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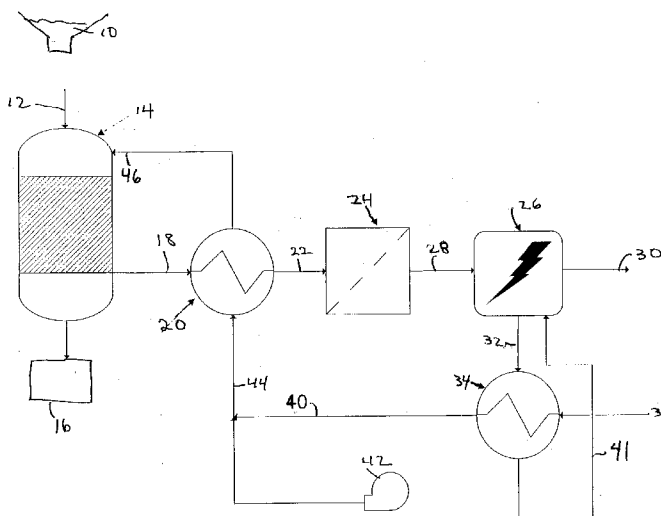
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- of inventorship (Rule 4.17(iv))

[Continued on next page]

(54) Title: METHOD FOR IMPROVING GASIFICATION EFFICIENCY THROUGH THE USE OF WASTE HEAT



(57) Abstract: A method for recycling the waste heat generated from an external process, which is fuelled by syngas, into a gasification process to enhance the energy density of the syngas produced as well as the overall gasification efficiency of the system. A method is provided for utilizing the waste heat contained in a stream exiting in the syngas fueled process to vaporize water and produce steam. The steam is then upgraded by first exchanging energy with the hot syngas exiting the gasifier and then within the gasifier itself to a temperature where significant steam gasification of the biomass occurs. The process within the gasifier is driven by introducing a small amount of air into the gasifier such that some biomass is directly combusted to provide the heat required by the process.

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**APPLICATION UNDER THE PATENT COOPERATION TREATY**

**TITLE**

**METHOD FOR IMPROVING GASIFICATION EFFICIENCY THROUGH THE USE  
OF WASTE HEAT**

**INVENTORS**

**PHILIP D. LEVESON**

**JOHN PAUL GAUS**

**CROSS-REFERENCE TO RELATED APPLICATIONS**

[001] This application claims benefit of co-pending U.S. Provisional Patent Application Nos. 60/785,519, filed March 24, 2006, entitled METHOD TO IMPROVE GASIFICATION EFFICIENCY THROUGH THE USE OF WASTE HEAT, and  
5 60/785,520, filed March 24, 2006, entitled GASIFICATION SYSTEMS, and commonly assigned to the assignee of the present application, the disclosures of which are incorporated by reference in their entirety herein.

**FIELD OF THE INVENTION**

[002] The present invention relates to gasifier equipment and to the process of gasification of carbon containing solids into combustible gases. The improvement may be used to enrich the calorific density and hydrogen content of the produced syngas while  
5 simultaneously improving the thermal efficiency of the gasification process.

**BACKGROUND OF THE ART**

[003] Gasification processes convert carbon-containing solids or liquids into combustible gases that ideally contain all the energy originally present in the feed. In reality this is not easily achieved, although with good thermal management it is possible  
10 to operate with energy efficiencies in excess of 90%. The technique yields a combustible gas, which is typically rich in carbon monoxide, hydrogen and methane from a carbon containing solid. Gaseous fuels have many advantages over solid fuels. They are typically cleaner burning reducing particulate carbon, hydrocarbon and carbon monoxide emissions. It is also much easier to remove sulphur, halogen and nitrogen containing  
15 volatile compounds from the syngas through scrubbing and adsorption techniques prior to combustion rather than cleaning the flue gases or the solid fuels. It is becoming increasingly attractive to consider maximizing the hydrogen concentration in the produced syngas through the water gas shift reaction and then sequestering the carbon dioxide for this gas stream. This technique is being adopted by some integrated  
20 gasification combined cycle ("IGCC") coal gasification plants as a method to reduce carbon oxide emissions.

