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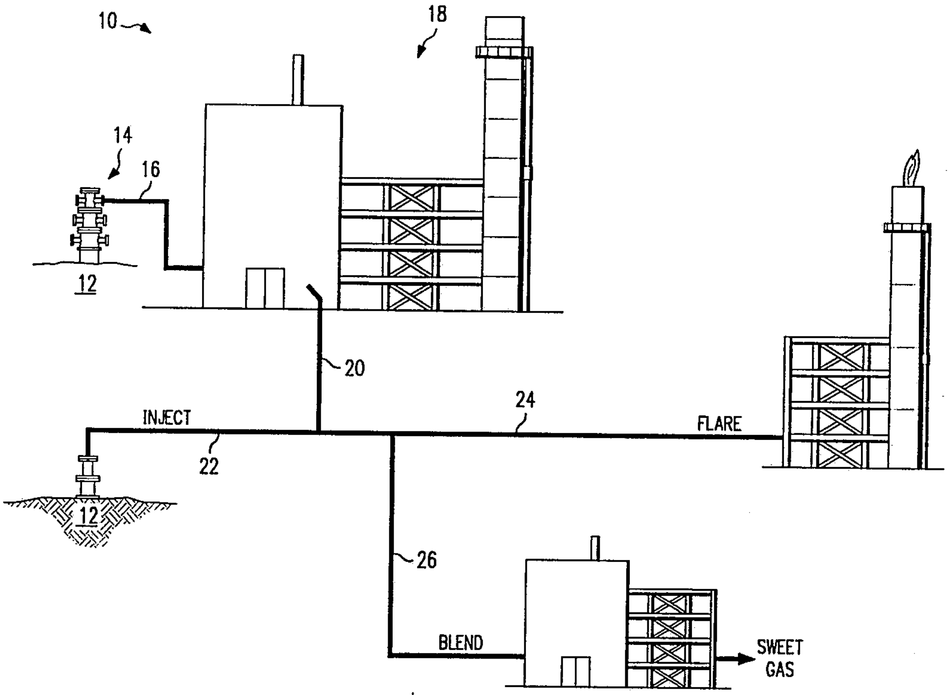

(57) Abstract

A method of producing electric power using sour natural gas that contains a high sulfur content and a gross heating value of less than 750 BTUs per cubic foot in an internal combustion engine such as a gas turbine electric power generating plant. The method entails removing sulfur from the sour natural gas to produce a de-sulfurized low-BTU natural gas having a gross heating value of less than 750 BTUs per cubic foot. Next, the method requires flowing the de-sulfurized low-BTU natural gas to the internal combustion engine. The method further includes operating the internal combustion engine to burn the de-sulfurized, low-BTU natural gas and, then, directing the output energy from the combustion engine to an electrical generator for generating electrical energy.

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PROCESS FOR PRODUCING ELECTRIC ENERGY USING SOUR NATURAL GAS

TECHNICAL FIELD OF THE INVENTION

The present invention generally relates to electrical power generation, and more particularly to a method for generating electrical power using a natural gas having a high sulfur content and a relatively low gross heating value in an internal combustion engine.

BACKGROUND OF THE INVENTION

Gas turbine engines have become increasingly popular systems for electric power generation. Because of their low capital costs, quick construction, and high efficiencies utility companies around the world are making gas turbine engines an important part of current and future electric power generating strategies. Current and prospective gas turbine engines are revolutionizing the electric power utility industry by providing both simple cycle and combined cycle operation with efficiencies exceeding existing power plant efficiencies and reliability meeting, and often exceeding, the reliability of other forms of electric power generation.

An attractive feature of using gas turbine generators is a relatively high availability of the natural gas that is potentially useable as fuel. Although, natural gas is available as potential gas turbine fuel, the electrical utility industry does not consider all obtainable natural gas useable for gas turbine electric power generation. In particular, electric power generating utilities presently only use a "sweet" natural gas for electric power generation. The sweet natural gas typically contains nitrogen in concentrations of less than approximately 25 mole percent, methane gas in concentrations of at least approximately 60 mole percent and very low levels of hydrogen sulfide.

