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(54) METHOD AND APPARATUS FOR TREATING RADIOACTIVE WASTE GASES

(71) We, TOKYO SHIBAURA DENKI KABUSHIKI KAISHA, Japanese company, of 72, Horikawa-Cho, Saiwai-Ku, Kawasaki-Shi, Kanagawa-Ken, Japan, NIPPON GENSHIRYOKU JIGYO KABUSHIKI KAISHA, Japanese company, of 13—12, Mita 3-Chome, Minato-Ku, Tokyo-To, Japan, and KABUSHIKI KAISHA KOBE SEIKOSHO, Japanese company, of 3—18, Wakihama-Cho, Fukiai-Ku, Kobe-Shi, Hyogo-Ken, Japan, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a method and apparatus for treating radioactive waste gas and more particularly to a method and apparatus for treating waste gas discharged from a nuclear power plant to recover radioactive rare gases.

In a nuclear power plant, that is a plant utilizing energy produced by the fission of a fissionable substance such as U^{235} and Pu^{239}, or a plant for treating burnt fuel it is inevitable to exhaust a gaseous mixture containing radioactive rare gases such as Kr and Xe formed as a result of nuclear fission. With the increase in the number and scale of the nuclear power plants it is necessary to remove such radioactive rare gases from the exhaust gas in order to avoid local contamination of the atmosphere and accumulation of the radioactive rare gases on the globe. Among these gases there are gases that can be used as radioactive isotopes, for example Kr^{85}, or gases such as Xe which are contained in a large quantity but lose their radioactivity in a relatively short time. For this reason, it is highly desirable to develop an efficient method and apparatus that can remove harmful radioactive rare gases and can remove useful radioactive rare gases.

According to a prior art method of treating the gas exhausted from a nuclear power plant for recovering radioactive rare gases, apparatus as shown in FIG. 1 of the accompanying drawing has been used in which the waste gas is treated in a pretreating system 1 to remove water and carbon dioxide. Then, the gas is cooled by a heat exchanger 2 which is cooled by effluent gas from a concentrator 4. Then the cooled gas is sent to a primary condenser 4 or a rare gas concentrator normally containing a low temperature absorption bed which is also cooled by the liquid nitrogen from bomb 3. The interior of the heat exchanger and the primary condenser is maintained at atmospheric or superatmospheric pressure.

As shown in FIG. 2, the primary condenser 4 comprises a tank 11 covered by a thick heat insulating layer 12, an absorption bed 13 contained in the tank, a gas distributing plenum chamber 14 beneath the absorption bed, and a coil 15 embedded in the heat insulating layer 12 and passed through the liquid nitrogen. When concentrating the radioactive rare gases by absorbing at a low temperature the rare gases by the absorption bed and then releasing the absorbed rare gases by heating the bed, the temperature of the absorption bed is raised stepwisely for making easy the recovering of the radioactive rare gases in the subsequent step.

The exhaust gas is concentrated in the primary condenser 4 by a factor of about 1700. The gas concentrated in this manner contains a major proportion of air (N_2, O_2, etc.) and about 1/30th of the rare gases (for example Xe, Kr, etc.). The concentrated gas is then supplied to a secondary condenser 6 by a pump 5, where the radioactive rare gases are absorbed by an activated carbon bed which is cooled by the liquid nitrogen from bomb 3 and the absorbed rare gases are recovered into a bomb 7.

In this manner, according to the prior art method, since the gas is treated under atmospheric pressure or a superatmospheric pressure it is necessary not only to use a number of valves and joints for the heat exchanger and the primary and secondary condensers, but also to pay due consideration not to leak the harmful radioactive rare gases. For this reason, the cost of installation is high and it is necessary to frequently inspect and repair.

Further, with the primary condenser described above, since the absorption bed 13 is cooled by liquid nitrogen via the tank 11 and the heat insulating layer 12, the efficiency of cooling is low and it takes a long time before the absorption bed is cooled to a desired low temperature. Moreover, it is difficult to quickly respond to a small variation in the temperature within tank 11. Where liquid nitrogen is used as the coolant since it is impossible to use 100% of the latent heat and cold evaporated nitrogen, the consumption of the liquid nitrogen is large.

Since the concentrated and recovered radioactive rare gases pass only once through the absorption bed, dependent upon the type and the temperature of the absorption agent it might be impossible to recover the rare gases at the desired high concentration. Further, when the concentration is increased by using a secondary condenser, its load will be increased. Further, where the flow quantity decreases below a designed value the utilization factor of the absorption bed and hence the concentration of the rare gases decrease.

