COMBINED HEAT INTERCHANGER AND ELECTROSTATIC PRECIPITATOR

Filed Oct. 20, 1966 5 Sheets-Sheet 1

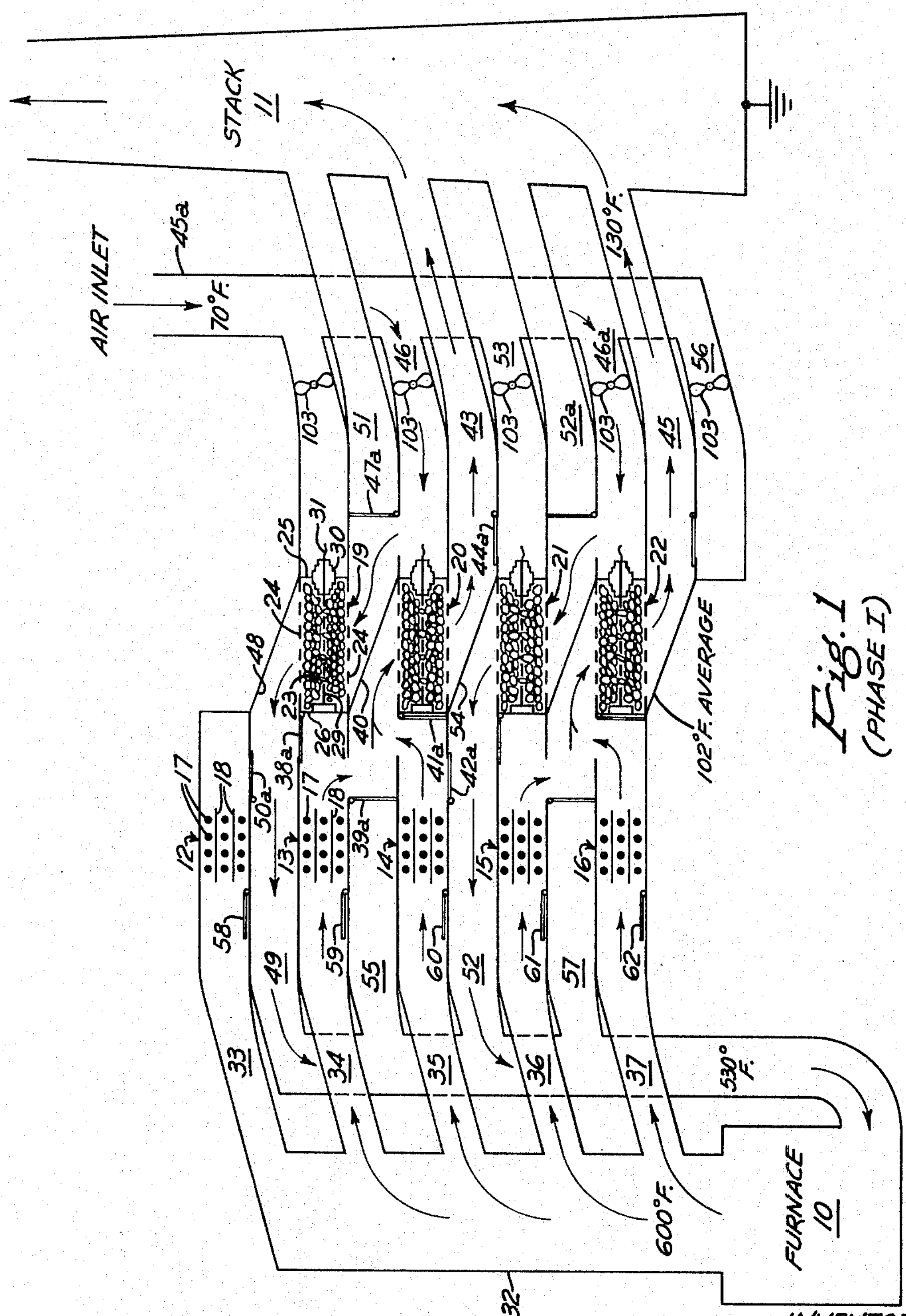

Fig. 1 (PHASE I)

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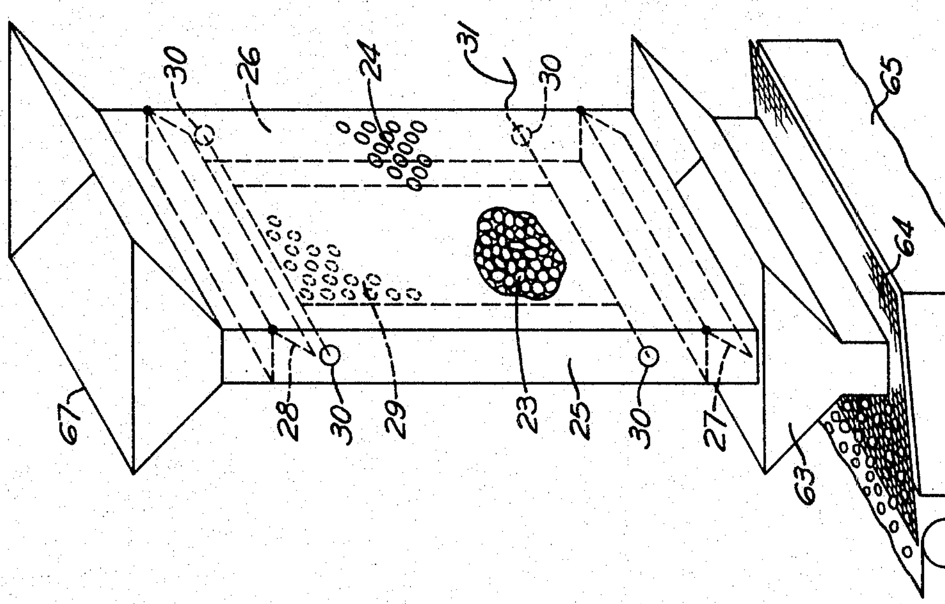