[004] Almost all carbon containing solids are suitable fuels for gasification systems. Examples include, but are not limited to, coals, lignites, plant matter and plant matter derived products, animal wastes, oil and oil derived products. Increasing interest is being  
25 expressed towards the use of biomass and animal wastes as these offer a potentially viable route to creating fuel streams which do not contribute to the addition of carbon dioxide to the atmosphere. The mechanism is that the plant picks up carbon dioxide during the growing season and a similar quantity of carbon dioxide is released during combustion resulting in a near net zero addition of carbon dioxide to the atmosphere. This technique  
30 offers a large scale route were a significant fraction of the energy requirements of the

planet can be readily produced in an environmentally friendly manner as well as being eligible for carbon based tax credits as presently offered by various governments.

5 [005] One disadvantage of gasification is that the gas stream produced has a relatively weak energy density. For an air blown system the energy content per unit volume is around a fifth to a seventh that contained in natural gas and around one twentieth that of liquefied petroleum gas (“LPG”). This low energy density detracts from the economics of compressing the gas and transporting through pipelines to anywhere other than over short to moderate distances. Thus the gaseous fuel produced from gasification is typically used on or near the production facility.

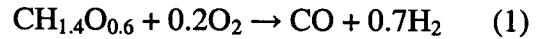
10 [006] The use of biomass as a feedstock for gasification systems is becoming increasingly economically as well as environmentally attractive. Potential local uses for the syngas may include, running generators to produce electrical power, using the fuel to offset natural gas in heating applications or to convert the syngas into a liquid fuel, and other uses. The conversion to a liquid fuel can be readily accomplished by the catalytic  
15 reduction of carbon monoxide by hydrogen to produce methanol, ethanol or synthetic middle distillates. In this case the fuel can be readily transported to be the market place.

[007] A typical biomass has an energy density around 18kJ/g on a dry basis. On a wet basis this value can be substantially less and can even be less than zero, indicating that the fuel is not capable of burning in a sustainable manner while liberating energy. On a dry  
20 basis biomass has a calorific value around half that of coal. The low energy density, its low packing density and difficulty in handling make the economics of transporting biomass large distances unfeasible. Thus the utilization of biomass for small to medium scale distributed energy producing processes has some synergy. The biomass for such a process would be sourced locally and probably within a twenty mile radius. Power may  
25 be generated and used to reverse feed already saturated power delivery lines. In such a system local communities would utilize locally grown biomass and potentially make use of some volume of waste currently being land filled to generate their own power or convert the material into fuels. In effect a community could become power and fuel self sufficient while producing no greenhouse gas emissions.

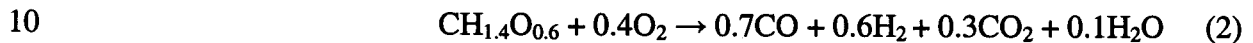
30 [008] Biomass is a very broad term and includes all solids derived from plant matter, animal wastes as well as organic municipal waste. Suitable biomasses include, but are not

limited to, sawdust, wood, straw, alfalfa seed straw, barley straw, bean straw, corn cobs, corn stalks, cotton gin trash, rice hulls, paper, municipal solid waste, barks and animal wastes. It is interesting that almost all biomass has the same ratio of carbon to hydrogen to oxygen, which is summarized as  $\text{CH}_{1.4}\text{O}_{0.6}$ .

