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(54) **STEEL MILL THERMAL ENERGY RECOVERY FOR CALCINATION**

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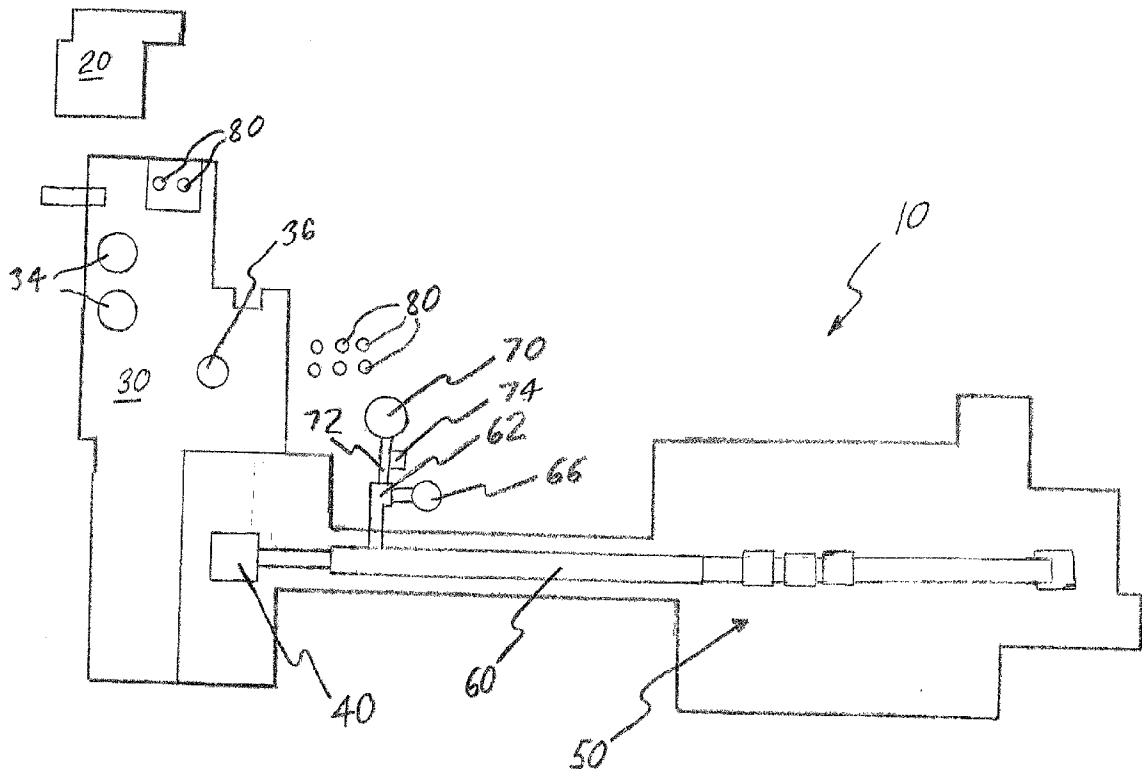
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(57) **ABSTRACT**

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The invention relates to a steelmaking thermal energy recovery system. The steelmaking thermal energy recovery system comprises a steelmaking waste flue gas, a calcinable material, and a kiln. The steelmaking waste flue gas provides at least a portion of the thermal energy to the kiln for calcination of the calcinable material.