Fig. 3

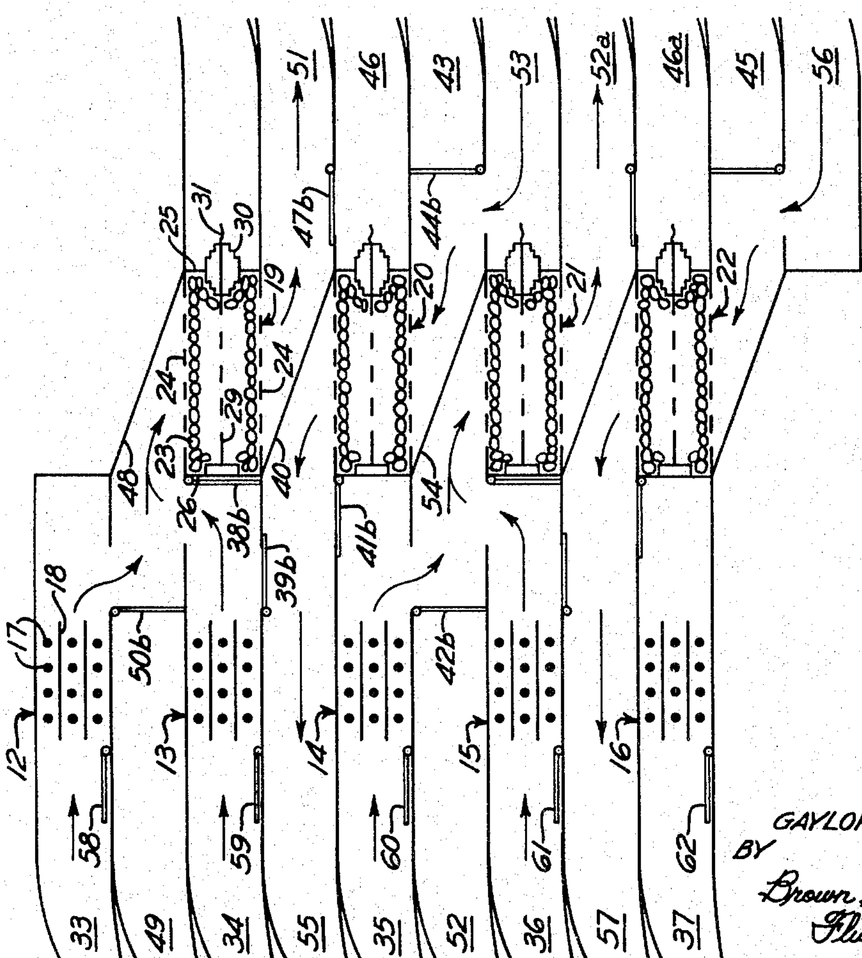

Fig. 2 (PHASE II)

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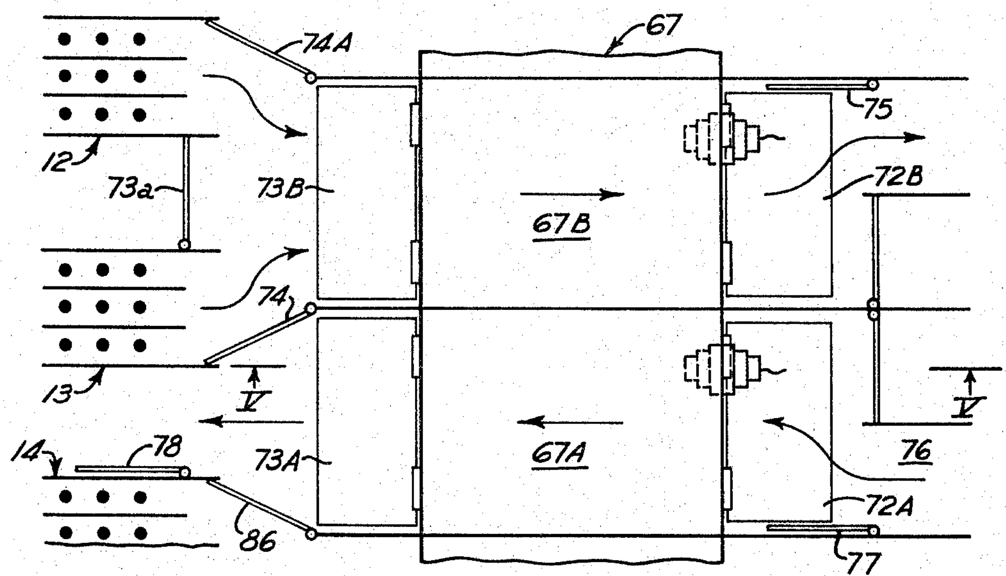