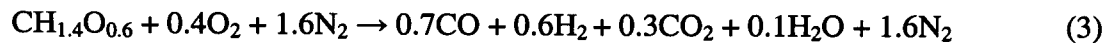
5 [009] The stoichiometric gasification equation is shown below:



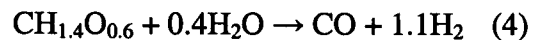
[0010] Performing an energy balance across the system reveals that the products contain more energy than the reactants, hence some of the biomass is burnt to offset this imbalance. Hence a more realistic gasification process may be represented as:



[0011] If air is used as the oxidant the process becomes



[0012] As can be seen in equation (3) the nitrogen associated with the oxygen acts to dilute the energy containing components by approximately one half. The reaction may  
15 also be facilitated through utilizing steam as the oxidant. This process is expressed as:



[0013] The syngas produced through equation 4 has a much higher energy density than air derived syngas. The total energy content of the syngas is also about twice than that of the air derived product, however, the process is strongly endothermic and requires a  
20 substantial external energy input. The energy can be transferred into the process through heat transfer mechanisms, which may include externally heating the gasifier through the use of heating elements within the gasifier or through passing hot inert solids into the gasification bed. Either of these techniques greatly complicates the overall design of the gasifier. A second technique utilizes a large excess of superheated steam, such that the  
25 sensible heat contained in the steam is used to provide the energy for the process. However, this involves the construction of a large steam generator, thus increasing the capital expenditure of the process and generates the need for an external fuel input.

**SUMMARY OF THE INVENTION**

[0014] The present invention comprises, in one exemplary embodiment, a method which allows the waste heat generated from an external process, which is fueled by syngas, to be recycled into a gasification process to enhance the energy density of the syngas produced as well as the overall gasification efficiency of the system. The invention also relates to a method of utilizing the waste heat contained in a stream exiting in the syngas-fueled process to vaporize water and produce steam. The steam is then upgraded by first exchanging energy with the hot syngas exiting the gasifier and then within the gasifier itself to a temperature where significant steam gasification of the biomass occurs. The process within the gasifier is driven by introducing a small amount of air into the gasifier such that some biomass is directly combusted to provide the heat required by the endothermic processes. By the exchange of heat in this manner the volume of oxygen required by the process is vastly reduced and hence the volume of associated nitrogen diluent introduced is also minimized. This manner of operation significantly reduces the cost of the ancillary equipment as no external steam or oxygen generator is required. The method maximizes the energy content of the produced gas and under certain circumstances allows gasification efficiencies greater than 100% to be achieved. For the purposes of the present disclosure, the gasification efficiency is defined as the energy content of the produced gas divided by the energy content in the original biomass. The improvement becomes much increased if amounts of steam much higher than required by stoichiometry are utilized. Particularly favorable results are achieved with steam ratios in the range of 1:10 times that of stoichiometry.

**BRIEF DESCRIPTION OF THE DRAWINGS**

[0015] Exemplary embodiments of the present invention are illustrated in the drawings in which like reference characters designate the same or similar parts throughout the figures of which:

[0016] Fig. 1 is a schematic flow diagram illustrating how waste energy from a generator powered by an internal combustion engine can be effectively recycled back to the gasification process to improve the quality of the syngas produced and improve the thermal efficiency of the gasification process, and

[0017] Fig. 2 is a schematic flow diagram illustrating how waste energy from a generator powered by an internal combustion turbine can be effectively recycled back to the gasification process to improve the quality of the syngas produced and improve the thermal efficiency of the gasification process.

## 5 **DETAILED DESCRIPTION OF THE EMBODIMENTS**

[0018] Gasification systems often make use of air as the oxidant in the process. The disadvantage of the use of air is that the associated nitrogen acts to dilute the syngas produced and results in the production of a syngas with a low energy density. A weak syngas can still be readily utilized but results in larger downstream equipment, higher blower costs and higher de-rates of downstream electrical generation equipment. The nitrogen can be removed from the system by utilizing an air separation unit to enrich the air. The gas produced in this case has a much higher energy density, approaching twice that obtained from an air blown system, but the capital and operational costs of an air separation unit is high. A third technique is to utilize steam as the oxidant. Utilizing steam results in a syngas which has a high calorific value and is high in hydrogen and so exhibits good flame velocity attributes. However, the gasification reactions which involve steam are highly endothermic such that external energy must be supplied to the system, either through external heating techniques, the introduction of hot inert material into the gasification bed or through the use of large volumes of excess steam such that the steam contains appreciable quantities of sensible heat. This results in a process which requires some form of external energy input and as such requires utilizing a fuel.

