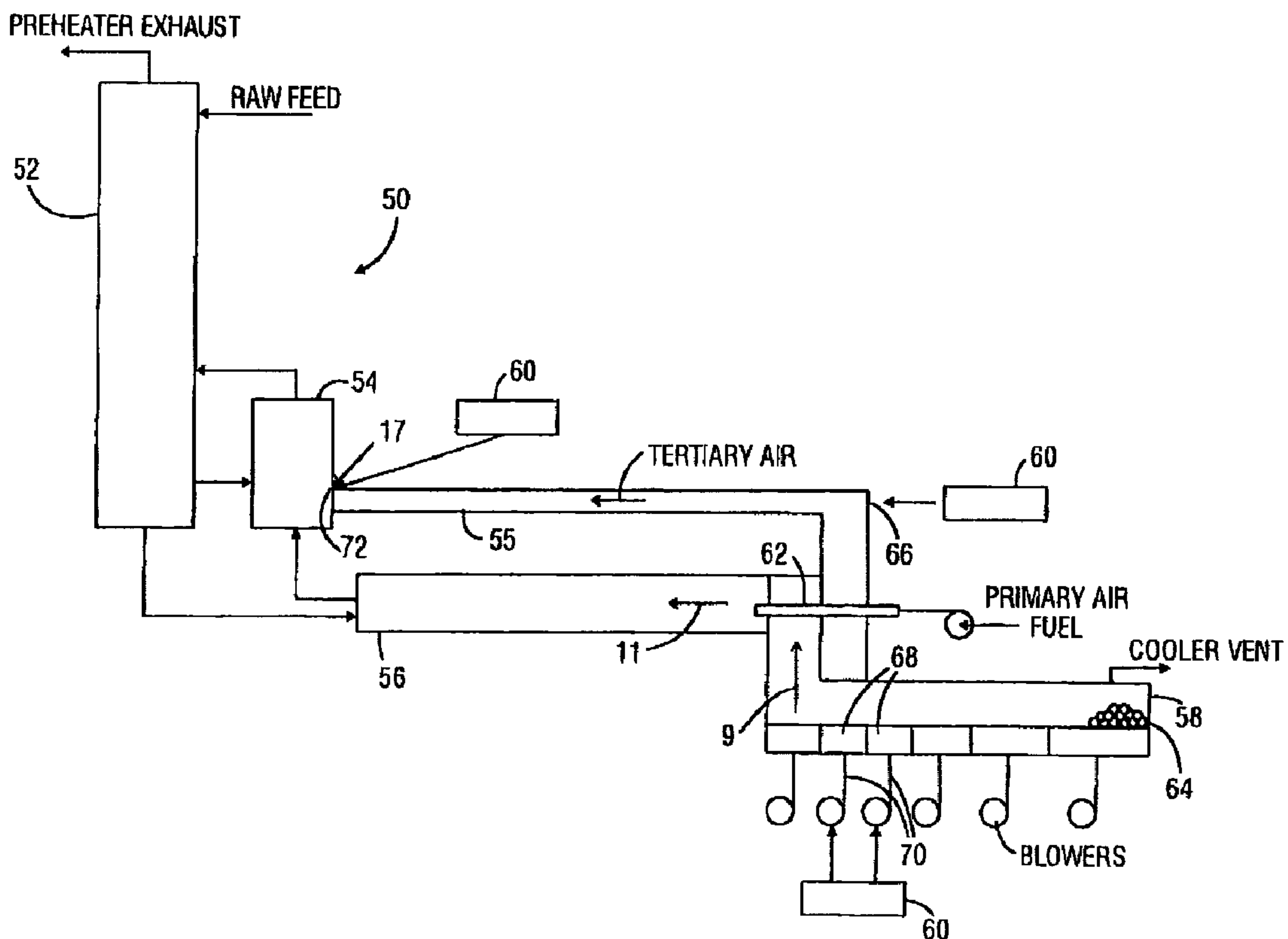




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 (54) Title: OXYGEN ENRICHMENT OF CEMENT KILN SYSTEM COMBUSTION



(57) **Abrégé/Abstract:**

The invention in its various embodiments includes an apparatus and a method for improving combustion in a cement kiln system (10). The apparatus in one embodiment includes a precalciner (16) and an oxygen source (60) coupled to the precalciner. The method in one embodiment includes introducing oxygen into the precalciner (16) of a cement kiln system (10).