Fig. 4

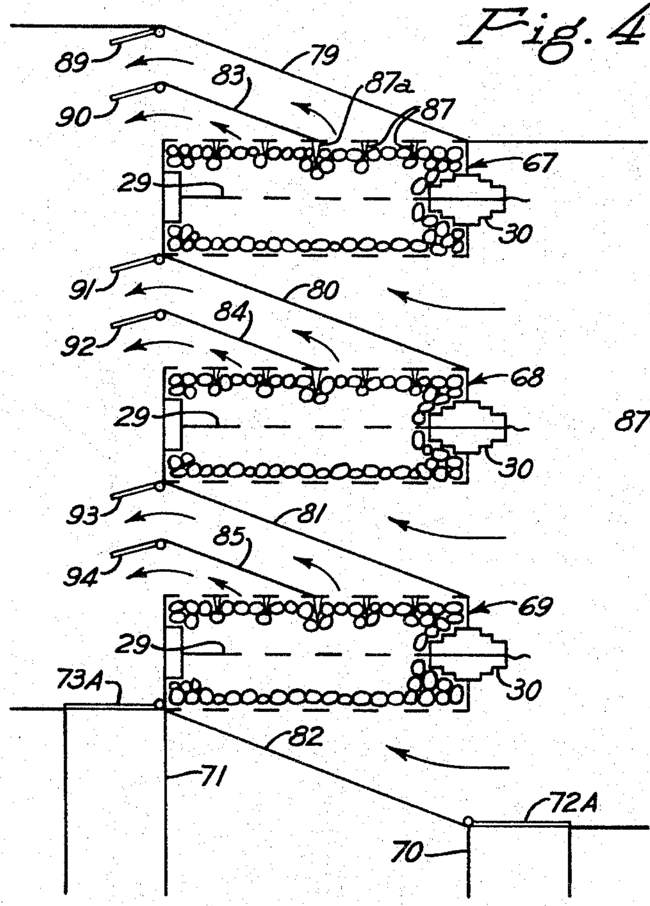

Fig. 5

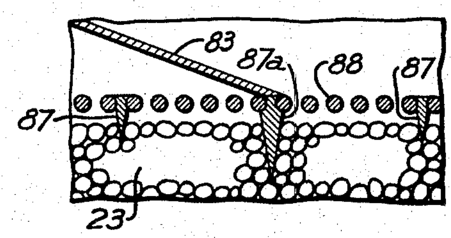

Fig. 6

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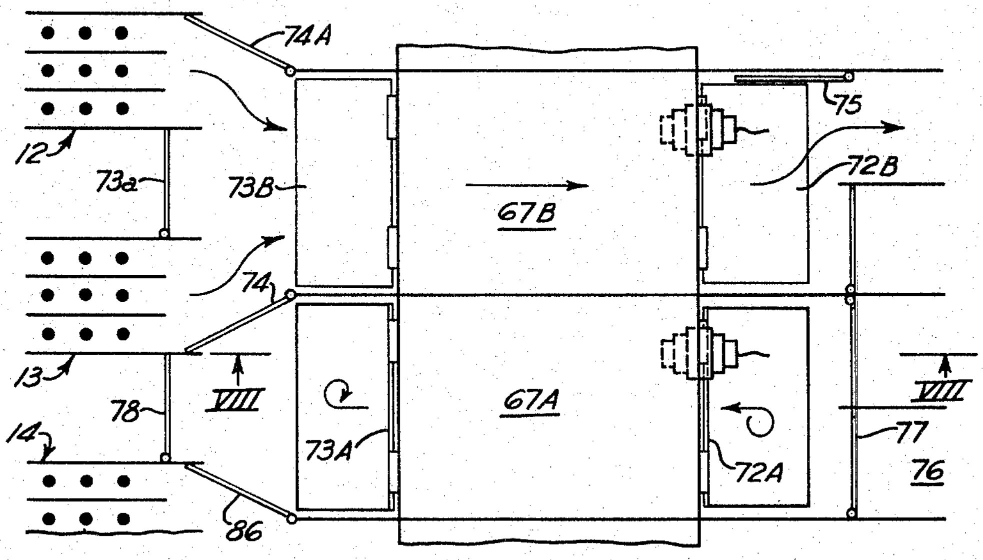

Fig. 7

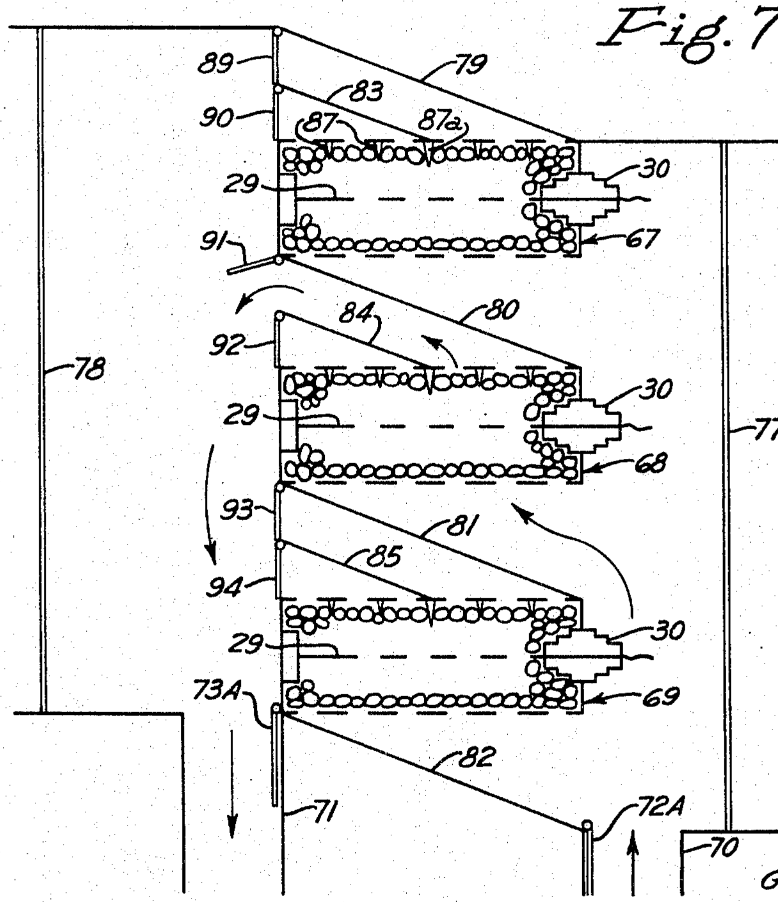

Fig. 8

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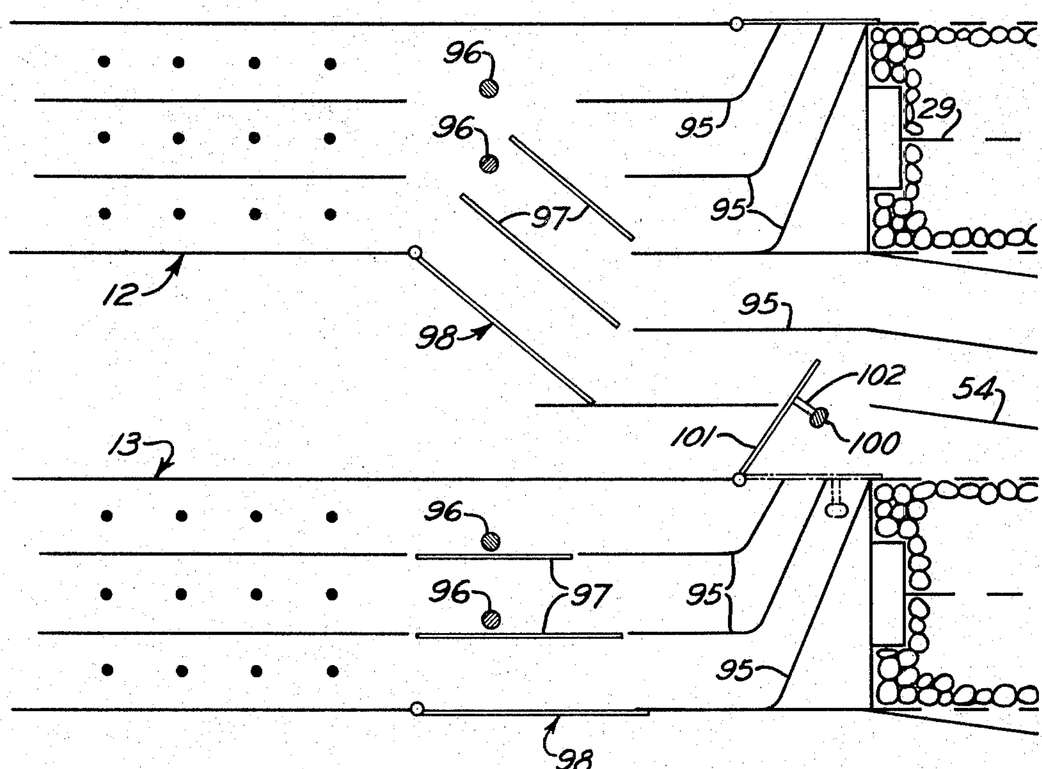