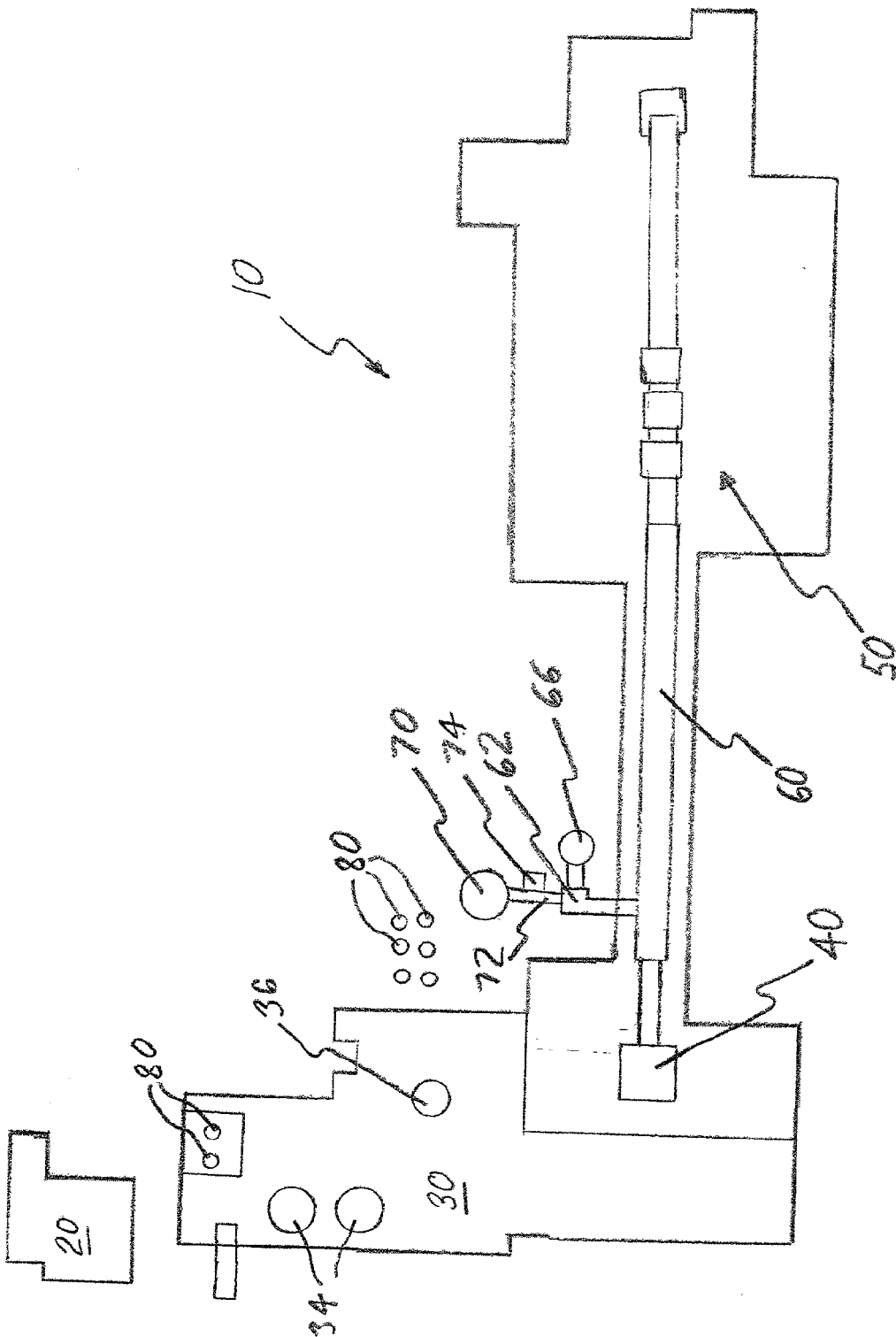


FIGURE 2

STEEL MILL THERMAL ENERGY RECOVERY FOR CALCINATION

TECHNICAL FIELD

[0001] The present invention relates to the recovery of the thermal energy from steel mill waste gases for calcination.

