

Nov. 3, 1959

J. I. YELLOTT ET AL
ASH SEPARATOR FOR POWDERED COAL BURNING
PRESSURIZED COMBUSTION SYSTEM

2,911,065

Filed Jan. 7, 1953

10 Sheets-Sheet 1

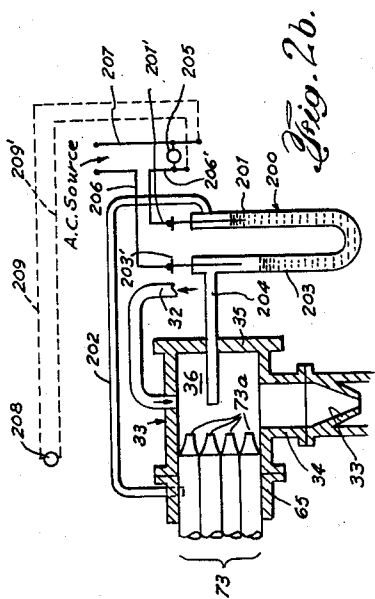
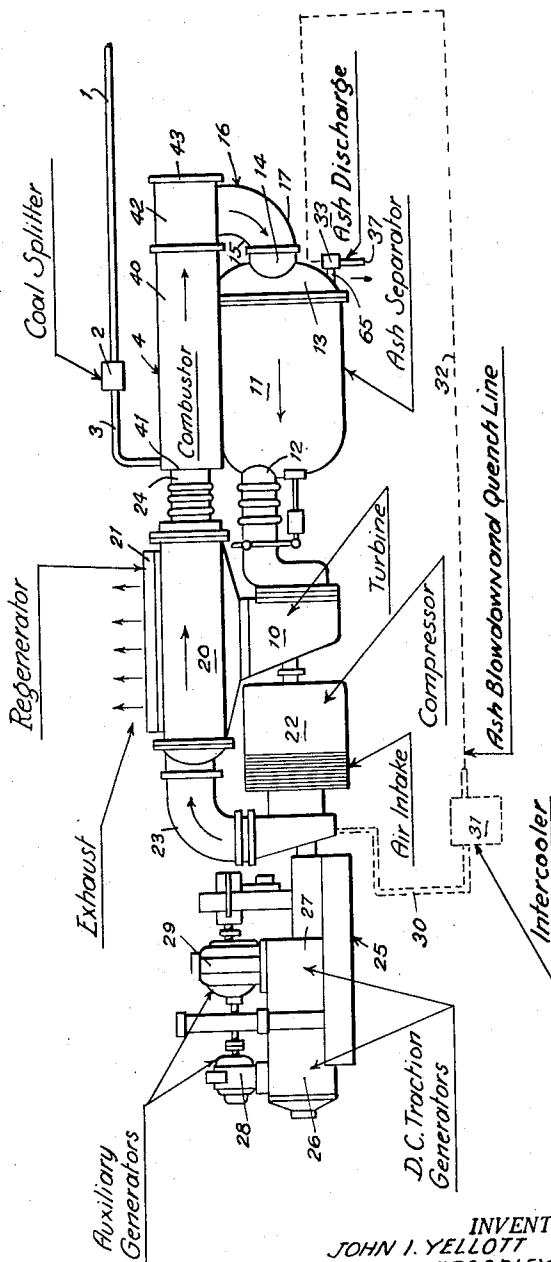


Fig. 1.



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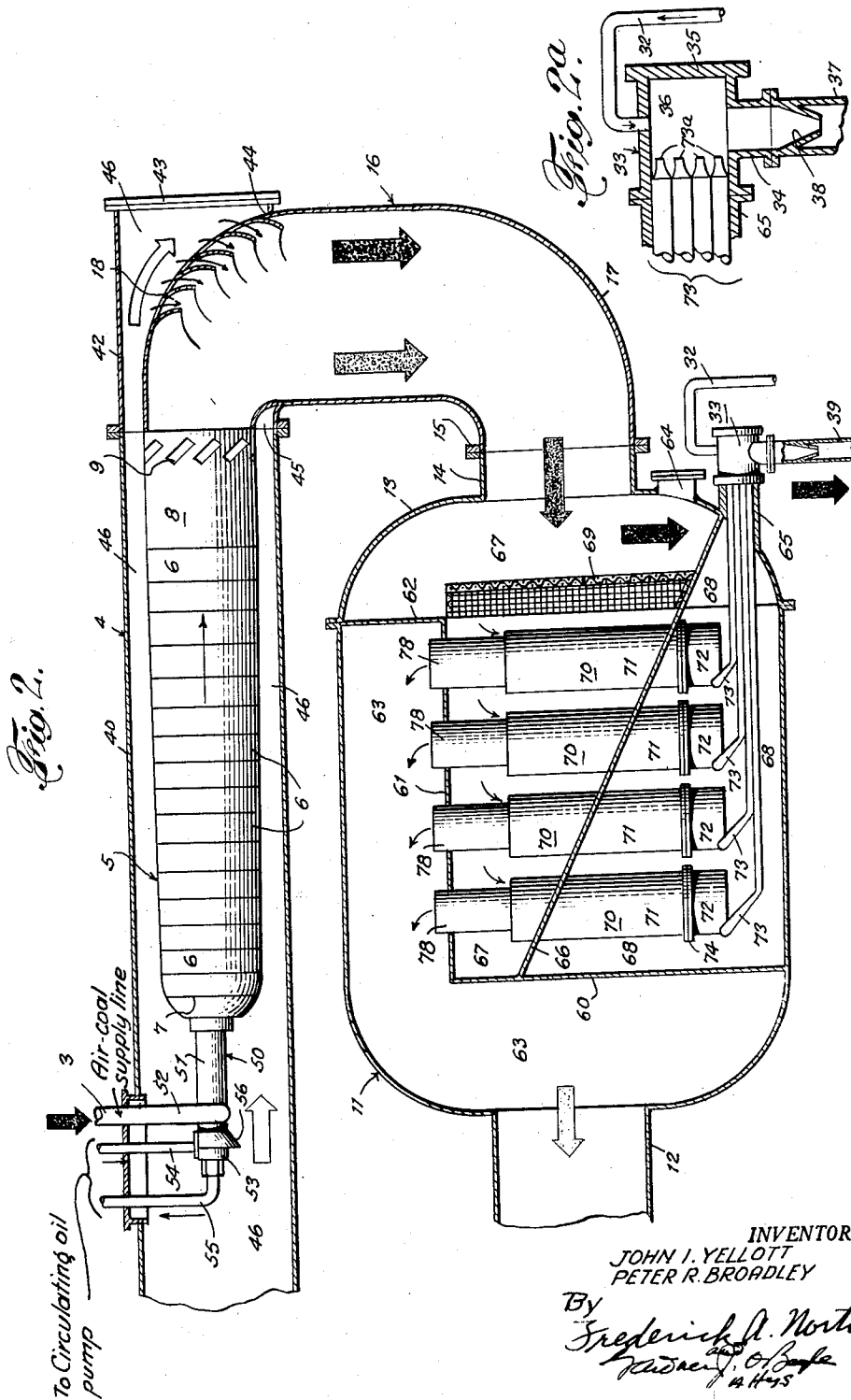
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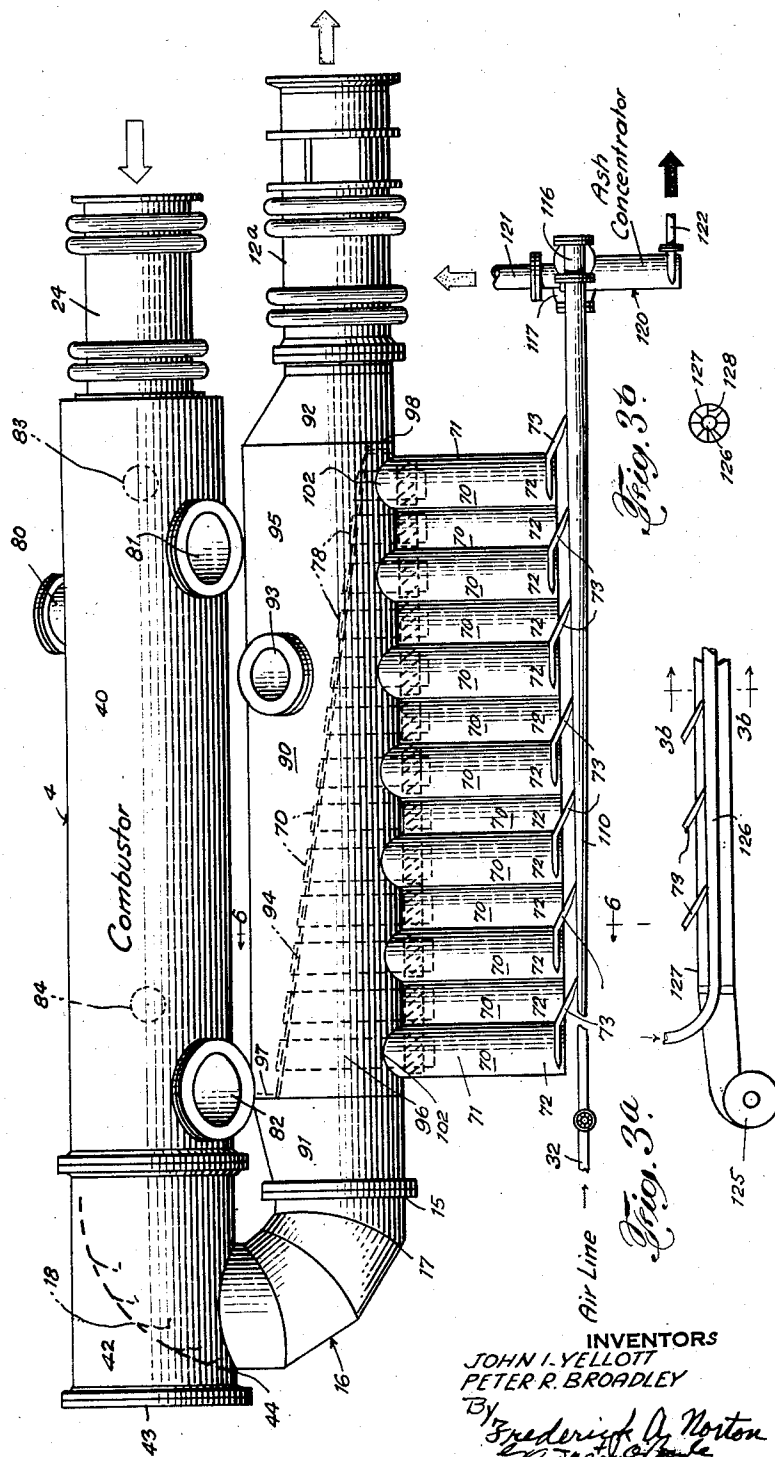
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Fig. 3.