Fig. 9

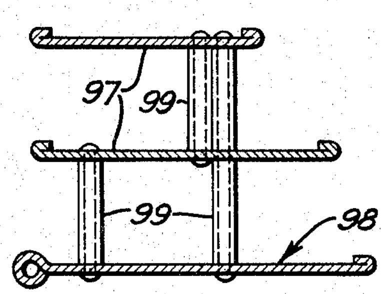

Fig. 10

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United States Patent Office

3,365,858

Patented Jan. 30, 1968

3,365,858

COMBINED HEAT INTERCHANGER AND ELECTROSTATIC PRECIPITATOR

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Continuation-in-part of abandoned application Ser. No. 273,904, Apr. 18, 1963. This application Oct. 20, 1966, Ser. No. 588,013

12 Claims. (Cl. 55—11)

ABSTRACT OF THE DISCLOSURE

A combined heat interchanger and electrostatic precipitator in combination with a powdered-fuel fired industrial furnace and an exhaust stack, the combined heat interchanger and electrostatic precipitator positioned in ductwork connecting the flue and the stack and electrostatically precipitating and thereby removing dust from the furnace exhaust gas while preheating air fed to the furnace.

Related application

The present application is in part a continuation of Ser. No. 273,904, filed April 18, 1963, now abandoned.

In power plants it is usual to provide a heat interchanger in which the hot gases leaving the furnace are used to pre-heat the incoming air. It is also usual to provide an electrostatic precipitator to remove dust from the exhaust gases before they are discharged into the atmosphere. The use of two separate pieces of equipment for these two operations involves extra cost, both as to installation and upkeep. The present invention reduces these costs by performing both heat interchange and dust collection in a single apparatus.

This object is accomplished by providing a number of "combination units" which serve both as dust collectors for precipitation and as heat interchange units. These units contain material having a low electrical conductivity, preferably in granular form. This material is used both to provide collecting surfaces for charged dust particles and as a heat-interchanger material.

The material used in the combination units may be any cheap material having low electrical conductivity, such as commercial river gravel, crushed rock, or ceramic material. The individual pieces are of irregular shape and vary considerably in size. A preferred range of sizes is from ¼ to ¾ inch in diameter, although a presently preferred optimum is a diameter of approximately ½ inch. This material, for want of a more accurate word, will be referred to herein as "granular" material.

The apparatus includes ionizing units, as well as ductwork which conducts the hot exhaust gases from the furnace through the ionizing units to the combination units, which are then serving to absorb heat and to collect dust. After the apparatus has been operated in this position for a certain length of time, the granular material has become heated to the desired temperature, and then the flow through the combination units is reversed. During the reversed flow, incoming cool air is passed through the combination units so that the air is pre-heated by passing over the heated granular material as it goes on its way to the furnace. During this portion of the operating cycle the combination units serve as heat interchangers.

In order to create a voltage gradient between adjacent surfaces of the granular material, a high-voltage electrode is embedded within the bed of granular material. There are temperature differences in different parts of bed due to the cyclical reversal of hot and cool gas, and it is therefore important to locate this electrode within the bed at

the zone of highest efficiency of precipitation, as will be explained later herein.

An important feature of the invention is that it provides optimum conditions both for electrical charging of the dust particles and for collection of the charged dust particles.

Optimum charging conditions are provided by placing the ionizing unit next to the furnace, where it receives the hot furnace gas at a temperature of approximately 600° F. At this high temperature the dust has a low electrical resistivity and it is therefore possible to apply an ionizing voltage with little or no trouble from "back corona."

Optimum dust collecting conditions are provided by precipitating the dust in the combination units, which, because they serve also as heat interchangers, are (when collecting dust) at a lower temperature than the ionizing units. In fact, it is possible to locate the high voltage electrode in a zone of the combination units where the temperature is such that both the dust and the granular material have maximum resistivity. This makes it possible to apply maximum voltage with economical use of electric current.

Since conventional industrial precipitators combine the charging and dust collecting functions in one unit, it has not been practical to locate the charging section where it receives directly the hot furnace gas. This is due to the fact that an excessively large collector section is required to accommodate the large volume of gas at the high temperature involved. For this reason it has been necessary to locate the precipitator after the air preheater, where the charging must be done at lower temperatures, and therefore with less efficiency.

The present invention overcomes this difficulty by reason of the following features:

(1) By separating the charging and collecting sections.

(2) By using a bed of granular material for the collecting section.

(3) By subjecting the bed of granular material to reverse flow of hot gas and cool incoming air.

It will be understood that the invention also provides for a low installation cost, since it combines two pieces of equipment in one, and utilizes low-cost material for the granular material that provides both a heat-interchanger and collecting surfaces for the ionized dust. Due to the low cost of the granular material it is possible to use a large volume of this material in the combination unit, thereby producing a number of advantageous features.

The invention further provides for the maximum conservation of heat and hence savings in fuel. This is important in all power plants, as well as in cement mills, steel mills, and other industrial plants burning fuel.

State of the prior art

The following prior-art patents show features that have some similarities to individual elements of the present invention:

Fahrbach 1,871,166 shows a furnace regenerator in which incoming cool air and hot combustion gas are alternately passed through beds of granular material, thus utilizing the heat absorbed from the combustion gas to pre-heat the incoming air. Fahrbach also withdraws the granular material to clean it before returning it to the heat-interchange beds.

Cole 2,990,912 shows an electrical precipitator which is particularly adapted for household use and in which the collecting section consists of a bed of uniform balls of semi-conductive material. The bed of balls is retained between a pair of screen grids arranged perpendicular to the direction of gas flow. This arrangement would not be suitable for use where there is a counter-flow of hot gases and cool air through the bed, for Cole specifies that the bed of balls is a thin bed. Moreover, in Cole the flow through the bed is always in the same direction, the temperature of the bed is uniform throughout, and it is therefore possible to locate the high-voltage electrodes at the inlet side of the bed of balls. In the present invention the bed of granular material is alternately subjected to hot and cool air, and the high-voltage electrode is located in the interior of the bed of the zone of temperature in which both the dust and the granular material have maximum resistivity.

Tigges 2,537,558 shows a system for treating power plant gases using an electrostatic precipitator to remove dust and using a separate air-preheater to serve as a heat interchanger. This system calls for the use of two separate pieces of equipment, which is usual, as stated previously herein. The particular feature of this Tigges patent is placing the precipitator after the feed water heater, but ahead of the heat interchanger in order to reduce corrosion in the heat interchanger. This patent therefore points away from the present invention which combines these two devices in one economical unit.