BACKGROUND OF THE INVENTION

[0002] In electric arc melting of steel, the energy efficiency and overall cost is greatly improved by the creation of a basic foamy slag within the furnace. Foaming of the slag in order to engulf the electric arc is well known in the art, and is described, for example, in U.S. Pat. No. 4,447,265 and in U.S. Pat. No. 4,528,035. The procedures described involve the injection of carbonaceous material, such as lime, into the furnace slag to cause carbon monoxide gas evolution, and the escaping gas causes the slag to effervesce or foam. As a result of the effervescence or foaming, the slag is increased in its volume, engulfing the electric arcs and improving electrical and heat transfer efficiency. Also described in the prior art, calcium oxide (lime) is sometimes injected along with the carbon and the oxygen in order to raise the slag basicity and stabilize the foam that is created. In addition, other benefits are derived such as reduced refractory lining wear, higher productivity, reduced graphite electrode consumption, and increased yield of iron units from the melted scrap. Foamy slag practice is arguably one of the greatest improvements to electric arc steel melting technology of the 20th century.

[0003] Several steel mill operations within a single plant may result in offgas streams which contain large quantities of thermal energy. For the most part, steelmaking operations are intermittent and as a result, many of these gas streams are not continuous. In addition, the thermal load contained in many of the offgas streams fluctuates throughout the steel-making cycle. As a result, it has generally not been possible to attempt recovery of the thermal energy contained in the offgases. One notable exception is the plethora of scrap heating processes developed over the past 30 years. The offgases produced in the electric arc furnace are passed through scrap in order to pre-heat the scrap prior to charging it to the furnace. The scrap may be held in a scrap bucket, a pre-heating tunnel or a shaft sitting above the furnace. (For example, U.S. Pat. No. 4,328,388, U.S. Pat. No. 4,543,124, U.S. Pat. No. 5,153,894, U.S. Pat. No. 5,264,020 and U.S. Pat. No. 6,024,912). For preheating scrap offgas temperature fluctuations are acceptable and a continuous off gas stream is not necessary.

[0004] However, there are some steelmaking operations in which a continuous offgas stream is generated which may be more consistent in temperature and flowrate such as from hot strip mill tunnel or reheat furnaces or continuous annealing lines including hot dip coating lines. Still, these offgases may not be efficiently used.

SUMMARY OF THE INVENTION

[0005] In one embodiment, the invention relates to a steelmaking thermal energy recovery system. The steelmaking thermal energy recovery system comprises a steelmaking waste flue gas, a calcinable material, and a kiln. The steelmaking waste flue gas provides at least a portion of the thermal energy to the kiln for calcination of the calcination material.

[0006] In another embodiment, the invention is directed to a means of providing the thermal energy requirement for calcination operations located adjacent to steel making operations by re-using waste off gases from the steelmaking operations.

[0007] In another embodiment, the invention relates to a method of calcinating limestone. The method comprises providing a kiln and supplying limestone as feedstock for calcination. The method further provides a steel manufacturing operation's hot waste gases as a heat source. The heat source heats the limestone within the kiln to the calcination temperature.

[0008] In another embodiment, the invention is directed to another method of steelmaking. The method comprises making a first heat of steel in a melting operation and converting the heat of steel to slabs. The method further comprises heating the slabs, capturing hot off gases from the heating of slabs, and supplying the hot off gases to a calcination process.

[0009] In yet another embodiment, the invention relates to a captive calcination facility. The facility comprises a raw material, a waste flue gas from a steel making continuous process, a kiln, and a steel melting operation. The raw material comprises at least some calcinable material. The steelmaking waste flue gas provides at least a portion of the thermal energy to the kiln to calcinate the calcinable material. At least a portion of the calcinated material from the kiln is added to the steel to form slag.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] While the specification concludes with claims particularly pointing out and distinctly claiming the present invention, it is believed that the same can be better understood from the following description, taken in conjunction with the accompanying drawing, in which:

[0011] **FIG. 1** illustrates a schematic view of an exemplary embodiment of a steel mill recovering thermal energy of waste gases in accordance with the present invention.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

[0012] Reference can now be made in detail to various exemplary embodiments of the invention, some of which are also illustrated in the accompanying drawing. Throughout the specification and claims, all parts and percentages are by weight unless otherwise specified.