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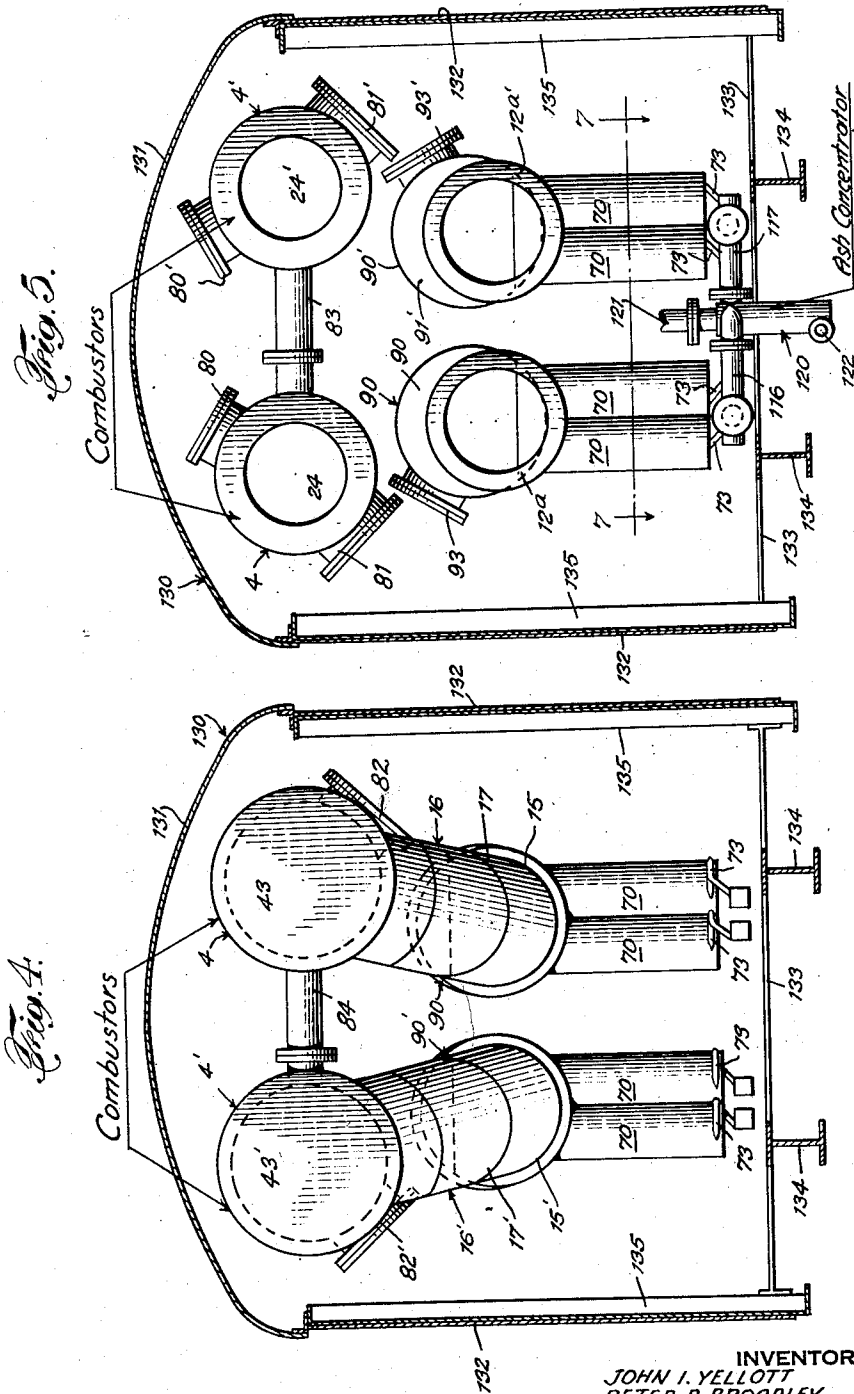
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Fig. 11.

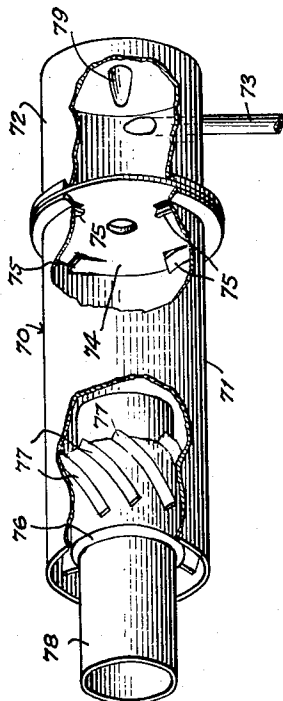
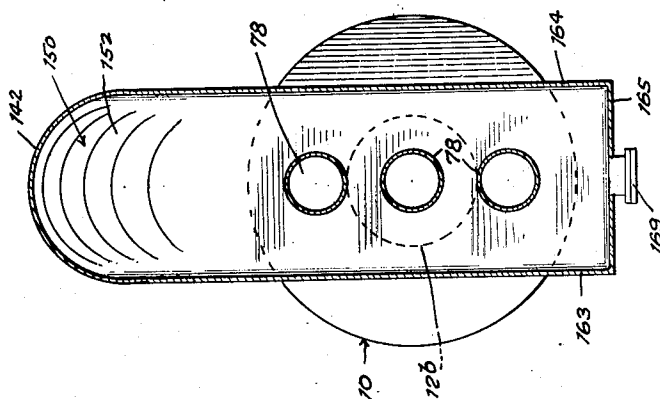


Fig. 10.



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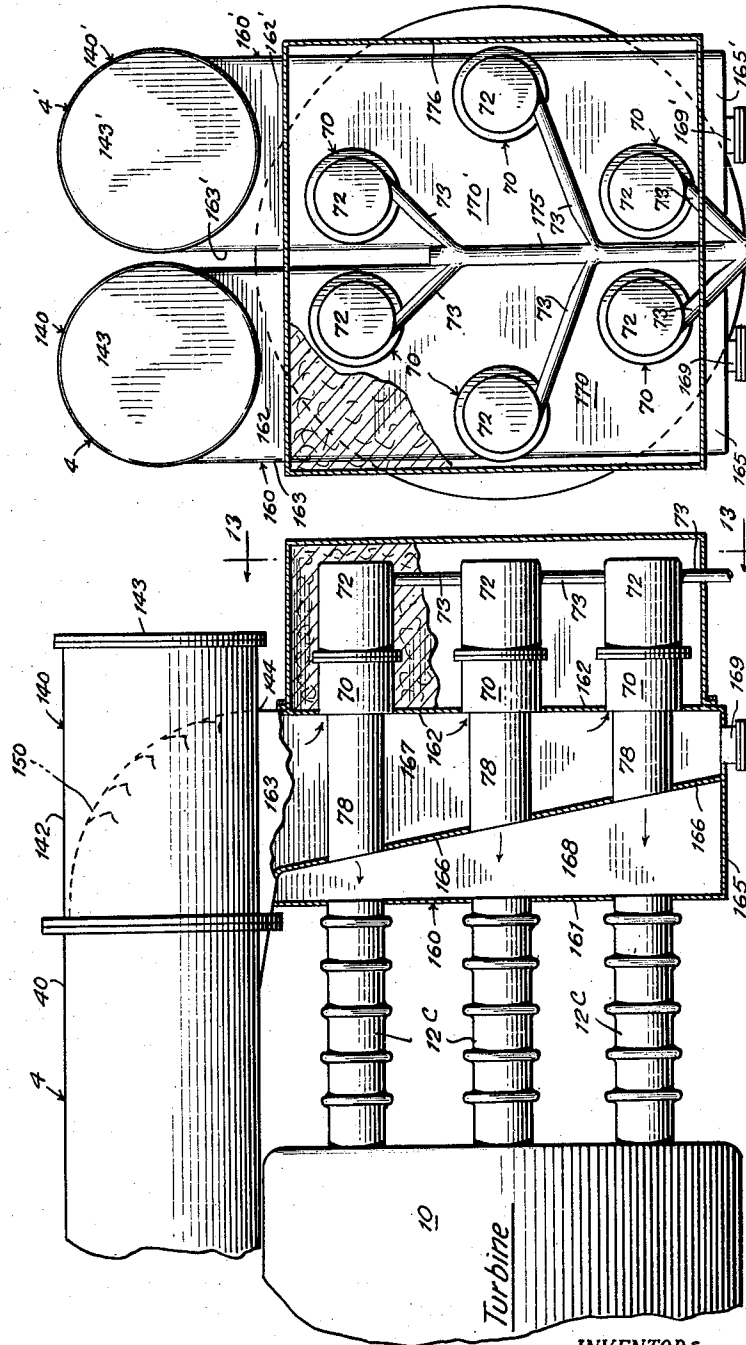
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Fig. 13.