Where, according to a prior art method, an activated carbon bed is used also in the secondary condenser 6 a certain amount of oxygen will be absorbed together with the rare gases, with the result that the oxygen will be activated by the radioactivity of the radioactive rare gases thereby converting a portion of the oxygen into ozone. Since ozone is explosive it is very dangerous to recover it into bomb 7 together with the radioactive rare gases. Further, the heat of decay of the radioactive gas or reaction of the ozone burns and consumes the activated carbon thereby greatly decreasing the absorption capability of the activated carbon.

For the reason described above it is highly desirable to completely remove oxygen admixed with the radioactive rare gases before recovery.

Accordingly, there has been proposed a method in which a H_2—O_2 recombiner is used in the secondary condenser instead of the low temperature absorption bed. According to this method hydrogen gas is blown into the condenser for causing it to react with oxygen. With this method it is possible to nearly completely remove the oxygen under approximate conditions so that this method has been used for the secondary condenser for recovering the radioactive rare gases.

However, this method is defective in that it is necessary to install a hydrogen tank or a hydrogen generating plant near the rare gas recovering plant. Installation of such explosive equipment near the rare gas recovering plant may cause serious disaster.

According to one aspect of the invention there is provided a method of concentrating and recovering radioactive rare gas wherein waste gas containing said rare gas and oxygen is contacted against an absorption agent contained in a primary condenser and maintained at a low temperature so as to absorb said rare gas by said absorption agent, the temperature of said absorption agent is raised to release the absorbed rare gas, and the released rare gas is recovered by a secondary condenser, wherein said released radioactive rare gas is treated in said secondary condenser with one or more reactive metals consisting of zirconium, titanium, copper or alloys thereof for absorbing and fixing the oxygen in the released gas but not abosrbing the radioactive rare gases.

According to another aspect of the invention there is provided apparatus for carrying out this method which further comprises the steps of recirculating said released rare gas through said primary condenser together with said waste gas, and repeating said absorption and release of said rare gas several times, the apparatus comprising a plurality of absorbing tanks each provided with cooling means, heating means, and an absorbing bed, an ejector for supplying to said absorbing tanks waste gas containing radioactive rare gas for absorption of the radioactive rare gas by said absorbing beds, valve means for causing said absorbing tanks to alternately operate to absorb said rare gas and to release absorbed rare gas, when under suitable temperature conditions, means to recirculate the released rare gas through said ejector for admixing the released rare gas with said waste gas, a succeeding recovering device containing one or more reactive metals consisting of zirconium, titanium, copper or alloys thereof, and a pump for sending the released rare gas to said succeeding recovering device.

The invention can be more fully understood from the following detailed description taken in conjunction with the accompanying drawings in which:

FIG. 1 is a diagrammatic representation of a prior art apparatus utilized to remove radioactive rare gases;

FIG. 2 is a sectional view of the primary condenser 4 shown in FIG. 1.

FIG. 3 shows apparatus utilizable to carry out the method of this invention;

FIG. 4 is a longitudinal sectional view of the primary condenser 24 shown in FIG. 3;

FIG. 5 is diagrammatic representation of a modified embodiment of this invention; and

FIG. 6 is a diagrammatic sectional view of the injector shown in FIG. 5.

When a coolant is caused efficiently to cool the adsorbing agent, preferably by direct contact, its cooling efficiency can be improved and hence the cooling time can be shortened. As a consequence, it is possible to quickly respond to a minute change in the temperature of the absorption bed and to decrease the quantity of the coolant.

The coolant utilized may be an inert coolant, that is a coolant that does not contaminate the gas to be treated, or a coolant that can readily be removed in a subsequent step. For example, where exhaust gas from a nuclear power plant is to be treated air is contained in the exhaust gas so that admission of inert nitrogen gas does not cause any trouble. Accordingly, it is advantageous to use liquid nitrogen as the coolant. It is desirable that the liquid nitrogen is pure as far as possible. Although any well known absorbing agent may be used so long as it does not react with the coolant. In this manner, the coolant and the absorbing agent utilized in the primary condenser are selected in accordance with the type of the radioactive rare gases to be treated.

The invention will now be described in detail.