Beaver 2,800,193 shows an arrangement which, broadly speaking, uses a "combination electrostatic precipitator and heat conserving device." However, this arrangement is a special design using rotating discs, and is adapted only for use with furnaces burning black liquor in sulphate paper mills. It cannot be used in power plants generally.

Cooper 2,795,401 discloses a system in which two drum-type heat interchangers are used in connection with an electrostatic precipitator. The drum-type interchanger ahead of the precipitator is used to cool the gases to the usual temperature for precipitation while the second drum-type interchanger is to further cool the gases before discharging them. Cooper therefore actually adds an extra piece of equipment, so that he has 3 pieces (two heat interchangers and a precipitator) in place of the conventional 2 pieces (a heat interchanger and a precipitator). In the present invention the combination units perform the services of these 3 pieces of equipment in Cooper.

In the drawings:

FIG. 1 is a diagrammatic horizontal cross-section through an apparatus embodying the invention.

FIG. 2 is a partial view similar to FIG. 1 but showing the parts in position to cause a reverse flow of gas and air through the apparatus.

FIG. 3 is a perspective view, of one of the combination units.

FIG. 4 is a diagrammatic plan view showing an alternate construction.

FIG. 5 is a vertical section on line V—V of FIG. 4.

FIG. 6 is an enlarged sectional detail of part of the apparatus of FIG. 5.

FIG. 7 is a view similar to FIG. 4 but showing a different cycle of operations.

FIG. 8 is a section on line VIII—VIII of FIG. 7.

FIG. 9 is an enlarged sectional diagram illustrating a further variation.

FIG. 10 is an enlarged sectional view of a damper provided with baffles for use in the structure of FIG. 9.

Description of the invention

A preferred form of the invention will now be described in connection with the drawings.

In FIG. 1 the numeral **10** indicates a furnace of any conventional or preferred type, and **11** indicates the smokestack which eventually discharges the combustion gases to the atmosphere. The units which constitute applicant's combined heat interchanger and electrostatic precipitator (herein called "combination units") are located between the furnace and the stack and are connected to both by suitable ductwork. This ductwork is of any suitable construction to form a closed passage

from the furnace through the ionizing units and the combination units to the stack.

The ionizing units **12** to **16** inclusive have ionizing electrodes **17** in the form of wires, and passive electrodes **18** in plate form. These ionizing units are of conventional construction and as the combustion gases pass through them, the dust particles receive a negative charge, as is well understood in the art.

The "combination units," which act both as dust collectors and heat interchangers are shown at **19** to **22** inclusive. These combination units are in the nature of large bins that hold the granular material **23**. For a modern 200 megawatt power plant these units would be about 30 ft. long by 20 ft. high and approximately 2 to 3 ft. thick, and each unit would hold about 55 to 85 tons of river gravel, if that were the material used. Such a power plant would use about 14 of such combination units, thus providing for a total of 800 to 1200 tons of granular material.

The granular material **23** may be any of the materials described previously herein. In FIG. 1 the combination units are shown as being filled with granular material, and this is their normal operating condition. In other views the granular material is shown along the sides and ends but is omitted in the interior to simplify the drawings.

A preferred construction for the combination units is illustrated in greater detail in FIG. 3, which shows that the side walls **24** have openings or perforations large enough to permit ready passage of gas, but small enough to retain the combination material. Both ends **25** and **26** are imperforate. The side and end walls are formed from a suitable metal or other material that conducts electricity.

The bottom of the combination unit is closed by a hinged door **27**, and a hinged door **28** closes the top of the unit.

A screen-type electrode **29** is located in the interior of the combination unit. This electrode **29** is supported by insulating bushings **30** and is connected by a lead **31** to a source of high direct voltage (not shown). This electrode is slightly smaller than the dimensions of the combination unit, since it is advisable to have the edges of this electrode spaced from the boundaries of the combination unit the same distance as that from the electrode to the side walls of the combination unit. The reason for this equal spacing of the electrode from all grounded surfaces is that it should provide an electrical field on all of the granular material. Thus in a 30′ x 20′ x 3′ bin the electrode should be 27′ x 17′.

The body of granular material **23** is in direct contact with electrode **30** and also with the walls of the combination unit. These walls form part of the ductwork, which is electrically grounded. As a result, when high direct voltage is applied to the electrode **29** by way of the lead **31**, a voltage gradient exists between surfaces of adjacent pieces of the granular material.

When the gas from the furnace passes through an ionizing unit the dust particles are given a negative charge. When this gas then passes through a "combination unit," the dust particles are attracted to those surfaces of the granular material which carry a positive charge. In this manner the dust is collected in the body of granular material **23**.

In carrying out the invention it is necessary to provide suitable ductwork and dampers to conduct the hot furnace gas through the ionizing units and the combination units to the chimney stack during the dust-collecting cycle, and to conduct outside air through the combination units and to the furnace during the pre-heating cycle. In the drawings the individual pieces of equipment and the ductwork are shown diagrammatically, and their general construction and operation will be understood by those skilled in the art.

During one phase of operation some of the combination units will be receiving hot furnace gas that has passed through ionizing units, and will therefore be on the heat-receiving and dust-collecting cycle. At the same time other combination units that have previously been heated will be receiving cool incoming air and will therefore be on the pre-heating cycle. This phase of operation will be called Phase I, and is illustrated in FIG. 1.

After a suitable time interval the combination units that have been on the heat-receiving and dust-collecting cycle are changed over to the pre-heating cycle, and vice versa. This phase of operation will be called Phase II and is illustrated in FIG. 2.

The equipment may be operated continuously by alternating between Phases I and II.

PHASE I

In explaining Phase I we will start with the combination units **20** and **22** of FIG. 1, making particular reference to unit **20**.

The heat-receiving and dust-collecting cycle

With the equipment in the positions illustrated in FIG. 1, hot combustion gases leave furnaces **10** by way of the main flue **32**, and thence through branch flues **33** to **37** inclusive to the ionizing units.

The hot gas from branch flue **34** passes through ionizing unit **13**, and then is directed into the combination unit **20**. This flow results from the fact that dampers **38** and **39** are in the *a* position causing the gas to impinge on inclined partition **40** which diverts the flow laterally into unit **20**.

At the same time the hot gas from branch flue **35** passes through ionizing unit **14**, and then is diverted into the combination unit **20**. This flow results from the fact that dampers **41** and **42** are in the *a* position, causing this flow of gas also to impinge on inclined partition **40** which diverts the flow laterally into unit **20**.

As the hot gases pass through the unit **20** they transfer heat to the granular material and at the same time the negatively-charged dust is deposited on surfaces of the granular material. The cooled and cleaned gas then passes to the stack by way of duct **45**, damper **44** being in the *a* position.