[0019] In the present invention, the external process that is consuming the syngas produced in the gasifier is thermally integrated with the gasification process itself. By operating in this regime waste heat from the process can be efficiently and conveniently used to enhance the gasification process to produce a syngas with a higher energy density, a higher in hydrogen concentration and in a thermally more efficient manner as compared to an air blown system. The exemplary embodiment of the method described hereinbelow utilizes a gasifier operating with and without the energy recycle and discusses how the process becomes integrated within a continuous process to convert biomass into electrical power using an internal combustion engine generator and a turbine powered generator.

**EXAMPLES**

[0020] The invention will be further described in connection with the following examples, which are set forth for purposes of illustration only. Parts and percentages appearing in such examples are by weight unless otherwise stipulated.

## 5 Example 1

[0021] A 15cm, down-draft stratified gasifier with an integral tar cracking and hydrocarbon reforming lower chamber was used to convert biomass into syngas. In the upper zone the biomass undergoes the decomposition process commencing with devolatilization followed by flaming pyrolysis and finally char gasification. In the lower zone a small amount of air is introduced into the syngas such that a small fraction is further oxidized. The heat liberated by this oxidation allows higher order hydrocarbons and tars to be broken down into carbon monoxide and hydrogen. The result of the thermal treatment is that a syngas which is essentially free of tars and higher order hydrocarbons is produced. The air flow to the gasifier was adjusted such that the maximum bed temperature was 850°C. The syngas produced exiting the system was cooled to 40 °C such that any condensable matter is liquefied. The syngas was filtered using a 5 micron polyester filter, passed through a blower and was then used to power a 4KW YAMAHA™ TRIFUEL™ generator. The air entering the system was preheated in a plate heat exchanger using the hot syngas exiting the gasifier, in a counter current arrangement.

20 A gas chromatograph was used to analyze the composition of the gas exiting the gasifier system. A typical analysis of the syngas produced is shown below in Table 1.

[0022] Table 1: Gas composition produced by an air blown system

Gas	% by volume	Range
H <sub>2</sub>	17.6	+/- 2%
CO	21.0	+/- 2%
CO <sub>2</sub>	9.9	+/- 1%
CH <sub>4</sub>	>0.5	+/- .1%
C <sub>2</sub> H <sub>4</sub>	0	-
C <sub>2</sub> H <sub>6</sub>	0	-
N <sub>2</sub>	51.0	+/-3

[0023] In a subsequent experiment the oxidant was adjusted to contain a mixture of air and steam. The steam flowrate used represented the volume of steam that could be raised using half of the waste heat that is available to be captured from the generator. A similar experiment was conducted, the oxidants again being preheated by the syngas exiting the system and the gas analysis was found to be as shown in Table 2 below.

[0024] Table 2: Gas composition produced by an air-steam blown system:

Gas	% by Volume
H <sub>2</sub>	27.5
CO	26
CO <sub>2</sub>	8
CH <sub>4</sub>	>0.5
C <sub>2</sub> H <sub>4</sub>	0
C <sub>2</sub> H <sub>6</sub>	0
N <sub>2</sub>	38

[0025] Table 2 clearly demonstrates the improvements in the syngas energy density and hydrogen content that are achieved by recycling the waste heat from an external device into the gasification system.