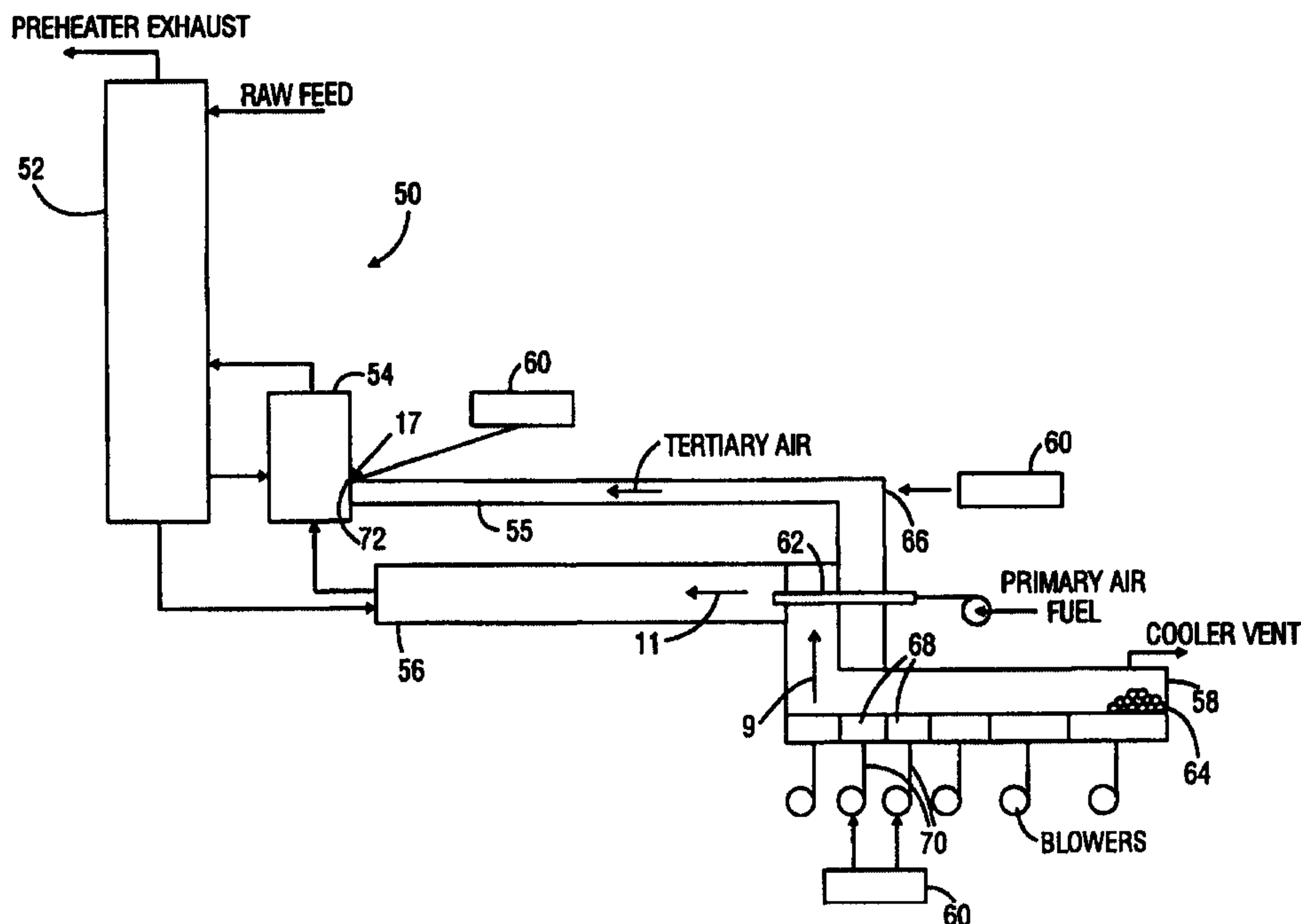
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(54) Title: OXYGEN ENRICHMENT OF CEMENT KILN SYSTEM COMBUSTION



(57) Abstract

The invention in its various embodiments includes an apparatus and a method for improving combustion in a cement kiln system (10). The apparatus in one embodiment includes a precalciner (16) and an oxygen source (60) coupled to the precalciner. The method in one embodiment includes introducing oxygen into the precalciner (16) of a cement kiln system (10).

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OXYGEN ENRICHMENT OF CEMENT KILN SYSTEM COMBUSTION

BACKGROUND OF THE INVENTION

Field of the Invention

5 This invention generally pertains to the field of Portland cement manufacturing and, more particularly, to the combustion process in Portland cement manufacturing.

Description of Related Art

The Portland cement manufacturing process has, in its most general form, long been established. As shown in Figure 1, a raw feed material 12 is fed into a cement kiln system 10
10 wherein it is heated until it calcines and transforms into a material 13 known as "cement clinker" or "clinker." More particularly, the raw feed material 12 is fed into the cyclone preheater 14. The preheater 14 heats the raw feed 12 to a temperature ready for calcination and then passes the preheated feed 12 to the precalciner 16. The precalcined feed 12 then enters the rotary kiln 18 wherein it is transformed into the clinker 13 that is deposited in
15 clinker cooler 20.

The calcination reaction in the precalciner 16 takes place at a relatively narrow temperature range of about 1500 to 1600°F. The heat for calcination is provided by the flameless combustion of fuel injected at point 17 of the precalciner 16 and the preheated feed 12 can reach over 90% calcination before entering the rotary kiln 18. The residual carbonate
20 is calcined in the rotary kiln 18, where the temperature of the calcined feed 12 is raised to a clinkering temperature of about 2650°F by firing a mixture of fuel and air by kiln burner 22. At the clinkering temperature, approximately 25% of the hot meal is liquefied and, to reach the clinkering temperature, a flame temperature of over 3500°F is required.

The tumbling action of the rotary kiln forms the partially liquefied feed into clinker
25 nodules 13 that drop into the clinker cooler 20, where they cool and are taken for pulverization. The air in the clinker cooler 20 cools the clinker 13 by absorbing heat

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therefrom and the air is thereby heated. This heated air is recycled into the rotary kiln 18 as "secondary air" to support the combustion therein and into the precalciner 16 via a tertiary air duct 21 as "tertiary air."

In the late 1950's and 1960's, prior to the development of the precalciner, the industry
5 began experimenting with oxygen enrichment of kiln combustion as a potential refinement. Martin J. La Velle, in 1959, suggested such in "Oxygen Enrichment of Primary Air Can Improve Kiln Production," published in the journal *Rock Products*, but no practical application is known. Oxygen enrichment of secondary air has been practiced on several occasions. A report by Robert A. Gaydos, entitled "Oxygen Enrichment of Combustion Air
10 in Rotary Kiln," published by the Portland Cement Association, indicated that oxygen enrichment could improve kiln production.

One common method of oxygen enrichment for a rotary kiln is to place an oxygen lance in between kiln burner 22 and the feed 12 in the rotary kiln 18. Oxygen is injected through the lance of the burner 22 at a certain tip velocity. Since the underside of the flame
15 in contact with pure oxygen will exhibit high flame temperature, the oxygen lance is placed so that excessive flame temperature will not impact refractory and kiln coating. The drawbacks of this practice are many: (1) oxygen lance is subject to high temperature, (2) proper direction and velocity of oxygen jet is critical, (3) high flame temperature promotes increased NOx formation, and (4) high flame temperature may adversely impact refractory
20 life.

