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(54) KOH FLUE GAS RECIRCULATION POWER PLANT WITH WASTE HEAT AND BYPRODUCT RECOVERY

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(57) **ABSTRACT**

The invention relates to an integrated power plant, which burns fuel using an oxygen-enriched stream in a combustion furnace and converts emissions of air pollutants and carbon dioxide into byproducts. The combustion flue gas stream, after leaving an economizer of a steam generation system, splits into stream A and stream B. Stream A recirculates back to the combustion furnace through the first flue gas recirculation fan for combustion temperature control. Stream B, after passing through a dust collector for fly ash removal, a series of condensers for byproduct recovery, and the second flue gas recirculation fan, mixes with an oxygen-enriched stream from an air separation unit and flows back to the combustion furnace. The plant does not need an exhaust stack and does not discharge combustion flue gases into the atmosphere.

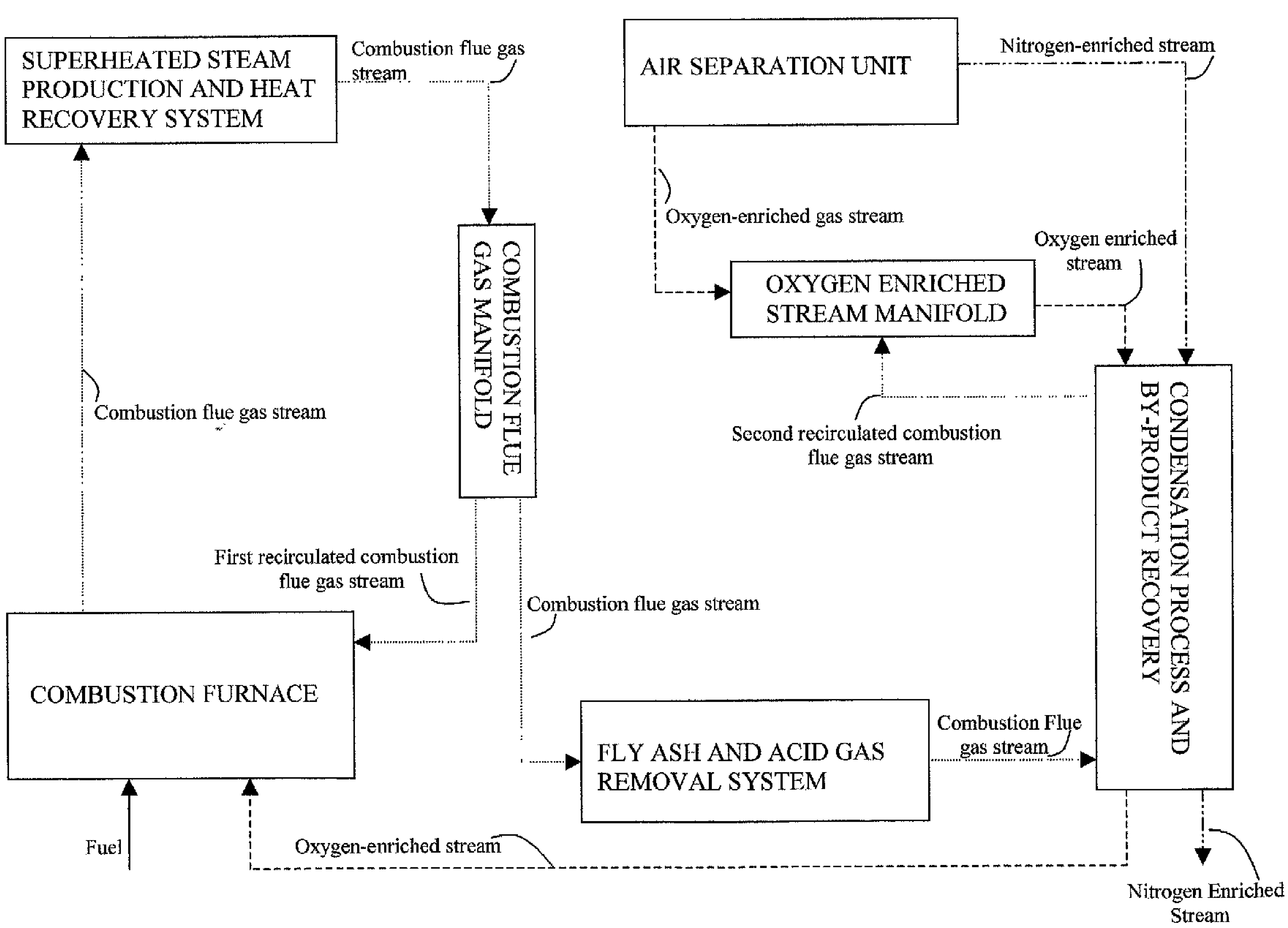
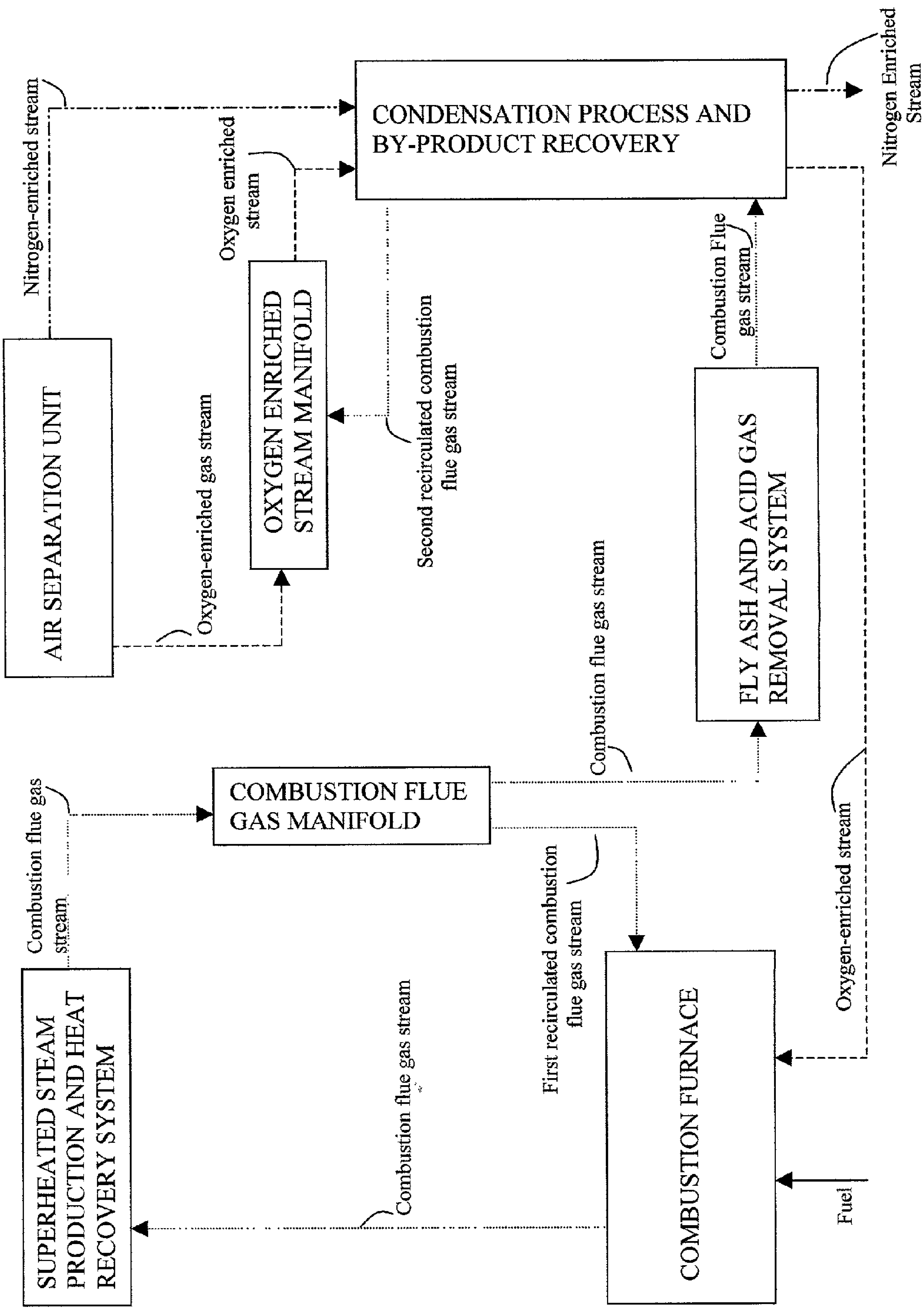