#### Example 2

[0026] Fig. 1 illustrates an exemplary, nonlimiting embodiment of a continuous process for recycling waste heat from an electricity generator powered by an internal combustion engine into a gasification system. The result is to both enrich the quality of the gas being produced there and improve the overall thermal efficiency of the gasifier. Biomass 10 is fed via stream 12 into a gasification apparatus 14 known to those skilled in the art. In the gasifier 14, volatile matter and a good fraction of the fixed carbon are converted into gaseous components. The ash, non-volatiles and any unconverted fixed carbon exit via the ash outlet into a collector 16. The hot syngas stream 18 exits the gasifier 14 and is partially cooled in a booster heat exchanger 20. A number of heat exchangers are suitable for this operation, including, but not limited to, shell and tube, plate duct, welded plate and diffusion bonded plate heat exchangers. It may be advantageous to orientate the exchanger 20 such that the gas stream flows in a vertical plane to minimize any ash deposits occurring there to minimize fouling effects. The heat exchanger 20 is used to transfer energy from the hot syngas exiting the gasifier and preheat the oxidants entering

the gasifier 20. The partially cooled syngas exits the heat exchanger via stream 22 and then may undergo some treatment in a syngas clean up module 24. Typically, this will involve further cooling of the syngas to allow the separation and collection of condensables followed by some method of particulate removal. Cyclones, spray system, wash columns and filters are all suitable for this operation. If required or desired, volatile compounds containing sulphur, halogens or nitrogen can be removed at this stage using scrubbing and/or adsorbent-based techniques. Carbon dioxide may also be sequestered at this stage. The cooled and cleaned gas then enters a generator 26 via stream 28. A number of different generators are suitable to utilize syngas. Some, such as the Jenbacher range, use a compressor to increase the energy density per unit volume of the syngas. The two output streams 30, 32 from the generator 28 include the electrical power 30 and the waste heat 32 contained in the cooling system and the sensible heat contained in the exhaust gases. In Fig. 1 the waste heat and sensible heat have been combined to form a combined waste heat stream 32. Some generators already have a waste capture system in place to provide combined heat and power solutions, again the Jenbacher range is an example of such a unit. The combined waste heat stream 32 flows into a steam generator heat exchanger 34 where the energy is used to provide the latent heat of vaporization to water 36 and convert liquid water into steam which exits the unit via stream 40. If desired some of the steam generated can be diverted as a stream 41 to ancillary equipment or processes (e.g., back to the generator 26). The remaining steam is mixed with the air or oxygen from a source 42 prior to entering the booster heat exchanger 20 via stream 44. The stream is superheated to a temperature close to the temperature of the syngas exiting the gasifier 20 and to a temperature above where gasification processes are initiated. The superheated stream 46 exits the heat exchanger 20 and then enters the gasifier 14.

[0027] Fig. 2 illustrates one exemplary embodiment of a continuous process for recycling waste heat from a generator powered by some form of internal combustion turbine. The system is similar to that described above with respect to the exemplary embodiment shown in Fig. 1, the difference being that only the exhaust stream 50 from a turbine 52 is utilized to convert liquid water to steam.

[0028] Although only a few exemplary embodiments of this invention have been described in detail above, those skilled in the art will readily appreciate that many modifications are possible in the exemplary embodiments without materially departing

from the novel teachings and advantages of this invention. Accordingly, all such modifications are intended to be included within the scope of this invention as defined in the following claims.

[0029] Therefore, it is intended that the invention not be limited to the particular  
5 embodiments disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope and spirit of the appended claims. It should further be noted that any patents, applications and publications referred to herein are incorporated by reference in their entirety.