The precalciner 16 also contains a firing point, which firing point can be equipped with multiple burners. The preheated feed 12 entering the precalciner 16 is suspended and calcined in the vessel thereof. The fuel injected at point 17 supplies the heat necessary to dissociate carbon dioxide from limestone in the feed 12. The combustion air is primarily
25 supplied as tertiary air from the clinker cooler 20 through the tertiary air duct 21. Due to the large amount of limestone powder present, the feed 12 undergoes an endothermic reaction in the precalciner vessel and the combustion is flameless. Oxygen enrichment in the precalciner

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has a reduced risk to refractory life or to increased NO_x formation, mainly due to the low temperature combustion.

However, a major deterrent to oxygen enrichment in cement kiln systems has always been the cost of oxygen. Some reports have also indicated technical concerns arising from oxygen enrichment in the kiln, such as refractory life, burning zone shift and coating stability. Thus, despite the optimistic tenor of some experiment reports and even though it is commonly used in lime kilns, oxygen enrichment in cement kiln systems never became a common practice because of a variety of technological and economic considerations.

By contrast, so far as is known, nobody has attempted oxygen enrichment of combustion in the precalciner. One authority in the field, Kurt E. Peray in *The Rotary Kiln* (2nd ed. 1985), has suggested this specifically for precalciners without tertiary air ducts or for "air through" systems in order to reduce the excess air drawn through the kiln, but admits not knowing of any previous attempts and makes no mention of oxygen enrichment in systems using a tertiary air duct. Further, Peray admits that "[t]his idea would require research before deciding whether or not it could be feasibly implemented." *Id.*, at p. 75. However, after approximately 12 years, nobody in the industry has reported such an experiment and certainly there are no known successful attempts.

Thus, it is desirable to develop a cement manufacturing process with higher productivity than is otherwise available from existing pyroprocessing equipment. It would also be desirable to avoid the disadvantages of traditional introduction of oxygen to the kiln burner.

SUMMARY OF THE INVENTION

The invention in its various embodiments includes a method and an apparatus for improving combustion in a cement kiln system. The method in one embodiment comprises enriching the tertiary air stream to the precalciner of a cement kiln system with oxygen. The

apparatus in one embodiment comprises a precalciner and an oxygen source coupled to the precalciner.

5 According to one aspect of the invention there is provided a method for producing cement clinker in a rotary cement kiln system having a precalciner comprising a fueled burner and receiving a tertiary air stream drawn from an air source associated with the kiln system, wherein the method comprises enriching the tertiary air stream with oxygen such that the oxygen will comprise up to about 25% of the stoichiometric requirement to combust a precalciner fuel.

10

 According to a further aspect of the invention there is provided a method for manufacturing cement clinker in a rotary kiln, comprising the steps of:

preheating a feed material;

precalcining the preheated feed material in a precalciner having a fueled burner;

15 supplying tertiary air to the precalciner;

enriching the tertiary air with oxygen such that the oxygen will comprise up to about 25% of the stoichiometric requirement to combust a precalciner fuel; and

converting the precalcined feed material into clinker in the kiln.

20

 According to another aspect of the invention there is provided an apparatus for improving the production of cement clinker in a cement kiln system, the apparatus comprising:

a precalciner equipped with at least one burner;

a tertiary air source coupled to the precalciner; and

25 an oxygen source coupled to the precalciner such that the oxygen will comprise up to about 25% of the stoichiometric requirement to combust a precalciner fuel.

25

 According to yet another aspect of the invention there is provided an apparatus for improving combustion in a cement kiln system, the apparatus comprising:

a precalciner;

30 means for introducing oxygen enriched tertiary air into the precalciner such that the oxygen will comprise up to about 25% of the stoichiometric requirement to combust a precalciner fuel.

30

 According to still another aspect of the invention there is provided an apparatus for manufacturing cement, the apparatus comprising:

35 a preheater;

a precalciner coupled to the preheater;

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an oxygen source coupled to the precalciner such that the oxygen will comprise up to about 25% of the stoichiometric requirement to combust a precalciner fuel;

a rotary kiln coupled to the precalciner;

5 a clinker cooler coupled to the rotary kiln and to the precalciner.

According to a further aspect of the invention there is provided an apparatus for manufacturing cement, the apparatus comprising:

a preheater;

10 a precalciner coupled to the preheater;

an oxygen source including at least one of a source of cryogenic oxygen and a vacuum swing adsorption installation;

a rotary kiln coupled to the precalciner;

an air source including a clinker cooler coupled to the precalciner and to the rotary kiln; and

15 a duct coupling the oxygen source to the precalciner and the air source to the precalciner and to the rotary kiln such that the oxygen will comprise up to about 25% of the stoichiometric requirement to combust a precalciner fuel.

According to another aspect of the invention there is provided an apparatus for
20 manufacturing cement, the apparatus comprising:

a preheater;

a precalciner coupled to the preheater;

an oxygen source coupled to the precalciner such that the oxygen will comprise up to 25% of the stoichiometric requirement to combust a precalciner fuel, the oxygen source including at least
25 one of a source of cryogenic oxygen and a vacuum swing adsorption installation;

a rotary kiln coupled to the precalciner; and

an air source including a clinker cooler coupled to the precalciner and to the rotary kiln.

