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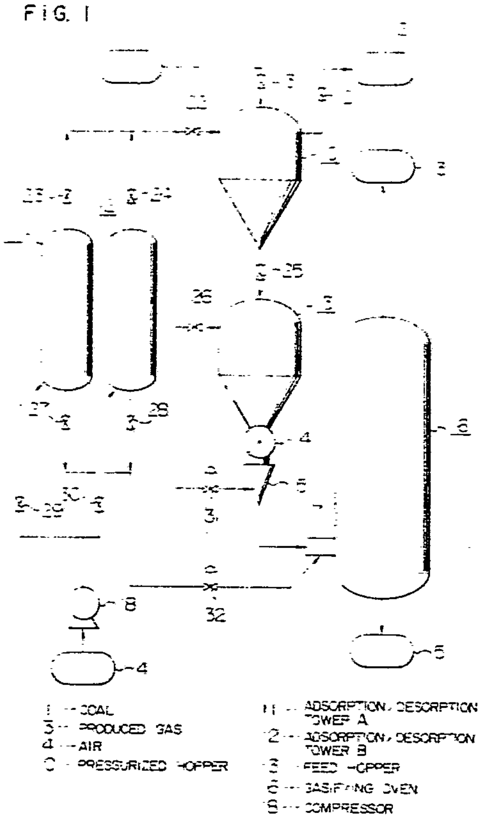
(54) Coal gasification process and apparatus therefor.

(57) The invention provides a coal gasification process and apparatus therefor in which coal (1) or other hydrocarbon is carried by a gas produced by an air separating apparatus, supplied into a coal gasifying oven (16) along with a gasifying agent also produced by the air separating apparatus and reacted at a high temperature and under a high pressure to produce a combustible gas (3). According to this invention, since both

gasifying agent and coal carrier gas used for coal gasification can be produced at the same time from air (4) without using much energy for the production, the equipments necessary for the gasification can be noticeably reduced in size and also the cost of producing electricity by coal gas power generation can be reduced.

FIG. 1



COAL GASIFICATION PROCESS AND APPARATUS THEREFOR

DETAILED DESCRIPTION OF THE INVENTION

FIELD OF INDUSTRIAL UTILIZATION

This invention relates to a coal gasifier. More particularly, it relates to a coal gasification process and apparatuses therefor in which coal or other hydrocarbons carried with a gas generated by an air separating apparatus is supplied into a coal gasifying oven together with a gasifying agent also generated by said air separating apparatus and they are reacted under a high temperature and high pressure to produce a combustible gas.

PRIOR ART

Coal is a useful energy source with abundant reserves, but as it is solid and contains a high percentage of ash, its fields of use are limited in comparison with petroleum and natural gas. However, if coal is converted into gas or liquid, its fields of use will expand greatly and it will become a very useful energy source. In view of such potentialities of coal, the researchers in many countries have made efforts for the development of coal fluidization techniques.

Under these circumstances, intense studies have been made especially on coal gasifier as an elemental unit of the coal gasification combined power generation system which is highlighted as the power generating method of the next generation.

For gasification of coal, coal is broken into fine pieces and supplied into a high-temperature gasification oven together with an oxidizing agent. In the high-temperature oven, coal is reacted to cause a gasification reaction such as partial oxidation, thereby producing a combustible gas mainly composed of carbon monoxide and hydrogen.

In the coal gasification combined power generation system, sensible heat of high-temperature combustible gas produced in said coal gasification oven is recovered and utilized to form steam whereby to drive the steam turbines while simultaneously driving the gas turbines with the combustible gas. This system can improve the power generating efficiency by several % over the conventional systems using the steam turbines alone. In order to comply with the voluminous demand for coal gas in such complex power generation, efforts are being made for the enlargement of capacity and higher efficiency of the coal gasifier.

In case coal gasification is conducted for the purpose of power generation, there are available roughly two types of gasification process: oxygen gasification where oxygen is used as oxidizing agent and air gasification where air is used as oxidizing agent. A comparison of gasification efficiency, oxidizing agent production cost and power generation cost between these two types of gasification method is shown in Table 1.

Table 1

Gasifying agent	Gasification efficiency	Oxidizing agent production cost	Power generation cost
Oxygen	Good	High	High
Air	Bad	None	Low

In the case of oxygen gasification, the gasification oven efficiency is good since the oxidizing agent is entirely reacted. However, the production cost of oxygen adds to the power generation cost. On the other hand, in the case of air gasification, the gasification oven efficiency is low because of supply of non-reactive air as oxidizing agent, but the power generation cost is reduced as no oxygen production cost is required. Use of the so-called PSA (Pressure Swing Adsorption) system in place of the conventional low-temperature method for the production of oxygen, which makes it possible to obtain a higher gasification efficiency at a lower oxidizing agent production cost, will enable a further reduction of power generation cost in comparison with the system in which coal is gasified with air alone.

Coal gasification does not require oxygen of extremely high purity. The internal temperature of the oven rises when using an oxygen-enriched air which would be only slightly higher in oxygen concentration than the air. Therefore, in the case of gasification in entrained state for instance, the ash produced coal in the oven can be easily melted, so that there is no need of effecting rise of temperature by unduly promoting the combustion reaction, and accordingly the gasification efficiency increases. Also, since the partial pressure of oxygen rises, the reaction is promoted to enhance the gasification efficiency. An application of PSA to the production of oxygen-enriched air by making use of said principle is disclosed in Japanese Patent Application Kokai (Laid-Open) No. 50298/76.

PROBLEMS TO BE SOLVED BY THE INVENTION

Adaptation of PSA to the formation of oxidizing agent in the coal gasification oven, however, had various problems.

Firstly, use of nitrogen of extremely high purity is required for the safe carriage of coal into the gasification oven. This is necessary for precluding the danger of dust explosion of coal which might occur when oxygen is contained in the gas used for supplying coal into the oven. Generally, locked hopper system is used for supplying powder into high-pressure oven but in this system, since powder is mixed with pressured gas, there is a danger of dust explosion of coal when oxygen is contained in the gas.

In the conventional low-temperature method, nitrogen is produced along with oxygen, so that this nitrogen can be utilized as coal carrier gas. In the PSA method, however, the gas discharged on generation of oxygen, although high in nitrogen concentration as compared with air, is also high in oxygen concentration and can not be used as carrier gas. Accordingly, it is necessary to introduce nitrogen for carrying coal from a different plant or to build up a nitrogen producing plant beside the plant for producing the oxidizing agent. Naturally, this elevates the whole plant cost, resulting in a substantial rise of power generating cost.

Another problem is that the increase of capacity necessitates the excess enlargement of the installation. PSA system has been operated at around normal pressure from the concept of this technique to make normal-pressure products. Therefore, the treating tower must be enlarged excessively for treating a large volume of gas. Generally, enlargement of gasifier capacity leads to a rise of operating pressure, but in the case of PSA, even if the operating pressure is raised, a large volume of gas must be discharged eventually, hence the working efficiency lowers. Therefore, for producing the oxidizing agent necessary for the conventional gasifier by using PSA techniques, there is required a site which is 30 times the space for the gasifier. A system in which desorption is conducted in two stages for the enlargement of capacity is disclosed in Japanese Patent Application Kokai (Laid-Open) No. 80682/76, but no proposal has ever been made for attaining such an enlargement of capacity as appliable to gasifier.

The present invention was achieved as a result of studies on PSA from its basic principle for solving said problems.

This invention relates to an application of PSA for coal gasification which makes it possible to produce gas of materials such as oxidizing agent used for a large volume of coal gasification with a very small apparatus, and a coal gasifier making use of said PSA which enables a phenomeral improvement of working efficiency of the whole system.

MEANS FOR SOLVING THE PROBLEMS

Said problems of the prior art can be solved by applying the coal gasification system of this invention in which high-purity nitrogen gas is used for the carriage of coal and for pressurization of the coal-packed hoppers, and oxygen-enriched air is used as coal gasifying agent. According to this system, there is used a plural number of towers packed with an adsorbent having greater equilibrium adsorption of oxygen than that of nitrogen under the same pressure and at the same temperature, and air pressurized enough to be able to effect coal carriage and pressurization of coal-packed hoppers is passed into said towers to generate high-concentration nitrogen gas, and before the equilibrium adsorption of oxygen is reached, the pressure of air passing through said towers is reduced to a level which enables sufficient supply of the gasifying agent into the gasification oven, causing desorption of oxygen adsorbed on the adsorbent to form oxygen-enriched air, said operations being repeated by staggering the time of operation for each tower to thereby produce high-concentration nitrogen gas and oxygen-enriched air continuously, said high-concentration nitrogen gas being used for carriage of coal and for pressurization of the coal-packed hopper while said oxygen-enriched air being used as coal gasifying agent.

According to the method of this invention, because of use of pressurized air for generating high-concentration nitrogen gas, it is possible to form a large volume of gas with the towers of a small capacity, and the oxygen adsorbed on the adsorbent is desorbed under a pressure lower than said air pressure for the regeneration of towers while the produced oxygen-enriched air is used as gasifying agent, so that the system suffers from no loss and its working efficiency can be improved.

Examples

Before describing the details of the present invention, the basic concepts of PSA and coal gasifier are explained below.

Referring to Fig. 2, there is shown a simple flow chart of a coal gasifier. The gases necessary for the coal gasifier are shown in Table 2.

Table 2

	(1) Oxydizing agent for coal gasification	(2) Gas for carriage for coal
Oxygen concentration (%)	25 or above	5 or below
$\frac{\text{Necessary amount of gas}}{\text{coal feed}}$ $\left(\frac{kg}{kg}\right)$	4.0	1.0
Required pressure (ata)	Gasifying oven pressure 30	Oven pressure plus differential pressure for carriage 35

The ratio of oxidizing agent for coal gasification to coal feed is preferably so set that it will give the highest cold gas efficiency. The cold gas efficiency represents the ratio of calorific value of coal supplied to that of the gas produced. Generally, coal gasification basically comprises a partial gasification reaction expressed by the following formula:

$$C_nH_m \text{ (coal)} + \frac{n}{2} O_2 \rightarrow nCO + \frac{m}{2} H_2$$

Here, coal is represented by hydrocarbon, with other components such as ash being excluded for the sake of simplicity. It is seen from the above formula that the calorific value of the produced gas becomes the highest when carbon in coal has been entirely turned into carbon monoxide. Since this reaction is exothermic, it proceeds without heat being applied from the outside. However, in case of carrying out cost gasification by use of air, even if the produced gas has a prescribed level of calorific value, it is weakened by nitrogen, an inert gas, contained in the air, making it unable to raise the internal temperature of the oven, resulting in a lowered gasification reaction rate, hence, a reduced gasification rate. Especially when coal gasification is carried out with air stream, in which case ash in coal is melted out, it is necessary to raise the oven temperature above the melting point of ash, for which the calorific value provided by said partial oxidiation reaction is insufficient. In this case, therefore, usually the amount of oxygen is increased to let a combustion reaction proceed coincidently with the reaction of the above-shown formula.

$$C_nH_m \text{ (coal)} + \left(n + \frac{m}{2}\right)O_2 \longrightarrow nCO_2 + \frac{m}{2} H_2O$$

However, when such combustion reaction is allowed to take place simultaneously with said reaction, the calorific value of the produced gas is reduced to lower the cold gas efficiency. It is therefore suggested to reduce the nitrogen level of inert gas contained in the air by use of oxygen-enriched air to thereby effect rise of temperature. In case of using such oxygen-enriched air, especially in the case of air stream, it suffices to keep the oven temperature above the melting temperature of ash, and the oxygen concentration of said oxygen-enriched air is about 25%.