[0013] In one embodiment and as shown in **FIG. 1**, a steel mill **10** recovers some of the thermal energy from the steel making process for the calcination of lime. In this embodiment, the steel mill **10** has a bag house **20**, a melt shop **30**, a caster **40**, and a rolling mill **50**. This steel mill **10** also includes a kiln **70**.

[0014] The rolling mill **50** has a tunnel furnace **60** for heating or maintaining heat in slabs supplied by the caster **40**. Hot waste gases, usually about 2000° F., from the tunnel furnace **60** are exhausted into the exhaust system **62**. In the prior art, the exhaust system typically exhausts all of the waste gas to an exhaust stack. However, in this embodiment of the present invention, at least some of the exhaust gas is fed to the kiln duct **72**. The kiln duct **72** delivers the hot waste gases to the kiln **70**.

[0015] In this embodiment of the present invention, limestone is feed into the kiln 70. The limestone is at least partially calcinated in the kiln 70 to make a calcinated product. Storage containers 80 may then be filled with the calcinated product. These storage containers 80 may have insulation to maintain heat in the calcinated product. In other embodiments, the storage containers may be externally heated, have internal heaters, or be simple metal containers or bags providing no insulation or they may be of any other similar configuration as would be known to one of ordinary skill in the art.

[0016] The storage containers 80 of FIG. 1 may then be transported to the melt shop 30 where the calcinated material may be added directly into the melting process. For example, the calcinated material may be lime or dolomitic lime added to an electric arc furnace 34 to produce slag in a heat of molten steel. This process will further be discussed below.

[0017] Thus, the present invention relates to the recovery of the thermal energy from steel mill waste gases for calcination. The invention further relates to heat treatment of calcinable materials such as calcium carbonate bearing material, magnesium carbonate bearing material or blends of materials bearing both. The limestone calcined hereunder and the production of lime is understood to include, among other things, dolomite and like materials composed of a carbonate fraction that decomposes upon thermal treatment.

[0018] In comparison, conventional calcining technologies usually use the combustion of gases in air as the primary source of energy input for the heating and calcination of the calcinable material. The present invention uses waste exhaust gases from steel mill operations. Utilization of the waste gases provides substantial fuel savings, cost savings and a reduction in the amount of greenhouse gases generated per unit of calcined material produced, as will be discussed in more detail.

[0019] Steel mills typically have a heating requirement for raising or maintaining the temperature of semi-finished product, such as rolling mill reheat furnaces, annealing lines, or hot dip coating line preheat furnaces. For example, rolling operations, such as rolling mill 50, make semi-finished product by deforming the steel into various shapes or thicknesses as required for the finished, saleable product. In most cases, this requires intermediate steel product to be heated to approximately 2000 to 2300° F. Usually, this heating is accomplished using reheat or tunnel furnaces such as tunnel furnace 60. These furnaces are large refractory lined structures and may contain several different "heating" zones, which have air/fuel fired burners to provide thermal input to the furnace. The intermediate steel product passes through the reheat furnace and in doing so is heated to the required temperature for rolling operations.

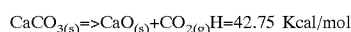
[0020] Much of the heat that is input to the re-heat furnace is lost to the offgas stream when it exits the furnace. Typically, reheating operations in the steel mill will consume between 500,000 and 1,000,000 Btu per ton of steel processed. The amount of heat in the offgases leaving the heating furnaces represents between 30 and 50% of this total energy input. Offgases from reheating operations are frequently cooled through the addition of ambient air prior to discharge from a stack, such as waste gas stack 66. The offgas temperature leaving the stack is typically in the range

of 1000 to 2300° F., depending on the amount of dilution air that is added. These properties make the offgas streams ideal for thermal recovery in ancillary steelmaking operations. In one embodiment of the present invention, this gas is used in a calcination operation in order to recover a portion of the thermal energy contained in these offgases.

