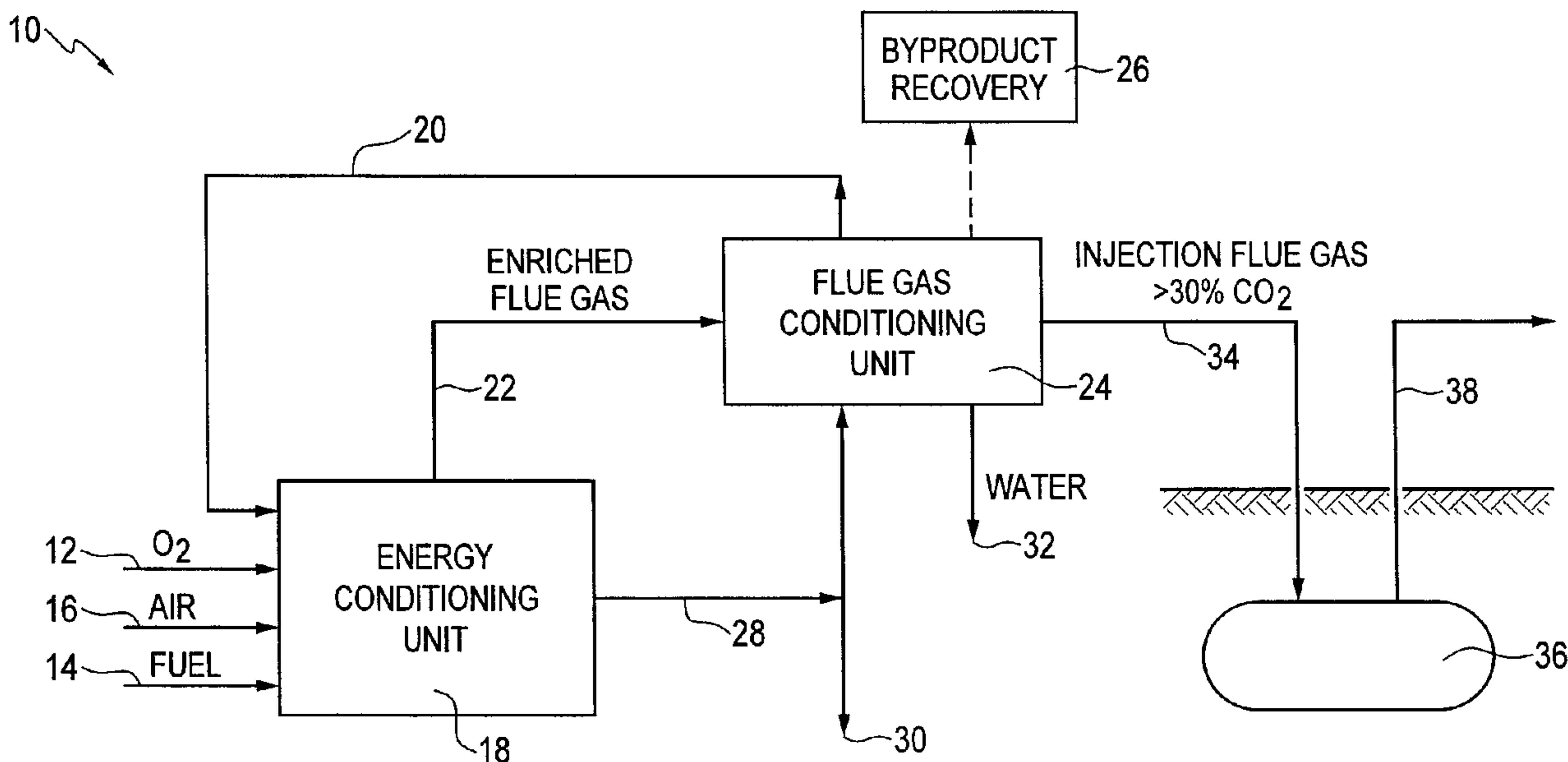




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(54) Titre : INJECTION DE GAZ DE COMBUSTION ENRICHÉ EN DIOXYDE DE CARBONE POUR LA RECUPERATION D'HYDROCARBURES  
 (54) Title: CARBON DIOXIDE ENRICHED FLUE GAS INJECTION FOR HYDROCARBON RECOVERY



(57) Abrégé/Abstract:

A process for enhanced oil and gas recovery. An enriched flue gas is synthesized from utility plant flue gas. The enriched flue gas is customizable for specific requirements; however, the gas is formed to have a high concentration of carbon dioxide. This is used as an injectant for enhancing the liberation of gas and/or oil from subterranean formations. The injection elevates recovery while sequestering carbon dioxide from the power plant source.