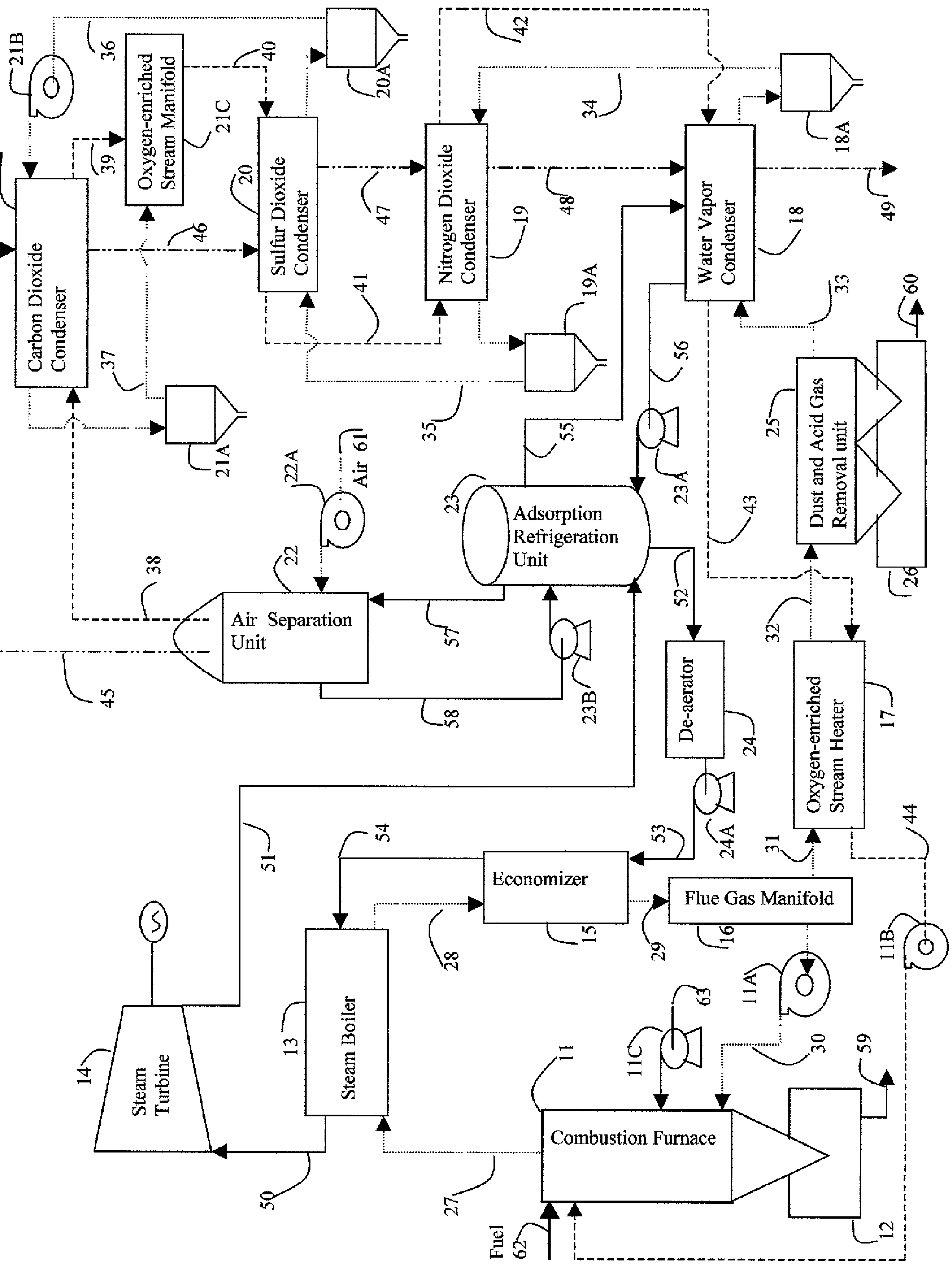
FIG. 1


AIR SEPARATION UNIT
Nitrogen-enriched stream
Oxygen-enriched gas stream
OXYGEN ENRICHED STREAM MANIFOLD
Oxygen enriched stream
CONDENSATION PROCESS AND BY-PRODUCT RECOVERY
Nitrogen Enriched Stream
Second recirculated combustion flue gas stream
Combustion Flue gas stream
FLY ASH AND ACID GAS REMOVAL SYSTEM
Combustion flue gas stream
Combustion flue gas stream
COMBUSTION FLUE GAS MANIFOLD
First recirculated combustion flue gas stream
Oxygen-enriched stream
SUPERHEATED STEAM PRODUCTION AND HEAT RECOVERY SYSTEM
Combustion flue gas stream
COMBUSTION FURNACE
Fuel