[0021] Next to iron-bearing materials, the largest material usage in steelmaking is calcined material, which are used to produce a flux for steelmaking operations. Typical lime requirements for steelmaking operations can range from 30 to 90 pounds per charge ton. MgO requirements are typically in the range of 5 to 20 pounds per charge ton.

[0022] Currently the methods of choice for producing calcined material include various commercial processes. These commercial processes are usually conducted in a kiln 80, such as the shaft kiln, stone preheater kiln and straight kiln calcination systems. In all of these processes, the material to be calcined undergoes several processing steps including crushing and sizing of raw material, drying and preheating the calcium carbonate bearing material, delivery of the preheated material into a calcining zone, calcining the material, and collecting the calcined product. These processes provide a heated gas stream to dry, heat and calcine the limestone material.

[0023] Large-scale lime calcination operations use combustion gases from an oil or gas burner and are typically carried out in an inclined rotary kiln, or a vertical shaft kiln, although flash calciners may be used. In one embodiment of the current invention, the lime kiln 70 is dimensioned with an outside diameter of 3 m and a length of 80 m and has a production capacity of 180 tons of CaO per day. Limestone is conveyed from a stockpile and fed to the kiln at the upper end thereof. As the mud moves through the kiln by gravity, it is dried and heated counter currently, instead of by combustion gases from oil or gas burners, by the offgases from the rolling mill tunnel furnace 60 at the lower end of the kiln 70. Calcination, which theoretically requires 770 Btu/pound of limestone (428 kcal of heat per kg) of CaCO₃, begins at a location where the material temperature reaches about 1470° F. (800° C.), in accordance with the equation:



[0024] Lime calcining is a heat-transfer controlled process, i.e. the limestone will decompose immediately if sufficient heat is supplied to raise its temperature above the calcination temperature, which varies from about 1110° F. to 1600° F., (600° C. to 870° C.), depending on the CO₂ partial pressure of the surrounding gas. The higher the gas temperature, the more rapidly the heat is transferred to the material and the faster the material is calcined. However, if the temperature is excessively high, in excess of 2200° F. (1200° C.), the resulting lime becomes "dead-burned" and less reactive. Maintaining the temperature between 1650 to 2010° F. (900 degree and 1100 degree C.) is critical in such prior art procedure for ensuring a high quality product. In one embodiment of the present invention, the gases supplied from the steel mill thermal energy recovery operations are tempered with dilution air to maintain the gas temperature at the optimum required for the calcination process.

[0025] The theoretical energy required to calcine one pound of limestone to lime is 770 Btu per pound of limestone. This typically results in the production of approxi-

mately 0.56 pounds of lime. Therefore, the theoretical energy consumed to produce one pound of lime is about 1373 Btu per pound of lime. Lime kilns typically consume between 1400 and 5150 Btu per pound of limestone produced depending on the kiln design. In one embodiment of the current invention and as depicted in **FIG. 1**, the kiln **70** design is 3000 Btu per pound of lime produced. The tunnel furnace **60** exhaust approximately 30 to 50% of the total energy input (1 million Btu/ton steel). The offgases in the exhaust system **62** contain between 300,000 and 500,000 Btu per ton of steel processed. Having sufficient gas temperature and the gas flows for the design of calcining kiln **70** in use, each ton of steel processed generates sufficient waste gases from tunnel furnace **60** to process between 100 and 167 pounds of lime. Typical lime requirements for steelmaking, such as for electric arc furnaces **34**, lie between about 30 and 90 pounds per charge ton, or, at 90% yield, about 34 to 100 pounds per cast ton. Thus, a steel mill operation, such as rolling mill tunnel furnace **60**, should generate sufficient waste gases from reheating operations to process a large percentage of the lime requirement for the steelmaking operations.