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BRIEF DESCRIPTION OF THE DRAWINGS

A more particular description of the invention briefly summarized above is set forth
5 below by way of particular embodiments disclosed in the drawings of this specification and
as described in connection therewith. The drawings nevertheless illustrate only typical,
particular embodiments of the invention and are not to be considered limiting thereon as the
invention may admit to other equally effective embodiments. In the drawings:

Figure 1 schematically illustrates a conventional cement manufacturing kiln system
10 having a precalciner such as is known in the prior art;

Figure 2 schematically illustrates a cement manufacturing kiln system constructed in
accordance with the invention, and illustrating several alternative embodiments for
interfacing an oxygen source to the kiln;

Figure 3 details an oxygen supply apparatus generally illustrated in Figure 2; and

15 Figures 4A-4C detail three alternative embodiments to interface a source of oxygen
for the kiln in Figure 2.

DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

Numerous specific details are set forth below in the detailed description of particular
embodiments to provide a thorough understanding of the present invention. However, one of
20 ordinary skill in the art having the benefit of this disclosure will understand that the present
invention may be practiced without many of the details presented since such details will be
necessary or useful depending on the particular embodiment being employed. Conversely, in
other instances, well known details have not been described for the sake of clarity so as not to
obscure the invention. It will be appreciated that supplying such details would be a routine
25 undertaking for those of ordinary skill in the art, even if a complex and time-consuming task,
given the benefit of this disclosure.

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Figure 2 illustrates a cement manufacturing kiln system 50 constructed in accordance with one embodiment of the invention. The kiln system 50 generally comprises a cyclone preheater 52, a precalciner 54 equipped with a tertiary air duct 55 and coupled to the preheater 52, a rotary kiln 56 coupled to the precalciner 54, and a clinker cooler 58 coupled to the rotary kiln 56. The preheater 52 of the embodiment illustrated in Figure 2 is a four-stage preheater, but other embodiments may employ, for instance, a single stage preheater. The precalciner 54 partially calcines the preheated feed material 12. As used herein, the term "precalcination" shall refer to that portion of the calcination process occurring prior to the feed material entering the rotary kiln 56 and the term "precalcined feed material" shall refer to the feed material partially calcined before it enters the rotary kiln 56. As is known in the art, the main burner 62 provides heat in the rotary kiln 56 to produce the clinker 64. The combustion air required to completely combust the fuel 17 comes in the form of primary air 11 and secondary air 9.

As shown in Figure 2 and in accordance with the invention, oxygen enrichment of combustion in the precalciner can be accomplished in at least three locations. Oxygen can be introduced from oxygen source 60:

- (a) at the tertiary air take-off 66 near the kiln burner platform (not shown), which is conveniently situated for operator supervision and where tertiary air duct 55 provides sufficient retention time for mixing;
- (b) into the clinker cooler 58 at the second part of the recuperating zone 68 via proper air ducts 70 of the clinker cooler blowers, whereupon the oxygen from the source 60 may be preheated to improve the thermal efficiency; and
- (c) at a point 72 proximate the precalciner burner(s).

Oxygen source 60 provides gaseous oxygen from a cryogenic source, from a vacuum swing adsorption installation, or from any other oxygen production system as may be suitable depending on the quantity of usage, duration of usage and other economy considerations.

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Note that oxygen source 60 provides a gas having an oxygen content greater than that of the ambient atmosphere. Thus, for example, clinker cooler 20 of the cement kiln system 10 of Figure 1 is not an "oxygen source" as that term is used herein. However, sources providing a gas at 90% oxygen content or greater are preferred although concentrations even as low as 50% may be highly desirable in some embodiments.

Figure 3 details the oxygen apparatus 74 by which oxygen source 60 interfaces with the kiln system 50. The oxygen supply apparatus 74 is a valve train comprising a block valve 76, a pressure regulator 78, a flow measuring device 80 with an indicator and a controller, a flow control valve 82, and a safety shut off valve 84, all as are known to those in the art. The same valve train comprising the embodiment of Figure 3 may be used for each of the embodiments disclosed herein but the invention is not so limited. Other valve trains as may be suitable for this purpose may be employed instead.

Figure 4A details the interface between oxygen source 60 and kiln system 50 in the embodiment wherein oxygen is introduced at the tertiary air take-off 66. Gaseous oxygen flows from oxygen source 60 through oxygen supply apparatus 74, to oxygen nozzle 86 through which it is introduced into tertiary air duct 55 and tertiary air take-off 66. The nozzle size of oxygen nozzle 86 is determined by the oxygen pressure and flow rate in a manner that will be apparent to those versed in the art having the benefit of this disclosure. In one particular embodiment, oxygen nozzle 86 is a lance such as is used for oxygen enrichment in a lime kiln.

Figure 4B details the interface between oxygen source 60 and kiln system 50 in the embodiment wherein oxygen is introduced into the clinker cooler 58 at the second part of the recuperating zone 68 via proper air duct(s) 70 of the clinker cooler blowers (shown in Figure 2). Oxygen nozzle 86 in this embodiment is connected to the discharge duct 70 of a cooler fan 88. As shown in Figure 2, this embodiment may be deployed using multiple clinker cooler blowers. Due to a usually short duct run, the oxygen nozzle 86 can be perforated to facilitate mixing in this embodiment. A suitable cooler fan duct shall be selected for the

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oxygen injection so that the added oxygen is not wasted through the cooler vent (shown in Figure 2) on one end and only a minimal amount of oxygen is directed into secondary air.

Figure 4C details the interface between oxygen source 60 and kiln system 50 when oxygen is introduced at a point 72 proximate the precalciner burner 90. Because of the close proximity between the oxygen introduction and the precalciner, oxygen is introduced in this particular embodiment into a chamber 75 to mix with air therein before the introduction. There is no need for a chamber such as the chamber 75 in the embodiments of Figures 4A and 4B because the distance the oxygen and tertiary air must travel through the tertiary air duct 55 to reach the precalciner 54 provides ample opportunity for the oxygen and air to mix.