Not all natural gas reserves, however, contain natural gas with these characteristics. In fact, the electric utility industry does not use substantial reserves of "sour" natural gas that contain significant levels of hydrogen sulfide (H_2S) and high levels of nitrogen. The sour natural gas may undergo a process to remove the high sulfur content, but the high nitrogen content causes the sour gas to possess a low gross heating value. For this reason, the electric utility industry has not used the sour gas for electric power production in gas turbine power plants.

U.S. Patents No. 4,347,811 and 4,419,968 issued to Lee on September 7, 1982 and December 13, 1983, respectively, and assigned to Phillips Petroleum Company (hereinafter the Lee patents) describe a method and apparatus for removing H_2S from fuel for an internal combustion engine. The Lee patents do not, however, teach or suggest the use of sour gas which contains H_2S for electric power generation. In a similar vein, U.S. Patent No. 4,884,530 issued to Bockhaus on December 5, 1989 and assigned to Atlantic Richfield Company (hereinafter Bockhaus) discloses a method for adapting an internal combustion engine to run at optimum compression ratios on a variety of fuels requiring different compression ratios. Bockhaus may contemplate the use of various commercially available fuels such as sweet natural gas in an automobile piston engine. Neither Bockhaus nor any other system solves the problem of using what has heretofore been considered waste or nonusable sour natural gas for large scale electric power generation in a gas turbine electric power plant.

Failure to use the low-BTU sour natural gas creates numerous technical and environmental problems. For example, because they cannot profitably sell the available large quantities the sour gas, natural gas refining companies typically flare or burn this gas to the atmosphere or reinject the gas into the natural gas reservoir or production formation as they extract the higher-BTU sweet natural gas. Flaring the sour gas releases harmful pollutants into the atmosphere. Reinjecting the sour gas either may spoil a good reservoir of sweet natural gas or, at least, may cause a refinery to extract more sweet natural gas than they would extract if they sold the sour gas to partially satisfy the same natural gas demands. Although some refineries sell this gas as a supplement to the sweet natural gas, the demand for sour gas is sufficiently large to permit the refineries to avoid flaring or rejecting the gas. In most cases, the sellers of the sour natural gas who also sell high-quality sweet natural gas may sell, for example, only one cubic foot of sour natural gas for every six cubic feet of sweet natural gas. Sour gas, however, is often found in much greater proportions to sweet gas than 1-to-6. Consequently, even the refineries that sell the sour gas often end up flaring or reinjection significant quantities of sour natural gas.

If it were feasible to use the sour natural gas for electric power generation in gas turbine power generating plants, then the electric power utility industry could realize substantial benefits from using available supplies of the sour natural gas. Moreover, since the use of the sour natural gas for electrical power generation avoids flaring the sour natural gas, the refineries will introduce fewer pollutants into the atmosphere. Because sour gas could at least partially satisfy demands for sweet natural gas.

Consequently, there is a need for a method to generate electric power using sour natural gas in gas turbine electric power generating plants.

There is a need for a method of producing electrical power with sour natural gas that avoids the pollution problems inherent of conventional practices of flaring the sour natural gas to the atmosphere and of reinjecting the gas into the production formations.

Moreover, there is a need for a method of using sour natural gas for electric power generation that relieves, at least partially, the growing demand for natural gas in the gas turbine electric power generating industry.

SUMMARY OF THE INVENTION

The present invention, accordingly, provides a method for using sour natural gas in an electric power generating plant that overcomes or reduces the disadvantages and limitations associated with prior practices of natural gas utilization for electrical power generation.

According to one aspect of the present invention, there is provided a method of producing electric power using a sour natural gas that contains a high sulfur content and a gross heating value of less than 750 BTUs per cubic foot in an internal combustion engine. The method entails removing sulfur from the sour natural gas to produce a de-sulfurized low-BTU natural gas having a gross heating value of less than 750 BTUs per cubic foot. Next, the method requires flowing the de-sulfurized, low-BTU natural gas to the internal combustion engine. The method further includes operating the internal combustion engine to burn the de-sulfurized, low-BTU natural gas and then directing the output energy from the combustion engine to an electrical generator for generating electrical energy.