[0026] The cost of fuel for providing the energy input for the calcining process typically represents between 25 and 40% of the total processing costs of calcining. In the case of a rotary kiln, electricity may represent another 5 to 10% of the total cost. In one embodiment of the present invention, between about 20% and about 100% of the thermal energy required for the calcination operations is supplied by waste gases from steel mill operations.

[0027] Calcining operations generate greenhouse gases from several sources including the CO₂ which is driven off the material being calcined and those greenhouse gases arising from the fuel that is burned to provide the thermal energy necessary to dry and calcine the limestone. Typically, the amount of greenhouse gases generated by calcining 1 ton of limestone to produce 1120 pounds of lime is approximately 880 pounds of CO₂ purely from the calcining operations. Dependent on the fuel type used, the amount of CO₂ arising from fuel combustion can range from 700 to 1000 pounds of CO₂ per ton of limestone processed. The present invention could reduce the generation of greenhouse gases attributed to lime production by 40 to 60%.

[0028] Commercial calcining operations attempt to produce a product which is nearly all calcined, as this is the desired material for most end-users of the calcined material. Material, which is only partially calcined, is not readily available on the commercial market because it is not typically viewed as a desirable. The commercial form of these materials are generally only available as very pure, highly calcined (>95%) materials.

[0029] In some applications for steelmaking, however, the use of a partially calcined material may in fact be advantageous to the steelmaking operation. Several patents (for example U.S. Pat. Nos. 4,128,392; 4,218,209; 5,260,041; 5,919,038) have been developed which deal with processing of fine, partially calcined material (20-40% calcined). The desired blend of calcined/uncalcined material has been mixed from processed and unprocessed material at additional cost which may have prohibit its use. Alternatively, the captive process of the present invention allows steel mills to produce material which is designed specifically to

their needs while also giving the steel mills flexibility to produce commercially acceptable material.

[0030] Alternatively, and in another embodiment of the present invention, limestone may be supplied to the kiln **70** that is already partially calcined. The kiln may further calcinate the limestone.

[0031] Also, commercial producers and end users may demand a high grade of limestone be used for calcination. However, a lower grade may be adequate for the steel industry in some applications.

[0032] In addition, heating of calcined material in the steelmaking process may consume as much as 6% of the total energy input. That is, about 5 to 15% of the total energy consumed in steelmaking operations is used to heat and melt slag components. Lime typically makes up between about 30 and 50% of the slag. If these materials are charged at elevated temperature, energy savings and process benefits result.

[0033] At least one embodiment of the invention, therefore, makes the installation of custom calcining operations adjacent to a steel mill economically feasible. Steel companies can produce some of their calcined materials for their own use, i.e. by a captive process as illustrated in **FIG. 1**. Operation of the captive calcination process allows a steel mill, such as the steel mill **10**, to produce materials with varying degrees of calcination such that materials, like lime, may be optimized in the steelmaking process. Utilization of partially calcined material will allow for some of the material to calcine in a steelmaking vessel such as arc furnace **34**. This has been shown to be beneficial to the steelmaking process. The captive calcination process also allows for charging hot materials to the steelmaking operations. Hot charging of lime will result in earlier formation of a foamy slag resulting in better arc stability and improved operating conditions. Thus, one embodiment of the present invention provides the thermal energy input required to carry out the calcination operations in a facility located in close proximity to a steel mill operation having the advantages of, among other things, the custom processing of materials with varying degrees of calcination and hot charging of fluxes directly to the steelmaking operations.

[0034] Also, in most commercial calcining operations, there is a cooling section in the process, which is used to cool the calcined product from approximately 900° C. to ambient temperature. Most kilns use the cooling air from the cooling section (now warmed by the hot lime) as combustion air for the burners. This allows some of the energy to be recovered to the process. However, in one embodiment of the present invention, the lime is hot charged to the steelmaking operation, taking advantage of considerable energy and process benefits. In this embodiment, lime may be discharged hot into refractory lined containers for transfer to the steelmaking operations. In another embodiment, there is no cooling zone in the kiln because hot charging eliminates the need for a cooling zone altogether.