## CLAIMS

I claim:

1       1) An improved method of generating electricity using a process comprising the  
2 steps of (a) introducing a biomass feedstock into a gasifier to convert volatile matter and  
3 at least a portion of fixed carbon into syngas, (b) removing ash, non-volatile components  
4 and unconverted fixed carbon, (c) cooling the syngas using a booster heat exchanger, (d)  
5 conveying the syngas to a generator, (e) generating electricity and waste heat, and (f)  
6 capturing at least a portion of the waste heat,

7       wherein the improvement comprises: (g) conveying the waste heat to a steam  
8 generator heat exchanger, (h) converting water in the steam generator heat exchanger into  
9 steam, (i) combining the steam of step (h) with air or oxygen and conveying the combined  
10 stream to the booster heat exchanger of step (c), (j) heating the combined stream to a  
11 temperature proximate to the temperature of the syngas exiting the gasifier of step (a) and  
12 to a temperature above where gasification processes are initiated, and, (k) conveying the  
13 superheated stream to the gasifier of step (a).

1       2) The method of Claim 1, wherein the ratio of steam to stoichiometry is about 10:1.

1       3) A method of generating electricity using a gasifier and generator, comprising:

2           a. introducing a biomass feedstock into a gasifier to convert volatile matter  
3           and at least a portion of fixed carbon into syngas;

4           b. removing ash, non-volatile components and unconverted fixed carbon;

5           c. cooling the syngas using a booster heat exchanger;

6           d. conveying the syngas to a generator;

7           e. generating electricity and waste heat;

8           f. capturing at least a portion of the waste heat;

- 9 g. conveying the waste heat to a steam generator heat exchanger;
- 10 h. converting water in the steam generator heat exchanger into steam;
- 11 i. combining the steam of step (h) with air or oxygen and conveying the  
12 combined stream to the booster heat exchanger of step (c);
- 13 j. heating the combined stream to a temperature proximate to the temperature  
14 of the syngas exiting the gasifier of step (a) and to a temperature above  
15 where gasification processes are initiated; and
- 16 k. conveying the superheated stream to the gasifier of step (a).

1 4) The method of Claim 3, wherein the ratio of steam to stoichiometry is about 10:1.

1 5) Syngas with improved energy density and hydrogen content produced by a  
2 process, comprising:

- 3 a. introducing a biomass feedstock into a gasifier to convert volatile matter  
4 and at least a portion of fixed carbon into syngas;
- 5 b. removing ash, non-volatile components and unconverted fixed carbon;
- 6 c. cooling the syngas using a booster heat exchanger;
- 7 d. conveying the syngas to a generator;
- 8 e. generating electricity and waste heat;
- 9 f. capturing at least a portion of the waste heat;
- 10 g. conveying the waste heat to a steam generator heat exchanger;
- 11 h. converting water in the steam generator heat exchanger into steam;
- 12 i. combining the steam of step (h) with air or oxygen and conveying the  
13 combined stream to the booster heat exchanger of step (c);

- 14           j. heating the combined stream to a temperature proximate to the temperature  
15           of the syngas exiting the gasifier of step (a) and to a temperature above  
16           where gasification processes are initiated; and
- 17           k. conveying the superheated stream to the gasifier of step (a).