**ABSTRACT**

A process for enhanced oil and gas recovery. An enriched flue gas is synthesized from utility plant flue gas. The enriched flue gas is customizable for specific requirements; however, the gas is formed to have a high concentration of carbon dioxide. This is used as an injectant for enhancing the liberation of gas and/or oil from subterranean formations. The injection elevates recovery while sequestering carbon dioxide from the power plant source.

## CARBON DIOXIDE ENRICHED FLUE GAS INJECTION FOR HYDROCARBON RECOVERY

The present invention relates to enhanced hydrocarbon recovery. More  
5 specifically, the present invention relates to enhanced oil and gas recovery and  
carbon dioxide sequestration using carbon dioxide enriched flue gas.

Green house gas has become an escalating concern in the environment  
and is believed to be contributing to uncharacteristic weather patterns and  
temperature fluctuations.

10 The anthropomorphic sources of carbon dioxide are largely from industrial  
and automobile use. In terms of the industrial source, power generation plants  
factor heavily into the equation. As is typical, North American plants employ coal,  
natural gas, fuel oil, *inter alia* to create high pressure steam which is then used to  
drive steam turbines or used in diesel and gas turbine engines directly for electric  
15 power production. This, of course, creates carbon dioxide emissions,  
exacerbating the emissions problem.

A number of studies and attempts have been recently developed to take  
advantage of the volumes of carbon dioxide for enhanced oil and gas recovery in  
subterranean formations. It is well known that such formations, despite having  
20 been previously produced to the most economically feasible extent still contain  
vast reserves of oil and gas. Flue gas injection has now provided an  
economically viable avenue to continue to produce from the once produced  
formations. As an attendant feature, carbon dioxide can be sequestered in the  
formation thus eliminating handling concerns and ensuring compliance with the  
25 stringent requirements of the Kyoto accord.

Enhanced hydrocarbon recovery processes use miscible and immiscible  
gases such as natural gas, natural gas liquids, carbon dioxide, nitrogen, or  
combustion flue gases that maintain pressure, repressurize or expand in a

reservoir to push additional oil or natural gas to the wellbore, or use the same or other gases to dissolve in the oil to lower its viscosity and increase its flow rate.

Capture and permanent storage of carbon dioxide in geologic formations has become an increasingly popular option for sequestering carbon dioxide emissions from industrial processes and coal-fired power generation. The U.S. Government is currently developing policies to encourage geologic sequestration with the view of long-term emission reduction.

The costs related to capture of carbon dioxide from power plants, and high-purity carbon dioxide sources is high at between \$20 to \$200 USD per metric ton of carbon dioxide emissions. Capturing and sequestering 90 percent of the carbon dioxide from a new power plant in the United States is estimated to add \$0.02 per kilowatt-hour to the cost of electricity, with 75 to 80 percent of the cost for the capture, treatment and injection. Considering that capture technology is a critical aspect of plant design, installing capture technology at existing facilities presents very high costs. The present invention not only addresses capture, but further results in economic recovery of previously uneconomically recoverable hydrocarbons and provides excess usable energy.

Accordingly, an object of the present invention is to provide an improved tertiary oil and /or gas recovery method using a CO<sub>2</sub> enriched flue gas, which method is observant of green house gas concerns. A further important object of one embodiment of the present invention is to provide a sequestration mechanism for carbon dioxide.

A further object of one embodiment of the present invention is to provide a method for enhancing oil and gas production from a subterranean formation containing at least one of gas and oil, comprising providing an energy conversion unit, recovering flue gas from the energy conversion unit, re-circulating the flue gas into said energy conversion unit to form a carbon dioxide enriched stream, and injecting the carbon dioxide enriched stream into the subterranean formation to recover at least one of the gas and oil.

According to another object of one embodiment of the present invention, there is provided a method for enhancing oil and gas production from a subterranean formation containing at least one of gas and oil, comprising providing an energy conversion unit, providing a source of flue gas, re-circulating  
5 the flue gas into the energy version unit to form a carbon dioxide enriched stream, and injecting the carbon dioxide enriched stream into the subterranean formation for sequestration of carbon dioxide in the formation.

Conveniently, in terms of the use of fuel for the process, the method can use any economic fuel source, such as natural gas, sour gas, solution gas, diesel  
10 fuel, heavy oil, bitumen, vacuum residue, asphaltene, coal, petcoke, biomass or any suitable combustible waste product. For economic reasons, it is preferred that the feedstock for the fuel be a low cost source, such as from a heavy or extra heavy fraction of bitumen or heavy oil, low cost source, such as from a heavy or extra heavy fraction of bitumen or heavy oil, such as atmospheric or  
15 vacuum residuum, asphaltene or visbroken residue. These feedstocks are used to create the Multiphase Superfine Atomized Residue (MSAR™) oil in water emulsion fuel. This alternate fuel is emulsified in the continuous water phase of 10 to greater than 35%wt to create an easily managed liquid fuel that has similar burning characteristics as natural gas. The heavy oil is pre-dispersed in water  
20 with surfactant chemistry to produce a consistent droplet size. The immediate benefit is that the fuel achieves greater than 99.99% carbon burnout with similar burning characteristics as with natural gas, in terms of flame length and radiant heat flux. The net benefit is that the least valuable fraction of the feedstock is made into a useful fuel that can be directly adapted to a natural gas boiler or  
25 furnace as an economically viable replacement for expensive natural gas.