Fig. 12.



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Fig. 15.

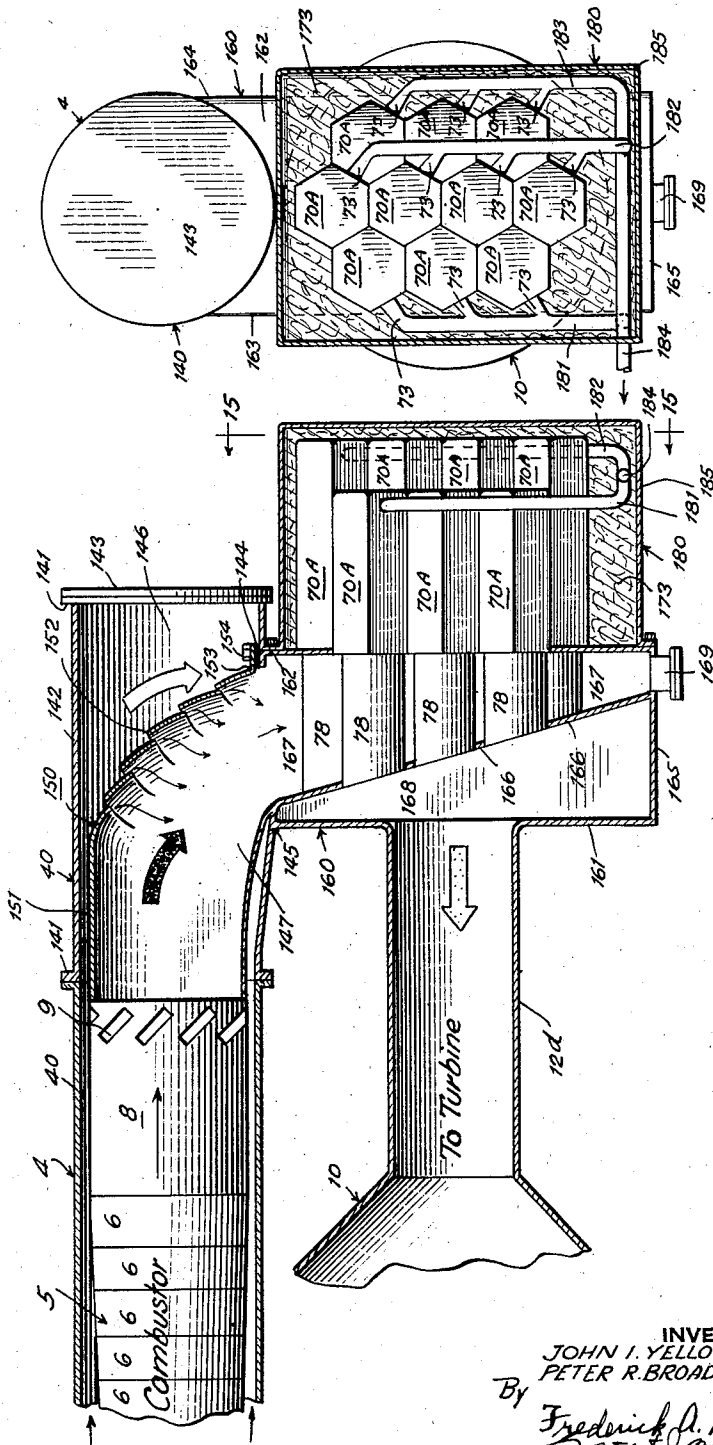


Fig. 14.

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ASH SEPARATOR FOR POWDERED COAL BURN-
ING PRESSURIZED COMBUSTION SYSTEM

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Application January 7, 1953, Serial No. 330,077

4 Claims. (Cl. 183—80)

This invention relates to pressurized combustion and ash disposal systems, and to coal-burning gas turbine power plants utilizing heated motive fluids resulting from the pressurized combustion of fluidized, residue-forming fuels, such as pulverized coal, as streaming entrainments of discrete particles in combustive air streams. The invention also relates to special ash separating and disposal equipment operatively integrated with coal-burning pressurized combustion systems, the said equipment incorporating novel pressure-sustaining vortical whirl separators specially arranged in batteries having input and output plenum chambers in mutual heat-exchanging relation. Because of the reduced bulk of the component parts of the novel power plants herein, they are specially adapted for use as prime movers for the generators of generating electric locomotives.

The space and operative requirements of power plants for locomotives are rigidly restricted. This means that all necessary equipment must be as small as possible, consonant with the power required. More power in less space is possible with gas turbines, and it is interesting to note the following comparison of horsepower per cubic foot of essential space among several typical power plants:

Item:	H.P. per cu. ft.
Diesel electric locomotives.....	0.535
Destroyers	0.685
Central stations.....	0.0537
Gas turbine electric locomotives.....	1.02

Considering the economic advantages of the invention herein, and using the diesel-powered generating electric locomotive as a norm or basis of comparison, the following figures, based upon present average prices, are instructive: (1) At an average price of approximately \$5.30 per ton, a million B.t.u., in the form of bituminous coal, cost the railroads 22 cents. Diesel fuel, at 9.79 cents per gallon, costs 76 cents per million B.t.u.; (2) the gas turbine herein, although less efficient than the highly developed railroad diesel engine, can burn low cost bituminous coal. The diesel must use high priced oil. The efficiency advantage which the diesel enjoys over the gas turbine is not enough to overcome the three-to-one differential in fuel costs; (3) at all loads above 10% of full load, the gas turbine herein burns less dollars worth of fuel per hour than comparable locomotive diesel engines. For example, at 4000 shaft H.P. the turbine burns only \$11.20 worth of coal per hour; a pair of 2250 H.P. diesels turning out 4000 shaft H.P. will use \$22.75 worth of oil per hour.

Fuel costs for coal-burning gas turbine power plants rise from \$4.00 per hour at idling to \$12.80 per hour at full load, 4250 shaft H.P. Oil for diesels costs less than \$1.00 per hour at idling, but reach \$25.60 per hour at 4250 shaft H.P. The break even point is approximately 700 H.P. The savings in fuel cost of operating a coal fired gas turbine power plant as against the cost of operating a diesel, with uniform power output, and based on

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operating test data, as of the date of filing this application, are listed in the table below:

Saving in fuel cost—coal-fired gas turbine vs. diesel

Horsepower Output	Fuel Cost, Dollars per Hour		
	Two 2,250 H.P. Diesel Engines	One 4,250 H.P. Coal- Fired Gas Turbine	Savings: Dollars/Hr. With Gas Turbine
4,250.....	\$25.60	\$12.80	\$12.80
4,000.....	22.75	11.20	11.55
3,500.....	20.00	9.10	10.90
3,000.....	17.15	8.00	9.15
2,500.....	14.50	7.20	7.30
2,000.....	11.77	6.40	5.37
1,500.....	8.92	5.90	3.02
1,000.....	6.25	5.00	1.25
750.....	4.90	4.60	.30

To take the fullest advantage of economies now available, and to develop other worthwhile economies, hitherto thought impossible, the improvements of the present invention comprehend the utilization of combustion and ash handling equipment of novel design. In accordance with the teachings of the present invention, the initial cooling of solid residues from the combustor is effected by the secondary air of the system, while in the preferred form of the invention the ash removal equipment is simplified by eliminating pressure-sustaining casings for housing the batteries of vortical whirl separators, which separators now function as individual pressure-sustaining vessels, suitably insulated in light weight housings. The marked economies effected in weight reduction of the parts of the power plants herein are accompanied by important increases in operative efficiency. This desirable combination permits added savings in locomotive manufacture, operation, and maintenance, as well as in marine and stationary power plants.

The foregoing desiderata are substantially accomplished by the novel improvements of the present invention, according to which ash separator plenum chamber casings of uniform cross-section incorporate juxtaposed wedge-shaped input and output plenum chambers, of mutually inverse cross-section, in heat-exchanging relation. Vortical whirl separators of the type described and claimed in our prior application, Ser. No. 257,702, filed November 23, 1951, for Vortical Whirl Separators and Method of Operation, are operatively coupled to the said casings. The barrels and adjacent discharge sections of the individual separators are secured on the outside of the input plenum chamber, and in fluid communication with the interior thereof, while the cleaned gas discharge tubes of the separators are hermetically embouched in the partitions or septa dividing the input and output plenum chambers, and deliver cleaned gas to the output or cleaned gas plenum chambers, whence it is delivered to gas turbines or other use devices, through suitable ducts.