Regarding the gas used for carrying coal, it is essential that the oxygen concentration thereof is 5% or less in view of the concept of spontaneous ignition. As for the necessary amount of such coal carrier gas, it is most desirable to make nitrogen feed/coal feed = 0.1 for the stable carriage of coal. The pressure necessary for the carriage of coal varies greatly depending on coal feed and volume of carrier gas, but generally a pressure of several atm. is required.

In order to accomplish such coal gasification at high efficiency, we tried to supply the required gases at once with a small-sized PSA system.

Thus, in the present invention, oxygen is adsorbed by utilizing a combined force of oven pressure and differential pressure of carriage to generate high-purity nitrogen and this is used as the gas for carrying coal, while adsorbed oxygen is desorbed by making use of oven pressure to generate oxygen-enriched air which is used as oxidizing agent for coal gasification.

Fig. 3 shows a flow chart of the PSA system. In the PSA system, a gas of the prescribed composition is adsorbed under high pressure and desorbed under low pressure. Therefore, the purge gas of low pressure is too high in concentration of said gas of prescribed composition, while the gas taken out under high pressure is too low in concentration of said prescribed composition gas. So, generally, for separating oxygen and nitrogen in the air, nitrogen is adsorbed by using a zeolite type adsorbent to generate a gas with high oxygen concentration. The oxygen-enriched air produced by such method, however, is unfavorable for use in coal gasification. The gas obtained by the nitrogen adsorption type oxygen-enriched air producing method is shown in Table 3.

Table 3

	(3) Product gas	(4) Waste gas
Oxygen concentration (%)	60 or above	10 or below
$\frac{\text{Amount of produced gas}}{\text{Amount of feedstock gas}}$ $\left(\frac{kg}{kg}\right)$	0.2	0.8
Required pressure (ata)	Pressure required for adsorption 1.5	Pressure required for desorption 0.5

It is seen that the gas produced by PSA is very bad in compatibility as compared with said gas required for gasification. Especially, the product gas is too high in oxygen concentration to use as coal carrier gas. Therefore, for use of such product gas, it must be again introduced into another PSA unit to further elevate the nitrogen concentration. This method is unfavorable as the system is complicated. Also, there exists no other utility which requires gas with oxygen concentration of about 10%.

Even in case the gas is used after again introducing it into another PSA to elevate the nitrogen concentration, since the gas is produced always with a lower pressure than gasifier oven pressure, there arises the necessity of again pressurizing the gas, which leads to a substantial loss of energy.

Further, oxygen-enriched air to be used as gasifying agent, which is essentially required in a great amount, is produced only in a small amount, while nitrogen-enriched gas to be used as coal carrier gas, which is actually needed in a small amount, is produced in bulk.

This is a major reason for the limited capacity of PSA.

Pressurization is a measure for enlarging capacity. In this case, however, since a large volume of gas is wasted, a substantial portion of pressurized energy goes for nothing, resulting in an elevated cost. The conventional system also had the serious defect that the inside pace of the tower is not used effectively because of retention of inutile gas in the tower.

As described above, PSA which has been generally used for the production of concentrated oxygen is very irrational for application to coal gasification.

The present inventors have made a complete about-face in conception and invented PSA with amazingly high adaptability to coal gasification. By using this new type of PSA, a high-efficiency power generation system was deviced.

The gas (1) necessary for coal gasification (Table 2) is oxygen-enriched gas and therefore corresponds to the gas produced by PSA (Table 3), but the former (1) is low in pressure (gasification oven pressure) and required in a large amount, while the latter (3) is just contrary; it is high is pressure and produced only in small quantities. This accounts for the poor adaptability of PSA gas to coal gasification.

The fact that inutile waste gas exists indicates that there exists an idle space in the apparatus due to production of inutile gas. This is a major obstacle to the scale-up of PSA.

The adsorbents currently used for PSA include oxygen adsorbing type beside the above-mentioned nitrogen adsorbing type. Since the nitrogen adsorbing type has the problems such as mentioned above, studies are being made on the application of oxygen adsorbing type to coal gasification.

The presently used oxygen adsorbing type PSA is designed for production of pure nitrogen and very high in efficiency. According to this PSA, oxygen is adsorbed at a very low rate, and after oxygen has been adsorbed sufficiently, nitrogen of high purity is produced. The process thereof is exemplified in Fig. 4. For making the nitrogen concentration of the product gas 99.9% or higher, approximately 20 times as much amount of feedstock gas as the product gas is wasted.

In use of such conventional PSA for gasifier, the waste gas used as oxydizing agent is too low in oxygen concentration and also too short in amount. Also, since adsorption is effected at low rate, the system is necessarily enlarged and can not be applied to gasification where a large volume of gas is required.

As a result of more extensive studies, the present inventors have succeeded in finding a process of and an apparatus for gasifying coal by applying PSA using an oxygen adsorbing type adsorbent, and thus achieved the present invention.

The present inventors have adandoned the idea of having the gas adsorbed with nitrogen and instead tried to have the gas adsorbed with oxygen and use this oxygen-adsorbed gas as coal carrier gas in coal gasification, while also trying use of purge gas as gasifying agent for coal gasification. An outline of this new scheme is shown in Fig. 5.

An agent for effecting selective adsorption of oxygen is disclosed in Japanese Patent Application Kokai (Laid-Open) No. 33979/83. There is also available MSC (molecular sieving carbon) which is subject to wide change in adsorbing rate although having no selectivity. This substance has the nature that its initial adsorbing rate is greatly different between oxygen and nitrogen although the equilibrium adsorption is substantially the same for both oxygen and nitrogen. Therefore, oxygen is adsorbed in a large amount in the initial phase and because of small adsorption of nitrogen, oxygen alone is adsorbed from the gas which has passed the towers to elevate the nitrogen concentration, so that if the desorbing operation is commenced at a time when the adsorption of nitrogen is still small, there is obtained almost the same effect as when oxygen was adsorbed selectively.

An embodiment of this invention will be described below with reference to Fig. 1.

The apparatus is composed of an air separating apparatus, a coal feeding apparatus and a coal gasifying oven.

The air separating apparatus comprises a compressor 18 for supplying air, an adsorption/desorption tower A 11 capable of performing both adsorption and desorption of gas, valves 23, 27 and 29 designed to periodically oven or close the passage of gas from or to said adsorption/desorption tower A 11 to or from other units, another adsorption/desorption tower B 12 having the same function as A 11, and valves 24, 28 and 30. Packed in said towers is an adsorbent which is capable of adsorbing oxygen selectively in bulk or at high speed.

The coal feeding apparatus is composed of a pressurized hopper 10 in which coal 1 is reservoired in a pressurized state, a feed hopper 13 in which coal 1 is pressurized to a level suitable for supply, a metering feeder 14 of coal 1, a mixer 15 for mixing coal 1 and its carrier gas, valves 22, 26 and 21 for further pressurizing coal 1, and an adjuster 31 for controlling the amount of carrier gas supplied.

The coal gasifier over is composed of the oven body and a coal burner 17.

The described embodiment of this invention operates as follows. Air 4 taken in is first cleared of dust as it passed through a filter provided at the inlet of compressor 18 and then pressurized by said compressor 18. The level of pressure to which air is pressurized is so set that it will be higher than the pressure combining the pressure P_1 capable of effecting sufficient supply of carrier gas to the coal feed hopper 13 and ejector 15 and the pressure loss ΔP_P suffered when gas is passed through the adsorption/desorption towers 11, 12 packed with the adsorbent. Pressurized air is supplied into adsorption/desorption towers 11, 12 through valves 29 and 30, respectively. PSA functions to repeat adsorption and desorption according to the change of pressure in said towers 11, 12. The pressures in said towers 11, 12 are decided by the valves 23, 24, 27, 28, 29 and 30. The patterns of opening and closing of the respective valves corresponding to the cycle of operation are shown in Table 4.

Table 4

Cycle	1	2
Valves 23, 29	Open	Closed
Valves 24, 30	Closed	Open
Valve 27	Closed	Open
Valve 27	Open	Closed
Adsorption/ desorption tower A 11	Adsorbing	Desorbing
Pressure	High	Low
Adsorption/ desorption tower B 12	Desorbing	Adsorbing
Pressure	Low	High

The mechanism of adsorption/desorption tower A 11 is first described. When the system is brought into the operating mode of cycle 1, valve 29 is opened to supply pressurized air directly from compressor 18 into adsorption/desorption tower 11, so that the internal pressure of adsorption/desorption tower A 11 is elevated, and accordingly oxygen is selectively adsorbed by the adsorbent packed in the inside of said tower A 11, that is, an adsorbing operation is conducted in said adsorption/desorption tower A 11. Thus, the gas sent from said tower A 11 to the coal feed and carriage system through valve 23 is low in oxygen content, that is, high in nitrogen content, and is therefore suited as a coal carrier gas with no possibility of causing spontaneous ignition of coal.

When the above operation is carried out continuously for a certain period of time, adsorption/desorption tower A 11 becomes unable to perform selective adsorption of oxygen. In this embodiment of the invention, adsorption/desorption tower is packed with MSC, an adsorbent which is capable of adsorbing oxygen selectively at a higher rate than nitrogen. Therefore, it is not that the tower became incapable of further performing oxygen adsorption only because the equilibrium adsorption of the adsorbent has been reached. This reason will be explained with reference to the basic performance curves of MSC shown in Fig. 6. In the graph of Fig. 6, the elapsed time from start of adsorbing operation is plotted as abscissa and the amount of gas adsorbed per 1g of absorbent as ordinate. MSC shows an almost equal equilibrium adsorption for both oxygen and nitrogen, but the initial adsorbing rate differs greatly between oxygen and nitrogen, that is, as seen from the graph, the oxygen adsorbing rate is far higher than the nitrogen adsorbing rate in the initial phase of operation. Thus, at around the point of 1 minute from start of operation, the oxygen adsorption is greater than the nitrogen adsorption, and consequently oxygen is adsorbed selectively. When the gas is kept flowing for more than one minute, nitrogen begins to be adsorbed, too, so that selectivity is lost. Based on these facts, the time of switching from the adsorbing operation to the desorbing operation is decided.