A typical example of gas to be treated is the waste gas exhausted from a nuclear reactor of the BWR type from a plant treating the burnt fuel and comprises a mixture consisting of a major proportion of air (O_2, N_2, etc.) and about 1 to 200 ppm of radioactive Kr and 0.08 to 200 ppm of radioactive Xe.

As described above, according to one aspect of this invention, the released gas containing oxygen and radioactive rare gases is treated by one or more reactive metals selected from a group consisting of zirconium, titanium, copper and alloys thereof. These metals or alloys absorb and fix the oxygen in the released gas but do not absorb the radioactive rare gases thus increasing the concentration thereof. In addition, it is not necessary to install a hydrogen bomb or a hydrogen generating plant near the treating and recovering plant, thus increasing the safeness.

The reactive metal and alloy may be used singly or in combination. The components of the reactive metal other than zirconium, titanium and copper are used for the purpose of removing other gases than the radioactive rare gases, and oxygen, that is nitrogen. Accordingly, the composition of the reactive metal or alloy is determined in accordance with the composition of the gas to be treated.

One important factor necessary to remove the oxygen component from a gas mixture is the surface area of the reactive metal, that is the area in which the metal reacts with the oxygen, because the reactivity of the metal increases in proportion to the surface area thereof. For this reason, where the reactive metal is used in the secondary condenser for concentrating the exhaust gas from a nuclear power plant (in this case, the volumes of the oxygen and the radioactive rare gases in the gas mixture are nearly equal) the surface area of the reactive metal should be more than 10 cm^2 per 1 ml of the oxygen. As has been described above, zirconium, titanium and copper do not absorb the radioactive rare gases to any appreciable extent but absorb and remove substantially only oxygen (depending upon the composition of the reactive metal, nitrogen may also be removed).

There is no limit on the shape of the reactive metal. However, for the purpose of increasing the surface area and hence the activity, spheres, granules, powders, wire nets, fibers, foils or sheets are preferred.

When approximately 16%, by weight, of aluminum is incorporated into the reactive metal, and when the reaction system is heated to a temperature of about 400°C, it is possible to absorb and remove oxygen together with a substantial amount of nitrogen.

Although different depending upon the type of the reactive metal, the reaction temperature between the reactive metal and the oxygen and nitrogen generally ranges from about 400 to 800°C because within this range, it is not only economical but also the reaction with oxygen and nitrogen undergoes efficiently.

Preferred reaction pressure is at about the atmospheric pressure or at a slightly higher or lower pressure in view of economy although the pressure varies depending upon the reaction temperature and the type of the reactive metal. Thus, in this invention the reaction pressure is not critical.

Further, the reaction time is normally from 1 to 50 hours although different depending upon the reaction temperature, the reaction pressure and the type of the reactive metal. With a reaction time of less than 1 hour, the oxygen or nitrogen will not be reacted sufficiently. On the other hand, too long reaction time is uneconomical.

Since the reaction between oxygen and nitrogen and the reactive metal is effected under mild conditions, the method of this invention is extremely safe when compared with the prior art activated carbon bed method and recombiner method.

When the activity of the reactive metal decreases due to the reaction with oxygen and nitrogen, that is when the entire or substantially entire activity of the reactive metal is lost, the reactive metal is discarded. Where the reactive metal consists of copper or copper alloy, the used reactive metal can be regenerated by heating it to a temperature of 800° to 1000°C to remove oxygen.

FIG. 3 diagrammatically shows one example of the apparatus utilized to carry out the method of this invention. Similar to the prior art apparatus shown in FIG. 1, the apparatus shown in FIG. 3 comprises a pretreating system 21 for removing water and carbon dioxide from the waste gas from a nuclear power plant, a heat exchanger 22, a primary condenser 24, a pump 25, a secondary condenser 26, an exhaust pump 28 and a recovery bomb . According to this invention the secondary condenser 26 is charged with one or more reactive metals described above. In this embodiment, as shown in FIG. 4, the primary condenser 24 is different from that shown in FIG. 2 in that instead of passing the liquid nitrogen through the coil 15, it is admitted into the primary condenser 24 through an inlet port 16, and that an inverted cone type perforated gas distributor 17 is mounted on the adsorbing bed 13.