The invention herein provides for increased efficiency of operation of gas turbine power plants using residue-forming fuels, in that the pressure losses inherent in earlier designs are substantially reduced through the elimination of sudden enlargements and reductions in the diameter of the gas-conveying conduits. By providing suitable housings or sheathing for the externally oriented ash separating barrels, these members can be heat insulated with relatively inexpensive heat-insulating materials. The separator units can be maintained at a substantially uniform operating temperature, without distortion which would otherwise be caused by temperature inequalities. The external mounting of the separator tubes makes possible inspection, cleaning, and like procedures, without the necessity of closing down the plant in order to open or

dismantle the pressure tank hitherto used to contain the separator tubes.

The novel power plants of the present invention not only utilize the special vortical whirl separators of our above-identified application, ensheathed in pressure-sustaining tanks or vessels, but advance the art in teaching that the individual vortical whirl separators of our said prior application can now be made pressure-sustaining and self-supporting. As a result of this important discovery, it has been found that it is possible to eliminate the costly and unduly bulky pressure-sustaining tanks or vessels in which the vortical whirl separators have been housed, and to mount the novel pressure-sustaining and self-supporting vortical whirl separators exteriorly of the input plenum chambers of special motive fluid conduits, ducts, or casings. These novel motive fluid conduits connect a motive fluid source, such as a compressor and a combustor using residue-forming fuel dispersed in a current of combustible or primary air, with a use device, such as a gas turbine. The conduits, ducts, or casings, are divided, lengthwise (that is, in the direction of flow of the motive fluid) into a convergent wedge-shaped dirty gas input plenum chamber, and an output or cleaned gas plenum chamber, the said plenum chambers being incorporated in casings having a common interior wall which serves as a support for the hermetically embouched, cleaned gas discharge tubes of the vortical whirl separators, which tubes discharge cleaned gas into the output plenum chamber. Tangential blowdown lines for separated ash are provided for the discharge sections of the vortical whirl separators, and manifolds conduct the collective separated ash blowdown streams to an ash concentrator comprised of a single, low capacity (volume) vortical whirl separator, from which the concentrated ash is conveyed to suitable storage means, while the final quantum of cleaned gas is returned to the system, or vented to the atmosphere, as the exigencies of the operation of any particular installation may require.

The quenching of ash and other combustion residues, particularly unburned coal particles or agglomerates, must be effected as quickly as possible to prevent after-combustion in the pressurized ash separating equipment. The improvements of the present invention permit the separation of coarse combustion residues and unburned combustibles by projecting them from out of the rectilinearly flowing stream of motive fluid, combustion gases plus cooling and diluting secondary air, in which they are entrained, into a co-flowing, marginal stream of cooler, secondary air. This secondary air is introduced through louvers in the top of a down-comer duct mounted in the discharge end of the combustor casing, which casing, as will be described more in detail hereinafter, subserves the function of a secondary air plenum chamber. The downcomer duct causes an abrupt change in the direction of flow of the horizontally projected stream of ash- and combustion residue-bearing motive fluid gases, with the result that the said heavier entrained material is transferred to the down-flowing marginal stream of secondary air, and is cooled and quenched therein, according to the "ash-transfer" principle, enunciated in the application of one of us, John I. Yellott, Ser. No. 148,594, filed March 9, 1950, for Method and Apparatus for the Separation of Particulate Material From Entraining Gaseous Fluids, now Patent No. 2,650,675, issued September 1, 1953.

The downcomer ducts can be of various configurations, according to the particular installations in which they are to be incorporated, and are severally hermetically connected to the input plenum chambers of the novel ash separator batteries herein. Means are provided at the bases of the ducts, or in fore chambers of the input plenum chambers, for receiving and withdrawing separated, quenched residues from the motive fluid, the fly ash contained in the fluid being separated therefrom in its passage through the battery of special vortical whirl separators forming an integral part of the ash separator

system herein, and continuously removed from the system in a blowdown stream of motive fluid comprising up to 1-1½ percent of the total throughput volume of the fluid.

It is, therefore among the features of novelty and advantage of the present invention to provide coal burning gas turbine power plants for motivating generators of generating electric locomotives, the power plants being characterized by improved combustion and ash separating equipment.

A further feature of novelty and advantage of the invention herein is the incorporation of special ash transfer and quenching means in the combustor discharge ducts.

An additional feature of novelty and advantage is the provision of specially louvered downcomer ducts coupling combustion chambers with ash separating equipment, the louvered ducts receiving cooling secondary air from plenum chambers in combustor casings.

Another feature of novelty and advantage of the present invention is the provision of motive fluid conduit or duct means, forming plenum chamber casings hermetically divided, in the direction of flow, into dirty gas input and cleaned gas output plenum chambers, in mutual heat-exchanging relation, and coupling the cleaned gas plenum chambers with use devices, such as gas turbines, the motive fluid being stripped of entrained solids by passage through special vortical whirl separators, mounted externally of the motive fluid duct means and severally coupling the said dirty gas input and cleaned gas output plenum chambers.

It is also a feature of novelty and advantage of the present invention to provide ash separating means for the turbine motive fluid, the separating means being comprised of batteries of self-sustaining, heat-resistant and pressure-sustaining special vortical whirl separators, incorporating blowdown lines for separated ash, and with or without light-weight heat-insulating casings therefor.

Another feature of novelty and advantage of the present invention is the provision of flow restrictor means in the ash blowdown lines and the incorporation of tell-tale manometer means coupled across the flow restrictor means of the individual blowdown lines, whereby plugging of any blowdown line is promptly detected.

Other features of novelty and advantage of the present invention include the special orientation of vortical whirl separators in batteries, as well as specially shaped separators, assembled in juxtaposed honeycomb relation to form batteries of mutually supported ash separators, with the juxtaposed barrels of the separators being in mutual heat-exchanging relation.

With these and other important features of novelty and advantage which may be incident to the improvements herein, the invention consists in the parts and combinations to be hereinafter set forth and claimed, with the understanding that the several necessary elements comprising the invention may be varied in construction, proportions and arrangements, without departing from the spirit and scope of the appended claims.

In order to make the invention more clearly understood, there is shown in the accompanying drawings means for carrying the same into practical effect, without limiting the improvements in their useful application to the particular constructions, which, for the purpose of explanation, have been made the subject of illustration.

In the drawings, like numerals refer to similar parts throughout the several views, of which—

Figure 1 is a schematic showing of a coal burning, gas turbine-powered, generating electric locomotive power plant incorporating improved combustion and tank enclosed ash separating means;

Fig. 2 is a longitudinal section through a combustor and associated ash separator of Fig. 1, showing novel ash transfer means for initially separating and quenching incandescent and incompletely combusted fuel particles, and vortical whirl ash separating means housed in a pres-

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sure-sustaining vessel incorporating dirty gas input and cleaned gas output plenum chambers in mutual heat-exchanging relation;

Fig. 2a is a vertical axial section through the blowdown manifold (33) of the separator battery of Figs. 1 and 2, showing the flow-restrictor discharge ends of the individual blowdown lines together with the coolant or quenching air inlet, and the manifold discharge line incorporating a flow restrictor;

Fig. 2b is a sectional view similar to Fig. 2a, showing a manometer and associated alarm means coupled across the flow restrictor of one of the blowdown lines;

Fig. 3 is an elevational view of another combustor and one unit of an associated ash removal system having juxtaposed dirty gas inlet and cleaned gas outlet plenum chambers in mutual heat-exchanging relation, and incorporating a battery of special vortical whirl separators, the individual separators forming pressure vessels provided with tangential blowdown lines for ash discharge, the blowdown lines incorporating flow restrictor means and spacedly discharging into a flaring blowdown manifold coupled to a concentrator, the manifold having a valved coolant air inlet;

Fig. 3a is a diagrammatic showing of an external tubular forced air coolant means for the ash discharge manifold of Fig. 3;

Fig. 3b is a cross-section taken on line 3b—3b of Fig. 3a, and showing radial extended surface coolant fins and air ducts formed thereby with the external sheath tube and the manifold;

Fig. 4 is a transverse vertical section of the power car of a generating electric locomotive showing, in end elevation, the discharge ends of a pair of combustion units coupled to their ash separator units, as shown in Fig. 3;

Fig. 5 is a view similar to Fig. 4, showing the secondary air input ends of the combustors and the discharge output ends of the ash separator assemblies and the coupling of their ash blowdown systems to a common ash concentrator and blowdown unit;

Fig. 6 is a transverse section taken on line 6—6 of Fig. 3, showing the orientation of the vortical whirl separator units of the ash separators, and the mutual heat-exchanging relation of the dirty gas input and cleaned gas output plenum chambers;

Fig. 7 is a horizontal cross-section, taken on line 7—7 of Fig. 5, showing a pair of separator batteries and their constituent separator tubes with individual blowdown lines, together with the ash discharge manifolds and terminal vortical whirl ash concentrator coupled thereto;

Fig. 8 is a longitudinal section taken on line 8—8 of Fig. 9, through the discharge end of a combustor incorporating a downcomer duct having secondary air admitting louvers, and a modified ash battery having a box-like plenum chamber casing incorporating juxtaposed dirty gas inlet and cleaned gas outlet plenum chambers in mutual heat-exchanging relation, the dirty gas plenum chamber being hermetically coupled to the downcomer duct, with the individual vortical whirl separator units of the ash separator being shown in horizontal elevation, mounted exteriorly of the casing, and encased in an insulating housing;

Fig. 9 is a cross-section, taken on line 9—9 of Fig. 8, showing flow restrictive ash blowdown lines and discharge manifold therefor;