When the selective adsorption of oxygen becomes no longer possible in adsorption/desorption tower A 11, the operating cycle 1 is switched to the cycle 2 where the desorbing operation is conducted in said tower A 11. On proceeding to the cycle 2, the produced gas switchover valve 23 and the valve 29 for supplying air (feedstock gas) into tower A 11 are closed at the same time, while the purge gas switchover valve 27 is opened. As valve 27 is opened, adsorption/desorption tower A 11 is communicated with burner 17 which supplies the gasifying agent into coal gasifying oven 16. Since adsorption/desorption tower A 11 is set to a higher pressure than oven 16, the gas in said tower A 11 flows into oven 16 and the pressure in the tower A 11 begins to lower. The adsorbent in said tower A 11 is adsorbed with a large volume of oxygen by the adsorbing operation under a high pressure. Oxygen adsorbed by the adsorbent in said tower A 11 is desorbed by said operation of lowering the pressure in said tower A 11. As a result, the oxygen concentration of the gas supplied into oven 16 as gasifying agent becomes higher than air 4 (feedstock gas), thus forming so-called oxygen-enriched air.

Upon completion of this desorbing operation, the operating cycle 1 is restarted. The similar operations are carried out in another adsorption/desorption tower B 12, too. However, the system is so schemed that when the adsorbing operation is carried out in tower A 11, the desorbing operation is conducted in tower B 12, and when the desorbing operation is performed in tower A 11, the adsorbing operation is carried out in tower B 12. In this way, there can be obtained almost continuously and simultaneously a coal carrier gas of high nitrogen concentration and oxygen-enriched air to be used as coal gasifying agent.

Next, the case of using an agent for selectively adsorbing oxygen is described. As the agent for selectively adsorbing oxygen, there can be used those obtained by metallizing zeolite type adsorbents. The adsorbing performance of such agents is shown in Fig. 7. Since these agents are different in equilibrium adsorption of oxygen and nitrogen, they are advantageous over MSC in that there exist no restrictive conditions on agent performance in application to PSA.

Coal carrier gas is supplied into pressurized hopper 10 via valve 22 and into feed hopper 13 via valve 26. It is also supplied into ejector 15 via valve 31 having a flow rate regulating function. Coal 1 is crushed and classified into particle sizes convenient for gasification in oven 16 and then supplied to pressurized coal hopper 10.

Being solid, coal 1 can not be supplied in the form as it is into the oven. In this invention, therefore, a locked hopper system is used. The principle of this system is described below. Firstly, valve 25 is closed while valve 31 is opened to keep the pressurized hopper 10 under normal pressure, and in this state coal 1 is led into said hopper 10. Then, valve 31 is closed and valve 22 is opened to supply the carrier gas to the hopper and pressurize it. When the gas was pressurized equally to the previously pressurized feed hopper 13, valve 25 is opened to supply coal 1 from said pressurized hopper 10 into feed hopper 13. Thereafter, valve 25 is closed and valve 21 is opened to vent out carrier gas in pressurized hopper 10 and bring pressurized feed hopper 13 into normal pressure to resume the initial mode of operation.

Coal 1 filled in feed hopper 13 is led into ejector 15 through metering rotary feeder 14. In ejector 15, coal 1 is mixed with the carrier gas adjusted in its flow rate by flow regulating valve 31, and sent to burner 17 through a conduit. In burner 17, coal is mixed with the oxidizing agent and passed into oven 16.

In oven 16 which is high in temperature, coal 1 is reacted with the oxydizing agent and gasified to form a combustible gas. Since oxygen-enriched air is used as the gasifying agent, the inside of the oven can be made higher in temperature than when using ordinary air, so that the ash in coal 1 can be melted even when gasification is conducted at a lower oxygen/coal ratio, and therefore the gasification efficiency is improved.

The ratio of the produced amount of oxygen-enriched air to the produced amount of carrier gas is variable depending on the cycle interval, space velocity of the adsorption/desorption tower, and other factors, but the range of operation corresponding to the necessary gas composition can be determined to a certain extent by calculations.

The relation between production of gasifying agent and oxygen concentration of gasifying agent at selected nitrogen concentrations (99.9%, 99%, 95% and 90%) of carrier gas is shown in Fig. 8. In the graph of Fig. 8, the oxygen concentration of oxygen-enriched air (gasifying agent) is plotted as abscissa and the ratio of produced amount of gasifying agent to stockfeed gas (air) as ordinate. Of course, such relation is affected by the adsorbent performance, but a desired relation can be obtained by properly selecting the adsorption/desorption switchover cycle in the tower or by changing the working pressure for the adsorbing and desorbing operations. Generally, nitrogen concentration of carrier gas can be raised by shortening the adsorption time and switching adsorption and desorption at an earlier period. It is also possible to raise nitrogen concentration of carrier gas by enlarging the difference in working pressure between adsorbing and desorbing operations.

The gasifying agent with 20% oxygen concentration is equal to air which has undergone no oxygen enrichment. In this case, therefore, there is produced no nitrogen as carrier gas and the whole amount of gas can be used as gasifying agent.

When nitrogen concentration of carrier gas is fixed, the higher the oxygen concentration of gasifying agent, the less becomes the produced amount of gasifying agent. For instance, when nitrogen concentration of carrier gas is 99.9%, if oxygen concentration of gasifying agent is 25%, the ratio of the produced amount of gasifying agent to the amount of feedstock gas will be 80%, the remaining 20% accounting for the produced carrier gas.

The lower the nitrogen concentration of carrier gas, the less becomes the ratio of the produced amount of gasifying agent to the amount of feedstock gas. That is, the portion of feedstock gas which can be utilized as gasifying agent decreases, and the portion to be used as carrier gas increases.

As mentioned before, the gasifying gas to carrier gas ratio is preferably about 5 to 1. This ratio corresponds to 80% in terms of ratio of the produced amount of gasifying agent to the amount of feedstock gas. In such a case, oxygen concentration of gasifying agent can be adjusted to about 25% and it becomes possible to sufficiently raise the gasification efficiency.

A specific effect of this embodiment of the invention is that since the pressure at the time of adsorbing operation in adsorption/desorption towers 11, 12 is regulated to a pressure which enables supply of coal carrier gas, there is no need of further pressuring the gas produced from PSA. Generally, a compressor is used for pressurizing the gas produced by PSA, but in the case of coal gasification where there are required two different types of gas, viz. coal carrier gas and oxydizing agent, and also these two types of gas differ by about 10 times in amount required, it becomes necessary to use two sets of compressor differing greatly in throughput capacity. According to the instant embodiment of the invention, however, there is required only one compressor and further it is possible to produce both coal carrier gas and oxydizing agent by using the compressor which is normally required for gasification. Accordingly, the system can be noticeably simplified as compared with the conventional scheme comprising a mere combination of PSA and coal gasifier, and further the production cost for oxygen-enriched air is almost unnecessitated.

In the conventional systems, a greater amount of gas was wasted than the product gas, and the wasted gas was also pressurized, causing waste of a large volume of energy. According to the present invention, however, since the whole amount of gas is used for gasification with no waste, gasification can be accomplished at high efficiency. Further, since the whole amount of gas is used, the interior space of air separator can be utilized in its entirety, which means that the same throughput can be achieved with a far smaller size of apparatus than used conventionally.

An adaptation of the coal gasifying apparatus of this invention to a coal gasification combined power generation system is illustrated in Fig. 9.

This coal gasification complex power generation system is composed of a coal gasifying oven 16, a gas turbine 110, and air producing equipments 11, 12.

Said oven 16 and air separating equipments 11, 12 are the same as shown in Fig. 1. The gas produced from oven 16 contains unreacted char and harmful sulfur compounds.

The gas containing unreacted char, etc., is led into a dust removing device such as cyclone, and after cleared of dust therein, this gas is reservoired in hopper 102, then passed through a locked hopper system consisting of hoppers 103 and 104 and recycled into oven 16 from feeder 105. The sulfur compounds contained in the gas stream are removed by a desulfurizing device 106. Before entering this desulfurizing device, the gas is lowered in temperature by heat exchanger 107 to a level convenient for desulfurization.

The dust-removed and desulfurized gas is burned by gas turbine combustor 108 to drive gas turbine 110. Further, steam is produced from the combustion gas by using heat exchanger 109 to drive steam turbine 111. By using the energy produced by driving said turbines, compressor 18 is driven to pressurize air 4 for using it for gasification and combustion of gas in said gas turbine combustor 108.

The greater the amount of gas fed, the easier becomes driving of gas turbine 110. hence the more advantageous for power generation. Therefore, in case of using air for gasification, a higher power generating efficiency is obtained than when using oxygen for gasification because a greater amount of gas is produced by use of air than when using oxygen. In the oven, however, as mentioned before, the ash in coal can not be melted with the generated heat as it can not be raised in temperature due to nitrogen contained in the air, so that there is no alternative but to carry on the combustion reaction. Consequently, the combustible gas in the produced gas decreases, resulting in a reduced gasification efficiency and an elevated coat of power generation.

However, according to the system using the coal gasifier embodying the present invention, it is possible to raise the gasification efficiency to the almost same level as gasification by oxygen, with the oxydizing agent production cost being unchanged from the case of conventional air-using gasification. That is, according to the present system, since the whole of pressurized gas is used, there can be obtained the same amount of gas as in the case of air-using gasification, and the entirety of such gas can be utilized for power generation. Further, since the gasification is conducted with oxygen-enriched air in the oven, it is possible to elevate the interval temperature of the oven, making it possible to carry out the gasification reaction at a lower oxydization rate. Moreover, no cost is required for producing oxygen-enriched air. These lead to a drastic reduction of power generation cost.

The present system also permits a marked reduction in size of air separating equipment as compared with the conventional systems. In the case of power generation, the plottage of the plant is directly associated with the power plant construction cost. In case of adopting PSA, it has been necessary to set up PSA units for both of coal carrier gas and product gas, and also, in the system using PSA, more than half of the towers must be stopped for the desorbing operation, so that a vast plottage has been required for the plant construction. According to the present invention, however, since the whole of gas supplied to PSA can be utilized effectively, a drastic reduction in size of equipments is made possible as compared with the conventional systems.

The second embodiment of the present invention will be described below with reference to Fig. 10.

The flow chart of this embodiment is substantially the same as that of the first embodiment, but in this embodiment, the operating pressure of the adsorption/desorption towers is low, and the produced oxygen-enriched air and coal carrier gas are pressurized by boost-up compressors 38 and 39, respectively.