[0035] As noted above, steel mill operations generate several by-product gas streams and in most cases, the thermal energy contained in these gas streams is not recovered. In addition, it has been noted that calcined material are among the principal reagents used in the steelmaking process. In one embodiment, reheating operations carried out in

the steel mill generate waste offgases that contain sufficient energy and are of sufficient temperature that they may be used to supply a percentage (30 to 100) of the thermal requirement for calcination operations carried out in a facility adjacent to the reheating operations. In this embodiment such a facility is capable of meeting a large portion (50-100%) of the lime demand for the steelmaking operation.

[0036] In another embodiment of the present invention, an electric arc furnace steelmaking operation produces 25 heats of steel per day with a tap weight of 185 tons each. The liquid steel is further processed and is cast into a thin slab, which then travels through a tunnel furnace for temperature equalization within the slab. The furnace utilizes approximately 600,000 Btu per ton of steel processed. Approximately 50% of this energy is lost in the offgas stream from the furnace. This offgas stream is used to provide thermal input to a calcining operation. The calcining operation requires 3000 Btu/pound of limestone processed. At the available gas flowrate and thermal load from the steelmaking operation, 231 tons of lime may be processed per day. The lime requirement of the steelmaking operations is 50 pounds per ton. At the specified steelmaking throughput rate, the total lime requirement is 116 tons per day. The calcining operation is capable of meeting all of the steelmaking operation's lime demand. The additional capacity may then be used to make calcined products for sale.

[0037] In another embodiment of the present invention, hot waste gases from steelmaking operations are used in a fluid bed heater to preheat calcined material fluxes prior to their use in the steelmaking process. The current steelmaking operation consumes approximately 600 kWh/ton steel produced (equivalent electrical+chemical energy). Slag heating and melting operations, without the aid of the present invention, may consume approximately 10% of the total energy input or 60 kWh/ton steel. Lime typically makes up 50% of the slag. In this embodiment of the present invention, if lime is supplied at 1100° F., the energy contained in the lime reduces the slag energy requirement by 2.3 kWh per ton of steel. This may equate to a saving of 3,510,000 kWh/year. In addition, slag foaming operations commence earlier in the scrap melting cycle resulting in an improvement of approximately 1% in the overall heat transfer efficiency from the arc to the steel. This results in a saving of approximately 5 kWh/ton steel or a total savings of 7,631,250 kWh. At a cost of \$0.035/kwh, a total savings of almost \$390,000 per year may be seen. Similar embodiments, wherein various production rates, energy costs, and the like may be configured, may now be configured by one of ordinary skill in the art.

[0038] Having shown and described the preferred embodiments of the present invention, further adaptations to the steel mill thermal energy recovery in the present invention, as described herein, can be accomplished by appropriate modifications by one of ordinary skill in the art without departing from the scope of the present invention. Several of these potential modifications and alternatives have been mentioned, and others can be apparent to those skilled in the art. For example, while exemplary embodiments of the inventive system and process have been discussed for illustrative purposes, it should be understood that the elements described can be constantly updated and approved by technological advances. Similarly, as described, the process of

this invention could be applied with any process generating waste gas of appropriate temperature and volume. Accordingly, the scope of the present invention should be considered in terms of the following claims and is understood not to be limited to the details of structure, operation or process steps as shown and described in this specification and drawing.

We claim:

1. A steelmaking thermal energy recovery system comprising:

a steelmaking waste flue gas;

a calcinable material; and

a kiln wherein the steelmaking waste flue gas provides at least a portion of the thermal energy to the kiln for calcination of the calcinable material.

2. The steelmaking thermal energy recovery system of claim 1, further comprising an air control system for dilution of the waste flue gas to maintain gas temperatures.