Coal Component	Pounds per Pound of Coal	Combustion Product	Pounds per Pound of Coal	Boiling Point at 1 atm, degree.F	Melting Point at 1 atm, degree.F	Heat of Vaporization, Btu/lb
Moisture	0.025	Water	0.025	212	32	972.9
Carbon	0.75	Carbon Dioxide	2.75	-109.3 (sublimation)	-71.5 at 5.2 atm	246.68 (sublimation)
Hydrogen	0.05	Water	0.45	212	32	972.9
Sulfur	0.023	Sulfur Dioxide	0.046	14	-98.86	167.6
Nitrogen	0.015	Nitrogen Dioxide	0.0493	70.16	11.84	134.74
Oxygen	0.067	Oxygen	Insignificant	-297.33	-362.12	91.63
Ash	0.07					
Heating value, Btu/lb	13,000					
		Nitric Oxide	Insignificant	-241.24	-262.48	198.42
		Carbon Monoxide	Insignificant	-326.2	-344.7.0	92.83
		Ammonia	Insignificant	-28.0	-107.9	590.93
		Methane	Insignificant	-263.20	-295.6	219.36
		Nitrogen	Insignificant	-320.44	-345.75	85.89

FIG. 2

FIG. 3


Carbon Dioxide Condenser
Oxygen-enriched Stream Manifold
Sulfur Dioxide Condenser
Nitrogen Dioxide Condenser
Water Vapor Condenser
Dust and Acid Gas Removal unit
Adsorption Refrigeration Unit
Air Separation Unit
Air 61
De-aerator
Oxygen-enriched Stream Heater
Economizer
Flue Gas Manifold
Steam Boiler
Steam Turbine
Combustion Furnace
Fuel 62
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11A
11B
11C
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18A
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19A
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KOH FLUE GAS RECIRCULATION POWER PLANT WITH WASTE HEAT AND BYPRODUCT RECOVERY

CROSS-REFERENCES

U.S. Paten Documents

[0001]

5,906,806	May 1999	Clark	60/649
5,937,652	August 1999	Abdelmalek	60/648
6,047,547	April 2000	Heaf	60/618
6,116,169	September 2000	Miyoshi, et al	110/216
6,196,000	March 2001	Fassbender	60/649
6,282,901	September 2001	Marin, et al.	60/649

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] The invention relates to a process for power generation, which is both environmentally sound and cost-effective. More specifically, the invention relates to a process of burning any combustible material for efficient power generation, elimination of air pollutants and carbon dioxide emissions, and recovery of liquid nitrogen dioxide, liquid sulfur dioxide, and liquid carbon dioxide.

[0004] 2. Description of the Prior Art

[0005] A conventional power plant consisting of a combustion furnace, a steam boiler, steam turbines, and a dust collector has been implemented for power generation and steam production for several decades. Conventional power plants, particularly for coal-fired plants, emit a huge amount of nitrogen oxides, sulfur dioxide, carbon monoxide, particulate matters, heavy metals, and incomplete combustion products. Since air pollution control requirements become more stringent from time to time, power plants must be equipped with more sophisticated and expensive pollution control systems to meet regulatory emission limits. For sulfur oxides emission control, a flue gas desulfurization system or a fluidized bed combustion furnace is widely used. For nitrogen oxides emission control, power plants have implemented a combustion flue gas recirculation for staged combustion with steam or water injection, low NOx burners, selective catalytic reduction systems, non-selective catalytic systems, or any combination thereof to meet the emission limits.

[0006] Since the 1980's, the integrated gasification combined cycle (IGCC) concept has been explored extensively. IGCC uses an oxygen stream for coal gasification and produces a gaseous stream consisting of methane, hydrogen sulfide, carbon monoxide, ammonia, etc. The gaseous stream passes through a sulfur removal system such as a Claus plant before burning in a gas turbine. In addition to requiring an expensive sulfur removal system, an IGCC plant must implement a nitrogen oxides removal system in order to meet regulatory requirements.

[0007] Since the Kyoto Accord for reduction of carbon dioxide, which is a greenhouse gas that causes global warming and associated climatic changes, coal-fired power plants have been extensively scrutinized. Although a coal-fired power plant is still the most cost-effective in power generation, its carbon dioxide emission is more than two times that of a natural gas fired plant. An MEA scrubbing system using monoethanolamine as absorbing agent has been implemented to recover carbon dioxide from combustion flue gases, but it is still not cost-effective. To enhance carbon dioxide recovery, oxygen is increasingly proposed as a replacement of air in fuel burning to reduce the volume of combustion flue gases and to increase the concentration of carbon dioxide in combustion flue gases.

