

As it is now also known, the efficiency of such expansion turbine (also referred to as Top pressure Recovery Turbine - TRT) can be increased by heating-up the cleaned—and thus cooled—top gas just before it enters the turbine. This is e.g. described in JP 62074009. While heating-up of the cleaned top gas is desirable in respect to TRT efficiency, the expanded top gas however has a higher outlet temperature. This may be problematic for a user such as e.g. a thermal power station, where the top gas will arrive at a temperature higher than expected.

OBJECT OF THE INVENTION

The object of the present invention is to provide an alternative method of recovering energy from blast furnace gas in a TRT plant as well as a corresponding system.
This object is achieved by a method as claimed in claim 1 and a blast furnace top gas recovery system as claimed in claim 4.

SUMMARY OF THE INVENTION

According to the present invention, expanded BF top gas leaving the expansion turbine in a TRT plant is used as a heat source in a heat-exchanger located inbetween the top gas cleaning unit/plant and the (conventional) pre-heating unit upstream of the expansion turbine. In other words, the residual heat of the expanded top gas flow downstream of the expansion turbine is used to warm-up (preheat) the cleaned top gas flow upstream of the expansion turbine.

This circulation scheme of the BF top gas in a TRT plant proves significantly advantageous. First, it allows increasing the temperature of the cleaned BF top gas at the turbine inlet, since heat can be removed in the heat exchanger downstream of the turbine, so that the cleaned, expanded gas can be delivered to the clean gas network at a temperature convenient for downstream users. Secondly, since cleaned top gas is already partially warmed-up in the heat exchanger before the pre-heating unit, the amount of energy required in the pre-heating unit can be reduced.

In practice, this mode of operation leads to an increase of energy output and efficiency of the whole BF top gas TRT process.

The term heat exchanger herein encompasses any appropriate type of device where the flow of cleaned top gas upstream of the turbine can be brought into heat exchange relationship with the expanded top gas flow downstream of the turbine, however without mixing with one another. It is clear that in such heat exchanger the heat is transferred from the expanded cold gas to the top gas flow upstream of the turbine by conduction but there is no combustion of the expanded top gas stream in the heat exchanger itself.

Preferred embodiments are recited in the dependent claims.
A blast furnace top gas recovery system in accordance with one aspect of the present invention comprises: a top gas cleaning unit/plant conditioning top gas released by a blast furnace; a heat-exchanger comprising a heat-receiving side and a heat-giving side (each having an inlet and an outlet), wherein a first piping connects the outlet of said top gas cleaning plant with the inlet of the heat-receiving side of said heat exchanger; a pre-heating unit having an inlet connected to the outlet of said heat-giving side of said heat exchanger via a second piping; an expansion turbine having an inlet connected to the outlet of said pre-heating unit via a third piping and an outlet connected to the inlet of the heat-giving side of said heat exchanger via a fourth piping; a load coupled to the output shaft (rotor) of the expansion turbine.

BRIEF DESCRIPTION OF THE DRAWING

The present invention will now be described, by way of example, with reference to the accompanying drawing, in which:

FIG. 1: is a schematic diagram of a gas energy recovery system for performing the present method.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

In order to further illustrate the present invention, an explanation of the involved thermodynamic processes, under simplified and ideal conditions, will now be given, in an exemplary manner.

Under the assumption of a perfect gas behaviour, regardless of the condensing water vapor and neglecting the expansion losses, the specific output work from the expanding top gas in the turbine is expressed as:

\[ a = \left[ K \cdot R \cdot T \cdot \frac{1}{(K - 1)} \right] \cdot \left[ 1 - \left( \frac{p_2}{p_1} \right)^{\frac{(K - 1)}{K}} \right] = [A][B] \]  

(1)

where:

- \( a \) [J/kg] : specific output work or specific output of mechanical energy, per kg of top gas
κ [-] : isentropic exponent, a value between 1.3 and 1.4 depending on the proportion of diatomic or tri-atomic gases in the top gas

R [J/(kg*K)] : gas constant

\( T_1 \) [K] : absolute temperature at turbine inlet

\( P_1 \) [Pa a] : absolute pressure at turbine inlet

\( p_2 \) [Pa a] : absolute pressure at turbine outlet

5 Since \( p_1 \) and \( p_2 \) appear as a ratio, they can also be more simply expressed in bars.

The term \([B]\) mainly depends on the pressure ratio before and after the turbine, i.e. on the top gas overpressure at the exit of the blast furnace and the pressure loss in the gas cleaning unit/plant on the one hand as well as on the clean gas network after the turbine, on the other hand. With a top gas overpressure at the BF top of about 2.5 bar or 3.5 bar a, a overall pressure loss of 0.4 bar in the cleaning apparatus, a pressure of about 0.1 bar g or to 1.1 bar a in the clean gas network and \( κ = 1.35 \), a value of 0.236 may e.g. be obtained for term \([B]\). It may be noted that \([B]\) increases with \( p_1 \), and tends towards 1 when \( p_2/p_1 \) drops towards 0.