To efficiently absorb the gas to be treated, the adsorbing bed 13 should be cold. Accordingly, after regenerating the bed by heating the same for releasing the adsorbed gas and by exhausting the released gas as by pump 25, the coolant, liquid nitrogen in this case, is admitted into the primary condenser 24. The liquid nitrogen evaporates in the condenser and the nitrogen gas adjusts the pressure in the absorption system. When the absorbing bed 13 has been cooled sufficiently, the waste gas is passed through the primary condenser. Since the adsorption bed 13 is maintained at a constant low temperature it is possible to pass the waste gas continuously or intermittently. When the activity of the absorbing bed 13 decreases, the primary condenser 24 is heated by suitable heating means, not shown, to regenerate the absorbing bed.

FIG. 5 shows another embodiment of this invention comprising an ejector 31, a pretreating system 32 for removing water and carbon dioxide from the waste gas exhausted from a nuclear power plant, a heat exchanger 23, absorption tanks 34a and 34b which act as a primary condenser, valves A, A′, B, B′, C, C′, D and E, a vacuum pump 35 and an exhaust pump 37 which are connected as shown and operate in a manner to be described later.

In the ejector 31, compressed gas from a recirculation pipe 36 may be used as the operating gas for compressing the waste gas, but it is advantageous to use a single stage or multistage steam ejector wherein the steam operating as the operating fluid may contain radioactive rare gases. In a multistage type, compressed gas from the recirculation pipe 36 may be used at an intermediate stage.

FIG. 6 diagrammatically illustrates a steam jet ejector 31 suitable for use in this invention. In this example, steam or a mixture of steam and recirculation gas, is ejected through a nozzle 39 and the waste gas is sucked into the ejector through an inlet pipe 38 by the partial vacuum created by the steam jet. The steam is condensed by a condenser 10 and the condensed water is discharged through a pipe 41. Not condensed oxygen, radioactive rare gases, etc, are discharged through pipe 42 to the pretreating system.

In the pretreating system 32 are provided a water removing apparatus and a carbon dioxide removing apparatus. These apparatus may include a molecular sieve column, a heat exchanger for removing frozen water particles, and a caustic soda column. The heat exchanger 33 may be of the indirect heat exchange type. But counter flow type is preferred. The absorption tanks 34*a* and 34*b* have the same construction and contain activated carbon beds or molecular sieves as the absorbing agent. Heating and cooling of these tanks may be done by using well known heating and cooling means. The vacuum pump 35 and the exhaust pump 37 may be of the same type. Rotary pumps are preferable than reciprocating pumps.

The method of concentrating the radioactive rare gases in the waste gas discharged from a nuclear power plant comprises three steps of absorption, recycling and the final concentration.

Absorbing step

The waste gas is sent to the pretreating system 32 by the ejector 31 to remove water and carbon dioxide. Then the waste gas enters into the absorption tank or bed 34*a* via heat exchanger 33 and valve A. The absorption tank 34*a* is cooled to a temperature of from −150°C to −170°C to absorb the radioactive rare gases. Not absorbed gas, that is air or a mixture of air and nitrogen, is discharged to the outside by vacuum pump 35 through heat exchanger 33 and valve C, thus cooling the waste gas. The gas discharged from the vacuum pump 35 is discharged into the atmosphere, preferably through a chimney. The vacuum pump 35 is used to maintain the absorption tank and the heat exchanger at a suitable pressure, but its use is not essential. If desired, the pressure in the absorption tank 34*a* may be maintained at a reduced pressure of 0.3 atmospheric pressure. Where the activity of the absorbing agent in the absorbing tank 34*a* decreases or breaks through (which may be calculated) valves A and C are closed, and valves A′ and C′ are opened for substituting absorbing tank 34*b* for tank 34*a*.

Recycling Step

While the rare gases are being absorbed in the absorbing tank 34*a*, the recycling step is performed in the absorbing tank 34*b* which has completed an adsorbing step. In this case, valves A′, C′ and E are closed but valves B′ and D are opened and the temperature in the absorbing tank 34*b* is increased to release adsorbed rare gases. The concentrated rare gases thus released are supplied to the ejector 31 via pipe 36 to be mixed with the waste gas. Although different depending upon the regeneration temperature, the type of the adsorbing agent, the efficiency of release and thermal efficiency, the regeneration temperature normally ranges from 50 to 150°C. After a predetermined time the absorbing tank 34*b* is cooled and the valve B′ is closed to prepare for the next absorption step.

Above described absorption and recycling steps are repeated several times by alternately using tanks 34*a* and 35*b* and thereafter the final concentration step is performed in the following manner.