[0008] U.S. Pat. No. 5,906,806 issued to Clark proposes to burn fuel using oxygen, water, and a recirculated combustion stream from a baghouse in two combustion furnaces. For additional air pollution control, Clark's proposal requires several expensive control systems, which include an electron beam reactor, an ozone oxidation chamber, and an electrostatic precipitator with catalytic reactor. In addition, the combustion product discharged to the atmosphere still contains some incomplete combustion products and nitrogen related products and excess oxygen discharged with combustion flue gases reduce utilization of oxygen generated by an air separation unit.

[0009] U.S. Pat. No. 6,196,000 issued to Fassbender proposes to burn fuel using oxygen and liquid carbon dioxide recovered from combustion process. For enhancing thermodynamic efficiency and carbon dioxide recovery, Fassbender proposes to operate an elevated pressure power plant. All operating units including a reaction chamber, a combustion chamber, a catalyst chamber, a hydrocone, heat exchanges, and condensers are under extremely high pressure, ranging from 300 to 500 psia. A pressurized vessel requires additional power to operate and become a safety concern. In addition, the pressurized power plant still vents to the atmosphere a combustion flue gas stream containing some air pollutants and oxygen.

BRIEF SUMMARY OF THE INVENTION

[0010] The invention is an integrated combustion process for efficient power generation, recovery of waste heat and byproduct, and elimination of air pollution. A combustion furnace, air separation units, a steam boiler with an economizer, a dust and acid gas removal system, several condensers, and adsorption refrigeration units are integrated with two combustion flue gas recirculation loops to enhance steam product and to prevent combustion flue gases from being discharged into the atmosphere.

[0011] When oxygen is used instead of air for fuel combustion, the temperature of combustion products is extremely high. For combustion temperature control, the first combustion flue gas recirculation loop is implemented to recirculate part of the combustion gas stream from the economizer to the combustion furnace. How much of the combustion flue gas stream from the economizer to be recirculated back to the combustion furnace greatly depends on the chemical composition and heat content of fuel.

[0012] The combustion flue gas stream from the economizer, which is not recirculated back to the combustion furnace, passes through an oxygen-enriched stream heater for additional waste heat recovery, a fly ash and acid gas removal system, and several byproduct condensation units. After leaving the carbon dioxide condenser, it mixes with an oxygen-enriched stream from the air separation unit and flows back to the combustion furnace. The purpose of the second combustion flue gas recirculation loop is to eliminate any incomplete combustion products in the combustion furnace and reuse oxygen present in the combustion flue gas stream. Therefore, a combustion process designed according to the invention does not discharge combustion flue gases and air pollutants to the atmosphere. The nitrogen-enriched stream from the air separation unit is used in the condensers for byproduct recovery.

[**0013**] Adsorption refrigeration units are integrated with the process to recover and convert waste steam from steam turbines to cooling. Cooling generated by adsorption refrigeration units is used for enhancing condensing processes as well as providing extra cooling for industrial, commercial, or residential uses.

BRIEF DESCRIPTION OF THE DRAWINGS

[**0014**] The integrated nature of the present invention's steps is better understood by reviewing the detailed description of the invention in conjunction with the accompanying drawings, in which:

[**0015**] **FIG. 1** is a block flow diagram of the present invention showing relationship between each combustion flue gas stream, oxygen-enriched stream, and nitrogen-enriched stream;

[**0016**] **FIG. 2** is a table listing coal chemical composition, combustion products, boiling and melting temperatures, and heat of vaporization; and

[**0017**] **FIG. 3** is a schematic representation of an integrated power plant incorporating the present invention to achieve no discharge of combustion flue gas and air pollutants.

DETAILED DESCRIPTION OF THE INVENTION

[**0018**] **FIG. 1** shows the objects of the present invention that is a process for combustion fuel or any combustible material with an oxygen-enriched stream for power generation without any discharge of combustion flue gas and air pollutants to the atmosphere. **FIG. 2** graphically depicts the relationship among various unit operations and various streams.