Generally, PSA is conducted at a low temperature and under a low pressure. For, in the system of PSA where oxygen and nitrogen in the air are separated by making use of the difference in equilibrium adsorption, the adsorbed gas can be desorbed more effectively under a lower pressure, resulting in a higher working efficiency.

The specific effect of this embodiment consists in the easy adsorbing and desorbing operations.

Now, the third embodiment of this invention will be described while referring to Fig. 11.

The flow chart of this embodiment is substantially identical with that of the first embodiment. One difference of this embodiment from the first embodiment is that buffer tank 41 is provided behind outlet valves 23, 24 of the gas which has undergone the adsorbing operation, that is, high-purity nitrogen gas used as carrier gas, and another buffer tank 42 is provided behind outlet valves 27, 28 of the gasifying agent which had undergone the desorbing operation.

Another difference is that there is provided adsorption tower 43 packed with an agent for removing moisture of air 4 after it has been pressurized by compressor 18.

In the system of PSA, the adsorbing and desorbing operations are performed by changing the internal pressures of adsorption/desorption towers A 11 and B 12 by operating valves 23 - 24 and 27 - 30. Therefore, a large variation of pressure is produced in the outlet gas of adsorption/desorption towers A 11 and B 12.

Also, in the early phase of the desorbing operation, since the pressure doesn't reach the level suited for desorption, the desorption of oxygen from the adsorbent is not yet sufficient, therefore the oxygen concentration of the produced oxygen-enriched air is low. On the other hand, in the last phase of the desorbing operation, since the oxygen desorption from the adsorbent is performed sufficiently, the oxygen concentration of the oxygen-enriched air is high.

In this embodiment, such variations of pressure or composition of the gas produced by the adsorbing and desorbing operations are to be eliminated by buffer tanks 41, 42.

Adsorption tower 43 for removing air moisture, which is another difference of this embodiment from the first embodiment, will now be explained. Generally, the adsorbent specific to PSA is susceptible to water and badly lowered in its efficiency when even a slight amount of water is contained therein. Further, in case of carrying out the adsorbing and desorbing operations under a relatively high pressure as in the present invention. the moisture contained in the air is condensed to adversely affect the performance of the agent packed in adsorption/desorption towers A 11, B 12.

So in this embodiment, it is schemed to remove moisture from air 4 by adsorption tower 43 specifically designed for adsorbing moisture after said air 4 has been pressurized by compressor 18 (whereby air 4, or feedstock gas, has the highest pressure in the system).

The specific effect of this embodiment is that the variations of pressure or composition of the gas produced by the adsorbing and desorbing operations are reduced to allow supply of the gasifying agent and carrier gas of the stabilized compositions with a stabilized pressure to improve the operatability of the gasifier.

The fourth embodiment of this invention will be described with reference to Fig. 12.

The flow chart of this embodiment is almost equal to that of the first embodiment shown in Fig. 7. The differences are that the adsorption/desorption towers in the air separating system are provided in multiple stages, and that the gas produced in the oven is used for the desorbing operation.

In PSA, the adsorbing and desorbing operations are repeated alternately as said above, and these repetitive operations cause instabilization of the outlet gas composition and the outlet pressure. Generally, the coal gasifier designed for power generation has a high throughput, and it is impossible to supply the whole amount of gas required for coal gasification by one unit of PSA. In this embodiment, therefore, as shown in Fig. 12, plurality of adsorption/desorption towers 130 are provided so that said repetitive operations may be performed continuously by slightly staggering the time of operation for each tower. This can eliminate instability of the outlet gas composition and the outlet pressure, which is the defect of PSA.

Further, the load variability is improved by providing a plurality of adsorption/desorption towers 130. In case only one adsorption/desorption tower 130 is provided, throughput of the gas must be changed by this tower 130 itself for varying the load. However, for changing the gas throughput by the adsorption/desorption tower 130 itself, it needs to change the space velocity in the tower 130 and/or the switchover interval of the valves. Such operations impose a restriction to the initial design conditions. On the other hand, in case a plurality of towers are provided as in this embodiment of the invention, when for instance the load is lowered, it is possible to cope with the load variation by merely reducing the number of the towers operated.

The feature of the present embodiment of the invention resides in that the gas produced in the oven is used for the desorbing operation. The low-grade steam which has passed steam turbine 111 in Fig. 9 is led into adsorption/desorption towers 130 via line 140. As the low-grade steam, there can be used, beside that from said steam turbine, other suitable heat sources such as return circulating water from the water-cooled walls of the oven. The heat source led through line 140 is supplied into adsorption/desorption towers 130 in the mode of desorbing operation. Thereby the oxygen adsorbed by the adsorbent is quickly desorbed. Also, in the present invention, since the desorbed gas serves as the gasifying agent in coal gasification, the gasifying agent is heated to a higher temperature, allowing a rise of internal temperature of the oven to improve the gasification efficiency.

The specific effect of this embodiment of the invention is that the composition and pressure of the produced gas are stabilized to improve the desorbing efficiency, enabling separation of a gas of higher performance.

The fifth embodiment of the present invention will be described by referring to Fig. 13. It is expected that the performance of the oxygen adsorbent will be greatly improved in future, and this will enable a drastic reduction in size of the adsorption/desorption tower. In this embodiment of the invention, in anticipation of such future technology, all of the adsorption/desorption towers are assembled into a single air separation tower 90.

The specific effect of this embodiment is that the whole system is simplified in structure and its operatability is improved by integrating the component units.

EFFECT OF THE INVENTION

According to the present invention, both gasifying agent and coal carrier gas used in coal gasification can be produced at the same time from air without using must energy for the production. so that the equipments required for gasification can be remarkably reduced in size and also the cost of electricity production by coal gas power generation can be reduced.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a flow chart of the first embodiment of this invention. Fig. 2 shows a schematic flow chart of the coal gasifier and the compositions of the necessary gases. Fig. 3 shows a schematic flow chart of nitrogen adsorbing type PSA and the compositions of the produced gases. Fig. 4 shows a schematic flow chart of oxygen adsorbing type PSA and the compositions of the produced gases. Fig. 5 shows a - schematic flow chart of the system of this invention comprising a combination of coal gasifier and PSA and the compositions of the carrier gases. Fig. 6 shows the relation between adsorption of the adsorbent used in the first embodiment and time. Fig. 7 shows the adsorbing performance in case of using an agent capable of selectively adsorbing oxygen. Fig. 8 is an illustration of the operating conditions of the first embodiment. Fig. 9 is a flow chart of the power generating system using coal gasifier of the first embodiment of the invention. Fig. 10 is a flow chart of the second embodiment of the invention. Fig. 11 is a flow chart of the third embodiment of the invention. Fig. 12 is a flow chart of the fourth embodiment of the invention. Fig. 13 is a flow chart of the fifth embodiment of the invention.

1: coal, 2: waste gas, 3: gas produced by coal gasification, 4: air, 5: slag, 10: pressurized hopper, 11: adsorption/desorption tower A, 12: adsorption/desorption tower B, 13: feed hopper, 14: rotary feeder, 15: ejector, 16: coal gasifying oven, 17: coal burner, 18: compressor, 23: adsorption/desorption tower A product gas switchover valve, 24: adsorption/desorption tower B product gas switchover valve, 27: adsorption/desorption tower A purge gas switchover valve, 28: adsorption/desorption tower B purge gas switchover valve, 29: stock gas supply valve for adsorption/desorption tower A, 30: stock gas supply valve for adsorption/desorption tower B.

Claims

1. A coal gasification process which comprises:

passing pressurized air (4) through the towers (11, 12) packed with an adsorbent capable of adsorbing oxygen faster and in a greater amount than nitrogen under the same pressure and at the same temperature to thereby produce high-concentration nitrogen gas,

reducing the pressure of air (4) passing through said towers (11, 12) before nitrogen begins to be adsorbed by said adsorbent to effect desorption of oxygen adsorbed by said adsorbent to thereby produce oxygen-enriched air,

conducting said operations repeatedly by staggering the time of operation for each tower (11, 12) to continuously produce high-concentration nitrogen gas and oxygen-enriched air, and

using said high-concentration nitrogen gas for carriage of coal (1) and pressurization of the coal-packed hopper (10) while said oxygen-enriched air being used as coal gasifying agent.

2. The coal gasification process according to claim 1, wherein the pressure of pressurized air (4) is so set that it will be higher than the pressure of P_1 plus ΔP_P, where P_1 is the pressure capable of sufficiently supplying coal carrier gas to coal feed hopper (13) and ejector (15) and ΔP_P is the pressure loss suffered when the gas passes through said adsorption/desorption towers (11, 12).

3. A coal gasification process which comprises:

passing pressurized air (4) through the towers (11, 12) packed with an adsorbent having a greater equilibrium adsorption of oxygen than that of nitrogen under the same pressure and at the same temperature to thereby produce high-concentration nitrogen gas,

reducing the pressure of air (4) passing through said towers (11, 12) before the equilibrium adsorption of oxygen is reached to effect desorption of oxygen adsorbed by said adsorbent to thereby produce oxygen-enriched air, conducting said operations repeatedly by staggering the time of operation for each tower (11, 12) to continuously produce high-concentration nitrogen gas and oxygen-enriched air, and

using said high-concentration nitrogen gas for carriage of coal (1) and pressurization of the coal-packed hopper (10) while said oxygen-enriched air being used as coal gasifying agent.

4. The coal gasification process according to claim 3, wherein the pressure of pressurized air is so set that it will be higher than the pressure of P_1 plus ΔP_P, where P_1 is the pressure capable of sufficiently supplying coal carrier gas to coal feed hopper (13) and ejector (15) and ΔP_P is the pressure loss suffered when the gas is passed through the adsorption/desorption towers (11, 12).