Returning now to Figure 2, the operation of kiln system 50 is the same as for conventional kilns such as that illustrated in Figure 1 with the exception for oxygen enrichment as noted immediately below. The commencement of oxygen enrichment begins once the pyrosystem stabilizes under normal operations. The oxygen introduction may be broken into several parts. At each part of the process, the fuel to the precalciner 54 is adjusted to maintain a desired excess oxygen level in the precalciner 54. Kiln feed can be added to maintain proper temperature in a manner well known to the art. Limitations of the system should be closely observed, such as cooler vent capacity, kiln feed capacity, fuel limitation, clinker temperature and other temperature limitations. In one particular embodiment employing a single stage precalciner kiln, yields of 3.5 tons of clinker per ton of oxygen was obtained using oxygen rates as high as 25% of stoichiometric requirement to combust the fuel in the precalciner 54.

Oxygen enrichment in accord with the invention as set forth above increases heat input for a given combustion gas flow, though in some configurations oxygen at ambient temperatures is substituted for preheated tertiary air. Thus, it can be seen that the present invention possesses numerous desirable characteristics. First, precalciner combustion is low temperature and flameless so that risk of damage to refractories is reduced and increases in thermal NO_x are avoided and do not artificially limit the addition rate of the oxygen. Second,

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injection is simple. Adding oxygen to a tertiary duct close to the clinker cooler take-off ensures adequate mixing before entering the precalciner vessel. (In contrast, oxygen enrichment of the main kiln burner requires optimal lance position and injection velocity to assure satisfactory flame conditions.) Third, the oxygen enrichment can be used selectively
5 on an as-needed basis to increase production capacity. Lastly, oxygen enrichment as disclosed above is typically a cost effective alternative to conventional high capital cost equipment modifications and can be implemented faster than equipment modifications.

The particular embodiments disclosed above are illustrative only as the invention may be modified and practiced in different but equivalent manners apparent to those skilled in the
10 art having the benefit of the teachings herein. Furthermore, no limitations are intended to the details of construction or design herein shown, other than as described in the claims below. It is therefore evident that the particular embodiments disclosed above may be altered or modified and all such variations are considered within the scope and spirit of the invention. Accordingly, the protection sought herein is as set forth in the claims below.

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The embodiments of the present invention in which an exclusive property or privilege is claimed are defined as follows:

1. A method for producing cement clinker in a rotary cement kiln system having a precalciner comprising a fueled burner and receiving a tertiary air stream drawn from an air source associated with the kiln system, wherein the method comprises enriching the tertiary air stream with oxygen such that the oxygen will comprise up to about 25% of the stoichiometric requirement to combust a precalciner fuel.
2. The method of claim 1, wherein the air source is a clinker cooler and the tertiary air stream is enriched at the point where the tertiary air stream is drawn from the clinker cooler.
3. The method of claim 1, wherein the receiving tertiary air stream is enriched at a point proximate the precalciner.
4. The method of claim 1, 2 or 3, wherein the tertiary air stream is enriched by introducing the oxygen through the air source.
5. The method of any one of claims 1 to 4, wherein oxygen comprises approximately 25% of the stoichiometric requirement to combust the precalciner fuel.
6. The method of any one of claims 1 to 4, wherein oxygen comprises less than 25% of the stoichiometric requirement to combust the precalciner fuel.
7. The method of any one of claims 1 to 6, wherein enriching the tertiary air stream includes receiving oxygen from an oxygen source.
8. The method of claim 7, wherein receiving oxygen from the oxygen source includes receiving air from at least one of a source of cryogenic oxygen and a vacuum swing adsorption installation.

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9. A method for manufacturing cement clinker in a rotary kiln, comprising the steps of:
- preheating a feed material;
 - precalcining the preheated feed material in a precalciner having a fueled burner;
 - supplying tertiary air to the precalciner;
 - enriching the tertiary air with oxygen such that the oxygen will comprise up to about 25% of the stoichiometric requirement to combust a precalciner fuel; and
 - converting the precalcined feed material into clinker in the kiln.
10. The method of claim 9, wherein the tertiary air stream is drawn from an air source which is a clinker cooler, and the tertiary air stream is enriched at the point where the tertiary air stream is drawn from the clinker cooler.
11. The method of claim 9, wherein the tertiary air is enriched at a point proximate the precalciner burners.
12. The method of claim 9, 10 or 11, wherein the tertiary air is enriched by introducing the oxygen through the air source.
13. The method of any one of claims 9 to 12, wherein the oxygen comprises approximately 25% of the stoichiometric requirement to combust the precalciner fuel.
14. The method of any one of claims 9 to 12, wherein the oxygen comprises less than 25% of the stoichiometric requirement to combust the precalciner fuel.
15. The method of any one of claims 9 to 14, wherein enriching the tertiary air includes receiving oxygen from an oxygen source.
16. The method of claim 15, wherein receiving oxygen from an oxygen source includes receiving air from at least one of a source of cryogenic oxygen and a vacuum swing adsorption installation.

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17. A method for producing cement clinker in a cement kiln system including a rotary kiln and a precalciner having a fueled burner, comprising the steps of:

preheating a feed material;

precalcining the preheated feed material with oxygen enriched tertiary air in the precalciner having a fueled burner, including:

drawing tertiary air from an air source including a clinker cooler;

receiving oxygen from an oxygen source including at least one of a source of cryogenic oxygen and a vacuum swing adsorption installation;

mixing the oxygen with the tertiary air such that the oxygen will comprise up to about 25% of the stoichiometric requirement to combust a precalciner fuel;

introducing the oxygen enriched tertiary air into the precalciner; and

converting the precalcined feed material into clinker in the kiln.

18. An apparatus for improving the production of cement clinker in a cement kiln system, the apparatus comprising:

a precalciner equipped with at least one burner;

a tertiary air source coupled to the precalciner; and

an oxygen source coupled to the precalciner such that the oxygen will comprise up to about 25% of the stoichiometric requirement to combust a precalciner fuel.

19. The apparatus of claim 18, wherein the oxygen source is coupled to at least one of the precalciner and the tertiary air source by a valve train.