These and other features, aspects and advantages of the present invention will become better understood with regard to the following description and accompanying drawings.

FIGURE 1 is a schematic illustration of the overall system of the present invention according to a first embodiment;

FIGURE 2 is a schematic illustration of the overall system of the present invention according to a second embodiment;

FIGURE 3 is a graphical representation of the oxygen requirement for flue gas carbon dioxide enrichment on a dry basis; and

FIGURE 4 is a graphical representation of the oxygen requirement for flue gas carbon dioxide enrichment on a wet basis.

For the purpose of the present invention, the following terms are defined below.

GHG refers to green house gas;  
FGT refers to flue gas treatment;  
FGR refers to flue gas recirculation; HP refers to high pressure;  
BFW refers to boiler feed water;  
OTSG refers to once through steam generator; and  
ECU refers to energy conversion unit.

Referring now to Figure 1, shown is a schematic illustration of one possible embodiment of the apparatus to practice the method. Numeral 10 globally denotes the elements.

An air separation unit operation ( not shown ) in Figure 1, separates oxygen and nitrogen in an air stream to provide 90% or greater purity oxygen gas

12 for use in the process. This is exemplary; variations are possible depending on the situation. Fuel 14, which may be selected from the non limiting examples of natural gas, sour gas, solution gas, fuel oil, diesel fuel, emulsion fuel, residuum, biomass, coal and petcoke, are mixed with oxygen 12 and 16 forming  
5 a fuel mixture for introduction into an energy conversion unit, generically represented by numeral 18. The energy conversion unit may comprise any suitable device such as a simple cycle, conventional or super critical steam generator circuit with a suitable steam turbine electric generator or steam turbine driven compressors. Other suitable arrangements incorporate a modified gas  
10 turbine cogen simple or combined unit with a heat recovery steam generator (HRSG). A further possibility may be a diesel slow speed engine driving an electric generator and/or gas compressor. The specific unit or combination of units will depend upon the design parameters.

As an example, for specific hydrocarbon production sites, a typical electric  
15 generation facility would be sized in the 10 to 500 mega watt range or in phases of this size suitable to meet power demands and create sufficient carbon dioxide injection volumes for the enhanced hydrocarbon recovery. The steam driven devices noted above may also include once through steam generators (OTSG), conventional packaged boilers, conventional utility boilers and circulating fluid  
20 bed boilers (CFBs) dimensioned to attend to the steam requirement for the electric power generation.

A flue gas recirculation circuit 20 is incorporated into the system for carbon dioxide enrichment. It is well known that a benefit of FGR is the reduction of nitrogen gas in the flue gas and thus the formation of NO<sub>x</sub> compounds with the  
25 concomitant benefit of an increase in the concentration of carbon dioxide in the flue gas. The graphical representations in Figures 3 and 4 depict compositional change for the flue gas for variations in the oxygen content. As an example, the graph in Figure 3 illustrates the clear advantage in carbon dioxide quantity attributed to a high concentration of oxygen resulting from the cycling process  
30 through the energy conversion unit. Figure 4 demonstrates the same data on a wet basis.

As will be appreciated with an increased oxygen to combustion air ratio for a fixed oxygen concentration, the temperature can become elevated to the extent that design parameters of the boiler/ heat equipment can be exceeded. To counteract this limitation, the flue gas recirculation circuit can recirculate a combustion stream back to the energy conversion unit 18 for thermal quenching. As will be appreciated, the quantity of flue gas recirculation will depend on the operational parameters of the equipment. This immediately results in significant advantages, namely:

- a) enhanced boiler efficiency and operation;
- b) greater ease for the designer regarding retrofitting of existing plants for the process without extensive re-engineering or equipment replacement;
- c) improved thermal combustion efficiency;
- d) reduced NOx emissions; and
- e) improved safety.

Returning to the overall process, the stream 22 exiting conversion unit 18, now an enriched flue gas stream, may then be treated in any number of steps, globally denoted by flue gas conditioning unit numerically represented by 24. Generally, the flue gas, depending on the assay of the fuel may contain in addition to CO<sub>2</sub>, such major components as CO, H<sub>2</sub>, excess O<sub>2</sub>, SO<sub>2</sub>, SO<sub>3</sub>, NOx, N<sub>2</sub>, soot, ash, water vapour metals, etc. The treatment may involve departiculation or flyash removal, flue gas dehydration, quenching, flue gas desulfurization and compression, NOx removal, byproduct recovery or any combination of these.