Final Concentration step

This step is performed by using either the absorbing tank 34*a* or 34*b* which has completed its absorption step. It is now assumed that the final concentration step utilizes the absorbing tank 34*b*. In this step, the temperature of the tank 34*b* is raised to a temperature (preferentially air releasing temperature) which is higher than the absorption temperature but lower than the regeneration temperature, and the values B′ and D are opened to supply to the ejector air rich released gases through pipe 36. When the vacuum in the tank 34*b* decreases to a predetermined value, valves B′ and D are closed to terminate the initial recycling step of the released gases. The preferentially air releasing temperature and the predetermined degree of vacuum at this stage are −100°C to −50°C, and 1—100 mm Hg. absolute respectively although different depending upon the type of the adsorbing agent. After heating the absorbing tank 34*b* to a regeneration temperature valves B′ and E are opened and the exhaust pump 37 is operated to send the concentrated rare gases to the secondary condenser. Regardless whether valve B′ is closed or opened the switching between the recycling step and sending of the gases to the secondary condenser can be accomplished by closing valve D and opening valve E.

As can be noted from the foregoing description, one cycle of the operation of this modified method of this invention comprises n absorbing steps (n ≧ 2), (n – 1) recycling steps and one final concentration step. By repeating the cycle it is possible to substantially continuously treat the waste gas containing radioactive rare gases.

According to this modified method of this invention wherein radioactive rare gases are concentrated and recovered by recirculating released gases through an ejector and by alternately using a plurality of regenerative absorbing tanks, the efficiency of concentration is greatly improved over one through process described in connection with FIG. 3, whereby the load on the secondary condenser can be reduced greatly. Furthermore, as the quantity of the released gas during the recycling steps and final concentration step is stabilized, the utilization efficiency of the absorbing tanks or beds can be improved. The use of an ejector eliminates a compressor in the recirculation pipe thus enabling the system to operate under a relatively low pressure. This greatly decreases the leakage of harmful radioactive rare gases. A flow quantity adjusting tank may be included in the recirculation pipe 6 for reducing the pulsation in the gas pressure.

To demonstrate the effectiveness of the method and apparatus of this invention, the following examples are given but not limiting.

Example 1.

Apparatus shown in FIG. 5 was used, and exhaust gas consisting essentially of air containing 1 ppm of Kr, and 0.08 ppm of Xe was admitted into the absorbing bed 34*a* cooled to a temperature of –170°C at a flow rate of 40 Nm³/hour. Each of the absorbing beds 34*a* and 34*b* had an inner volume of 900 l and contained 130 l of pellet shaped activated carbon. Initial cooling of the beds was effected by injecting liquid nitrogen into the absorption beds and heating thereof was done by electric heaters provided for the beds. The pressure at the time of absorption was 0.7 atmospheric pressure. After continuous absorption by bed 34a for 24 hours, the flow of gas was switched to the absorbing bed 34b. Thereafter, valves A, C and E were closed and the valves B and D were opened. Then the temperature of the bed 34*a* was raised and the released gases were recirculated through the ejector 31. These adsorption and releasing steps were repeated 10 times by alternately using the absorbing beds 34*a* and 34*b*. After the 11th absorption steps, valves A and C were closed and valves B and E were opened. Then, the temperature of the bed 34a was increased to –100°C to release the absorbed gas other than rare gases. When the pressure in the absorbing bed 34a has decreased to 10 mm Hg, absolute, valve D was closed and valve E was opened. The bed 34*a* was heated to 100°C, and when the pressure therein has decreased to 10^{-3} mm Hg absolute, valves B and E were closed, thus terminating the final concentrating step. The volume of the gas recovered by one cycle including 10 recycling steps was 560 Nl, of which Kr was 1.06 Nl, Xe was 0.77 l, the percentage of the rare gases being 3.6%. The degree of concentration corresponds to 19000 times.

For comparison one through method was carried out. That is without using the recycling steps, the gases were only once absorbed and released as in FIG. 3. In this case, the degree of concentration was only 1700 times. These results are shown in the following table 1 from which it can be readily noted that the recycling method is far more excellent than the once through process.

Table 1.

number of recyclings	amount of concentrated rare gases (Nl)	degree of concentration
once through process	Kr 1.06 Xe 0.77	1700
10	Kr 12 Xe 8.4	19000

Example 2.

53 kg of activated carbon acting as the absorbing agent was charged in the

tanks shown in FIGS. 2 and 4 each having an inner volume of 900 l. The quantities of the liquid nitrogen required to cool the absorption beds to a desired temperature are shown in the following table 2.