Term \([A]\) only sensibly varies with the turbine entry temperature. \([A]\) increases proportionally to temperature \( T_1 \) and thus also the specific output work \( a \), the latter being however moderated by term \([B]\). It may be noted that term \([A]\) represents the enthalpy of the top gas.

As it clearly appears, a consequence of the influence of \([A]\), i.e. the turbine entry temperature, onto the specific output work \( a \) is that a temperature drop of the top gas before entering into the turbine should be avoided as far as possible.

This can be achieved by replacing the wet, fine-cleaning by a dry fine-cleaning system, for example using an electro-filter or a bag filter - a solution
which has rarely been implemented. The additional costs for such pressure-proof, wet fine-cleaning device are in fact substantial.

Although energetically less satisfactory, it is therefore predominant practice to install the turbine behind a wet fine-cleaning device, the turbine providing for the expansion of cooled, steam saturated and water droplets containing blast furnace gas.

Based on this "cold" turbine configuration it has already been proposed to warm-up (preheat) the cooled blast furnace gas, downstream of the wet cleaning and upstream of the inlet of the turbine. This temperature increase of the previously "cold" and steam-saturated blast furnace gas at the turbine inlet has the advantage, in addition to the increase of the specific output work, of avoiding or reducing water vapor condensation and the formation of water droplets during the expansion. Indeed, water droplets can damage or cause the destruction of the turbine blades and the formation of droplets has therefore to be limited. The pre-heating of the "cold" blast furnace gas can e.g. be achieved in a pre-heating unit located upstream of the turbine inlet and exploiting the thermal energy gained from top gas combustion.

Let $T_0$ be the absolute temperature of the top gas at the outlet of the top gas cleaning unit, then $T_1 = T_0$ represents the conventional practice of the "cold" expansion turbine, and $T_1 > T_0$ represents the case with pre-heating.

This implies that the turbine outlet temperature $T_2$ is linked to the inlet temperature $T_1$ through the pressure ratio $p_2/p_1$, which can be expressed:

$$T_2 = T_1^* (p_2/p_1)^{-4/k} = T_1^* [C]$$

(2)

With the exemplary values for the calculation of $[B]$, a value of 0.764 is obtained for $[C]$.

For existing installations and designs, it is important for subsequent top gas users that temperature $T_2$ does not exceed $T_0$, i.e. that the turbine outlet temperature does not exceed the temperature at the outlet of the top gas cleaning plant. Then $T_1$ may not exceed the value $T_0/[C]$. For example, in case
T₂ shall not exceed T₀ = 50 °C ≈ 323 K, then the preheating temperature T₁ cannot exceed the value 323/0.764 = 423 K ~ 150 °C.

Accordingly, the increase in the specific output work due to pre-heating is limited to 1/[C] - 1 = 1/0.764 - 1 = 0.31 or 31%, as compared to the "cold" turbine operation. (It may however be noted that the increase in total output work by heating of the water vapor and evaporation and overheating of the residual liquid cleaning water in the top gas as well as the expansion of the overheated steam at reduced or no condensation, are not taken into account for the sake of simplification).

It shall be appreciated that, in order to further increase the specific output work, the present invention proposes introducing a heat-exchanger inbetween the top gas cleaning plant and the (conventional) pre-heating unit to take advantage of the heat remaining in the expanded top gas and warm-up the cold, cleaned top gas. Accordingly, upon leaving the top gas cleaning plant the cold, cleaned top gas is fed into the heat-exchanger, on the cold side (heat-taking/receiving side) thereof, where its temperature increases from T₀ to T₁. In the heat-exchanger, heat is transferred to the cold cleaned gas from the expanded top gas that is fed into the hot side (heat-giving side) of the heat-exchanger.

The top gas is subsequently fed into in the conventional, pre-heating unit, where its temperature increases from T₁ to T₂. Downstream of the turbine, upon traversing the heat-exchanger, the temperature of top gas stream is decreased from T₂ to the desired temperature, i.e. again about T₀, for entry into the clean gas network and use at a user facility.