5. A coal gasifier comprising:

an air separating apparatus in which pressurized air (4) is passed through the towers (11, 12) packed with an adsorbent capable of adsorbing oxygen faster and in a greater amount than nitrogen under the same pressure and at the same temperature to thereby produce high-concentration nitrogen gas, and before nitrogen begins to be adsorbed by said adsorbent, the pressure of air (4) passed through said towers (11, 12) is reduced to effect desorption of oxygen adsorbed by said adsorbent to thereby produce oxygen-enriched air, said operations being conducted repeatedly by staggering the time of operation for each tower (11, 12) to continuously produce high-concentration nitrogen gas and oxygen-enriched air, and

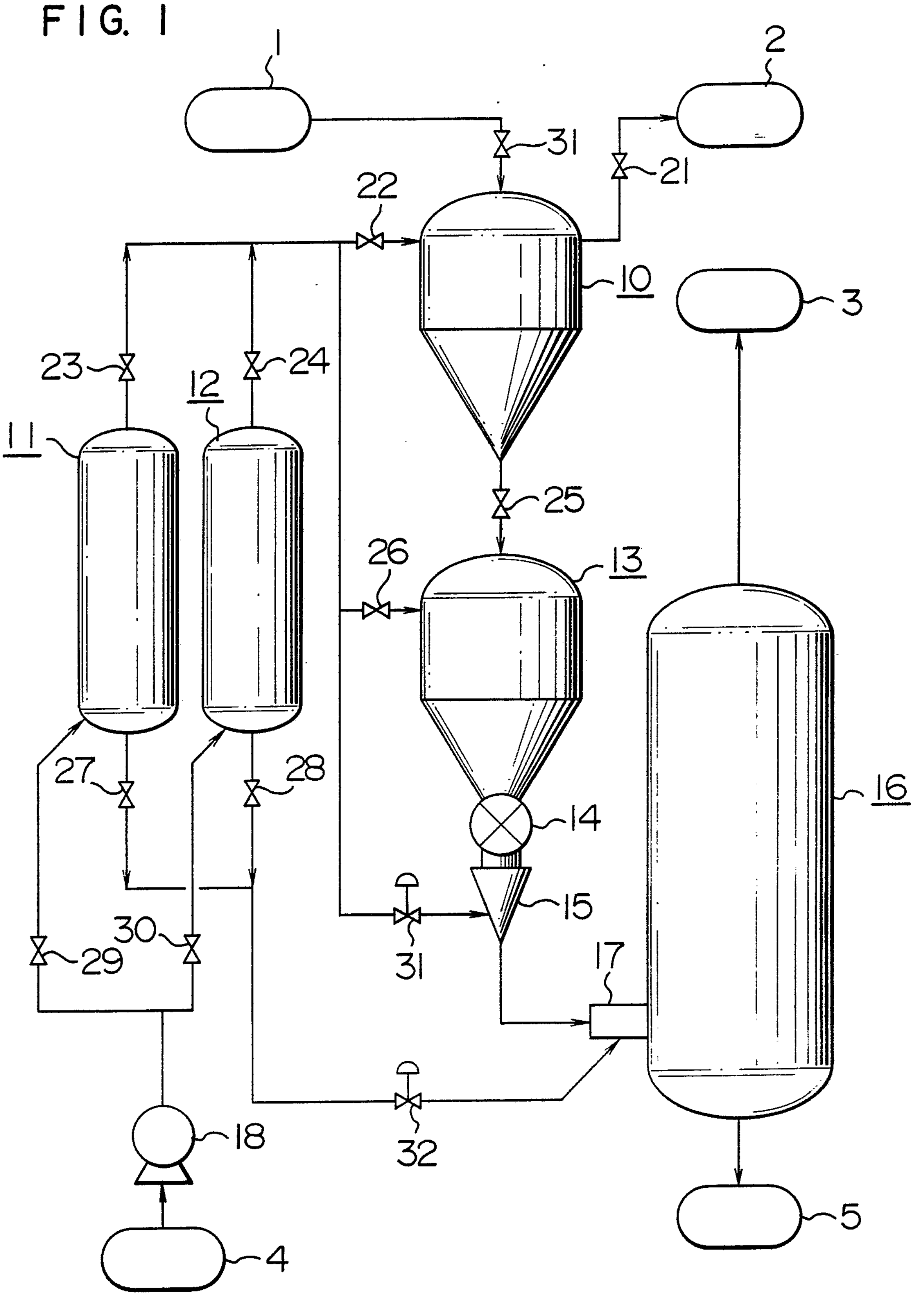
an oven (16) for gasifying coal (1) by using the high-concentration nitrogen gas produced by said air separating apparatus for carriage of coal (1) and for pressurization of the coal-packed hopper (13), while using said oxygen-enriched air as coal gasifying agent.

6. A coal gasifier comprising:

an air separating apparatus in which pressurized air (4) is passed through the towers (11, 12) packed with an adsorbent having a greater equilibrium adsorption of oxygen than that of nitrogen under the same pressure and at the same temperature to thereby produce high-concentration nitrogen gas, and before the equilibrium adsorption of oxygen is reached, the pressure of air (4) passed through said towers (11, 12) is reduced to effect desorption of oxygen adsorbed by said adsorbent to thereby produce oxygenenriched air, said operations being conducted repeatedly by staggering the time of operation for each tower (11, 12) to continuously produce high-concentration nitrogen gas and oxygen-enriched air, and

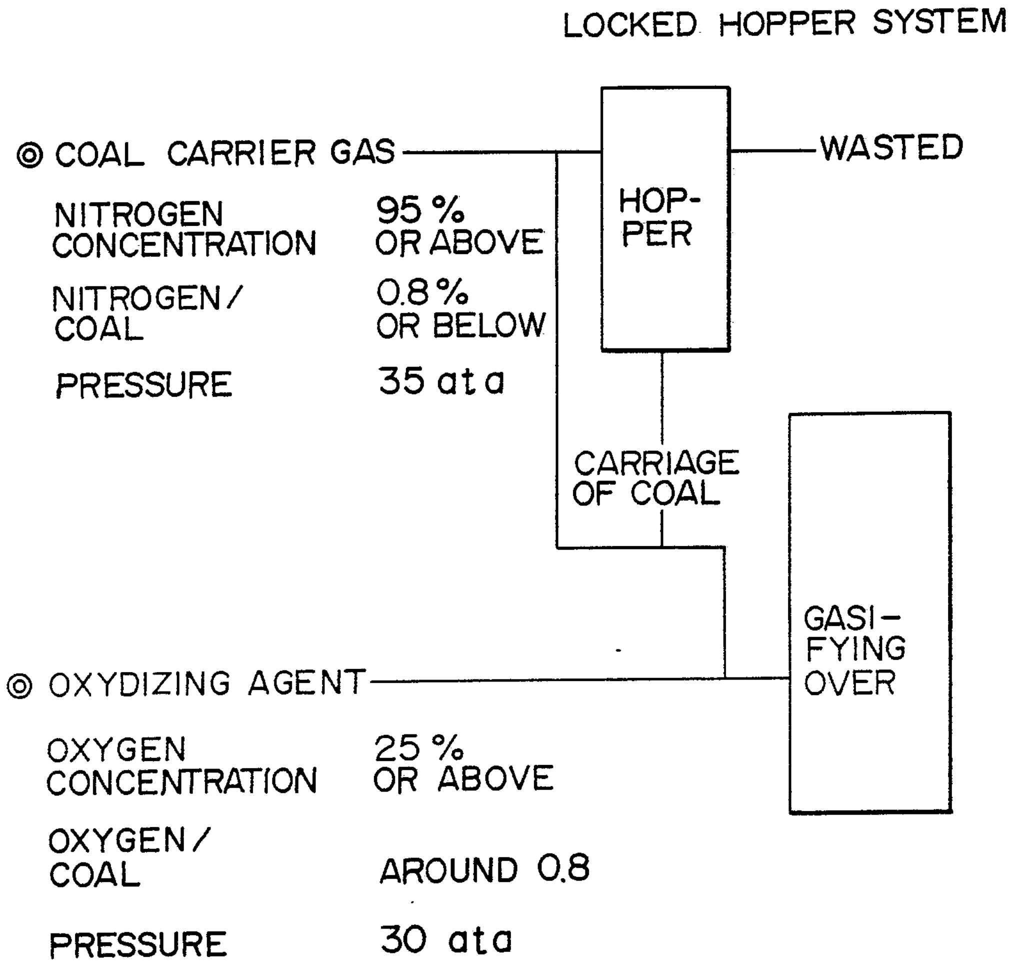
an oven (16) for gasifying coal (1) by using the high-concentration nitrogen gas produced by said air separating apparatus for carriage of coal (1) and for pressurization of the coal-packed hopper (13), while using said oxygen-enriched air as coal gasifying agent.

FIG. 1



1 --- COAL
3 --- PRODUCED GAS
4 --- AIR
10 --- PRESSURIZED HOPPER
11 --- ADSORPTION / DESORPTION TOWER A
12 --- ADSORPTION / DESORPTION TOWER B
13 --- FEED HOPPER
16 --- GASIFYING OVEN
18 --- COMPRESSOR

FIG. 2


LOCKED HOPPER SYSTEM
◎ COAL CARRIER GAS
NITROGEN CONCENTRATION
95 % OR ABOVE
NITROGEN/ COAL
0.8 % OR BELOW
PRESSURE
35 ata
HOP-PER
WASTED
CARRIAGE OF COAL
GASI-FYING OVER
◎ OXYDIZING AGENT
OXYGEN CONCENTRATION
25 % OR ABOVE
OXYGEN/ COAL
AROUND 0.8
PRESSURE
30 ata

F I G. 3

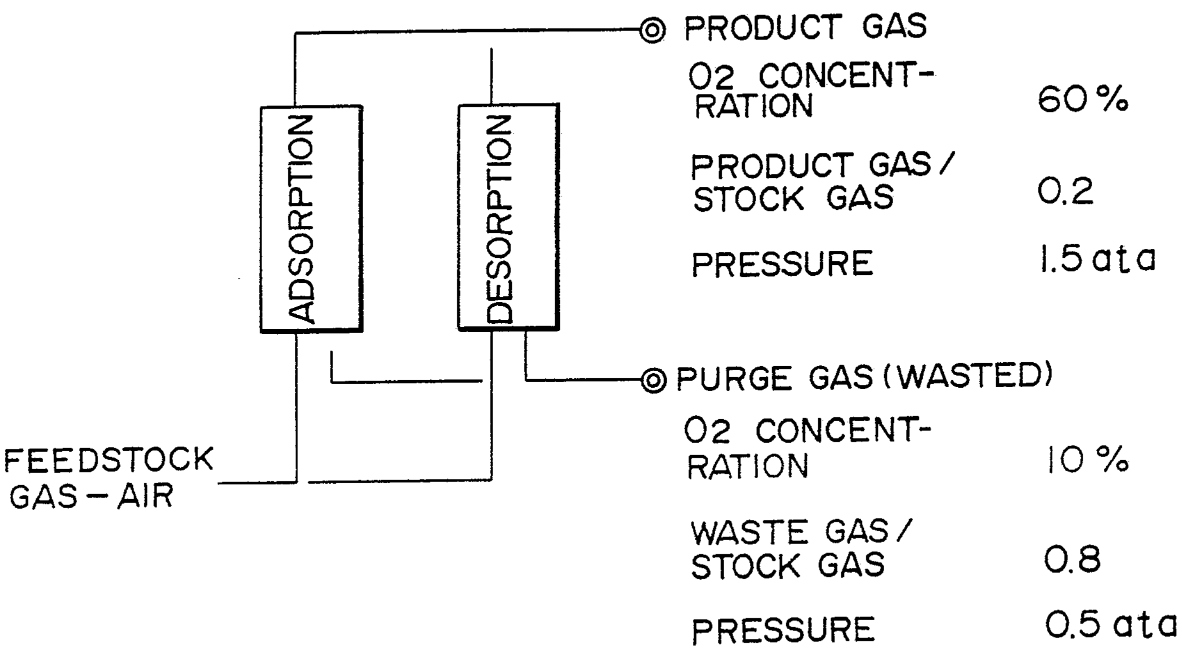

PRODUCT GAS
O2 CONCENTRATION 60%
PRODUCT GAS / STOCK GAS 0.2
PRESSURE 1.5 ata
ADSORPTION
DESORPTION
PURGE GAS (WASTED)
O2 CONCENTRATION 10%
WASTE GAS / STOCK GAS 0.8
PRESSURE 0.5 ata
FEEDSTOCK GAS - AIR