Table 2.

	quantity of liquid nitrogen
direct cooling (FIG. 4)	305 l
indirect cooling (FIG. 2)	1110 l

Remark. According to the direct cooling, the heat corresponding to the difference between the latent heat of evaporation of liquid nitrogen and the temperature difference (50°C—196°C)/2 was used for cooling whereas according to the indirect cooling, only the latter was used. This table shows that the cooling efficiency of the direct method is about 3 times higher than that of the indirect cooling method.

Example 3.

This example shows the use of Zr, Ti and Cu as the reactive metals and the results are shown in the following table 3 together with reaction conditions.

Table 3.

metal	shape and amount (Kg)	reaction temp. (°C)	reaction pressure (atm.)	reaction time (hr.)	amount of gas (Nl)		
						before reaction	after reaction
Zr	Spheres having a radius of 0.1 cm 6.3	700	1	10	N_2	240	239
					O_2	60	—
					Kr	30	30
					Xe	24	24
Ti	Spheres having a radius of 0.1 cm 9.2				N_2	240	220
					O_2	60	—
					Kr	30	30
					Xe	24	24
Cu	Spheres having a radius of 0.1 cm 8100				N_2	240	240
					O_2	60	—
					Kr	30	30
					Xe	24	24

WHAT WE CLAIM IS:—

1. A method of concentrating and recovering radioactive rare gas wherein waste gas containing said rare gas and oxygen is contacted against an absorption agent contained in a primary condenser and maintained at a low temperature so as to absorb said rare gas by said absorption agent, the temperature of said absorption agent is raised to release the absorbed rare gas, and the released rare gas is recovered by a secondary condenser, wherein said released radioactive rare gas is treated in said secondary condenser with one or more reactive metals consisting of

zirconium, titanium, copper or alloys thereof for absorbing and fixing the oxygen in the released gas but not absorbing the radioactive rare gases.

2. The method according to claim 1 wherein said waste gas is exhausted from a nuclear power plant and consists of a major proportion of air and a minor proportion of radioactive krypton and xenon gases.

3. The method according to claim 1 wherein inert coolant is admitted into said primary condenser at the time of initial cooling of an absorbing bed.

4. The method according to claim 3 wherein said inert coolant is liquified nitrogen.

5. The method according to claim 1 which further comprises the steps of recirculating said released rare gas through said primary condenser together with said waste gas, and repeating said absorption and release of said rare gas several times.

6. The method according to claim 1 wherein the component of said waste gas other than said radioactive rare gas and not absorbed by said absorbing agent is discharged to the outside.

7. The method according to claim 5 wherein after repeating said absorption and release of said rare gas a predetermined number of times the temperature for releasing the absorbed rare gas is increased stepwisely.

8. The apparatus for carrying out the method according to claim 5 which comprises a plurality of absorbing tanks each provided with cooling means, heating means, and an absorbing bed, an ejector for supplying to said absorbing tanks waste gas containing radioactive rare gas for absorption of the radioactive rare gas by said absorbing beds, valve means for causing said absorbing tanks to alternately operate to absorb said rare gas and to release absorbed rare gas when under suitable temperature conditions, means to recirculate the released rare gas through said ejector for admixing the released rare gas with said waste gas, a succeeding recovering device containing one or more reactive metals consisting of zirconium, titanium, copper, or alloys thereof, and a pump for sending the released rare gas to said succeeding recovering device.

9. The apparatus according to claim 8 which further comprises a heat exchanger connected between said ejector and said absorbing tanks and means for discharging to the outside of the apparatus the component of said waste gas other than said radioactive rare gas after passing through said heat exchanger.

10. The apparatus according to claim 8 or claim 9 wherein each absorbing tank comprises a heat insulating layer surrounding the tank, an absorbing bed contained in said tank and means for admitting inert coolant into said tank.

11. The apparatus according to claim 10 wherein said inert coolant is liquid nitrogen.

12. A method of concentrating and recovering radioactive rare gas according to claim 1 and substantially as hereinbefore described with reference to Figures 3 and 4, or Figures 5 and 6 of the accompanying drawings.

13. Apparatus for carrying out the method according to claim 1 and substantially as hereinbefore described with reference to Figures 3 and 4, or Figures 5 and 6 of the accompanying drawings.