Fig. 10 is a cross-section of an input plenum chamber taken on line 10—10 of Fig. 8;

Fig. 11 is an elevational view, partly in broken section, of a horizontally mounted vortical whirl separator, showing the details of the barrel or primary separator chamber and the adjacent discharge chamber with its tangential blowdown line;

Fig. 12 is a view similar to Fig. 8, showing multiple cleaned gas expansion ducts axially aligned with the cleaned gas discharge tubes of the separator units and

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coupling the gas turbine and the cleaned gas output plenum chamber;

Fig. 13 is a vertical cross-section, taken on line 13—13 of Fig. 12, and showing duplex combustor and associated ash separator units, together with ash blowdown lines and common discharge manifold;

Fig. 14 is a longitudinal axial section through a combustor and associated ash separator, the flame tube and ash separators being shown in elevation, the separators being hexiform and mutually juxtaposed in a honeycomb assembly;

Fig. 15 is a cross-section taken on line 15—15 of Fig. 14, showing the rear elevation of the honeycomb assembly and associated ash discharge manifolds;

Fig. 16 is a view similar to Fig. 14, showing a honeycomb arrangement of hexiform vortical whirl separator units, together with a corresponding number of expansion ducts axially aligned with the cleaned gas discharge tubes of the separator units, and coupling the cleaned gas outlet plenum chamber to a gas turbine, and

Fig. 17 is a cross-section, taken on line 17—17 of Fig. 16, showing the mounting of duplex combustors and associated ash separators severally incorporating honeycomb assemblies of hexiform ash separator units, together with ash blowdown lines and manifolds therefor.

Referring now to Figure 1, there is shown, schematically, a gas turbine-powered generating electric power plant, particularly adapted for use in generating electric locomotives. Mechanical transmission of power from the turbine shaft is also envisioned. A special feature of the power plant herein is that it uses pulverized coal as a primary fuel for the generation of pressurized combustion gases, which, when suitably diluted with cooling air, and thereby brought to optimum turbine operating temperature, serve as the motive fluid for a gas turbine. Coal and other residue-forming fuels, such as bunker oil, introduce fine ash, incandescent and incompletely burned combustible particles, and other residues into the combustion gases, which residues and ash must be removed from the motive fluid and immediately quenched to avoid damage to the turbine blading and the ash separator equipment.

In the power plant, diagrammatically illustrated in Fig. 1, a high pressure combustive air line 1 delivers a streaming entrainment of combustive air-borne pulverized coal, from a suitable coal supply, not shown, to a coal splitter 2, which divides the coal-bearing combustive air stream into a plurality of equal streams, each of which is delivered to an air-coal feed line 3 of a combustor 4. While the invention will be generally described with reference to a single combustor, the invention comprehends the use of a plurality of combustors, as illustrated in each of Figs. 4, 5, 13, and 17, and each combustor of a plural assembly will be fed by a feed line, severally designated by the numeral 3, and jointly coupled to the coal-splitter 2. The gas turbine system illustrated herein is of the open cycle type, and the component parts will be described generally in their mutual cooperative assembly, before proceeding to a specific consideration of the novel combustor and ash separator assemblies forming the basic features of the invention herein.

A gas turbine 10 receives cleaned motive fluid from pressure-sustaining ash separator 11, through an expansion duct or ducts, designated generally by the numeral 12. The separator housing 11 houses a plurality of individual vortical whirl separators, whose structure and function will be adverted to more in detail hereinafter. The ash separator housing 11 has a flanged head 13, mounting one or more symmetrically disposed flanged inlet ducts 14, depending upon the number of combustors utilized in a particular installation. The inlet ducts 14 are coupled to the flanged discharge ends 15 of downcomer ducts 16 having a bottom elbow section 17, and a louvered top elbow section 18 mounted in the discharge end of the combustor casing and in fluid communication

with the flame tube thereof. The elbow sections 17 and 18 connect parallel legs of the U-shaped duct 16, and face in the same direction. Because of this feature, motive fluid from the combustor will undergo two abrupt changes in direction, resulting in a double change in direction and complete reversal of flow before entering the ash separator 11.

The turbine discharges exhaust motive fluid through stack 20 in which may be mounted a regenerator, indicated generally by the numeral 21, in heat-exchanging relation with the exhaust gases. The regenerator is supplied with combustion and cooling air from compressor 22, through duct 23. A second expansion duct or ducts 24 delivers the regeneratively heated air to the combustor or combustors 4, as the case may be.

The turbine shaft is operatively coupled to the air compressor 22, and to the generator assembly, designated generally by the numeral 25, and incorporating D.C. traction generators 26, 27, and auxiliary D.C. generators 28, 29, respectively used for field excitation of the main generators, and for lighting and the like.

As will appear more fully hereinafter, one of the features of the present invention is the use of a gaseous coolant, such as air, to cool the separated ash discharged in the blowdown streams from the special vortical whirl separators into the ash discharge manifolds. One method of attaining this result is indicated in Fig. 1, wherein air from duct 23 is passed through line 30 to cooler 31, and thence through line 32 to ash discharge manifold 33, which is coupled to the flanged head 13 of the pressure-resistant ash separator housing 11. The cooler 31 may be of any conventional type, such as a fan for passing cool ambient air in heat-exchanging relation with the pressure air line, or it may comprise a water-jacketed cooler. Where the line 30—32 is of sufficient length, and is exposed to the ambient air, the cooler 31 may be dispensed with. In any event, the function of cooler 31, or its equivalent, is to reduce the temperature of the compressed air in line 30—32 to below 400° F., (which is the threshold ignition temperature of powdered coal in air), before its introduction as a coolant into the ash blowdown system.

Turning now to Fig. 2, the specific details of the improved combustor and ash separator installation and their cooperative assembly will be considered. The combustor 4, is comprised of a main pressure sustaining body portion of casing 40, an inlet end 41, (Fig. 1), receiving air inlet duct 24, and an end cap piece 42. The end cap piece is flanged at both ends, and is closed with a cap plate 43. The member 42 is essentially a continuation of casing 40, and is of the same diameter. The upper, louvered elbow section 18 of the U-shaped downcomer duct is received in a suitable aperture in the wall of member 42, as shown in Fig. 2, and is hermetically secured therein by welding, indicated generally at 44. A combustion chamber 5 is comprised of a plurality of spacedly interfitted rings 6, a burner dome section 7, and a terminal mixing and discharge section 8 incorporating an annular array of radial apertures 9. An apertured, circular baffle plate or dam 45 is secured around the discharge end of combustor casing 40. The rings of the flame tube are desirably supported for free radial movement, and simultaneously held from substantial axial movement by the special mounting means disclosed and claimed in the patent application of Frederick D. Buckley, Ser. No. 257,165, filed November 19, 1951, now Patent No. 2,823,627 for Cold Wall Combustor With Flexibly Mounted Flame Tube. A plenum chamber 46 for secondary air is defined by and between the inside of casing member 40 and the flame tube 5. This plenum chamber extends downstream into the end of the combustor defined by member 42. A special burner, designated generally by the numeral 50, is mounted in the burner dome 7 of the combustor tube 5. This burner is more particularly disclosed and claimed in the applica-

tion of Paul M. Rotzler, Ser. No. 257,079, filed November 19, 1951, now Patent No. 2,858,779, for Powdered Coal Burner for Pressurized Combustors, and will not be described in detail, except as to the gross structure necessary to an understanding of the invention herein.

The burner 50 has a tubular body 51 extending into the burner dome 7. Member 51 is essentially a double-walled hollow tube having an annular discharge orifice for the chamber defined by and between the double walls. A tangential supply pipe 52 discharges into the rear end of the annular chamber of member 51, and receives a streaming entrainment of combustible air-borne pulverized coal from a feed line 3, described hereinabove. The burner 50 is a duplex structure and mounts an oil burner axially of the member 51. This oil burner has a barrel section 53 provided with inlet and outlet lines 54, 55, respectively, which lines are coupled to a pressurized oil supply, so that the burner is supplied with a circulating stream of pressurized oil. An air scoop 56 is mounted at the upstream end of member 51 and about oil burner 53, and serves to direct secondary air from the plenum chamber 46 in the combustor casing into the annular passage or duct defined by and between the oil burner and the circumjacent air-coal burner.

In the special form of ash separator illustrated in Figs. 1 and 2, there is shown a pressure-sustaining, heat resisting casing 11 having a dirty gas input duct 14 and a cleaned gas discharge duct 12. The casing 11 is divided internally into three chambers in the following manner: An internal vertical wall member 60 is hermetically secured to the sides and bottom of casing 11 upstream of the discharge duct 12, its top edge being disposed below the top of the casing but above the top of the outlet duct 12. A second, horizontal internal wall member 61, extends from the top of member 60 toward the curviform head section 13 of the casing, and is hermetically secured to the wall of the casing and to the wall member 60. A riser 62, or vertical wall member, is hermetically secured across the upstream edge of partition member 61, and to the casing wall, as shown. The internal wall members 60, 61 and 62, will be seen to define a cleaned gas output plenum chamber 63 with the inner surface of casing 11. The curviform head 13 of casing 11 is provided with a clean-out port 64 below the input duct 14, and with a subjoined flanged stub pipe or collar 65 hermetically secured to blowdown chamber 33. A fourth partition wall member or slope sheet 66 is diagonally disposed in the casing 11, as shown, with its sides and lower edge conformed to the interior of the casing and hermetically secured thereto, and the upper, or downstream edge, hermetically secured to partition member 60, and in subjacent, spaced relation to horizontal partition member 61. Diagonal partition member 66 defines a dirty gas input plenum chamber 67 with internal wall members 60, 61, 62, and the casing wall, including the curviform head 13. Member 66 also defines a chamber 68 with partition member 60, and the inner surface of the casing, including a portion of head section 13 thereof. A screen 69 serves to divide plenum chamber 67 into a fore chamber and an after chamber.