3. The steelmaking thermal energy recovery system of claim 2, wherein the waste gas temperature is maintained from about 1650 to about 2010° F.

4. The steelmaking thermal energy recovery system of claim 1, wherein the steelmaking waste flue gas is a hot rolling mill tunnel furnace flue gas.

5. The steelmaking thermal energy recovery system of claim 1, wherein the calcinable material comprises limestone.

6. The steelmaking thermal energy recovery system of claim 1, wherein the calcinable material comprises dolomitic limestone.

7. The steelmaking thermal energy recovery system of claim 1, wherein the kiln is a rotary kiln, a vertical kiln, a rotary hearth kiln, a fluidized bed kiln, or a regenerative lime kiln.

8. The steelmaking thermal energy recovery system of claim 1, wherein the kiln does not have a lime cooling zone.

9. The steelmaking thermal energy recovery system of claim 1, wherein the kiln is adjustable to produce varying degrees of calcination from between about 20% to about 100% calcinated.

10. The steelmaking thermal energy recovery system of claim 1, wherein the steelmaking thermal energy recovery system comprises the captive production of at least a partially calcined material to a steelmaking facility.

11. The steelmaking thermal energy recovery system of claim 10, wherein the captive production comprises storing and transporting the at least partially calcined material at elevated temperatures.

12. The steelmaking thermal energy recovery system of claim 11, wherein the elevated temperatures comprise about 200° F. to about 2,000° F.

13. The steelmaking thermal energy recovery system of claim 1, wherein the captive production comprises adding the at least partially calcined material to a steel melting furnace.

14. A means of providing the thermal energy requirement for calcination operations located adjacent to steel making operations by re-using waste off gases from the steelmaking operation.

15. A method of calcinating limestone comprising:
providing a kiln;

supplying limestone as feedstock for calcination;

further providing a steel manufacturing operation's hot waste gases as a heat source; and

heating the limestone within the kiln to the calcination temperature.

16. The method of claim 15, wherein the steel manufacturing operation is a hot strip mill tunnel furnace.

17. The method of claim 15, further comprising calcinating from about 20% to about 100% complete calcination.

18. The method of claim 15, wherein the step of supplying limestone further comprises supplying limestone as dolomitic limestone.

19. The method of claim 15, further wherein the step of supplying limestone further comprises supplying a low-grade lime.

20. The method of claim 15, wherein the step of supplying limestone further comprises supplying a partially calcined limestone material from a conventional calcining operation.

21. The method of claim 15, wherein the waste steelmaking operation gases comprise about 20% to about 100% of the total thermal energy required for the calcination.

22. A method of steelmaking comprising:

making a first heat of steel in a melting operation;

converting the heat to slabs;

heating the slabs;

capturing hot off gases from the heating of slabs; and

supplying the hot off gases to a calcination process.

23. The method of claim 22, further comprising the step of supplying limestone as feedstock to the calcination process.

24. The method of claim 23, wherein the limestone feedstock for calcination comprises calcium and dolomitic limestone.

25. The method of claim 23, further comprising the step of at least partially calcinating the limestone with the hot off gases.

26. The method of claim 23, further comprising packaging the calcinated product at an elevated temperature of about 200° to 2,000° F.

27. The method of claim 23, further comprising the step of supplying the calcinated product back to the melting operation to form slag in a second heat of steel.

28. The method of claim 27, wherein the limestone added back to the melting operation comprises an elevated temperature of about 200 to 2,000° F.

29. A captive calcination facility comprising:

a raw material wherein the raw material comprises at least some calcinable material;

a waste flue gas from a steel making continuous process;

a kiln wherein the steelmaking waste flue gas provides at least a portion of the thermal energy to the kiln to calcinate the calcinable material; and

a steel melting operation wherein at least a portion of the calcinated material from the kiln is added to the steel to form slag.

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