In addition, based on economic merit, additional methods may be used to recover the useful and valuable byproducts denoted by numeral 26, such as CO, H<sub>2</sub>, SO<sub>2</sub>, water and heavy metals for other commercial ventures common to those skilled in the art. As a further clarification, the energy conversion unit 18

may be operated with combustion of the fuel in a sub-stoichiometric, stoichiometric or excess oxygen mode. Different byproducts can be generated in the enriched flue gas depending on the specific requirements. Typically, it is preferred that the mode be near stoichiometric to produce the highest concentration of carbon dioxide in the enriched flue gas. In some instances, it may be desirable to utilize the byproducts in flue gas design.

The useful energy 28 generated by the energy conversion unit 18 as one example, may be electric power or direct drive to compress the enriched flue gas and/or combustion air/oxygen in the operations of the flue gas conditioning unit 24. Depending on the design balance of the components and the required volume of the enriched injections flue gas, excess energy 30 may be created and sold to commercial markets as excess electric power.

Residual water 32 discharged from the flue gas conditioning unit 24 may be reused in other processes. Conditioned injection flue gas is transported via line 34 into the subterranean formation 36. The injection flue gas may contain greater than 30% by volume carbon dioxide; however, this will change depending upon the composition of the formation 36 according to Figure 2 and Figure 3.

Formation 36 may contain any one or all of oil, bitumen, heavy oil, natural gas, natural gas liquids or may be used purely for flue gas sequestration.

The recovered hydrocarbons leave formation 36 via line 38 and may be subjected to further processing. This is an optional step.

The composition of the treated flue gas is variable and will depend on the specific nature of the content and the physical and chemical properties of the formation. It will be appreciated that the treated flue gas composition may require compositional change dynamically as the formation changes over time. As an example, the composition could be 50% carbon dioxide and 50 % nitrogen to 70% carbon dioxide and 30 % nitrogen through to 100% carbon dioxide.

Turning to Figure 2, shown is a variation in the overall process, where a heat recovery unit 23 is interposed in the circuit between the energy conversion

unit 18 and the flue gas conditioning unit 24. In this variation the heat recovery unit 23 is employed to balance the energy produced and maximize the thermal efficiency of the combined cycle method. This arrangement provides for the use of prime movers, e.g. gas turbines and diesel engines. The heat recovery unit 23  
5 may be employed to generate additional steam for electric power generation or be used to preheat water, combustion air or oxygen to elevate the energy efficiency of the method.

The technology set forth has the advantage of enhancing recovery of the values, originally in place, a minimum of 5%; this represents a vast increase in  
10 the economics of recovery. This is further augmented by the generation of excess electrical power and/or stream.

In summary, by unifying the concepts of synthesizing an enriched flue gas for injection into a hydrocarbon formation , the following additional advantages are realized:

15

- i) Particulate emission reduction;
- ii) improved carbon burnout;
- iii) a reduction of N content in flue gas resulting in a volume reduction greater than 60%;
- 20 iv) economic benefit from increased hydrocarbon production;
- v) the absence of pipelines and compression devices for the flue gas;
- vi) self sufficing by generation of electrical power and/or stream for process control;
- 25 vii) self generation of low cost fuels, such as MSAR<sup>TM</sup> emulsion fuel asphaltenes, residuums; and
- viii) enhanced energy conversion unit efficiency by use of excess O<sub>2</sub>.

It will be understood that numerous modifications thereto will appear to  
30 those skilled in the art. Accordingly, the above description and accompanying

drawings should be taken as illustrative of the invention and not in a limiting sense. It will further be understood that it is intended to cover any variations, uses, or adaptations of the invention following, in general, the principles of the invention and including such departures from the present disclosure as come  
5 within known or customary practice within the art to which the invention pertains and as may be applied to the essential features herein before set forth, and as follows in the scope of the appended claims.

**THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:**

1. A method for enhancing oil and gas production from a subterranean formation containing at least one of gas and oil, comprising:

providing an energy conversion unit;

recovering flue gas from said energy conversion unit;

re-circulating said flue gas into said energy conversion unit to form a carbon dioxide enriched stream;

chemically modifying said carbon dioxide enriched stream in accordance with the chemical composition change in said formation during injecting of said carbon dioxide enriched stream; and

injecting said carbon dioxide enriched stream into said subterranean formation to recover at least one of said gas and oil while sequestering said carbon dioxide, wherein re-circulated flue gas reduces the temperature of said energy conversion unit compared to combusting in air.