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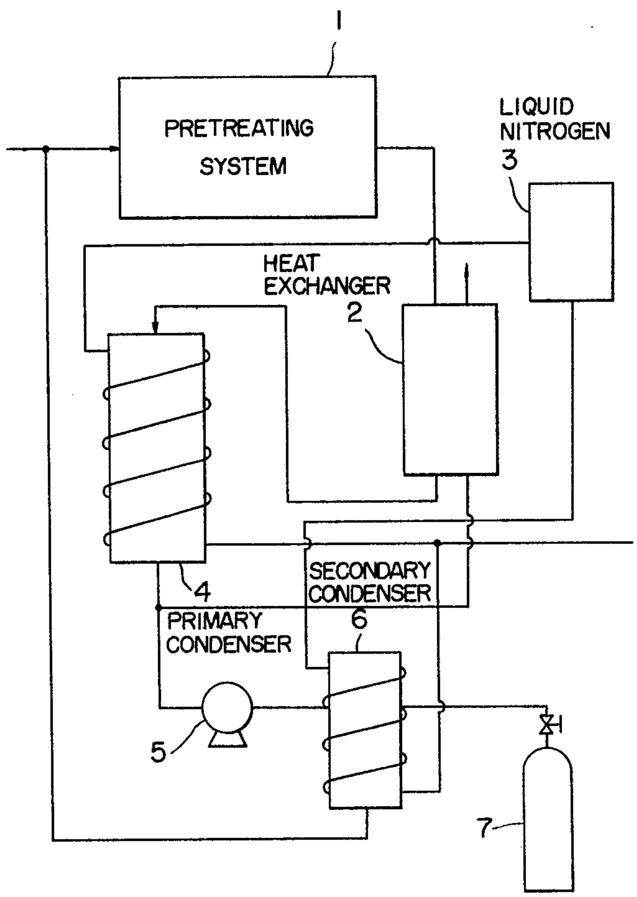
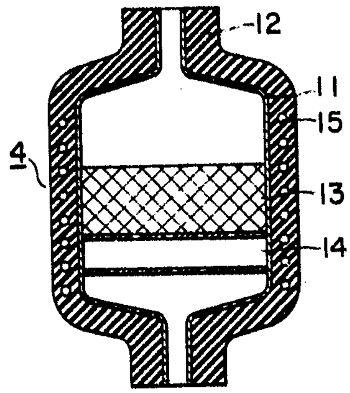
FIG. I