Such operating process can be performed in a blast furnace plant as illustrated in Fig.1 and where the temperatures T₀, T₁, T₂ are reported. Reference sign 10 designates a blast furnace that is coupled to the top gas recovery system to recover the pneumatic energy from the top gas released by the furnace. BF gas released from the BF 10 is fed into the top gas cleaning unit or plant generally indicated 12. The top gas cleaning unit 12 preferably
comprises a dry separator 16 serially connected with a wet separator 18. Any appropriate type of cleaning technology may be implemented in unit 12.

The cleaned top gas flow then enters into the heat exchanger 20 (where it is heated to $T_{01}$) and subsequently into the pre-heating unit 22, from which it is released at $T_1$. Subsequently, the pre-heated clean gas flow enters the expansion turbine 24 and exits therefrom at temperature $T_2$. This expanded gas stream flows through the heat-giving side of heat exchanger 20 and is delivered to the clean gas network at temperature $T_0$. The turbine 24 has a rotor with output shaft coupled to a load 30 such as for example an electric generator or an air compressor for the BF cold blast.

In the present embodiment, the heat-exchanger 20 is of the conventional type comprising: a plenum chamber on the cold (heat-taking) side that receives the cold top gas exiting from the cleaning plant 20; and a serpentine-like ducting traversing the plenum chamber and carrying the expanded top gas flow delivered by the turbine 24. As is clear for the skilled person, any other type of heat-exchanger allowing bringing the upstream and downstream (relative to the turbine) BF gas flows into heat-exchange relationship, however without mixing, may be used. This heat exchange is preferably carried directly between the upstream and downstream BF gas without the use of an intermediate fluid loop.

As for the pre-heating unit 22, it may of course also comprise a plenum/serpentine type heat exchanger, the heat-giving side of which may e.g. take its heat from a fluid heated via an external source, e.g. by combustion of BF gas or from the slag granulation installation, as e.g. described in JP 62074009

While in Fig.1 only the TRT system is represented and there is one piping system 14 interconnecting the various elements thereof, it is clear that not necessarily all but only a portion of top gas released by the BF 10 may be treated in the TRT, the remainder of top gas being used e.g. for heating (combustion) purposes in the pre-heating unit 22 or elsewhere, as it is clear to those skilled in the art.
Let us now explain how the present process influences the operation of the recovery turbine.

If, under simplified assumptions, in particular neglecting the remaining temperature difference in the heat exchanger 20 between the heat-giving outlet and the heat-taking inlet, and again without consideration of water vapor and liquid water, the temperature increase on the heat-taking side and the temperature decrease on the heat-giving side in the heat-exchanger are equal and an outlet temperature on the heat-giving side of \( T_0 \) is achieved, then \( \Delta T_0 = T_{0t} - T_0 = T_2 - T_0 \), while the temperature increase in the pre-heating unit 22 corresponds to \( \Delta T_2 = T_{i} - T_{0i} \), then there exists the following relationship between \( \Delta T_0 \) in the heat-exchanger 22 and \( \Delta T_1 \) the conventional pre-heating unit 22:

\[
\Delta T_0 = \{[0]/(1-[0])\}^* \Delta T_1 - T_0 \tag{3}
\]

In order for \( \Delta T_0 \) to be positive, i.e. to justify the use of the heat-exchanger 20, \( \Delta T_2 \) has to be larger than \( T_0 \cdot (1/[C] - 1) \). The limit value factor \( 1/[C] - 1 \) corresponds to the above-given limit for the pre-heating to avoid a temperature above \( T_0 \) at the turbine outlet, with a value of 0.31 in the exemplary calculation.

In the range above this limit value, i.e. from the temperature at which the heat-exchanger 20 is useful, the following relationship between the temperature increase \( \Delta T_1 \) in the conventional pre-heating unit 22 and the turbine inlet temperature \( T_i \) exists:

\[
T_1 = \{1/(1-[C])\}^* \Delta T_1 \tag{4}
\]

Based on the above exemplary values, this leads to \( T_1 = 4.24 \cdot \Delta T_1 \). In other words, \( T_1 \) increases about a fourfold quicker than the temperature increase in the pre-heating unit 22. The consequence is made clear by using equation (4) in relationship (1), while using \([C]\) as obtained from equation (2):

\[
a = [k R^*l(k-1)]^* \Delta T_1 \tag{5}
\]

Hence, each augmentation of the temperature increase in the pre-heating unit 22 leads to an increase in the specific output work by a ratio of 1:1, or to
the same extent as the change of enthalpy. In the initially discussed case implementing pre-heating without the heat-exchanger 20 (e.g. up to 150°C), the preheating (and hence the increase in turbine inlet temperature) leads to an increase in the specific outlet work attenuated by factor \([B]\), with a value of 0.236 in the example.