The casing 11, with its internal partitions, as described immediately above, serves as a pressure-sustaining housing for a battery of special vortical whirl separators of the type described and claimed in our application Serial No. 257,702, hereinabove identified and which we designate as the "Dunlab Tube." The special structural details of the novel vortical whirl separators of our said invention are shown herein in Figs. 3, 6, 7, and 11, and the description thereof will be repeated here, in view of the critical importance of these devices as integral parts and key members of the ash separating systems herein. These devices, designated generally by the numeral 70 (Fig. 11), comprise primary separator or barrel sections 71 and adjacent bottomed discharge sections 72 provided with tangential blowdown lines 73, as shown. An axially

apertured diaphragm 74 is mounted between the barrel and discharge sections of the separators. These diaphragms are provided further with marginal struck-up skimmer blades 75, extending into the barrel section and defining peripheral apertures establishing fluid communication between the said barrel and discharge sections, whereby centrifugally separated solids from the barrel section are delivered into the discharge section in spinning streams of motive fluid, and further separation of the solids then takes place with the eventual removal of the solids in a blowdown stream of motive fluid discharged through the tangential blowdown line 73. At the intake end of the barrel section there is provided peripheral vortical whirl imparting means for incoming dirty gas, and an axial cleaned gas outlet tube. In the form shown herein, a collar member 76 mounts peripheral vanes 77, severally set to give a discharge angle of substantially 30°. The outer edges of the vanes 77 are in frictional engagement with the inner surface of the cylindrical barrel section, and retain the collar 76 fixedly secured in the mouth of the barrel section of the separator. A cleaned gas discharge tube 78 is axially secured in the collar 76 and extends an appreciable distance on both sides thereof, so as to depend into the barrel section to place its mouth well below the downstream edges of the vanes 77. The output or discharge end of the tube can extend any desired distance, depending upon the particular installation. Wear resisting plugs 79 (Fig. 11) may be axially disposed in the bases of the discharge sections to prevent abrasion.

As shown in Figs. 1, 2 and 2a, a blowdown chamber or manifold 33 is hermetically secured to the flanged nipple 65 of pressure-sustaining casing 11. The member 33 comprises a T-shaped connector, including a depending, flanged leg 34. The cross-arm or top of the T is hermetically closed by end plate 35, in any suitable manner, and defines a plenum chamber 36 with the body of the T. A flanged ash discharge duct 37, incorporating a flow restrictor means, such as convergent nozzle 38, is subjoined to the depending leg 34. The ash blowdown lines 73 have their terminal ends embouched in duct 65 of the separator casing 11, and extending into plenum chamber 36. The terminal ends of the blowdown lines 73 are shaped to form convergent discharge nozzles, designated generally by the numeral 73a, and these nozzles function as flow restrictors, preventing blowback into the vortical whirl separators 70. These restrictors are purposely incorporated in each blowdown line 73 in order to equalize the blowdown flows from the various separator tubes 70. Each such restrictor can be designed to compensate for the length of its blowdown line, the presence of bends in efferent lines, and other like conditions affecting the flow of solids-bearing gaseous fluids through the blowdown lines. The pressure drop across each such restrictor can also be integrated into a flow measuring system, with alarm devices, as shown in Fig. 2b, to enable the plant operator to determine whether the tubes are severally functioning in a proper manner. Nozzle 38 (Fig. 2a) serves to reduce the pressure of the ash blowdown stream introduced into discharge pipe 37, so that the pressure of the stream will be reduced to a point where final ash concentration and storage can be made at atmospheric pressure.

Referring to Fig. 2b, there is shown a manometer 200 having one leg 201 connected to one of the blowdown lines 73, in advance of the restrictor 73a, through a line 202, the other leg 203 of the manometer being connected through a line 204 to the blowdown chamber 36. The legs 201 and 203 are fitted with platinum tipped contactors 201' and 203' which are connected in series with one side of the A.C. source to a warning light 205 through leads 206 and 206', and the other side of the source is connected to the light by a lead 207. A second warning light 208,

which is remotely located with respect to light 205, is connected to leads 206' and 207 by leads 209 and 209'.

When the blowdowns of the ash separators 70 are functioning properly, the normal reading of the manometer associated with an individual tube shows a pressure differential between the blowdown line 73 and the chamber 36. The contacts 201' and 203' in the manometer legs are set so that they are not bridged by the mercury when the separator tube is operating properly. If the blowdown discharge becomes partially or wholly blocked, the pressure differential is reversed by reason of the increase of pressure in line 202, thus causing the mercury to bridge the contacts, and complete the electrical circuit of the warning signals. In connection with the arrangement of the warning lights, it is contemplated that the light 205 will be mounted on or in the vicinity of the manometer, and that light 208 will be located on an instrument panel at a remote distance from the manometer.

Considering the operation of the motive fluid generating and cleaning system illustrated in Figs. 1, 2, and 2a, and with particular reference to the detailed showing of Fig. 2, it will be seen that combustion gases generated in combustion chamber 5 of combustor 4, are initially cooled and reduced to optimum turbine operating temperature by admixture with cooling, secondary air introduced into the combustion chamber through the channels or annular openings formed between the annular ring sections 6 of the flame tube. Final mixing of the secondary air with the combustion gases is effected in mixing chamber 8, into which more secondary air is radially projected through the annular array of apertures 9. The motive fluid thus discharged from the mixing chamber will be projected against the curviform louvered upper surface of upper leg 18 of the downcomer duct 16. As more clearly set forth in Yellott Patent No. 2,650,675, of September 1, 1953, hereinabove identified, the cooler, secondary air from the plenum chamber 46 will flow through the louvered openings and be deflected forwardly and downwardly against the rear surface of duct 16, forming a down-flowing film of cooling air thereover. The highly heated motive fluid (ca. 1350° F.) from the combustion tube will impinge against the said down-flowing film of cooler air and will form a second layer, co-flowing therewith, and without substantial mixing of the co-flowing streams, while the heavier combustion residues and uncombusted particles and agglomerates originally dispersed in and carried by the motive fluid stream will be transferred into the cool air film and be quenched therein and carried downwardly thereby against the curviform surface of bottom curviform section 17 of duct 16, to be deposited in the bottom of the fore chamber of inlet plenum chamber 67. As the motive gas passes through screen 69, the residual coarse solids will be separated out and fall to the bottom of the fore chamber, whence they may be removed intermittently through clean-out port 64, or continuously in a special separator of the type disclosed and claimed in Yellott Patent 2,652,792, issued September 22, 1953, for Pressurized Combustion and Ash Removal System for Coal-Fired Gas-Turbine Power Plant.

The preliminarily screened motive fluid flows into the after section of plenum chamber 67 and into the vortical whirl ash separators 70, of the ash separator battery. In these devices the ash is separated from the motive fluid, and is discharged to the ash disposal system through blowdown lines 73, chamber 33, and ash discharge line 37. As indicated hereinabove, a coolant gas stream may be introduced into the chamber 33 through line 32 from intercooler 31, whereby any unquenched residues are cooled below the ignition point (ca. 400° F.), and the blowdown stream is cooled to the ambient air temperature. The cleaned motive fluid gas from the separators 70 is discharged, through the individual cleaned gas discharge tubes 78, into the cleaned gas output plenum

chamber 63, whence it is delivered through expansion duct or ducts 12, to a gas turbine 10. It is to be noted that both the coarse and fine ash and combustion residues are separated and removed from the system, and concomitantly quenched and cooled, without recourse to the use of moving mechanical separating equipment. This novel feature is made possible by the use of 0.5% to 1.5% of the original volume of the motive fluid generated as ash blowdown streams, with or without the return of the cleaned gas from the final ash concentration and disposal step to the motive fluid gas system.

The system illustrated in Figs. 1, 2, and 2a, and described immediately hereinabove, utilizes a pressure-sustaining vessel 11, as a housing for the ash separator battery of special vortical whirl separators. This tank or vessel 11, is quite bulky, and is required to be made of heavy gauge, heat-resistant stainless steel, which is in critical supply, and is very costly.

Important savings in equipment costs, as well as in installation, maintenance and operation costs, are made possible by the novel power plant systems illustrated in Figs. 3-17, and including a first modification, illustrated in Figs. 3-7, and second and third modifications, illustrated in Figs. 8-17. The third modification is characterized by a vortical whirl separator having a hexiform barrel, and specially illustrated in Figs. 14-17. The pressure-sustaining tank 11, of Figs. 1 and 2, when suitably lagged with heat-insulating material, is very bulky, and reduces gangway space in a locomotive to a critical minimum. When trouble occurs, due to plugging of the individual ash separators in the encased battery, or from any other cause, as noted above, it is necessary to shut the entire plant down, and dismantle the tank 11, before the trouble can be located. When the trouble is remedied, the tank and its contained equipment have to be reassembled, all adding up to a very costly procedure, let alone loss of function of the power plant for considerable periods.