[**0019**] The heat content with chemical composition of fuel determines theoretical oxygen requirement. One pound of coal with heat content and chemical composition shown in **FIG. 2** needs about 2.4 pounds of oxygen compared to 4.0 pounds of oxygen needed for one pound of methane. During a startup mode, when fuel stream **62** burns with oxygen-enriched stream **44** in combustion furnace **11**, liquid carbon dioxide stream or water stream **63** is injected into combustion furnace **11** for combustion temperature control until the process reaches a normal mode of operation.

[**0020**] To maintain the combustion temperature between 2000 and 2500.degree.F. inside a refractory-wall combustion furnace, one pound of coal, with heat content and chemical composition shown in **FIG. 2**, requires between 8 and 12 pounds of liquid carbon dioxide or between 4 and 5 pounds of water. For one pound of methane, it needs between 18 and 24 pounds of liquid carbon dioxide or between 7.5 and 9.5 pounds of water. For a water-wall combustion furnace, it needs a less amount of liquid carbon dioxide or water for combustion temperature control because water flowing through water-wall tubes reduces combustion temperature. Combustion furnace **11** is a combustion device commonly known by those of ordinary skill in the art. Bottom ash from combustion chamber **11** drops into bottom ash collection tank **12**, which is equipped with water seals to prevent air from entering combustion chamber **11**. Sludge steam **59** is drawn from bottom ash collection tank **12** to an ash management and disposal system

[**0021**] Combustion flue gas stream **27** with a temperature between 2000 and 2500.degree.F. from combustion furnace **11** enters steam boiler **13** to convert water/steam stream **54** from economizer **15** to superheated steam **50** used in steam turbine **14** for electricity generation. Combustion flue gas stream **28** with a temperature between 800 and 1000.degree.F from steam boiler **13** enters economizer **15** to preheat water/steam stream **53** from de-aerator **24**. Combustion flue gas stream **29** with a temperature between 600 and 800.degree.F from economizer **15** enters flue gas manifold **16**, where it splits into combustion flue gas stream **30** and combustion flue gas stream **31**. Steam boiler **13** and economizer **15** are indirect heat exchanges commonly known by those of ordinary skill in the art.

[**0022**] Combustion flue gas stream **30** is recirculated back to combustion furnace **11**, through flue gas recirculation pump 11A, for combustion temperature control. Combustion flue gas stream **31** enters oxygen-enriched stream heater **17**. The ratio of combustion flue gas stream **30** to combustion flue gas stream **31** depends on fuel involved in combustion. When the process reaches its normal mode of operation, the ratio for coal discussed in **FIG. 2** is between 4 and 7 compared to a ratio between 5 and 8.5 for methane. The ratio of combustion flue gas stream **30** to combustion flue gas stream **31** is significantly lower for a water-wall combustion furnace.

[**0023**] In a normal operation mode, the volume of combustion flue gas stream **31** is less than 30 percent of that generated by a conventional power plant using air stream for combustion. Oxygen-enriched stream heater **17** is an indirect heat exchanger, which is commonly known by those of ordinary skill in the art. Inside oxygen-enriched stream heater **17**, combustion flue gas stream **31** preheats oxygen-enriched stream **43** from water vapor condenser **18**.

[**0024**] Combustion flue gas stream **32** with a temperature between 250 and 450.degree.F enters dust and acid gas removal unit **25** for fly ash and acid gas removal. Dust and acid gas removal unit **25** is a baghouse, a dry or wet cyclone, a dry or wet multiple-cyclone collector, a venturi scrubber, a packed bed absorber, an electrostatic precipitator, or any combination of thereof, which is commonly known by those of ordinary skill in the art. Dust and acid gas removal unit **25** is equipped with water seals to prevent air from entering combustion flue gas streams. For fuel containing chloride and other halogen, a multiple-cyclone collector with a packed bed absorber is preferably selected to remove fly ash, hydrogen chloride, sulfuric acid, and other hydrogen halides. If a baghouse is preferably implemented, carbon dioxide is used instead of air for bag cleaning to prevent air from entering combustion flue gas streams **32** and **33**. Fly ash and other acidic material collected by dust and acid gas removal unit **25** drop into fly ash collection tank **26** and sludge stream **60** is discharged to an ash management and disposal system.