2. The method as set forth in claim 1, wherein said carbon dioxide enriched stream is treated in at least one conditioning unit operation to modify said carbon dioxide enriched stream prior to injection.

3. The method as set forth in claim 2, wherein said conditioning comprises a unit operation selected from the group consisting of dearticulation, flue gas desulfurization, flue gas quench, flue gas dehydration, flue gas compression, NO<sub>x</sub> removal and combinations thereof.

4. The method as set forth in any one of claims 1 through 3, wherein carbon dioxide is sequestered in said formation.

5. The method as set forth in any one of claims 1 through 4, further including the step of recovering energy generated from said energy conversion unit.

6. The method as set forth in any one of claims 1 through 5, further including the step of selectively recovering byproducts from said method.

7. The method as set forth in claim 6, further including the step of utilizing said byproducts for flue gas augmentation.
8. A method for enhancing oil and gas production from a subterranean formation containing at least one of gas and oil, comprising:
  - providing an energy conversion unit;
  - providing a source of flue gas;
  - re-circulating said flue gas into said energy version unit to form a carbon dioxide enriched stream;
  - chemically modifying said carbon dioxide enriched stream in accordance with the chemical composition change in said formation during injecting of said carbon dioxide enriched stream; and
  - injecting said carbon dioxide enriched stream into said subterranean formation for sequestration of carbon dioxide in said formation, wherein re-circulated flue gas reduces the temperature of said energy conversion unit compared to combusting in air.
9. The method as set forth in claim 8, further including the step of selectively recovering gas and oil from said formation.
10. The method as set forth in claims 8 or 9, wherein said flue gas recirculation circuit reduces the temperature of said energy conversion unit.
11. The method as set forth in any one of claims 1 through 10, wherein said carbon dioxide enriched stream is treated in at least one conditioning unit operation to modify said carbon dioxide enriched stream prior to injection.
12. The method as set forth in claim 11, wherein said conditioning comprises a unit operation comprises a unit operation selected from the group consisting of dearticulation, flue gas desulfurization, flue gas quench, flue gas dehydration, flue gas compression, NO<sub>x</sub> removal and combinations thereof.
13. The method as set forth in any one of claims 1 through 12, further including the step of recovering energy generated from said energy conversion unit.
14. The method as set forth in any one of claims 1 through 13, further including the step of selectively recovering byproducts from said method.

15. The method as set forth in claim 14, further including the step of utilizing said byproducts for flue gas augmentation.

16. A method for enhancing oil and gas production from a subterranean formation containing at least one of gas and oil, comprising:

providing an energy conversion unit;

recovering flue gas from said energy conversion unit;

re-circulating said flue gas into said energy conversion unit to form a carbon dioxide enriched stream;

chemically modifying said carbon dioxide enriched stream in accordance with the chemical composition change in said formation during injecting of said carbon dioxide enriched stream; and

injecting said carbon dioxide enriched stream into said subterranean formation to recover at least one of said gas and oil while sequestering said carbon dioxide, wherein the mass flow rate through the energy conversion unit is the same or higher as compared to combusting in air.

17. A method for enhancing oil and gas production from a subterranean formation containing at least one of gas and oil, comprising:

providing an energy conversion unit;

providing a source of flue gas;

re-circulating said flue gas into said energy version unit to form a carbon dioxide enriched stream;

chemically modifying said carbon dioxide enriched stream in accordance with the chemical composition change in said formation during injecting of said carbon dioxide enriched stream; and

injecting said carbon dioxide enriched stream into said subterranean formation for sequestration of carbon dioxide in said formation, wherein the mass flow rate through the energy conversion unit is the same or higher as compared to combusting in air.