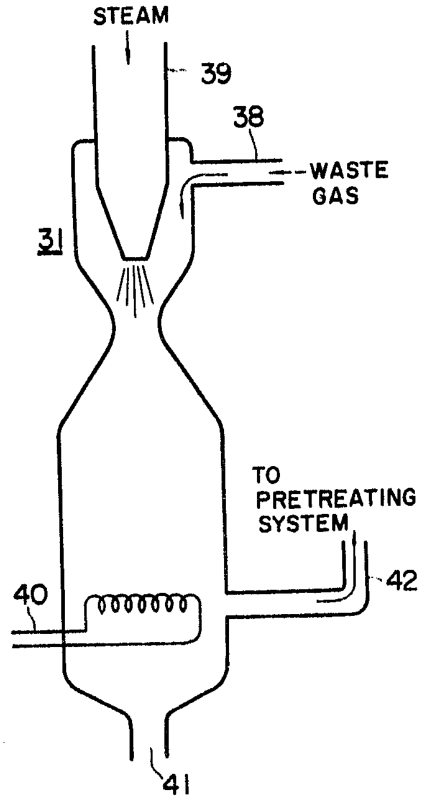
PRIOR ART



F I G. 2



F I G. 6



F I G. 4

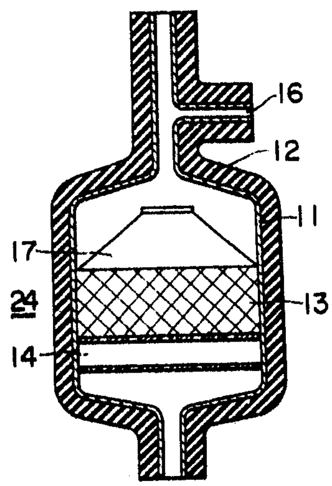


FIG. 3

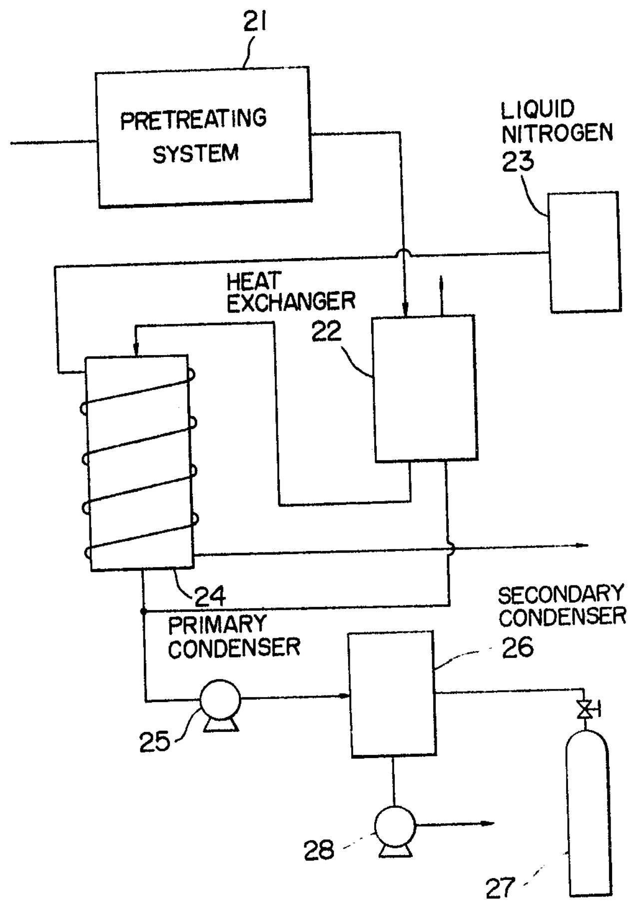
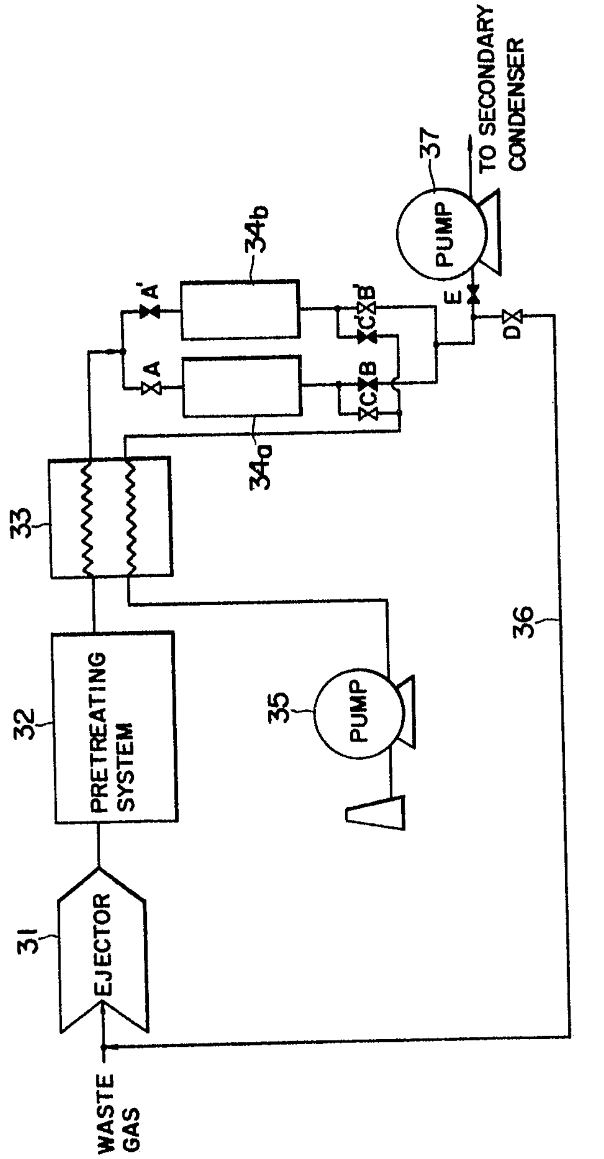

21
PRETREATING SYSTEM
LIQUID NITROGEN
23
HEAT EXCHANGER
22
24
PRIMARY CONDENSER
SECONDARY CONDENSER
26
25
28
27

FIG. 5


WASTE GAS
31
EJECTOR
32
PRETREATING SYSTEM
33
34a
34b
A
A'
B
B'
C
C'
D
E
35
PUMP
36
37
PUMP
TO SECONDARY CONDENSER