The 1:1 conversion of the additional heat supplied (increase of \(\Delta T_1\)) in extra output work (increase of \(a\)) — so to speak without Carnot efficiency — can be explained by the simultaneous displacement of the entire range of expansion temperatures to higher temperature levels, the ratio \(T_2/T_1\) remaining constant due to the also constant \(p_2/p_1\) ratio.

To further illustrate the present process, Table 1 below summarized exemplary cases, under simplified conditions and neglecting the pressure losses in the heat exchanger 20 and pre-heating unit 22.

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<th>(T_0 [\text{°C}])</th>
<th>(T_{01} [\text{°C}])</th>
<th>(T_1 [\text{°C}])</th>
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<td>0</td>
<td>-26</td>
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<td>100</td>
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<td>180</td>
<td>311</td>
<td>2.37</td>
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Table 1

In case top gas is used for combustion in the pre-heating unit 22 for the temperature increase \(\Delta T_1\), the requirement for top gas is directly proportional to \(\Delta T_1\).

The significant increase in the specific output work, and hence the effi-
ciency of the expansion of a predetermined flow mass of top gas, appears from the second to last column.

The last column represents the effect of the introduced pre-heating energy. The reference case is the heating-up to a temperature at which the expansion causes a lowering of the turbine outlet temperature to the turbine inlet temperature. For each case, the influence of the increase in specific output work with respect to the "cold" turbine and the corresponding temperature increase (and thus heat) is formed in the pre-heating unit and this behavior is compared with the same in the reference case. The increasing values show that increasing of the preheating (and thus the turbine inlet temperature), leads to an increase in efficiency.

As a further improvement of the performance may be obtained by injecting water into the heater. The water evaporates and overheats, of course, with a corresponding increase in the need for preheating energy, and increases the mass of the gas flow in the turbine that generates the output work.
Claims

1. A process for recovering mechanical energy from blast furnace top gas in a top gas recovery turbine system, wherein a pressurized blast furnace top gas stream released by a blast furnace (10) is subsequently passed through a top gas cleaning unit (12), a preheating unit (22) and an expansion turbine (24) coupled to a load (30), characterized in that said top gas stream is warmed-up in a heat-exchanger (20) located in-between said top gas cleaning unit (12) and said pre-heating unit (22); and in that said top gas, after expansion in said turbine (24), is fed through the heat-giving side of said heat-exchanger (20).

2. The process according to claim 1, wherein said blast furnace top gas stream is saturated with water vapor and/or contains water drops.

3. The process according to claim 1, wherein water is introduced into said top gas stream in said pre-heating unit (22).

4. A blast furnace top gas recovery system comprising an expansion turbine (24) in which blast furnace gas expands and provides mechanical work to a load (30) coupled to the turbine output shaft, a top gas cleaning unit (12) and a pre-heating unit (22) being connected to said expansion turbine (24) and located upstream thereof, a piping system (14) connecting the top gas cleaning unit (12), pre-heating unit (22) and expansion turbine (24) in this order, characterized in that a heat-exchanger is located in the piping system in-between said top gas cleaning unit (12) and said pre-heating unit (22) for heating said top gas stream, wherein said heat-exchanger comprises a heat-giving side having its inlet in communication with the outlet of said expansion turbine (24).

5. The system according to claim 4, wherein said pre-heating unit (22) comprises at least one nozzle for injecting water in the clean top gas stream flowing therethrough.
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C21B F27D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, COMPENDEX, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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<td>SU 1 177 351 A2 (ZAPOROZH IND INST [SU]) 7 September 1985 (1985-09-07) column 1, line 11 - column 2, line 7; figure 1</td>
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<td>A</td>
<td>JP 54 115605 A (MITSUI SHIPBUILDING ENG) 8 September 1979 (1979-09-08) Patent Abstracts of Japan figures 1, 2</td>
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Date of the actual completion of the international search

25 October 2010

Date of mailing of the international search report

04/11/2010

Authorized officer

Juhart, Matjaz

* Special categories of cited documents:

-A document defining the general state of the art which is not considered to be of particular relevance

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-& document member of the same patent family

Further documents are listed in the continuation of Box C. See patent family annex.
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