According to yet another aspect of the present invention there is provided a method of operating a gas turbine generator with a combustible natural gas that comprises, first, the steps of transforming a low-BTU, high-sulfur-containing natural gas into a combustible gas characterized by a less than 750 BTU per cubic foot gross heating value and a composition comprising less than approximately 50% methane, less than approximately 10% ethane, less than approximately 2% propane, and at least 30% nitrogen. The method requires passing the combustible gas into the gas turbine generator to start and operate the turbine generator to produce electric power. Next, the method entails discharging the exhaust gases from the combustion turbine.

A technical advantage of the present invention is that it provides a feasible use of high-sulfur, high-nitrogen, low-BTU natural gas for electrical power generation.

Another technical advantage of the present invention is that it minimizes environmental pollutants that typically arise in natural gas exploration and refining. Prior methods of producing natural gas often flare or burn off the low-BTU sour natural gas to the atmosphere. This process releases undesirable pollutants to the atmosphere. Instead of burning the low-BTU natural gas off to the atmosphere, the present invention makes it economically attractive to refine and use the low-BTU natural gas. Using the low-BTU natural gas for electrical power generator results in releasing fewer air pollutants into the atmosphere than occurs when the low-BTU natural gas is flared or burned.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention and its modes use and advantages are best understood by reference to the following description of illustrative embodiments when read in conjunction with the accompanying, wherein:

FIGURE 1 provides a conceptual flow diagram of the various known uses of sour natural gas; and

FIGURE 2 provides an illustrative block diagram of a gas turbine combined cycle generating plant for implementing the preferred embodiment.

DETAILED DESCRIPTION OF THE INVENTION

The preferred embodiment of the present invention is best understood by referring to the FIGUREs, wherein like numerals are used for like and corresponding parts of the various drawing.

In the electric power industry, the trend to incremental capacity expansion provides an increasingly important market for advanced combustion turbines that major manufacturers are developing. Their low capital cost, quick construction and high efficiencies put combustion gas turbines at the leading edge of new electric power generating capabilities. Although recent resource estimates indicate at least several decades of conventional gas supplies at competitive prices, concerns exist within the gas turbine-based utility industry over premium fuel availability at competitive prices. With increasing use of gas turbine-based electric power plants, the demand for supplies of natural gas increases. One way to alleviate some market pressures that are likely to drive up the cost of natural gas is to make available for general use natural gas that heretofore has been considered non-useable for electric power generation.

FIGURE 1 illustrates a problem that exists in the natural gas industry with regard to the use of low-BTU natural gas for electric power generation. Referring to FIGURE 1, there is shown a flow path 10 that begins with extracting from a natural gas reservoir or formation 12 a natural gas containing high H_2S levels. From manifold 14 the sour natural gas flows, for example, along pipeline 16. Pipeline 16 takes the high-H_2S natural gas to sulfur removal refining plant 18 to remove of the H_2S, oil and other impurities from the natural gas. What remains is a low-BTU high-nitrogen content natural gas that may, for example, flow from refining plant 18 along pipeline 20.

From pipeline 20, a refinery generally may take one or more of three steps to dispose of the low-BTU high-nitrogen containing natural gas. For example, a refinery may direct the low-BTU natural gas along pipeline 22 back into formation 12. Additionally, the refinery may direct the natural gas through pipeline 24 and simply burn or flare the natural gas in the atmosphere to dispose of the natural gas. Finally, and alternatively, the refinery may direct part or all of the natural gas along pipeline 26 to blend it with a higher-BTU low-nitrogen natural gas at a ratio of approximately 6-to-1. These are the known uses of the low-BTU high-nitrogen containing natural gas.

TYPICAL HIGH-BTU

GAS ANALYSIS BY CHROMATOGRAPH

Component	Mol%	GPM	Gross Heating Values (BTU/CF)
Methane	59.57		Dry = 950.49 Sat. = 935.05
Ethane	6.58	1.756	Part. Sat. at (lbs. water MMCF)
Propane	3.92	1.078	
Isobutane	.77	0.251	Sat. at Flowing conditions = 949.41
N-Butane	1.54	0.484	
Iso-Pentane	0.48	0.175	
N-Pentane	0.44	0.159	Specific Gravity (Air = 1,000)
Hexanes	0.29	0.118	Ranarex = 0.9020
Heptanes Plus	0.17	0.068	Calculated - 0.7969
Carbon Dioxide	0.00		
Nitrogen	26.24		Compressibility Factor: Z
Oxygen	0.00		Z = 0.9975
Hydrogen Sulfide			
Total	100.00	4.089	Base Conditions for Calculations: 14.6500 psta, 60 deg F, Real Volumes