[**0025**] Combustion flue gas stream **33** from dust and acid gas removal unit **25** enters water vapor condenser **18** for removal of water vapor, remaining fly ash, and any condensable material found in combustion flue gas stream **33**. Water vapor condenser **21** is an indirect heat exchanger, which is commonly known by those of ordinary skill in the art. Water collected from water vapor condenser **18** is preferably used for fly ash and bottom ash collection tanks. Inside water vapor condenser **18**, oxygen-enriched stream **42** from nitrogen dioxide condenser **19** serves as a main cooling stream. Nitrogen-enriched stream **48** from nitrogen dioxide condenser **19** as well as coolant stream **55** from adsorption refrigeration unit **23** is arranged in the process to provide sufficient cooling for water vapor condenser **18**.

[**0026**] Combustion flue gas stream **34** with a temperature between 90 and 180.degree.F. from water collection tank **18**A, which is connected to vapor condenser **18**, enters nitrogen dioxide condenser **19** for removal of nitrogen dioxide and any condensable material found in combustion flue gas stream **34**. Nitrogen dioxide condenser **21** is an indirect heat exchanger, which is commonly known by those of ordinary skill in the art. Inside nitrogen dioxide condenser **19**, oxygen-enriched stream **41** from sulfur dioxide condenser **20** serves as a main cooling stream. Nitrogen-enriched stream **47** from sulfur dioxide condenser **20** is arranged to provide sufficient cooling for nitrogen dioxide condenser **19**. Liquid nitrogen dioxide is a process byproduct, which could be used for production of nitric acid, nitrating or oxidizing agent, catalyst, rocket fuels, or polymerization inhibitor for acrylates.

[**0027**] Combustion flue gas stream **35** with a temperature between 20 and 60.degree.F. from liquid nitrogen dioxide collection tank **19**A, which is connected to nitrogen dioxide condenser **19**, enters sulfur dioxide condenser **20** for removal of sulfur dioxide and any condensable material found in combustion flue gas stream **35**. Sulfur dioxide condenser **20** is an indirect heat exchanger, which is commonly known by those of ordinary skill in the art. Inside sulfur dioxide condenser **20**, oxygen-enriched stream **40** from oxygen-enriched stream manifold **21**C serves as a main cooling stream. Nitrogen-enriched stream **46** from carbon dioxide condenser **21** is arranged to provide sufficient cooling for sulfur dioxide condenser **20**. Liquid sulfur dioxide is a process byproduct, which could be used for production of sulfuric acid, sulfite paper pulp, sulfonation of oil, antioxidant, reducing agent, and many other uses.

[**0028**] After leaving liquid sulfur dioxide collection tank **20**A, which is connected to sulfur dioxide condenser **20**, combustion flue gas stream **36** with a temperature between −60 and 10.degree.F. is pressurized by flue gas recirculation fan **211**B to a pressure above **77** psia and enters carbon dioxide condenser **21** for removal of carbon dioxide and any condensable material found in combustion flue gas stream **36**. Carbon dioxide condenser **21** is an indirect heat exchanger, which is commonly known by those of ordinary skill in the art. Inside carbon dioxide condenser **21**, both oxygen-enriched stream **38** and nitrogen-enriched stream **45** from air separation unit **22** serve as cooling streams. Liquid carbon dioxide is a major process byproduct, which could be used for refrigeration, carbonated beverages, aerosal propellant, fire extinguishing, fracturing and acidizing of oil wells, and many other uses.

[**0029**] After liquid carbon dioxide being removed, combustion flue gas stream **37** from liquid carbon dioxide collection tank **21**A, which is connected to carbon dioxide condenser **21**, is a small stream containing a small amount of carbon dioxide, carbon monoxide, nitric oxide, methane, ammonia, and oxygen. It enters oxygen-enriched stream manifold **21**C and combines with oxygen-enriched stream **39** from carbon dioxide condenser **21**. The purpose of this (second) combustion flue gas recirculation loop is to eliminate the discharge of combustion flue gases and air pollution into the atmosphere and fully utilize oxygen produced by air separation unit **22**. The combined stream, oxygen-enriched stream **40**, passes through sulfur dioxide condenser **20**, nitrogen dioxide condenser **19**, water vapor condenser **18**, and oxygen-enriched stream heater **17**. Then, it enters combustion furnace through forced draft fan **11**B to begin another combustion cycle.

[**0030**] Preferably, this invention incorporates adsorption refrigeration unit **23**, which is commonly known by those of ordinary skill in the art, to recover waste steam stream **51** from steam turbine **14** for cooling, which is used for water vapor condenser **18**, air separation unit **22**, and other industrial, commercial, or residential use. For reducing energy consumption by air separation unit **22** in air separation process, coolant streams **57** and **58** are circulated between adsorption refrigeration unit **23** and air separation unit **22**. To provide sufficient cooling for water vapor condenser **18**, coolant streams **55** and **56** are circulated between adsorption refrigeration unit **23** and water vapor condenser **18**.