In a similar manner the hot gases from branch flues **36** and **37** are conducted through ionizing units **15** and **16** to the combination unit **22**, and thence by way of duct **45** to the chimney.

These connections and damper arrangements would be duplicated for any desired number of combination units.

Air pre-heating cycle

Meanwhile, during Phase I illustrated in FIG. 1, certain other combination units (which previously had received hot furnace gas) are connected to pre-heat the incoming air for the furnace. This flow will be described in connection with combination unit **19**.

Cool atmospheric air (averaging 70° F.) passes into the air inlet **45** and thence by way of branch inlet **46** to combination unit **19**. This flow results from the fact that damper **47** is in the *a* position.

As the cool air passes through the unit **19** it absorbs heat from the hot granular material, thus pre-heating the incoming air before it goes to the furnace.

After passing through the bed of granular material in unit **18**, the gas is diverted laterally by inclined partition **48** and passes to the furnace by way of inlet duct **49**, damper **50** being in the *a* positions.

In a similar manner, incoming cold air from the air inlet **45*a*** passes through branch inlet **46*a*** to combination unit **21** and thence to the furnace by way of duct **52**.

PHASE II

The apparatus is run in the Phase I position for the desired length of time, after which the dampers are moved to their *b* positions, as illustrated in FIG. 2. The apparatus is now in condition to operate in Phase II, in the following manner:

The heat-receiving and duct-collecting cycle

In Phase II, combination units **19** and **21**, which were cooled during the air pre-heating cycle of Phase I, are placed on the heat-receiving and dust-collecting cycle.

Hot furnace gas now flows from furnace flue **33** through ionizing unit **12** and thence through combination unit **19**. This flow results from the fact that damper **50** is in the *b* position and the gas is directed laterally by the inclined partition **48**.

Similarly, hot furnace gas flows from furnace flue **34** through ionizing unit **13** and thence through combination unit **19**. This flow results from the fact that dampers **38** and **39** are now in the *b* position, and the gas is directed laterally by inclined partition **48**.

As the hot furnace gases pass through the unit **19** they transfer heat to the granular material and at the same time the negatively-charged dust is deposited on the surfaces of the granular material. The cooled gas then passes to the stack by way of duct **51**, damper **47** being in the *b* position.

In a similar manner the hot gases from branch flues **35** and **36** are conducted through ionizing units **14** and **15** to the combination unit **21**, and thence by way of duct **52*a*** to the chimney.

Air pre-heating cycle

Meanwhile, during Phase II illustrated in FIG. 2, combination units **20** and **22** (which previously had received hot furnace gas) are connected to pre-heat the incoming air for the furnace. This flow will be described in connection with the combination unit **20**.

Cool atmospheric air passes into air inlet **45*a*** and thence by way of branch inlet **53** to combination unit **20**. This flow results from the fact that damper **44** is in the *b* position.

As the cool air passes through the unit **20** it absorbs heat from the hot granular material, thus pre-heating the incoming air before it goes to the furnace.

After passing through the bed of granular material in unit **20**, the gas is diverted laterally by inclined partition **40** and passes to the furnace by way of inlet duct **55**, damper **39** being in the *b* position.

In a similar manner, incoming cold air from the air inlet **45*a*** passes through branch inlet **56** to combination unit **22** and thence to the furnace by way of duct **57**.

Change of phases

The system is operated in the condition of Phase II until the combination units **19** and **21** have attained the desired temperatures, after which the controls are changed back to Phase I. Typically this change of phases would occur at intervals of about 1 minute.

Flow controls

In some installations it will be advisable to control the change of gas flow by means of a controller responsive to the temperature, or dew point, of the gases going out to the stack. This is important because in a heat interchanger of this type which is adapted for removing large amounts of heat from combustion gases, it is possible under some conditions for the temperature of the outgoing gases to be reduced below the dew point. In this case moisture is deposited on the interchange surfaces and when the flow is changed this moisture would be evaporated into the ingoing gas thus increasing the moisture content and dew point of the outgoing gas. This process can thus become cumulative and result in trapping large amounts of moisture in the system, which must be avoided. This trapping of moisture can be avoided by lengthening the intervals between change of flow.

If the flow of outgoing gases is continued without reversal, the interchange media will gradually warm up. The method of preventing the trapping of moisture is then to use a control which is responsive to temperature or dew point of the outgoing gases. This control operates in conjunction with the fixed interval or timing control so that as long as the temperature of the outgoing gas is safely above the dew point, the reversals occur at the predetermined intervals. However, if the outgoing gas falls below the dew point, then this dew point control will prevent reversal of flow until the temperature of the outgoing gas is safely above the dew point. In this way the trapping of moisture is avoided.

It is also advisable to take steps to prevent dilution of the incoming air by combustion air trapped in the apparatus.

When all of the dampers are moved simultaneously from the "*a*" positions of FIG. 1 to the "*b*" positions of FIG. 2, any combustion gas remaining in an interchange unit will be drawn into the ingoing combustion air. To minimize this dilution it is desirable to utilize a particular time delay cycle [which will be illustrated by the changeover of unit **20** from damper positions *a* to positions *b*]. If all valves were switched simultaneously, the volume of combustion gas in combination unit **20** and the associated space between dampers would be drawn into the furnace with the combustion air. To minimize this it is proposed to change dampers **39** and **41** very slightly ahead of damper **44**. With damper **44** in the *a* and **39** and **41** in the *b* position air is forced through unit **20** by the fans **103**. The ideal is to change damper **44** just as the combustion gas has been forced out of unit **20** and the associated duct. In this way dilution of the ingoing combustion air is minimized.

Cleaning of ionizing units

The inlet end of each of the ionizing units is provided with a damper. These dampers shown, **58** to **62** inclusive, are normally in their open position. But by moving any one of these dampers to the closed position, flow is stopped through its associated ionizing unit, and this unit can then be rapped to remove its collected dust, which can be permitted to fall into a hopper.

Cleaning the granular material by removal

As stated previously, the granular material **23** is a material in granular form having low electrical conductivity. If it is a ceramic material it can be dumped into a hopper, cleaned, and returned to the combination unit.

Similarly, if granular limestone is used, it is usually dumped into a hopper, cleaned, and returned to the combination unit. Using a material such as limestone tends to neutralize acid in the gas and since the limestone is cheap it can be dumped and permanently discarded whenever it is excessively deteriorated by corrosion or mechanical handling.

A modern 200 megawatt unit would involve 400,000 c.f.m. and 1,600,000 lbs. of heat interchange material. Just bringing in 800 tons of material is costly. Reusing involves only screening and elevating both of which would also be required in using new material at each charging.