20. The apparatus of claim 18, wherein the oxygen source is coupled to the precalciner at a point proximate the precalciner's burner.

21. The apparatus of claim 20, wherein the oxygen source is coupled by valve train.

22. The apparatus of any one of claims 18 to 21, wherein the oxygen source is coupled to the precalciner by a duct through which oxygen enriched air may pass.

23. The apparatus of any one of claims 18 to 22, wherein the oxygen source is at least one of a source of cryogenic oxygen and a vacuum swing adsorption installation.

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24. The apparatus of any one of claims 18 to 23, further comprising an air source coupled to the precalciner and to the oxygen source.
25. The apparatus of claim 24, wherein the air source is a clinker cooler.
26. The apparatus of claim 24 or 25, further comprising means for mixing air from the air source and oxygen from the oxygen source.
27. The apparatus of any one of claims 24 to 26, wherein the air source is coupled to the oxygen source and the precalciner by a duct through which oxygen-enriched air may pass.
28. An apparatus for improving combustion in a cement kiln system, the apparatus comprising:
 - a precalciner;
 - means for introducing oxygen enriched tertiary air into the precalciner such that the oxygen will comprise up to about 25% of the stoichiometric requirement to combust a precalciner fuel.
29. The apparatus of claim 28, wherein the introducing means includes an oxygen source coupled to the precalciner.
30. The apparatus of claim 28 or 29, wherein the introducing means is coupled to the precalciner by a duct through which the oxygen enriched tertiary air may pass.
31. The apparatus of claim 28, 29 or 30, wherein the introducing means includes at least one of a source of cryogenic oxygen and a vacuum swing adsorption installation.
32. The apparatus of any one of claims 28 to 31, further comprising an air source coupled to the precalciner and to the introducing means.
33. The apparatus of claim 32, wherein the air source is a clinker cooler.

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34. The apparatus of claim 33, further comprising means for mixing air from the air source and oxygen enriched tertiary air from the introducing means.
35. An apparatus for manufacturing cement, the apparatus comprising:
a preheater;
a precalciner coupled to the preheater;
an oxygen source coupled to the precalciner such that the oxygen will comprise up to about 25% of the stoichiometric requirement to combust a precalciner fuel;
a rotary kiln coupled to the precalciner;
a clinker cooler coupled to the rotary kiln and to the precalciner.
36. The apparatus of claim 35, wherein the oxygen source is coupled by a valve train.
37. The apparatus of claim 35, wherein the precalciner is equipped with a burner, and the oxygen source is coupled to the precalciner at a point proximate the burner.
38. The apparatus of claim 37, wherein the oxygen source is coupled by valve train.
39. The apparatus of any one of claims 35 to 38, wherein the oxygen source is coupled to the precalciner by a duct through which oxygen enriched air may pass.
40. The apparatus of claim 39, wherein the oxygen source is further coupled to the precalciner by a valve train.
41. The apparatus of claim 39 or 40, wherein the oxygen source is at least one of a source of cryogenic oxygen and a vacuum swing adsorption installation.
42. The apparatus of any one of claims 39 to 41, further comprising an air source coupled to the precalciner and to the oxygen source.
43. The apparatus of claim 42, wherein the air source is a clinker cooler.

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44. The apparatus of claim 42 or 43, further comprising means for mixing air from the air source and oxygen from the oxygen source.

45. The apparatus of claim 42, 43 or 44, wherein the air source is coupled to the oxygen source and the precalciner by a duct through which oxygen enriched air may pass.

46. An apparatus for manufacturing cement, the apparatus comprising:
a preheater;
a precalciner coupled to the preheater;
an oxygen source including at least one of a source of cryogenic oxygen and a vacuum swing adsorption installation;
a rotary kiln coupled to the precalciner;
an air source including a clinker cooler coupled to the precalciner and to the rotary kiln;
and
a duct coupling the oxygen source to the precalciner and the air source to the precalciner and to the rotary kiln such that the oxygen will comprise up to about 25% of the stoichiometric requirement to combust a precalciner fuel.

47. An apparatus for manufacturing cement, the apparatus comprising:
a preheater;
a precalciner coupled to the preheater;
an oxygen source coupled to the precalciner such that the oxygen will comprise up to 25% of the stoichiometric requirement to combust a precalciner fuel, the oxygen source including at least one of a source of cryogenic oxygen and a vacuum swing adsorption installation;
a rotary kiln coupled to the precalciner; and
an air source including a clinker cooler coupled to the precalciner and to the rotary kiln.