TABLE 1

TYPICAL LOW-BTU GAS ANALYSIS BY CHROMATOGRAPH			
Component	Mol%	GPM	Gross Heating Values (BTU/CF)
Methane	49.77		Dry = 681.98
Ethane	5.77	1.540	Sat. = 671.12
Propane	2.00	0.550	
Isobutane	0.32	0.104	Sat. at Flowing conditions = 680.58
N-Butane	0.36	0.113	
Iso-Pentane	0.07	0.026	
N-Pentane	0.04	0.014	Specific Gravity (Air = 1,000)
Hexanes	0.02	0.008	Ranarex = 0.7920
Heptanes Plus	0.01	0.004	Calculated - 0.7870
Carbon Dioxide	0.00		
Nitrogen	41.64		Compressibility Factor: Z
Oxygen	0.00		Z = 0.9985
Hydrogen Sulfide			
Total	100.00		Base Conditions for Calculations: 14.6500 psta, 60 deg F, Real Volumes

TABLE 2

Tables 1 and 2 describe the gas chromatography analysis of the high-BTU and low-BTU natural gas, respectively. According to Table 1, gas chromatography shows that the methane content for the high-BTU natural gas is approximately 60 mole percent, ethane at approximately 7 mole percent and propane at approximately 4 mole percent. The typical high-BTU natural gas has trace percentages of other heat producing and other gases. Importantly, however, the high-BTU contains only approximately 26% nitrogen. With this composition, the high-BTU natural gas has respective gross heating values (in BTU per cubic foot) for dry gas of approximately 950 BTU per cubic foot, with saturated gas of approximately 935 BTU per cubic foot. Typically, however, at saturation flowing conditions the gross heating value for the typical high-BTU natural gas is approximately 950 BTU per cubic foot.

On the other hand, as Table 2 shows, the low-BTU, high-nitrogen containing natural gas has approximately a 10 lower mole percent of heat producing methane, and approximately the same amount of ethane as the high-BTU natural gas and approximately half the propane that the high-BTU natural gas contains. Moreover, the low-BTU natural gas contains typically over 40 mole percent nitrogen. In essence, therefore, the decrease in the mole percent of methane in the low-BTU natural gas relative to the high-BTU natural gas is made up by an over-abundance of nitrogen. The disadvantageous result of this shift from energy producing methane to the inert nitrogen is a reduction of nearly 300 BTU per cubic foot in the low-BTU natural gas. In particular, the dry gross heating value of the low-BTU, high-nitrogen natural gas is approximately 680 BTU per cubic foot. Saturation at flowing conditions plus heating value for this low-BTU natural gas is approximately the same, 680 BTU per cubic foot.

Conventional uses of the low-BTU natural gas for power production had been to mix at a ratio of approximately 6 cubic feet of 1,000 BTU gas for every one cubic foot of 650 BTU natural gas to achieve a pipeline quality mixture of approximately 950 BTU per cubic feet. No other acceptable use for power generation has ever been recognized by the electric power industry.

Most of the low-BTU sour gas is a by-product of the production of high sulfur (H_2S) hydrocarbon gas and oil. Instead of flaring this gas to the atmosphere, reinjecting the gas into the production formation, or selling the gas at a value of approximately 1/6th the value of the high-BTU natural gas, the preferred embodiment uses the low-BTU natural gas as a primary fuel for electric power generation. By using the low-BTU as a primary fuel for electric power generation, the preferred embodiment produces useful electric energy that heretofore was wasted in other methods of providing fuel for natural gas-based electric power generation.