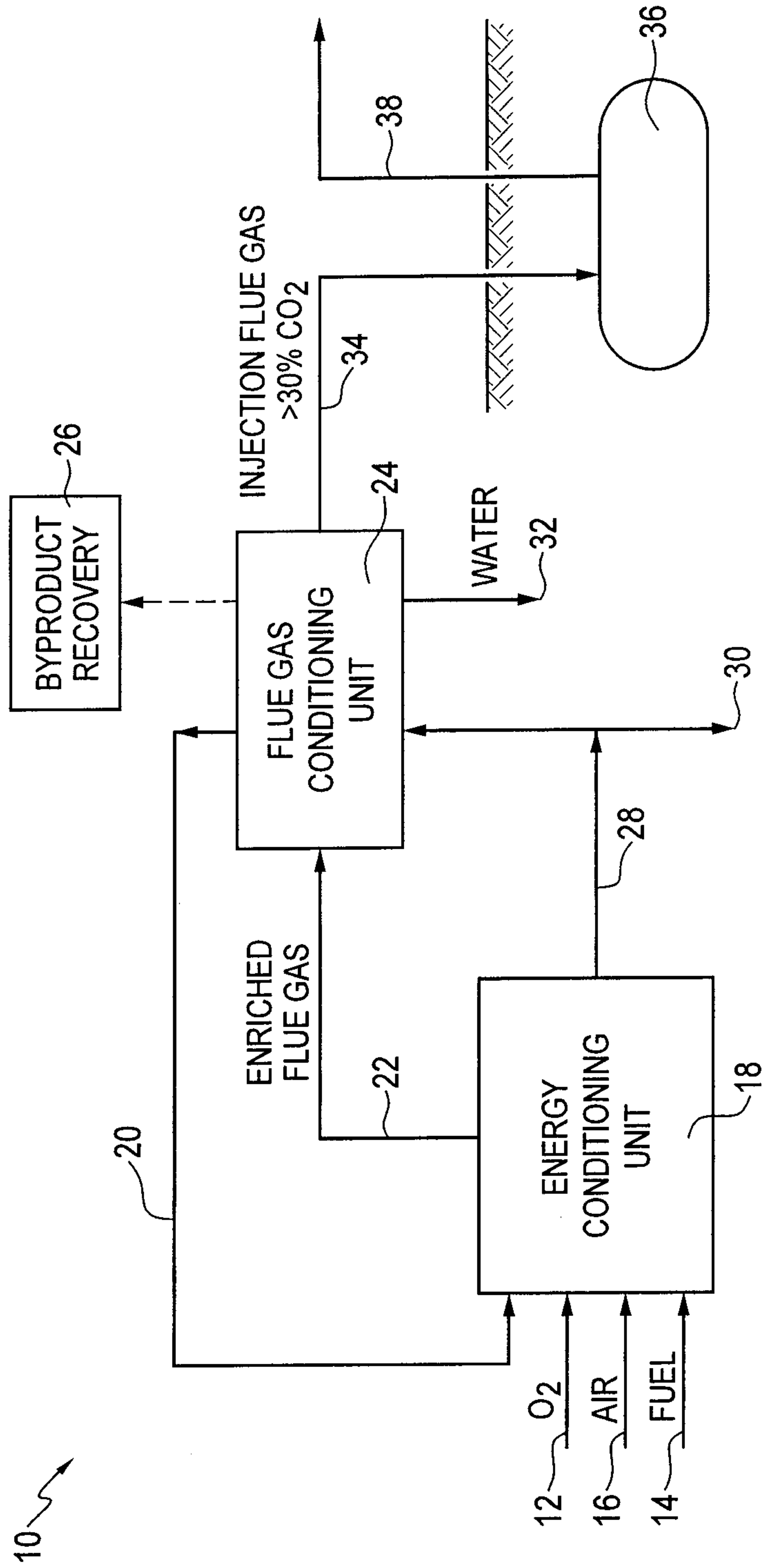


FIG. 1