FIG. 4

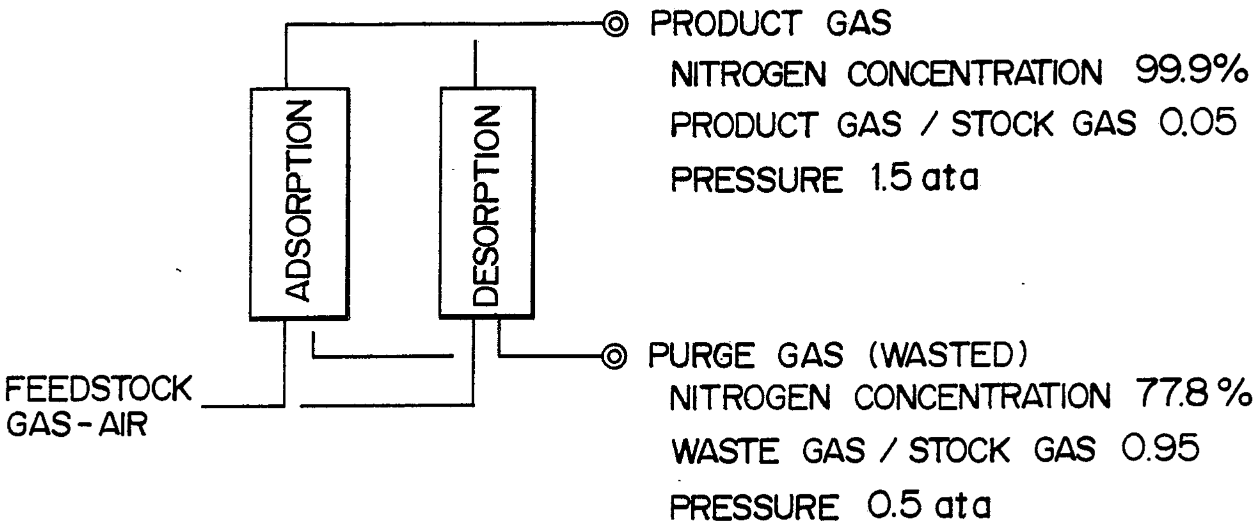

◎ PRODUCT GAS
NITROGEN CONCENTRATION 99.9%
PRODUCT GAS / STOCK GAS 0.05
PRESSURE 1.5 ata
ADSORPTION
DESORPTION
◎ PURGE GAS (WASTED)
NITROGEN CONCENTRATION 77.8 %
WASTE GAS / STOCK GAS 0.95
PRESSURE 0.5 ata
FEEDSTOCK GAS-AIR

FIG. 5

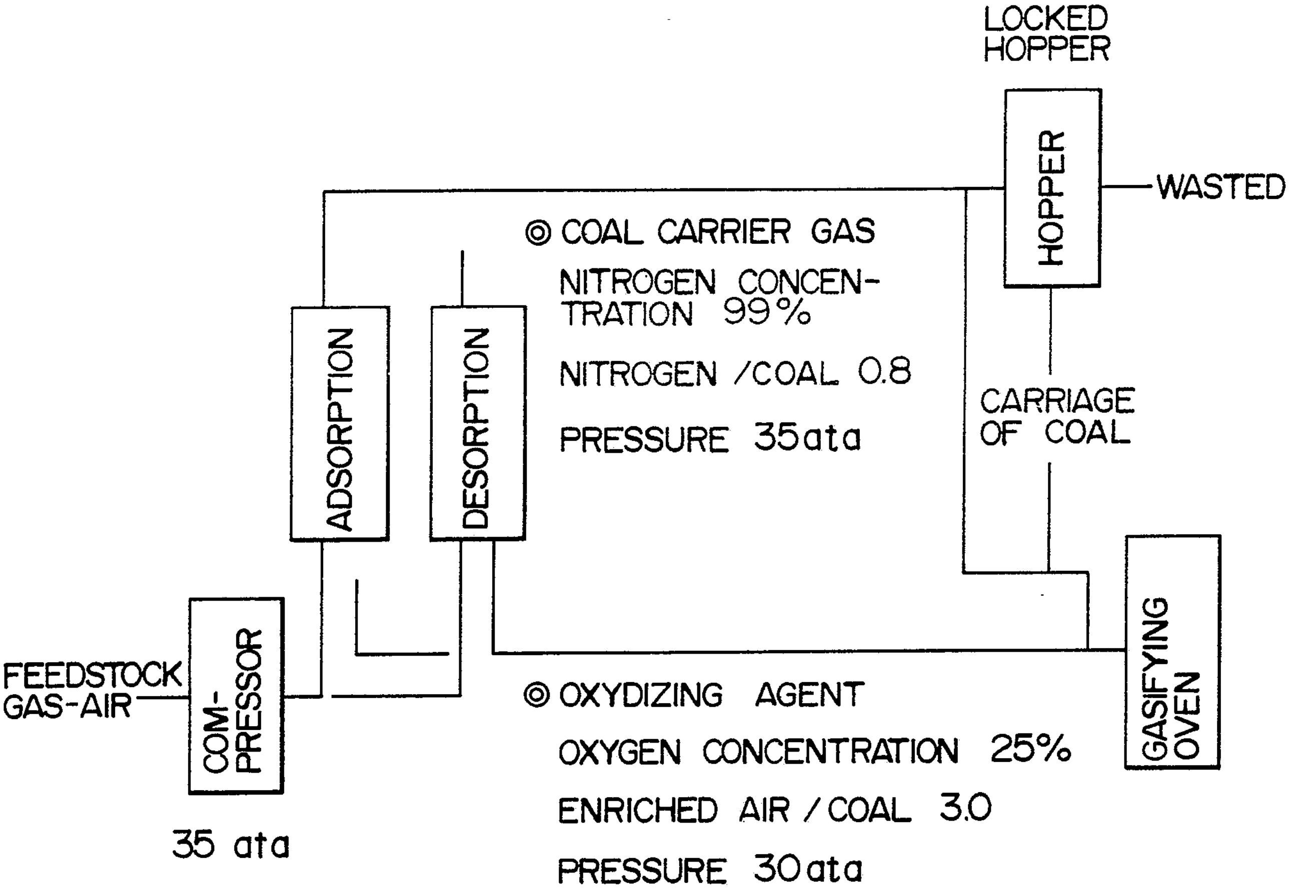

LOCKED HOPPER
HOPPER
WASTED
◎ COAL CARRIER GAS
NITROGEN CONCENTRATION 99%
NITROGEN /COAL 0.8
PRESSURE 35ata
ADSORPTION
DESORPTION
CARRIAGE OF COAL
GASIFYING OVEN
FEEDSTOCK GAS-AIR
COM-PRESSOR
35 ata
◎ OXYDIZING AGENT
OXYGEN CONCENTRATION 25%
ENRICHED AIR / COAL 3.0
PRESSURE 30ata

FIG. 6

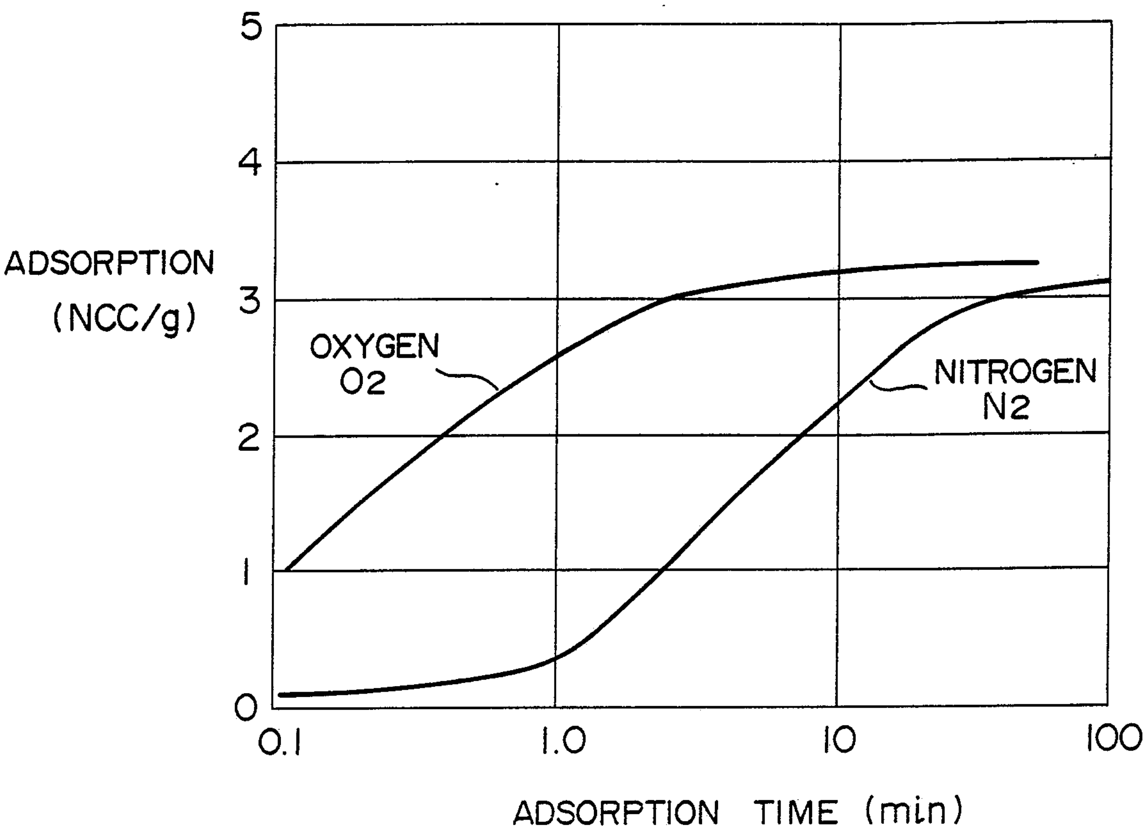

ADSORPTION (NCC/g)
5
4
3
2
1
0
OXYGEN O2
NITROGEN N2
0.1
1.0
10
100
ADSORPTION TIME (min)