The preferred embodiment takes advantage of the fact that a gas turbine engine such as that used in the preferred embodiment may receive and efficiently natural gas having varying gross heating values, by opening its input injectors and increasing the fuel injection pressure. By increasing flow volume and pressure, the preferred embodiment permits the use of the low-BTU natural gas where the gross heating value of the natural gas may be known and maintained at a predetermined level. For electric power generation, adequate reserves of the low-BTU natural gas or single cycle or combined cycle generators are available. Since the low-BTU has historically been treated as a waste gas, it is economical to use this gas if the sulfur and by-product prices are sufficiently high to warrant the development of various fields. It has been determined that known reserves of the low-BTU natural gas exist and may be easily exploited without major financial risks.

Fuel is the overriding consideration in any type of electric generation plant. One of the major advantages of the method of the present invention is the economical price of the low-BTU natural gas. In the preferred embodiment, even with the removal of sulfur from the natural gas, the cost of producing electrical energy with the low-BTU, high-nitrogen containing sour natural gas is significantly lower than any other available electric power generation method using high-BTU sweet natural gas. An example of this appears in the following analysis.

Suppose, for example, that a General Electric LM5000 Steam Injected Gas Turbine (STIG) combined cycle gas turbine plant is used. This is an 86 megawatt plant. Assuming an H_2S concentration of 1% in the gas, resulting sulfur emissions would approach 10,000 kilograms per day. To operate the power plant within environmental guidelines, it is necessary to remove the sulfur from the low-BTU gas. Operating within the EPA guidelines should reduce emissions by de-sulfurization to pipeline gas quality of approximately 10 to 15 parts per millon (ppm).

In the example of taking a 1% sulfur-containing low-BTU natural gas to a pipeline quality of 10 to 15 ppm, an increase in the cost of the gas could range between 10¢ to 25¢ per million BTU. Typically, the cost of low-BTU natural gas is approximately 15-30% less than the sweet pipeline quality natural gas. The desulfurization of the low-BTU natural gas may increase costs significantly depending upon the chemical content of the gas. Even with this increase in price, the method of preferred embodiment provides an economically viable way of producing electric energy with the low-BTU natural gas.

FIGURE 2 illustrates the LM5000 STIG combined cycle plant that the method of a preferred embodiment may use. The LM5000 STIG is a derivative of the General Electric

CF6-50 which various commercial aircraft use and for which significant reliability data has been generated. The LM5000 exhibits availability factors well above 90% approaching 99% in some cases. As a result, the use of LM5000 for power generation in the method of the preferred embodiment is highly desirable. Moreover, using the preferred embodiment, it can be shown that extremely competitive, low-cost electric power is producible using preferred embodiment.

FIGURE 2 illustrates the use of a dual LM5000 STIG co-generation plant 50 for electric power generation using the low-BTU, high-nitrogen containing natural gas. To implement the preferred embodiment, the LM5000 STIG fuel flow orifice may need to be opened or expanded and the sour natural gas fuel must be pressurized (for example to approximately 800 psi) in order to maintain a sustained combustion. However, experimental results indicate that these modifications are well within the design capacity of the LM5000 STIG. Referring to one side the dual LM5000 STIG generating plant, fuel input 52 permits the flow of the low-BTU natural gas to the LM5000 gas turbine 54. Gas turbine 54 burns the low-BTU natural gas causing generation of electrical power at gas turbine generator set 56. Exhaust from gas turbine 54 goes via line 58 to steam generation stack 60 to produce 85 PSIG, 360° Fahrenheit steam for steam turbine generator set 62. Steam generator set 62 comprises steam turbine 64 and generator 66. Also, output from the high pressure portion of steam generator 60 produces high pressure steam that goes along line 68 to the high pressure end of steam turbine 64. Additionally, the high pressure output from steam generator 60 goes through the super heater 70 for cooling gas turbine 54.

Parallel gas turbine steam generating side 72 operates identically and parallel to gas turbine 54, generator set 56, and steam generator 60 to produce electrical energy and steam to operate steam turbine generator set 62. The result of using the low-BTU high-nitrogen containing natural gas of the preferred embodiment is electrical energy being produced at generator set 56, generator set 66, and generator set 74 of parallel half 72.

Various other configurations of gas turbine electric power generating plants may be devised consisting with the scope of the present invention. Moreover, alternative embodiments to the present invention will become apparent to persons skilled in the art upon reference to the above description. It is therefore, contemplated that the appended claims will cover such modifications that fall within the true scope of the invention.