As will be readily apparent in considering the modifications illustrated in Figs. 3-17, and described in detail hereinafter, the pressurized tank 11, housing the battery of vortical whirl separators, is eliminated, and the individual separators are made pressure-sustaining, whereby they can be mounted on the outside of the dirty gas plenum chamber casings, where they are readily available for inspection, removal, and replacement, without requiring prolonged shutdown of the power plant and wholesale overhaul of the ash separating, concentrating and disposal system. The exposed separators are desirably lagged with suitable heat-insulating material, such as glass wool, which may be contained in demountable shields or housings mounted over the separators. The making of the barrel and discharge sections of the novel vortical whirl separators herein of heat-resisting stainless steel, in gauge thickness sufficient to render the devices pressure-sustaining, is a wholly novel idea, here presented for the first time, and is characterized by the fact that the initial fabrication and installation costs are but a minor fraction of the cost of the tank assembly illustrated in Figs. 1-2, and the maintenance and repair costs of the new installations are relatively small.

As noted above, one form of the improved ash separating and removal system is illustrated in Figs. 3-7. In this system, a symmetrically disposed pair of combustors 4, 4', severally incorporate expansible secondary air inlets 24, 24', discharge sections 42, 42' having end cap plates 43, 43', and downcomers 16, 16'. The downcomers 16, 16', as shown, incorporate the structural details of the downcomer duct, illustrated in detail in Fig. 2, including, respectively bottom elbow 17, 17', and flanged discharge ends 15, 15'. The combustors 4, 4', severally incorporate capped ports 80, 80', mounting the combustible air-coal and circulating oil lines connected to the burners, as specifically illustrated in Fig. 2. Spaced clean-out ports

81, 81', and 82, 82', are symmetrically disposed in the combustor casings, and are readily available from the two sides of the dual installation. A pair of combination flanged equilibrator ducts and stay members 83, 84, connect the interiors of the combustors 4, 4', adjacent the ends thereof, as shown, and establish isobaric equilibrium between the secondary air plenum chambers of the two combustors. A pair of parallel motive fluid conduits 90, 90', are severally mounted in subjacent relation to the combustors 4, 4', and are provided with flanged inlet ducts 91, 91' and flanged outlet ducts 92, 92', severally hermetically coupled to downcomers 16, 16', and cleaned gas expansion delivery ducts 12a, 12a'. Access ports 93, 93' are severally provided in the conduits 90, 90', as shown. The conduits 90, 90', in the form shown, are cylindrical, and are severally divided, longitudinally, in the direction of flow of the motive fluid, by diagonally sloping divided plates 94, 94', into mating cylindrical sections 95, 96, and 95', 96'. The plates 94, 94', are severally provided with upstream end riser sections 97, 97', hermetically secured to the inlet ducts, 91, 91', and to the juxtaposed ends of the upper conduit segments 95, 95'. End closure plates 98, 98', are severally provided at the downstream ends of the divider plates, and are hermetically secured to the lower conduit segments 96, 96'. The upper and lower segments of the conduits, together with the interposed divider plates, and the end closures, are respectively hermetically secured to co-operating elements of the conduits by any suitable means, such as welding, designated generally by the numeral 99, and more particularly shown in Fig. 6.

It will be seen that the divider plates 94, 94', divide the casings into lower, dirty gas input plenum chambers, 100, 100', of progressively decreasing cross-section, and into upper cleaned gas output plenum chambers, 101, 101', of inversely proportional increasing cross-section. The dirty gas is stripped of its contained solids, and the cleaned gas is delivered in the following manner: The barrels 71, of vortical whirl separators 70 are embouched in and conformed to apertures 102 in the bottom of the input plenum chambers. These barrels desirably have the lips 71a, of the conformed mouth sections, peened over against the inner surfaces of the plenum chambers, and conformed thereto, and they are hermetically sealed in place by welding, as indicated generally at 103, Fig. 6. As indicated hereinabove, the discharge ends of cleaned gas delivery tubes 78 are embouched in suitable apertures in the divider plates 94, 94', and are hermetically secured therein in any suitable manner, as by welding, indicated generally at 104, Fig. 6.

The separated ash blowdown system of the motive fluid generator illustrated in Figs. 3-7, will now be described: As shown more particularly in Figs. 4-6, the ash separator conduits or plenum chamber casings 90, 90', are severally provided with parallel rows of staggered, depending vortical whirl separators 70. The ash blowdown lines 73 from the individual separators debouch into ash discharge manifolds, a manifold being provided for each row of separators. Referring to the sectional showing of Fig. 7, the manifolds for the rows of separators of unit 90, are designated 110, 111, while those for unit 90' are designated 112, 113. Manifolds 110, 111, jointly discharge into a take-off duct 114, while manifolds 112, 113 jointly discharge into take-off duct 115. The ducts 114, 115 are severally coupled to converging ducts 116, 117, which, in turn, are severally coupled to opposed tangential inlets 118, 119, of a small capacity vortical whirl ash concentrator 120, having a cleaned gas discharge tube 121, and a concentrated ash blowdown line 122. To cool the ash blowdown streams, the manifolds may be severally provided with cooled air line connections 32, as shown in Fig. 3, or, as shown in Fig. 3a, a fan or blower 125 may be coupled to the upstream end of a jacket 127, which may encase manifold 126. This member may also be provided with radially disposed ex-

tended surfaces or fins 128 exposed to the ambient air, or encased in jacket 127 (Fig. 3b), and cooling air blown through the radial passages formed by and between the jacket and the longitudinal fins.

The power plants herein, and as shown more in detail in Figs. 4 and 5, are mounted in locomotive cabs 130 having roofs 131, side walls 132, flooring 133, floor-supporting I-beams 134, and vertically disposed framing members 135 serving for the conjoint support of the side walls and superjacent roof structure. The power plant illustrated in Figs. 1 and 2, is mounted in the locomotive cab in the same manner, the turbo-generator equipment being used with all of the combustor-ash separator assemblies described herein.

The operation of the improved power plant of Figs. 3-7 is identical with that of the system illustrated in Figs. 1-2, with the added features that the ash separating and concentrating equipment is very much more compact, and is readily fabricated, installed and maintained, at a minimum of cost. Additionally, and importantly, the vortical whirl separators are readily available for inspection, and repair, without requiring prolonged shutdown of the entire power plant.

As discussed hereinabove, a feature of major importance in the design of any element of a power plant intended for use in locomotives is the restriction of the size of the element to the smallest dimensions possible, consonant with the performance required. In the case of pulverized coal-burning motive fluid generating equipment, all elements of the ash separating, ash concentrating, and storage equipment must be added to the equipment normally required for oil-burning gas turbine-powered generating electric locomotives. Such added equipment must be as compact as possible, simple to construct, service and repair, and exhibit an ash-separating efficiency beyond the capacity of any such equipment hitherto described, or available. In the novel design of the ash separating equipment forming the special feature of novelty in the systems illustrated in Figs. 8-17, the above recited desiderata are successfully attained, as will now be disclosed.

Turning to the detailed showings of Figs. 8, 12, 14 and 16, the improved ash-separating equipment will be seen to comprise a modified combustor discharge section, designated generally by the numeral 140, a modified and louvered deflector 150 mounted in section 140 of the combustor and directing motive fluid from the combustor downwardly into the fore chamber or dirty gas input plenum chamber of the vertically disposed, box-like casing 160 embodying dirty gas input and cleaned gas output plenum chambers. Specially mounted batteries of horizontally disposed vortical whirl separators, of the type hereinabove described are hermetically coupled to the exterior of the casing 160, and establish fluid communication between the input and output plenum chambers thereof.

In the single combustor units illustrated in Figs. 8-10, 14-15, the combustors 4 are provided with modified discharge sections 140, of generally cylindrical shape, having flanged ends 141, and a body 142, capped by end cap plate 143. The body is provided with a rectangular cut-out 144 on its under surface to receive the top of ash separator casing 160. The casing 160 is hermetically secured to the member 140 in any suitable manner, as by welding, indicated generally by the numeral 145. A louvered curviform deflector 150 is mounted in the end section 140 of the combustor, and divides the latter into an upper, clean secondary cooling air plenum chamber 146, and a lower, dirty motive fluid plenum chamber 147. The deflector 150 comprises a rear body portion 151 of partially curviform section terminating in a downwardly directed forward lower section 152 provided with louvers 153 on its upper surface.

The ash separator casing 160 is comprised of respectively apertured front and back walls 161, 162, integral side walls 163, 164, and integral bottom 165. A di-

agonally disposed, apertured separator or divider plate 166 is hermetically secured, as by welding, to the top edge of front wall 161, and to the side walls 163, 164, as well as to the bottom 165. The bottom edge of separator plate 166 is spaced from the rear wall 162, as shown. The plate 166 divides the casing 160 into an input plenum chamber 167 for ash and combustion residue-bearing motive fluid, which is in fluid communication with plenum chamber 147 of the combustor, and into a cleaned motive gas plenum chamber 168 which is in fluid communication with a turbine 10, or other use device, through expansion duct or ducts 12b. A cleanout port 169, for separated coarse combustion residues and ash, is provided at the base of input plenum chamber 167.