I claim:

1. A process of a KOH flue gas recirculation power plant, wherein the process uses at least one air separation unit, two flue gas recirculation loops, at least one adsorption refrigeration unit, and condensers for combustion temperature control, waste heat recovery, elimination of air pollutants, and production of liquid sulfur dioxide, liquid nitrogen dioxide, and liquid carbon dioxide.

2. The process of claim 1, wherein the process comprising the steps of:

(a) an air separation unit to separate air into an oxygen-enriched stream and a nitrogen-enriched stream;

(b) a combustion furnace to burn fuel with an oxygen-enriched stream and a recirculated combustion flue gas stream;

(c) a fuel loading system with a carbon dioxide blanketing system to prevent air from entering combustion chamber with fuel;

(d) a bottom ash collection and management system with water seals to remove bottom ash from the combustion furnace and to prevent air from entering the combustion furnace;

(e) a steam and electricity generation system including a steam boiler equipped with a superheater and a reheater, an economizer, steam turbines, and a waste steam collection and recovery unit;

(f) a flue gas manifold to receive the combustion flue gas stream from the economizer and to split the combustion flue gas stream into stream A and B;

(g) one (first) flue gas recirculation fan to recirculate combustion flue gas stream A back to the combustion furnace for combustion temperature control.

(h) an oxygen-enriched stream heater to transfer thermal energy of combustion flue gas stream B to an oxygen-enriched stream;

(i) a dust and acid gas removal system with water seals to remove suspended particulate matters and acid gases such as sulfur trioxide and hydrogen chloride found in combustion flue gas stream B from the oxygen-enriched stream heater and to prevent air from mixing with combustion flue gas stream B;

(j) a water vapor condenser to liquefy water vapor and any condensable materials found in combustion flue gas stream B from the dust and acid gas removal system;

(k) a nitrogen dioxide condenser to liquefy nitrogen dioxide and any condensable materials found in combustion flue gas stream B from the water vapor condenser;

(l) a sulfur dioxide condenser to liquefy sulfur dioxide and any condensable materials found in combustion flue gas stream B from the nitrogen dioxide condenser;

(m) a carbon dioxide condenser to liquefy carbon dioxide and any condensable materials found in combustion flue gas stream B from the sulfur dioxide condenser;

(n) another (second) flue gas recirculation fan to mix combustion flue gas stream B from the carbon dioxide condenser with the oxygen-enriched stream from the air separation unit in an oxygen-enriched stream manifold;

(o) a waste steam recovery system including at least an adsorption refrigeration unit to collect waste steam from steam turbines for heating and cooling.

3. The process of claim 2, wherein a liquid carbon dioxide or water feed pump is used to inject liquid carbon dioxide or water into the combustion furnace for combustion temperature control during the plant's start-up mode or any emergency situation.

4. The process of claim 2, wherein said combustion furnace includes a water-wall combustion furnace, a refractory-wall combustion furnace, or any conventional combustion furnace.

5. The process of claim 2 wherein said fuel includes solid fuel, liquid fuel, gaseous fuel, or any combination thereof.

6. The process of claim 4, wherein said solid fuel includes coal, wood, refuse derived fuel, any combustible solid waste including hazardous waste, or any combination thereof.

7. The process of claim 4, wherein said liquid fuel includes distillate fuel oil, residual fuel oil, gasoline, any combustible liquid waste including hazardous waste, or any combination thereof.

8. The process of claim 4, wherein said gaseous fuel includes natural gas, propane gas, landfill gas, any combustible gaseous waste including hazardous waste, or any combination thereof.

9. The process of claim 2, wherein said air separation unit, water condenser, nitrogen dioxide condenser, sulfur dioxide condenser, carbon dioxide condenser, and adsorption refrigeration unit are integrated cooperatively to optimize heating, cooling and condensation.

10. The process of claim 2, wherein said dust and acid gas removal system includes a wet cyclone or multiple-cyclone collector, a dry cyclone or multiple-cyclone collector, a packed bed absorber, a venturi scrubber, a baghouse, an electrostatic precipitator, or any combination thereof.

11. The process of claim 9, wherein said baghouse is equipped with a carbon dioxide injection system instead of a conventional air injection system for bag filter cleaning and preventing air from entering the combustion flue gas stream.

* * * * *