WHAT IS CLAIMED IS:

1. A method of producing electrical energy using a sour natural gas containing a high sulfur content in a combustion engine, comprising the steps of:

removing sulfur from the sour natural gas to produce a de-sulfurized low-BTU natural gas;

flowing said de-sulfurized low-BTU natural gas to the combustion engine;

operating the combustion engine to burn said de-sulfurized low-BTU natural gas; and

directing the output energy from said combustion engine to an electrical generator for generating electrical energy.

2. The method of Claim 1, wherein said low-BTU natural gas has a gross heating value of approximately less than 750 BTUs per cubic foot.

3. The method of Claim 1, wherein said combustion engine operating step comprises the step of operating a steam injected gas turbine combined cycle plant to burn said low-BTU natural gas.

4. A method of operating an combustion turbine engine with a combustible natural gas, comprising the steps of:

transforming a low-BTU, high-sulfur content natural gas into a combustible gas comprising less than approximately 50% methane, less than approximately 10% ethane, less than approximately 2% propane, and at least 30% nitrogen;

passing said combustible gas to an internal combustion engine to start and operate said internal combustion engine; and

discharging the exhaust gasses from said combustion turbine.

5. The method of Claim 4, wherein said low-BTU natural gas has a gross heating value of approximately less than 750 BTUs per cubic foot.

6. The method of Claim 4, wherein said internal combustion engine operating step comprises the step of operating a steam injected gas turbine combined cycle plant to burn said low-BTU natural gas.

7. A system for producing useable energy, comprising:

a supply of low-BTU, high sulfur content natural gas;

means for refining said low-BTU, high sulphur content natural gas to produce a combustible gas comprising less than approximately 50% methane, less than approximately 10% ethane, less than approximately 2% propane, and approximately 30% nitrogen;

a combustion turbine for transforming said combustible gas into useable energy;

means for passing said combustible gas to said combustion turbine; and

means for discharging the exhaust gasses from said combustion turbine.

8. The system of Claim 7, wherein said low-BTU natural gas comprises a natural gas having a gross heating value of approximately less than 750 BTU per cubic foot.

9. The system of Claim 7, wherein said combustion turbine comprises a steam injected gas turbine combined cycle plant for burning said low-BTU natural gas and generating therefrom electrical energy.

10. A system for producing electrical power using a sour natural gas containing a high sulfur content in a combustion engine, comprising the steps of:

refining means for removing sulfur from the sour natural gas to produce a de-sulfurized low-BTU natural gas;

a combustion engine for burning said de-sulfurized low-BTU natural gas;

means for flowing said de-sulfurized low-BTU natural gas to said combustion engine;

control means for operating said combustion engine to burn said de-sulfurized low-BTU natural gas to produce sustained output power; and

an electrical generator associated with said combustion engine for receiving said output power and generating electrical power.

11. The system of Claim 10, wherein said low-BTU natural gas comprises a natural gas having a gross heating value of approximately less than 750 BTU per cubic foot.

12. The system of Claim 10, wherein said combustion engine comprises a steam injected gas turbine combined cycle plant for burning said low-BTU natural gas and generating therefrom electrical energy.