To permit the removal of the combination material from one of the combination units, the flow of gas is first cut off from that unit. Thus, assuming that the apparatus is in the condition of FIG. 1, to permit the removal of the material **21** from the combination unit **20**, the dampers **59** and **60** are moved to their closed positions, thus stopping the flow of hot gas through the ionizing units **10** and **11**, and also through the combination unit **20**.

FIG. 3 is a perspective view of one of the combination units.

When it is desired to clean the material **23**, the bottom hinged door **27** is opened and the material **23** is permitted to fall into the hopper **63**. The material then falls onto a dust screen **64**, which removes the dust from the material. The dust falls into a dust hopper **65**, and the cleaned material is delivered to a conveyor **66**. The material may then be transferred in any desired manner to the hopper **67**, from whence a fresh charge of cleaned material is admitted to the combination unit.

Cleaning the granular material by reverse gas flow

In some applications of the combined precipitator and heat-interchanger it may be desirable to use reverse gas flow to remove the dust that had been collected in the granular material. Normally this will require a pulsating gas flow with momentary pressures sufficiently high to agitate the granular material in order to dislodge the collected dust. This requires that the plane of the rectangular bed of granular material be horizontal with a downward flow of the gas to be cleaned, and an upward reverse gas flow.

One type of apparatus for accomplishing this is shown in FIGS. 4 to 8 inclusive.

In FIGS. 4 and 5 a series of combination units **67**, **68**, and **69** are arranged as a vertical series of horizontal beds one above the other. FIG. 4 is a plan view looking down on the top unit **67** while FIG. 5 is a section on line V—V of FIG. 4 and shows the vertical stack of beds.

FIG. 4 shows that the combination unit **67** is divided into two sub-units **67A** and **67B**, which are located in the same horizontal plane.

As shown in FIG. 5, a duct **70** introduces cleaning air from a high-pressure fan to one side of the stack of combination units, while a duct **71** conducts air from the other side to the dust collector.

In the position of FIGS. 4 and 5 the dampers **72A** and B in duct **70** are closed, and dampers **73A** and B in duct **71** are closed. This means that the apparatus is not in a cleaning cycle, and none of the combination units are being cleaned.

In the position illustrated in FIGS. 4 and 5, the sub-unit **67B**, and the sub-units below it, are receiving hot gas from the ionizing units **12** and **13**, and the gas leaving these sub-units is being delivered to the stack as shown by the arrows in FIG. 4. This is due to the fact that damper **73A** is closed, dampers **74** and **74A** direct gas toward the sub-units **67B**, etc., and the damper **75** leading to the stack is open.

As shown in the lower half of FIG. 4, a damper **77** is open, thus admitting cool incoming air to the stack of sub-units **67A**, etc. The position of dampers **74**, **86**, and **78** is such that the air which has been heated by passing through sub-units **67A**, etc., is then directed to the furnace.

As shown in FIG. 5, main partitions **80** to **82** inclusive, form the main ducts for the sub-units **67A**, etc. In addition intermediate partitions **83** to **85** inclusive, are provided. These intermediate partitions form smaller ducts, so that a smaller fan can be used to provide the high-velocity cleaning air, as will be explained below. The intermediate partitions also avoid space charge, as will become clear.

An enlarged section through a portion of one of the beds is shown in FIG. 6. This shows the space above the granular material **23**. During the operation electrical contact must be maintained between the ductwork and the top of the bed. This is done with the spike-like projections **87**, which project downwardly from the metal screen **88**. The number of these projections used depends on the operating resistivity of the bed. In most applications the temperature of the ingoing hot gas from the furnace is expected to be of the order of 600° F., which will give an average temperature of 570° at the top of the bed. At a temperature of 570° F. the granular material is relatively conducting. This results in a relatively conducting layer at the top of the bed. In this condition relatively few projections **87** are needed.

To minimize bypassing of air, a longer projection **87*a*** extends down into the bed of granular material at the end of the partition **83**.

A series of dampers **89** to **94** inclusive are used to control flow of cleaning air, as will be now explained. In FIG. 5 all of these dampers are open.

In the position of the parts illustrated in FIGS. 7 and 8, the tier of sub-units shown in the upper half of FIG. 7

(sub-units 67B, etc.), is in the same cycle as the corresponding units in FIG. 4, i.e., it is receiving and de-dusting hot gas. The tier of units in the lower half of FIG. 7 (sub-units 67A, etc.) is on the cleaning cycle.

For this purpose, the damper 72A is open to admit cleaning air from duct 70; damper 78 is closed to prevent access of the cleaning air to the furnace; and damper 73A is open to permit escape of the cleaning air by way of duct 71. From duct 71 the dust-laden air is discharged into a dust collector, which may be any of the various conventional devices, such as a cyclone, cyclone and precipitator, or bag filter.

In FIG. 8 the damper 91 is open, whereas the remaining dampers of this series (89, 90, 92, and 94) are all closed. As a result, the high-velocity cleaning air blown in through duct 70 is channelled through the narrow duct between partitions 80 and 84. This high-velocity air is concentrated on the right-hand end of the bed 68A of granular material, where it raises and agitates the granules of cleaning material. The dislodged dust is then blown out through the duct between partitions 80 and 84, and by way of duct 71 to the dust collector.

By opening, one at a time, the dampers related to damper 91, each end of the horizontal beds can be cleaned in turn. After the tier of sub-combination beds 67A, etc., has been cleaned, it can be returned to the regular heating and precipitating cycles previously described.

Space charge control

In my United States Patent 3,026,964 I have explained how in this type of apparatus, excessive "space charge" potentials can build up and how this space charge can discharge the negative charge on the dust, and thus prevent the dust from precipitating. This "space charge" can become a problem in the present apparatus if there will be high dust loadings in the spaces that follow after the ionizer. This problem can be controlled by subdividing the ducts into smaller ducts, and by providing the dampers with space-control members.

This potential is proportional to the square of the linear dimensions (assuming geometrically similar passages). Thus large spaces past the ionizer must be avoided wherever the dust loading is high. A conservative limit is to keep width of ducts past the ionizer less than, or only slightly greater than, the width between grounded plates in the ionizer, and to arrange grounded surfaces so that there are no projections having a small radius of curvature.

Means for insuring satisfactory limitation of space charge are illustrated in FIG. 9. In FIG. 1 the ducts of ionizers 12, 13, etc. each have three parallel ionizing units. Thus the duct leaving the ionizer is three times the width of the spacing between grounded electrodes in the ionizer. This is permissible for low dust loadings. For high dust loadings these ducts should be subdivided as shown in FIG. 9.