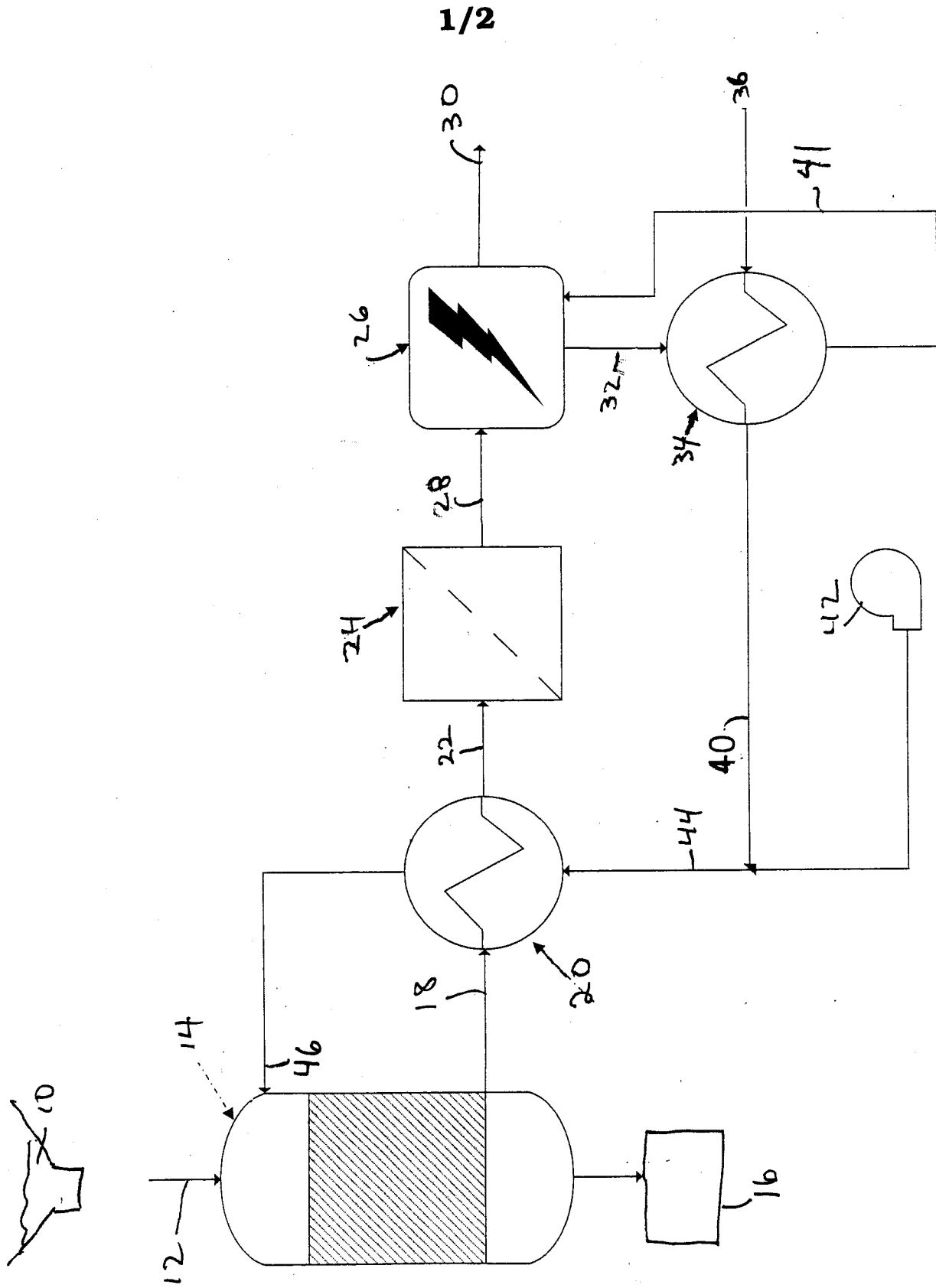
1           6) A method for improving the efficiency of electricity production by a gasifier and  
2 generator combination, comprising:

- 3           a) utilizing the waste heat produced by the generator to produce low quality steam;
- 4           b) exchanging heat from the gasifier outlet stream to increase the temperature and  
5           quality of the steam;
- 6           c) introducing the steam along with some air into a suitable gasifier device; and,
- 7           d) superheating the steam through oxidation of biomass to the point where at least  
8           partial reaction between the steam and biomass occurs.

1           7) The method of Claim 6, wherein a portion of waste heat produced by the  
2 generator is utilized in any biomass preparation operations.

1           8) The method of Claim 6, wherein where a portion of the electricity produced by the  
2 generator is utilized in any biomass preparation operation.

1           9) The method of Claim 6, wherein a portion of waste heat produced by the  
2 generator is utilized to preheat the oxygen containing stream prior to being fed into the  
3 gasifier.