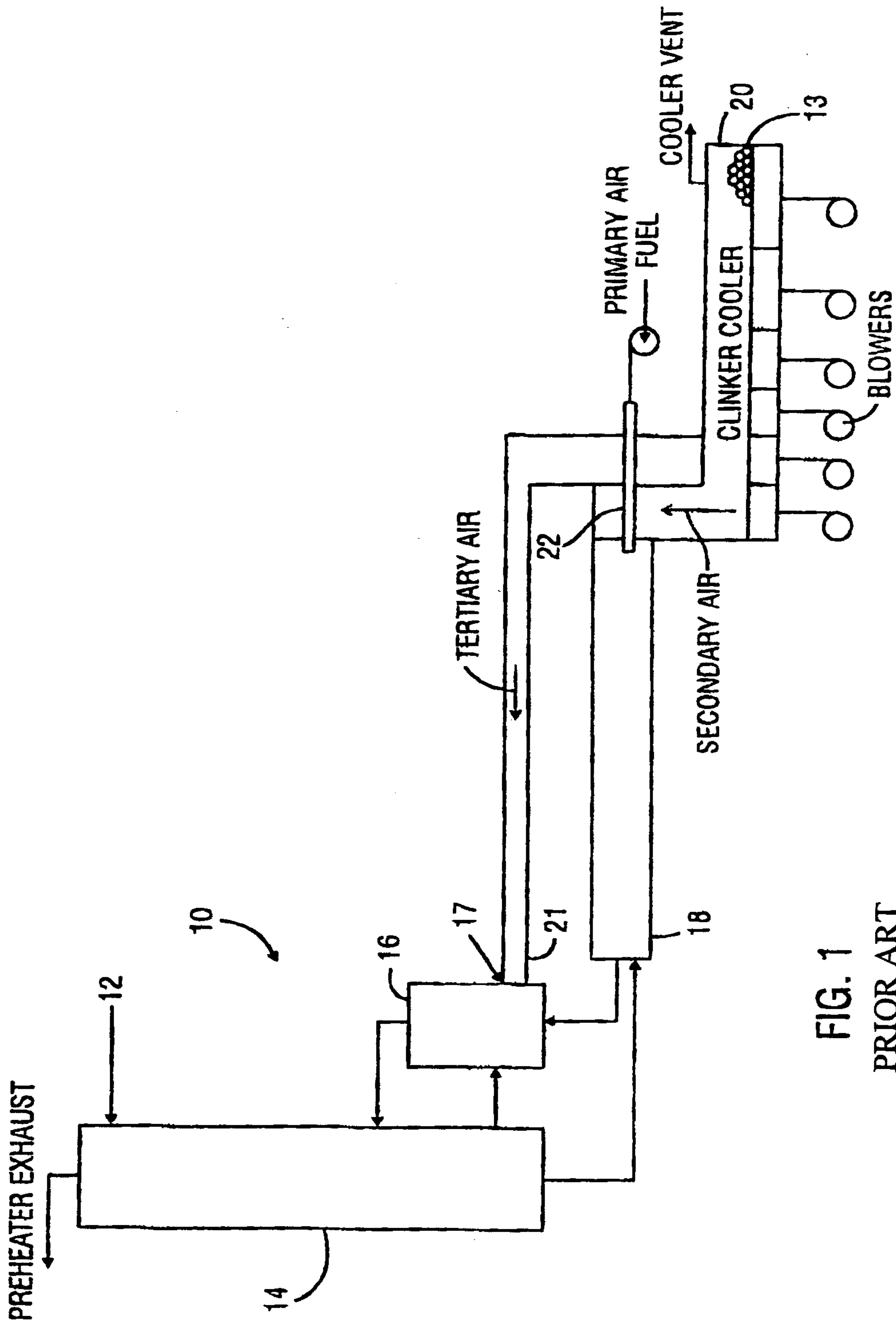


FIG. 1
PRIOR ART

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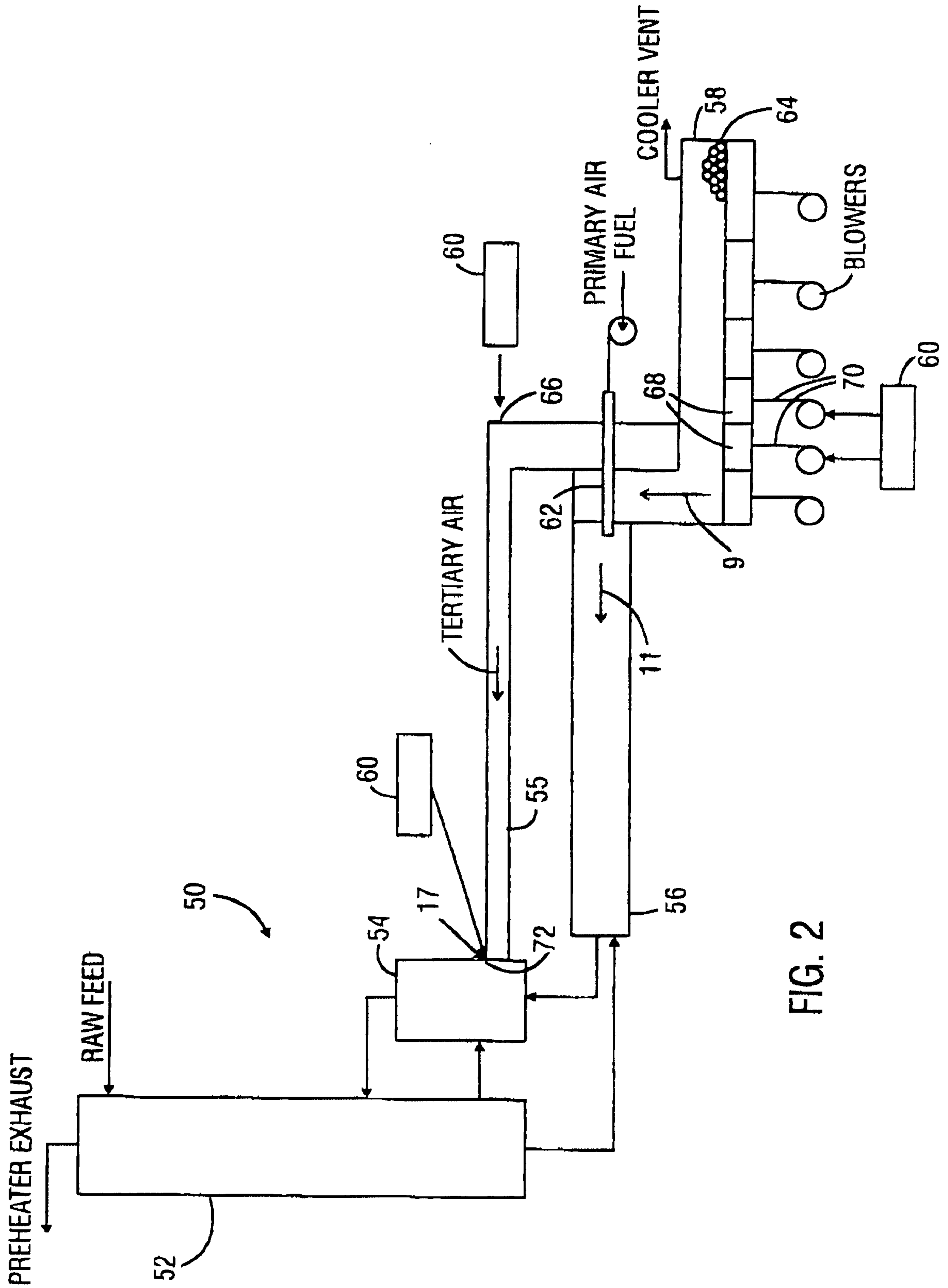