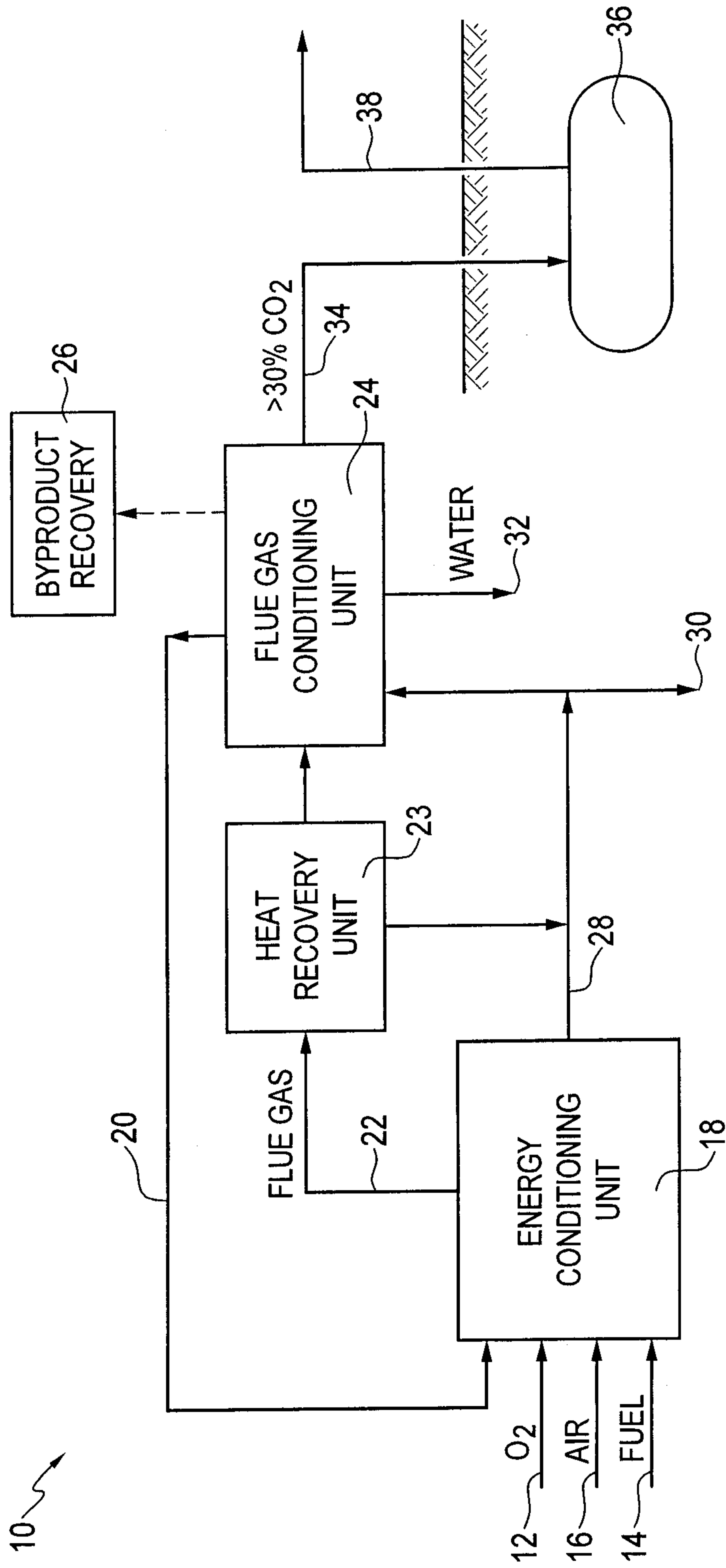


FIG. 2

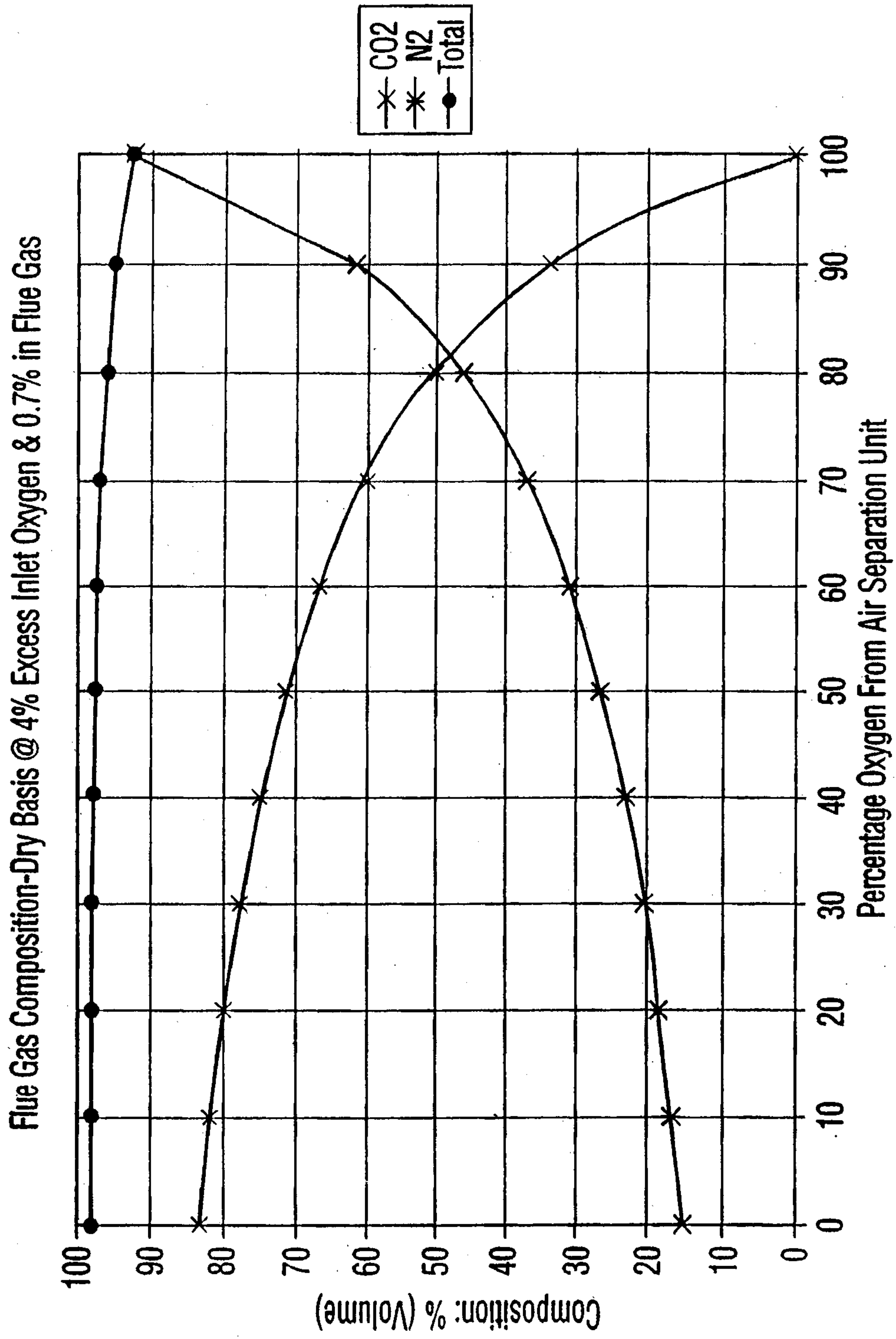