**FIG. 1**

2/2

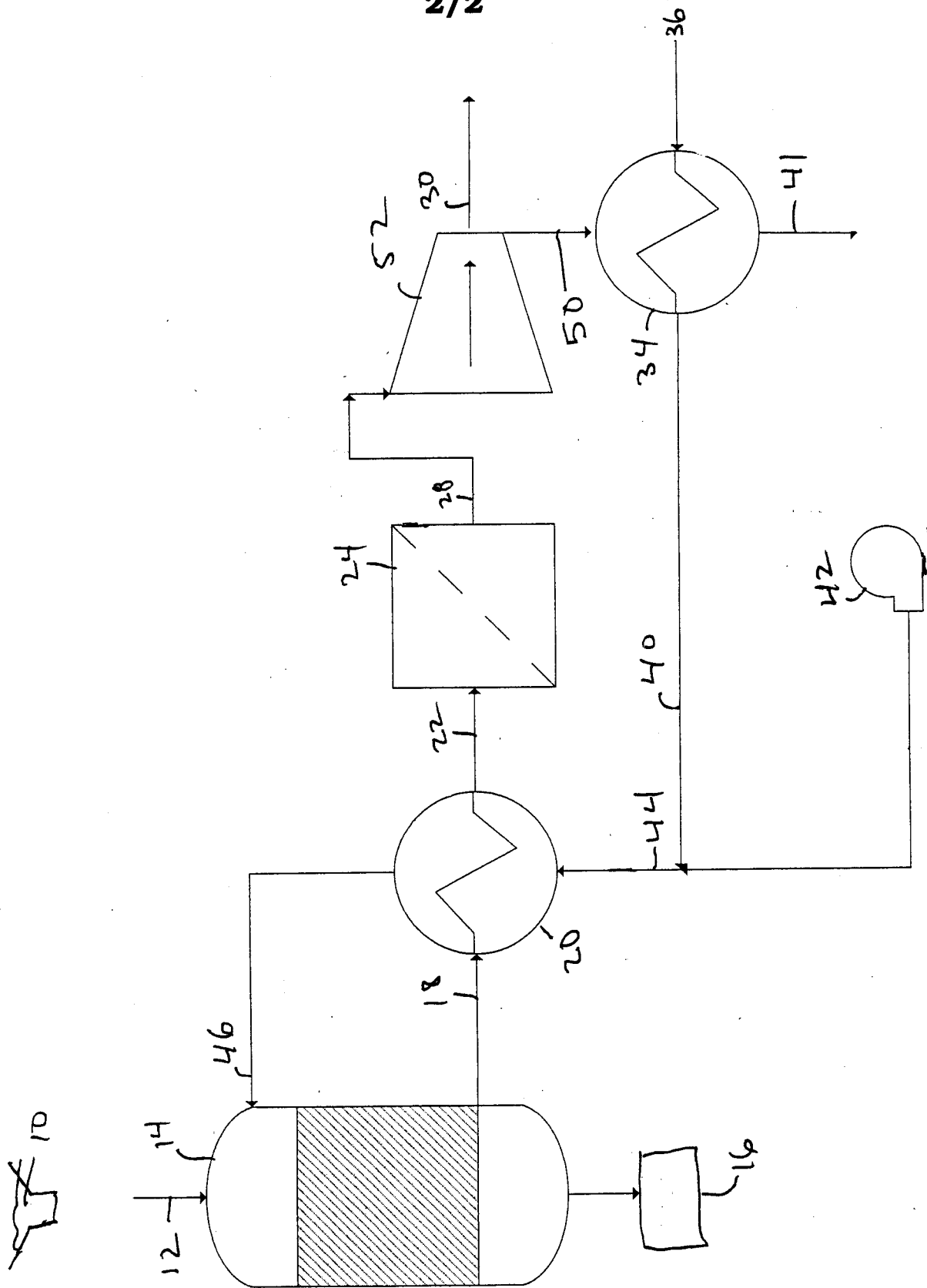


FIG. 2