FIG. 7

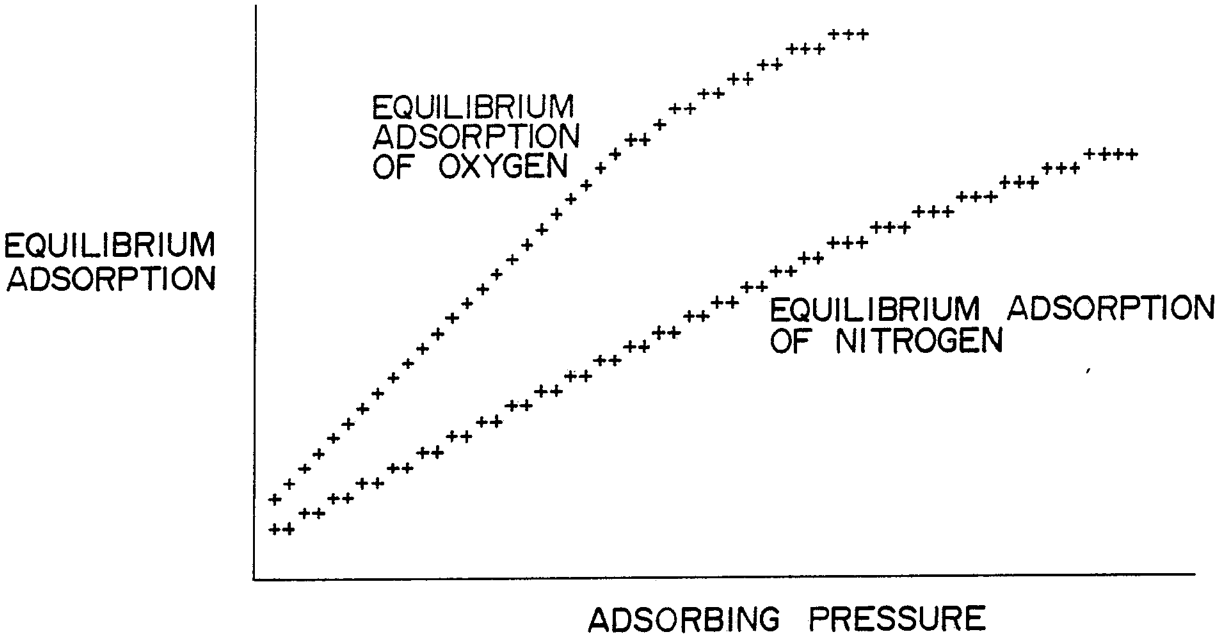

EQUILIBRIUM ADSORPTION
EQUILIBRIUM ADSORPTION OF OXYGEN
EQUILIBRIUM ADSORPTION OF NITROGEN
ADSORBING PRESSURE

FIG. 8

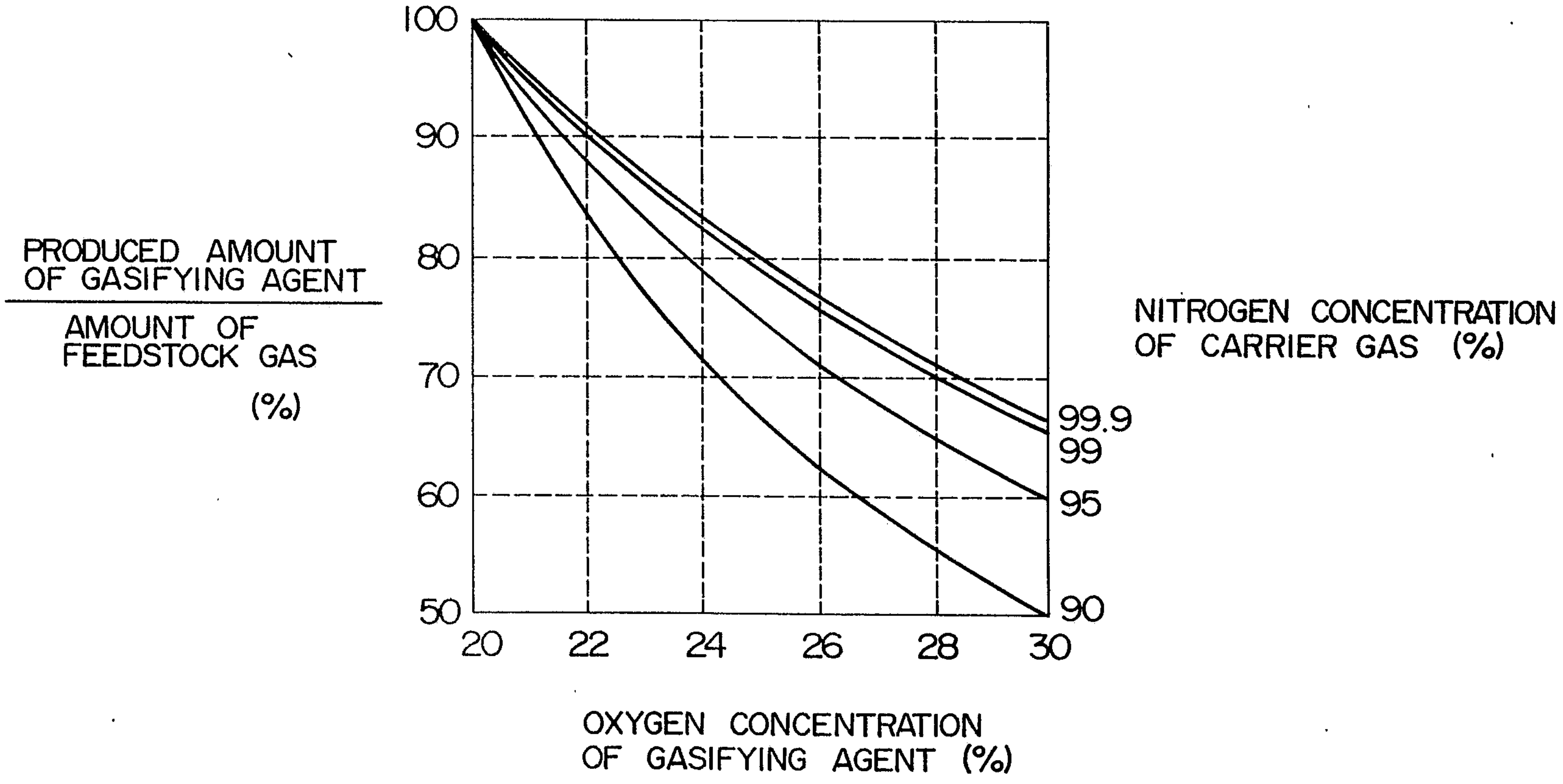
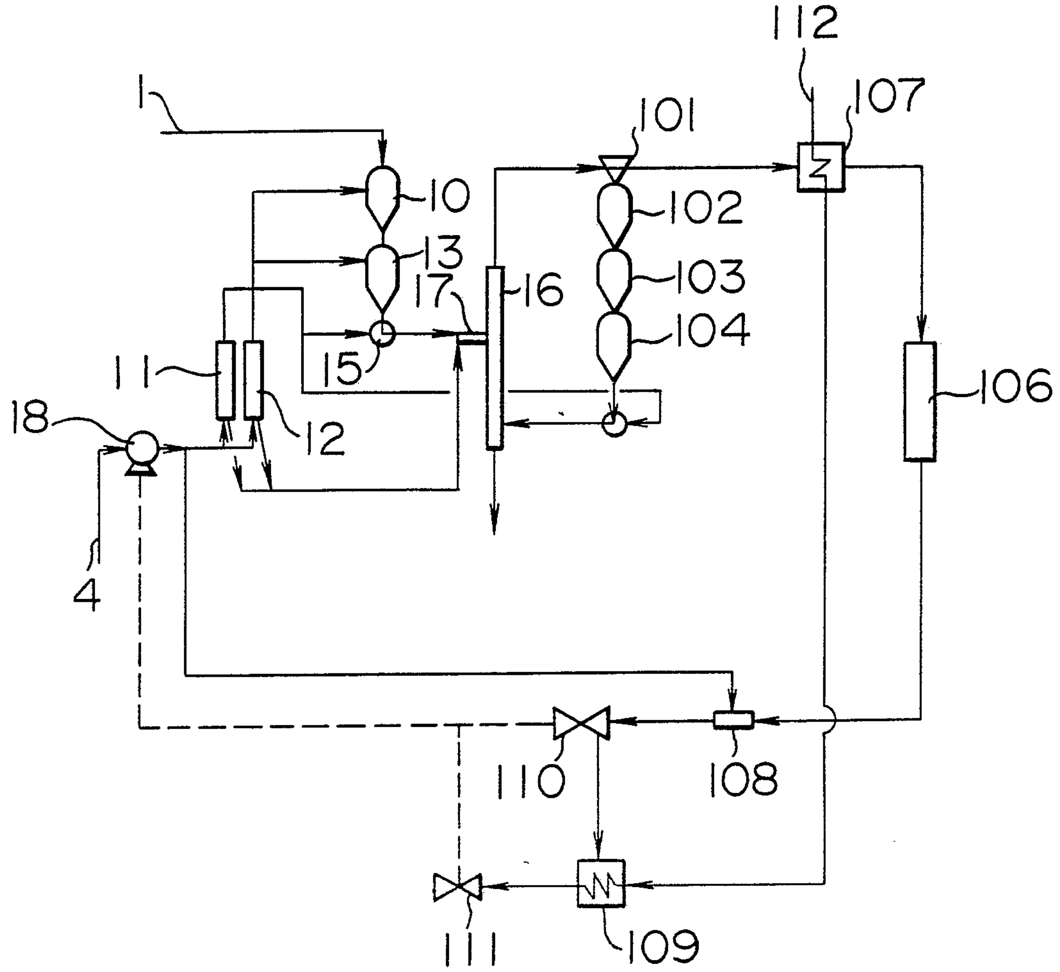
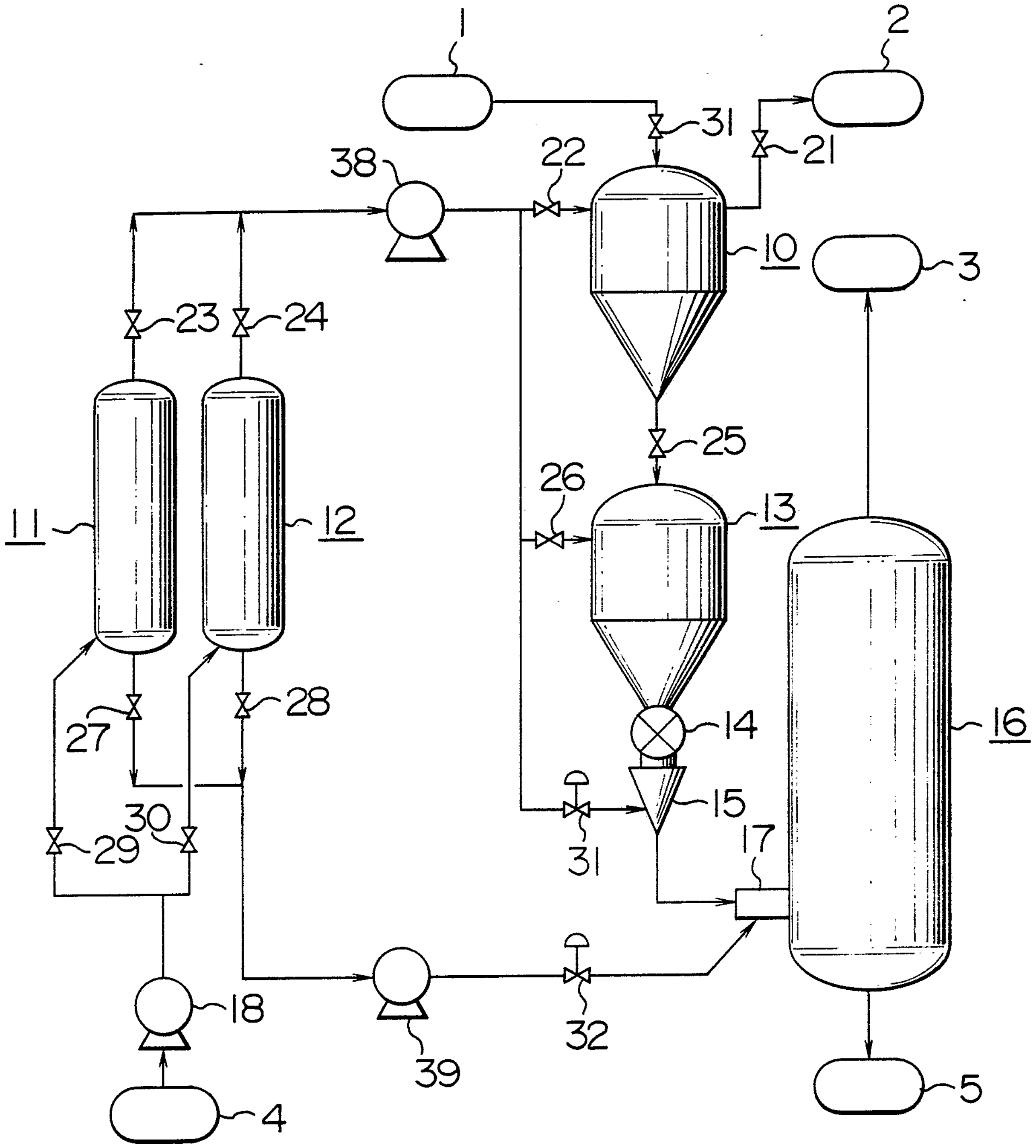