FIG. 3

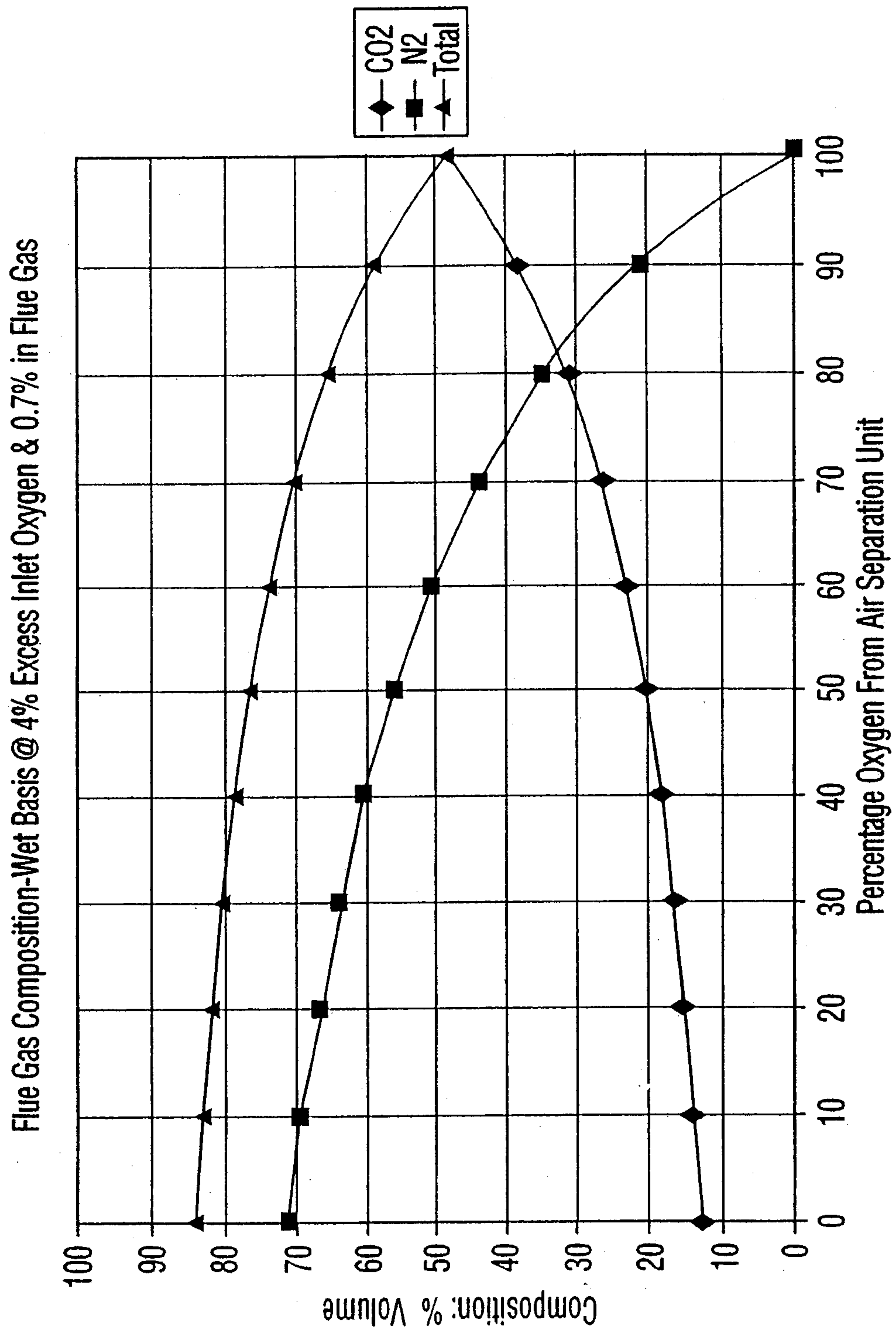


FIG. 4