A feature of prime importance of the invention herein, and particularly of the ash separator system of the modifications presently under discussion, is the special mounting of the pressure-sustaining vortical whirl separators 70, described in detail hereinabove. In this form of the invention, the separators 70 are horizontally arranged, in batteries, designated generally by the numeral 170, in the following manner: The casings 71 of suitably aligned separators 70 are hermetically secured in appropriate apertures in rear wall 162 of plenum chamber casing 160 in any desired manner, as by welding, thereby placing the barrels of the individual separators in fluid communication with the dirty gas input plenum chamber 167. The mouths of cleaned gas discharge tubes 78, which severally bridge plenum chamber 167, are hermetically embouched, as by welding, in the partition member or divider plate 166, being received in aligned apertures therein, and establish fluid communication with the cleaned gas plenum chamber 168. The tangential ash blowdown lines 73, which, as noted above, severally discharged separated solids from the discharge sections 72 of separators 70, collectively discharge their motive fluid-borne separated solids into a depending ash discharge manifold 171 (Figs. 8 and 9), which is in fluid communication with the ash concentrating and storage units of the system, described in detail hereinabove. The ash blowdown lines 73 will be provided with individual flow restrictors, as shown, to prevent blowback of separated solids. The barrels of the horizontally disposed separators 70 are desirably cylindrical.

It will be seen that the ash separator system incorporating the novel plenum chamber casings 160 clearly fulfill the basic requirement of maximum ash separating efficiency with minimum bulk and weight of equipment. The heat conservation of the present system is effectively maintained by suitably lagging all exposed surfaces of the equipment with heat insulating material. The lagging of the exposed surfaces of the horizontally disposed, pressure-sustaining vortical whirl separators 70, which are mounted on the outside of the plenum chamber casing 160, may be effected in the following manner: A box-like housing or sheath 170, generally conformed to the rear wall 162 of the plenum chamber casing 160, is provided with flanged edges 171, which are secured to the wall 162 in any suitable manner, as by machine screws, not shown. The housings 170 are filled with suitable low-cost heat-insulating material 173, such as glass wool, or asbestos fiber, which is packed in and around the horizontally disposed vortical whirl separators 70, so as to effectually insulate them and prevent any significant heat loss through the exposed surfaces thereof.

Turning to Figs. 12 and 13, there is shown the method of mounting duplex combustors and ash separator assemblies incorporating horizontally mounted, self-supporting, and pressure-sustaining vortical whirl separators. In this system, the duplex combustors, 4, 4', are arranged in substantial parallelism, and are severally provided with modified end discharge sections 140, 140', debouching into input plenum chambers 167, 167', of the parallel, juxtaposed box-like plenum chamber casings 160, 160'. Each of these casings mounts a battery

of vortical whirl separators, **170, 170'**, severally comprised of three separators, the horizontal axes of all the separators being arranged in parallelism and jointly intersecting the perimeter of a circle. In other words, the duplex array of separators is characterized by the fact that the axes of the several separators are equidistant from a common center. A common ash discharge manifold **175** is disposed between the batteries of separators **170, 170'**, and lies in a vertical plane coinciding with the vertical diameter of the turbine casing. The expansion ducts **12c**, connecting the cleaned gas plenum chamber and the turbine, are equal in number to the vortical whirl separators of the juxtaposed batteries, and are severally coaxial therewith. A common shield or housing, **176**, is disposed over the separator batteries **170, 170'**, and is demountably secured to the casings **160, 160'**. The usual heat insulating filling **173**, of glass wool, asbestos fiber, or the like, is packed into the housing **176**, and in and around the individual vortical whirl separators of the encased batteries. The common ash discharge manifold **175** receives the individual ash blowdown lines **73** of the vortical whirl separators **70**, each said line being provided with a flow restrictor, as shown, to prevent blowback between the several separators. The ash discharge manifold **175** discharges to the ash concentrator **120** in the usual manner.

The combustor elements **140, 140'**, and the associated plenum chamber casings **160, 160'**, described immediately above, are also used in the modified ash separating systems illustrated in Figs. 14-17, and essentially characterized by the use of batteries of horizontally disposed vortical whirl separators having hexiform barrels and discharge chambers, which are mutually juxtaposed in honeycomb arrangements in the several batteries. These batteries are severally designated **180**, and **180'**. Turning now to Figs. 14-15, the separator battery **180** is seen to comprise three vertical rows of hexiform separators, severally designated generally by the numeral **70A**. The hexiform separators **70A** are essentially similar to the cylindrical separators **70**, which have been described in detail hereinabove, and this description will not be repeated, as it is not required for an understanding of the honeycomb arrangement of the horizontally disposed separators. The battery **180** is characterized further by the fact that the central row of separators extend rearwardly beyond the bilaterally juxtaposed rows to permit the coupling of the ash blowdown lines **73** of the middle separators to clear the ends of the discharge sections of the separators of the side rows. The blowdown lines **73** of the several rows are hermetically connected to blowdown manifolds **181, 182, 183**, as shown in Fig. 15, and these manifolds are coupled to a common, horizontally disposed ash blowdown manifold **184**, which discharges to a suitable ash concentrating and disposal system, as described hereinabove. The mouths of the barrels of the juxtaposed separators **70A** may be separately hermetically embouched in rear wall **162** of plenum chamber casing **160**, or they may be mutually hermetically joined, and the unitary array embouched in wall **162** in a single aperture conformed to the honeycomb-like periphery of the array, and hermetically secured thereto. With either of these arrangements, the barrels of the separators are placed in fluid communication with the input plenum chamber **167**, and the cleaned gas discharge tubes **78** will traverse this chamber, and have their several mouths received in aligned apertures in divider plate or tube sheet **166**, thereby establishing hermetic connection with the cleaned gas plenum chamber **168**. The plenum chamber **168** discharges to the gas turbine **10** through the usual expansion duct **12d**. A flanged, box-like housing or sheath **185** is mounted over the battery **180** and is detachably secured to the plenum chamber casing **160** in the usual manner. Heat-insulating material **173**, of glass wool, asbestos fibers, or the like, will be packed in the housing **185**, in contact with the

exposed surfaces of the honeycomb array comprising separator battery **180**.

In Figs. 16-17, there is shown a duplex combustor and ash separator system, generally similar to the system illustrated in Figs. 12-13, and described hereinabove. The new system is characterized by duplex honeycomb arrays of hexiform vertical whirl separators **70A**, forming separator batteries, severally designated by the numerals **190, 190'**, and housed in a unitary, detachable box-like housing or sheath **191**, incorporating the usual heat insulating filler **173**. The batteries **190, 190'**, are mirror images of each other and severally comprise two vertical rows of separators hermetically embouched in plenum chamber casing walls **162, 162'**, respectively. The outside rows of the batteries are comprised of three separators, mutually abutted, and interfitted with juxtaposed inner rows comprised of four mutually abutted separators. The separators are coaxial with a like number of expansion ducts **12e** connecting the cleaned gas plenum chamber **168** and the turbine **10**. Each array of separators is hermetically embouched in suitably conformed apertures in walls **162, 162'**, of plenum chamber casings **160, 160'**. In the system shown in Figs. 16-17, it will be seen that the separators **70A** are of uniform length. As shown more particularly in Fig. 17, the ash blowdown lines **73**, severally provided with flow restrictors, debouch into vertical manifold **192, 193, 194**, which, in turn, debouch into common ash discharge manifold **195**. Manifold **195** discharges to the final ash concentrating and storage stage, as described hereinabove. Manifolds **192, 193**, and **194** are severally provided with flow restrictors to prevent blowback from the common ash discharge manifold **195**.

There have been described and illustrated ash separating and cooling systems capable of performing and effecting all of the specifically mentioned features of novelty and advantage of the invention, as well as others which are apparent to those skilled in the art. Various uses of the present invention may be made using the described structures. Accordingly, it is apparent that variations as to operation, size and shape, and rearrangement of the elements may be made without departing from the spirit of the invention. Therefore, limitation is sought only in accordance with the scope of the following claims.

What is claimed is:

1. In a gas turbine power plant of the character described, in which pulverized coal is carried and burned in a pressurized stream of primary air, and the gaseous products of combustion are diluted and cooled with secondary air to optimum turbine operating temperature to form an ash and combustion residue-bearing gaseous motive fluid, an improved ash and combustion residue separating means comprising, an ash separator unit having a dirty gas inlet and a cleaned gas outlet, said separator comprising a heat-resisting pressure-sustaining vessel having internal partition members hermetically dividing the vessel into an input plenum chamber and an output plenum chamber, said chambers being in heat-exchanging relation, a battery of vortical whirl separators, including barrel sections and discharge sections, encased within the pressure-sustaining vessel, and having their barrel sections in fluid communication with said input plenum chamber; cleaned gas outlet means in each of said vortical whirl separators and severally establishing fluid communication with said outlet plenum chamber; tangential blowdown lines at the ends of the discharge sections, said blowdown lines severally incorporating flow restrictors and jointly discharging into a common manifold, said manifold incorporating flow restrictor means and discharging to ash discharge and storage means.

2. An ash separator according to claim 1, characterized by the fact that the input plenum chamber of the ash separator casing is divided by screen means into a fore chamber and an after chamber in which the individual vortical whirl separators are mounted, and means

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is provided at the bottom of the fore chamber for the removal of initially separated and deposited coarse ash and quenched combustion residues.

3. An ash separator according to claim 1, characterized by the fact that the blowdown lines severally incorporate manometer means coupled across the flow restrictors, whereby variations of the discharge through the blowdown lines, are manifested by said manometer means. 5

4. An ash separator according to claim 1, characterized by the fact that the blowdown lines severally incorporate manometer means coupled across the flow restrictors, and that alarm means are operatively connected to the manometer means, whereby the non- or mal-functioning of any individual separator is manifested by said alarm means. 10 15

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