FIG. 2

Handwritten signature or mark

WO 99/06778

PCT/US97/13231

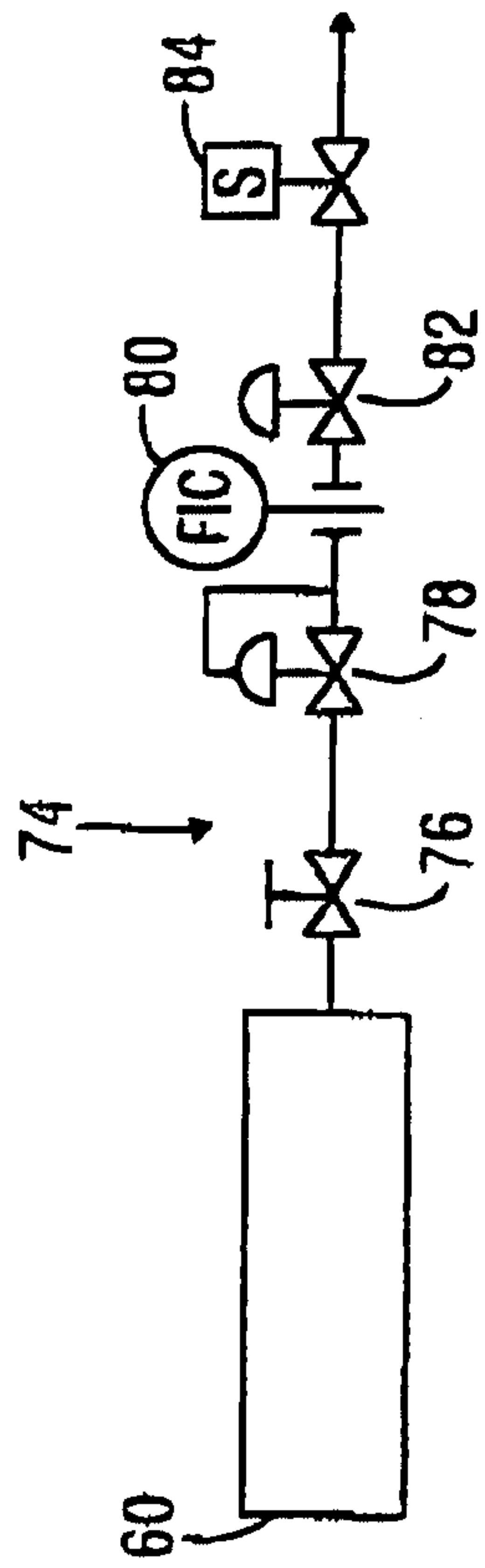


FIG. 3

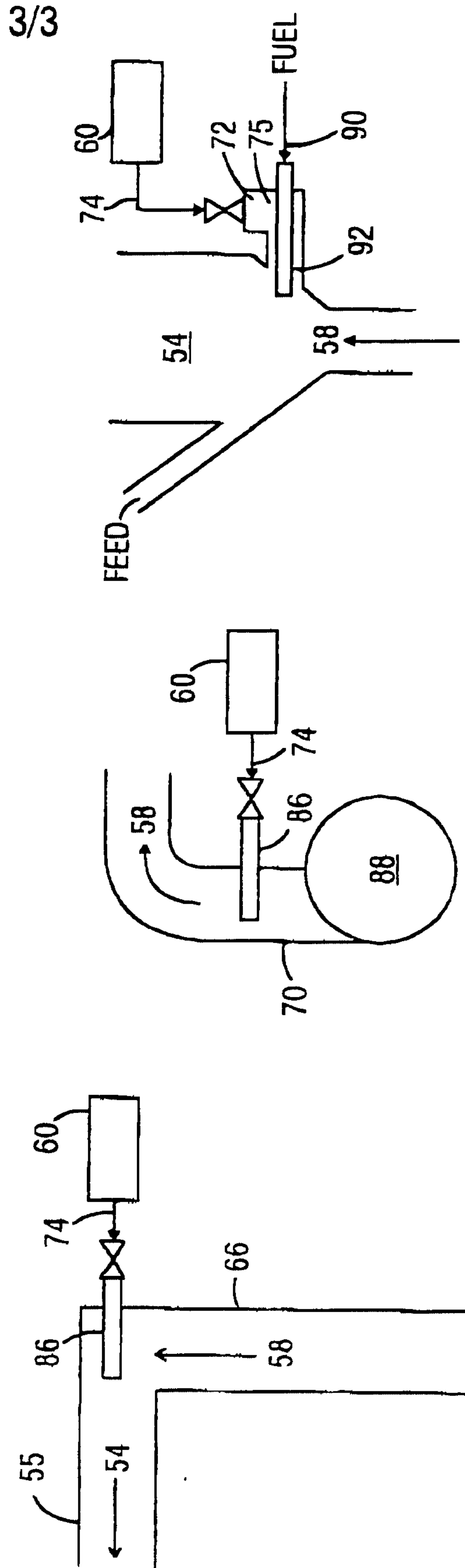


FIG. 4A

FIG. 4B

FIG. 4C

PREHEATER EXHAUST

RAW FEED

52

50

60

54

17

TERTIARY AIR

60

72

55

62

66

PRIMARY AIR

FUEL

COOLER VENT

56

11

9

68

58

64

70

BLOWERS

60