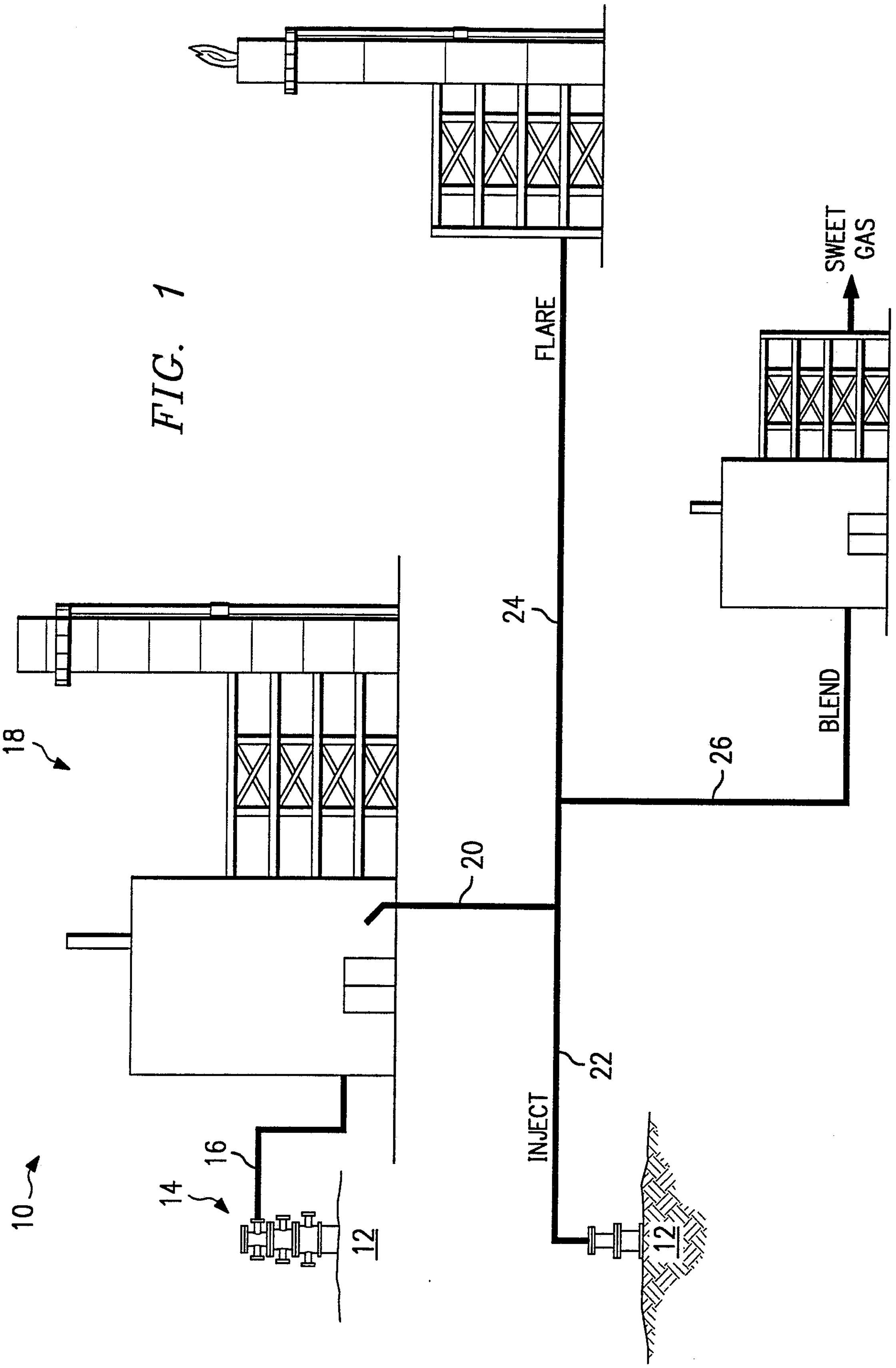

FIG. 1

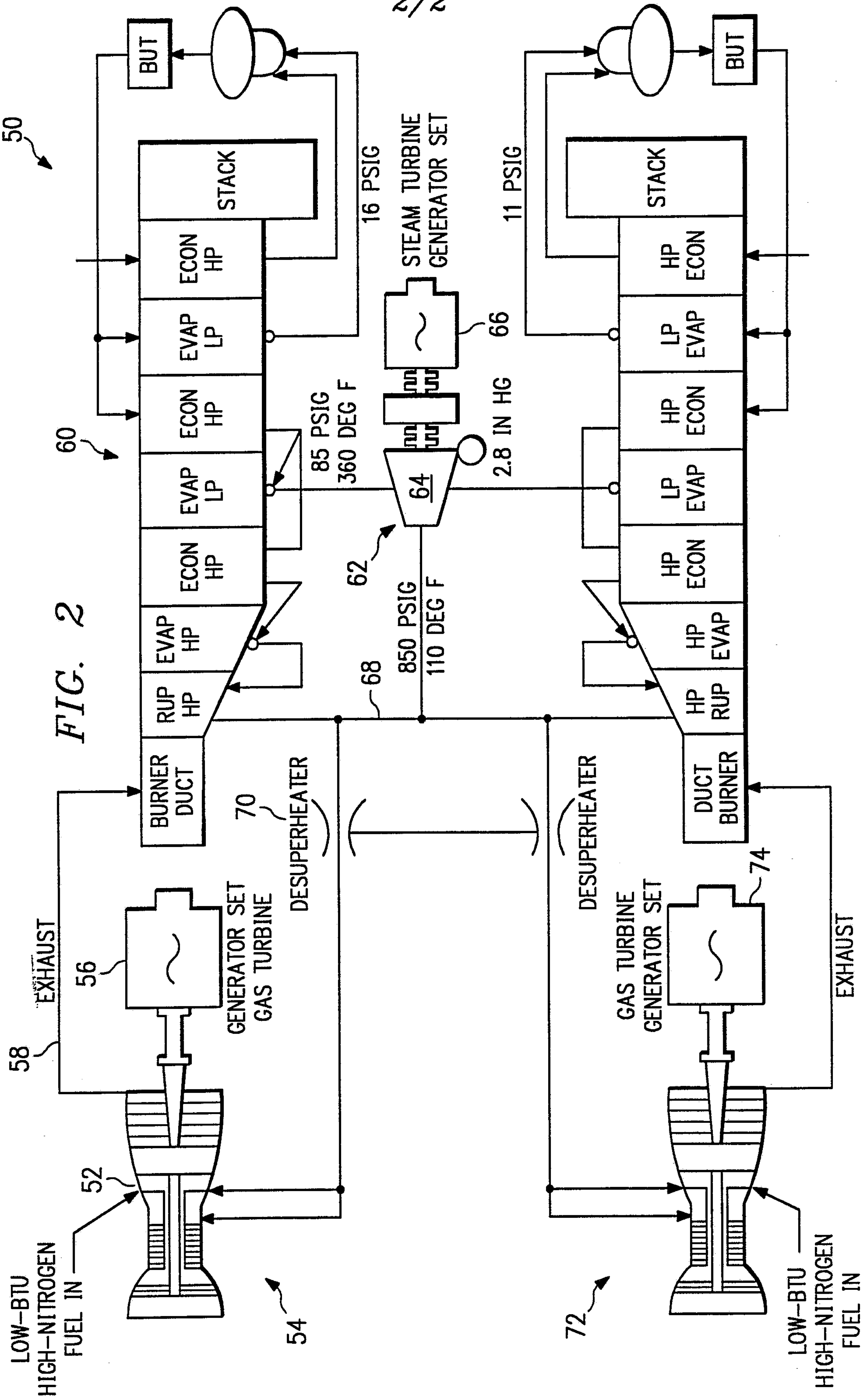

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FIG. 2

INTERNATIONAL SEARCH REPORT

PCT/US92/11364

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :F02G 3/00; F02C 3/22
US CL :60/39.02,39.05,39.465,39.55,204,48/127.3,127.5,197/FM
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P	US,AZ, 5,092,121 (AHNER ET AL) 03 MARCH 1992 (See entire document)	1-12
Y	US,A, 5,055,030 (SCHIMER) 08 OCTOBER 1991 (See entire document)	1-12
A	US,A, 4,890,453 (IWAI ET AL) 02 JANUARY 1990 (See entire document)	1-12
Y	US,A, 4,765,132 (AHNER ET AL) 23 AUGUST 1988 (See entire document	1-12
A	US,A 4,305,733 (SCHOLZ ET AL) 15 DECEMBER 1981 (SEE ENTIRE DOCUMENT)	1-12

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

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Date of the actual completion of the international search	Date of mailing of the international search report
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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US,A 4,285,917 (KNIGHT) 25 AUGUST 1981 (SEE ENTIRE DOCUMENT)	1-12
Y	US,A 4,202,168 (ACHESON ET AL) 13 MAY 1980 (SEE ENTIRE DOCUMENT)	1-12
Y	US,A 4,098,339 (WEISZ ET AL) 04 JULY 1978 (SEE ENTIRE DOCUMENT)	1-12
Y	GAS ENGINEER'S HANDBOOK, 1934, PAGES 168-169	1-12
Y	CHEMICAL PROCESS INDUSTRIES, 1945, R. NORRIS SHREVE, PAGES 83-89.	1-12