PRODUCED AMOUNT OF GASIFYING AGENT / AMOUNT OF FEEDSTOCK GAS (%)
100
90
80
70
60
50
20
22
24
26
28
30
OXYGEN CONCENTRATION OF GASIFYING AGENT (%)
99.9
99
95
90
NITROGEN CONCENTRATION OF CARRIER GAS (%)

FIG. 9



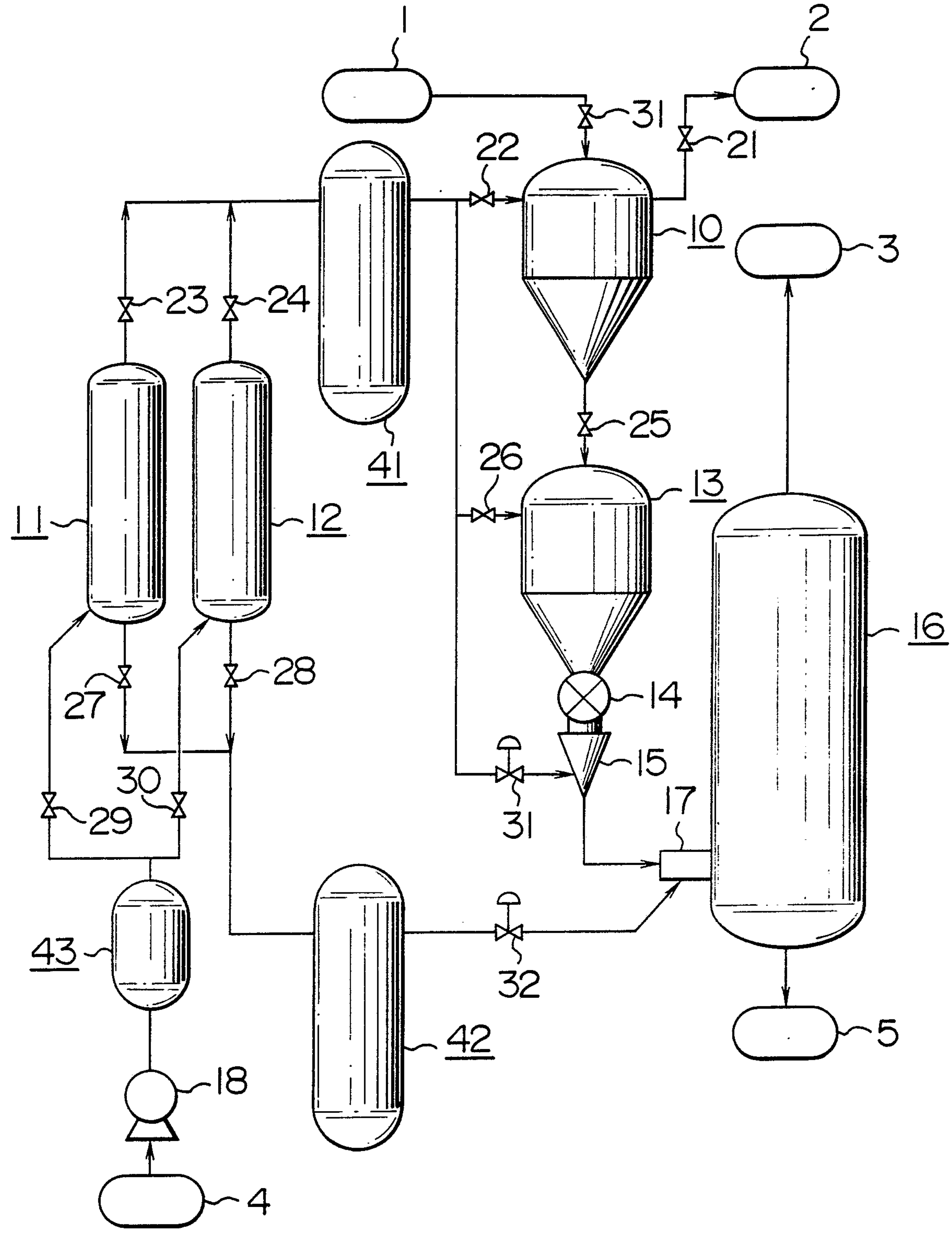
106---DESULFURIZER
110---GAS TURBINE
111---STEAM TURBINE

FIG. 10



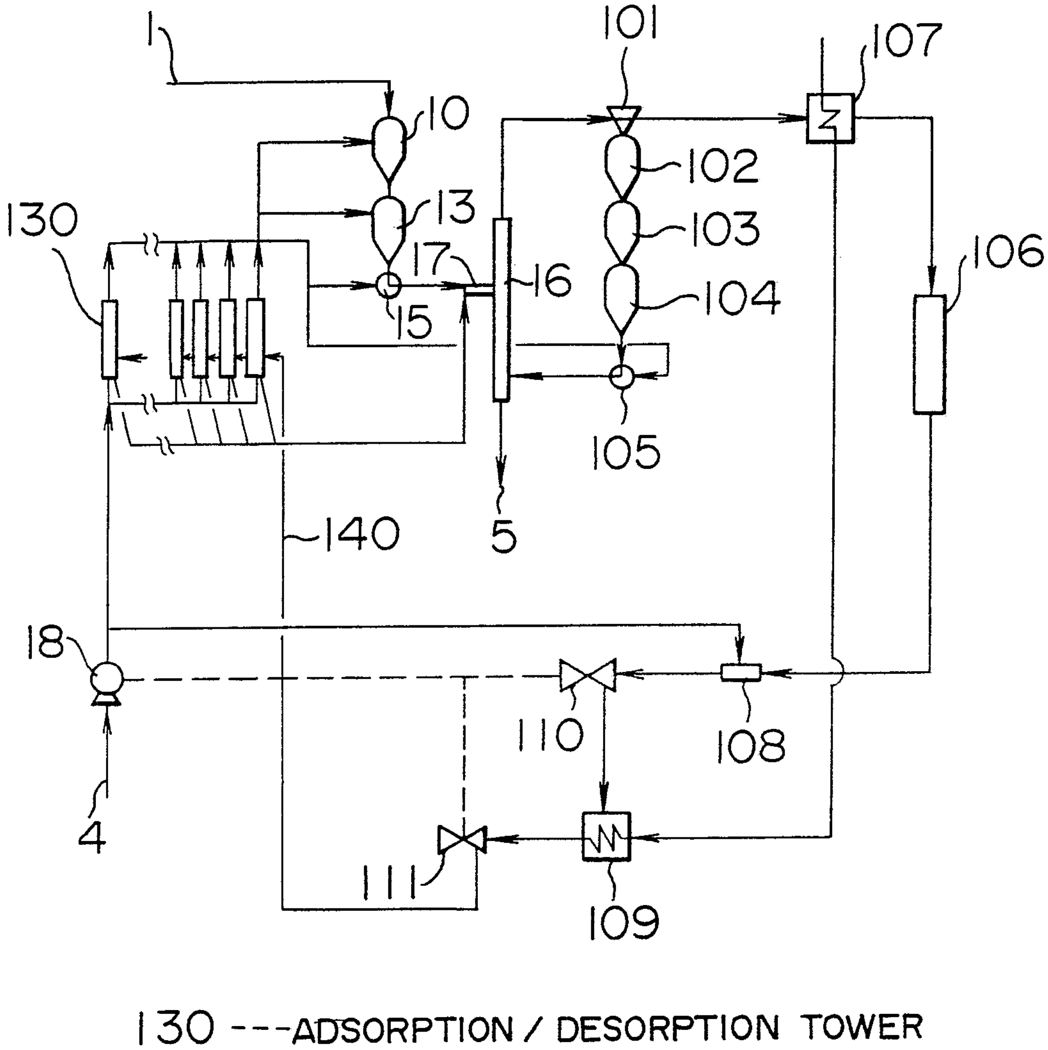
38 --- BOOST-UP COMPRESSOR
39 --- BOOST-UP COMPRESSOR

FIG. 11



41---BUFFER TANK
42---BUFFER TANK

FIG. 12



130 ---ADSORPTION / DESORPTION TOWER

FIG. 13