FIG. 9 shows an enlarged view of ionizing units 12 and 13. In this figure, partitions 95 divide the space past the dampers into spaces which are equal to or less than the spacing between grounded plates in the ionizer.

This leaves a space in the region of the dampers where gas must flow in several different directions, so that this space cannot be divided by fixed plate partitions. To control space charge in this region two devices are used. Fixed posts 96 (grounded surfaces) allow air to flow around in all directions but effectively limit the distance from any point in space to a grounded electrode. Baffles 97 can be attached to the damper 98 and swing with it and thus provide for gas flow in both directions while subdividing the space.

FIG. 10 shows in an enlarged view one form of damper 98 and baffles 97. This illustrates the method of attaching baffles 97 to damper 98. This is done by a post-like member 99. These posts of circular cross-section permit adequate space for gas flow.

The upper half of FIG. 9 shows that when damper 98 is in its lowered position, the posts 96 are located in the open gaps left by the baffles 97, thus reducing the space available for the production of space charge.

The lower half of FIG. 9 shows that when the damper 98 is in its upper position, the posts 96 do not interfere with this damper and its baffles 97.

Another instance of providing a grounded surface so that no point in space is too far away from a grounded surface, is provided by the post member 100 mounted on the damper 101. The post 100 is mounted on damper 101 by way of a bracket 102 in such a position that when the damper 101 is in its open position the post 100 is in the middle of the space through which damper 101 moves. When damper 101 swings to its closed position, the post 100 swings clear of the end of the partition 95 and comes to rest in the middle of a gas passage.

Improved heat efficiency

Industrial furnaces of the type to which this invention applies normally produce gas at a temperature of approximately 600° F. If gas at this temperature is treated in the ionizing units and combination units of the present invention, it will be discharged to the stack at a temperature of approximately 130° F. This corresponds with a discharge temperature of approximately 300° F. obtained in ordinary commercial installations.

This great increase in heat efficiency results from the fact that the present invention utilizes cheap and readily available granular material in the combination units. It is therefore possible to utilize a large amount of this material for purposes of heat interchange.

Improved efficiency of dust removal

Another advantage resulting from the use of a large quantity of the granular material is the possibility of obtaining precipitation of well over 99% of fly ash even with high-resistivity fly ash. Present commercial installations can be made to give this efficiency with low-resistivity fly ash, but almost never maintain this great efficiency with the high-resistivity fly ash characteristic of most modern power plants.

The dust in gas from industrial furnaces is principally fly ash, and this form of dust is particularly difficult to remove by precipitation.

In the conventional single-stage precipitator, in which the particles are deposited in a corona discharge, the corona current is able to maintain a reasonable negative charge on the dust and thus hold the dust onto the plate. Two-stage precipitators have not been commercially successful in the collection of fly ash, primarily because of the absence of corona current to cause the fly ash to adhere to the collecting electrode.

In the system of the present invention the absence of corona current is compensated for by the irregular pockets between pieces of the granular material. These pockets have been found to be very effective in trapping the collected dust. Apparently the dust particles do not always remain where originally deposited but in bouncing between surfaces will be caught in these pockets and adhere to the surfaces of the pieces of granular material.

Normally in electrostatic precipitation on a plate, an attempt is made to provide a relatively uniform field over the collecting surface. This is done because there is an upper limit to the electrical field, and an attempt is made to maintain this maximum value over the entire collecting surface.

In the present invention a uniform field cannot be maintained over the irregular surfaces of the granular material. However there are two offsetting advantages:

(1) Each piece of granular material forms an electrode, and since the spaces between pieces are small, higher voltage gradients can be maintained than with large spacings.

(2) The granular material is cheap so that a large

amount can be used, thus providing a large amount of surface area.

Under these conditions it is not necessary to have high effectiveness per unit of surface.

The location of the high-voltage electrode in the bed of granular material must be carefully considered in view of several factors. It is desirable to locate this electrode in a zone where both the fly ash and the granular material have maximum resistivity. Fortunately, such a position can be found.

In the bed of granular material the temperature of the granular material will vary over a wide range in different parts of the bed and the inexpensive rock-like heat interchange substances exhibit a large variation of resistivity as a function of temperature. Resistivities are commonly measured using either the material in a solid or in fine powdered form. Measured at a nominal voltage (2 to 4 kv. per inch) with the material in powdered form a typical range of resistivities might be

Ohm-cm.	at ° F.
10^{10}	130
10^{11}	180
10^{12}	250
2×10^{12} (max.)	280
10^{12}	310
10^{11}	400
10^{10}	500
10^{9}	600

Since the same current must flow through a wide range of resistivities this indicates a wide range of voltage gradients. However with the deep bed there is a zone with a considerable volume with an adequate gradient to give good precipitation, and the high voltage electrode should be located in this zone.

This table shows the variation in resistivity at a nominal voltage. This is the common practice in describing fly ash even though the resistivity tends to decrease as the applied voltage increases. Granular materials exhibit a greater decrease in resistivity with applied voltage than powders. Apparently this is due to the formation of a local glow discharge between adjacent granules when the voltage across their point of contact becomes excessive. This characteristic tends to make the actual voltage gradient through the granular material more uniform than would appear from considering resistivity as shown in the above table. This is due to the fact that, if any local region tends to be a region of high resistivity, as soon as the voltage drop exceeds a nominal value the voltage does not increase in proportion to the current (resistivity decreases). This minimizes high local voltage gradients. There will still be some variation in voltage gradient within the granular material. However with the deep bed used in this invention for heat transfer and dust holding capacity, a high precipitation efficiency is obtained.

It is to be noted that one face (meaning the granular material at the face) of each of the combination units always receives the hot furnace gas at a temperature close to 590° F., during the heat-receiving cycle. During the pre-heating cycle the temperature of this face drops to approximately 550° F. As a result the temperature at this face varies from 550 to 570° F. This face may be called the "hot face."

The opposite face of the combination unit always receives the cool incoming air, which is at an average temperature of 70° F., during the pre-heating cycle, but due to retained heat the combination material never gets below approximately 90° F. During the heat-receiving cycle the temperature of the face rises to approximately 110° F. Hence, the temperature of this face varies from 90° to 110° F. This face may be called the "cool face."

It has been found that all inexpensive granular materials that are suitable for use in the combination units have a maximum resistivity at temperatures between 225° F. and 375° F. when located in furnace gas which has a considerable moisture content. (Power plants burning hydrocarbon fuels always produce furnace gas with high moisture content. A typical figure would be 3.5 percent moisture by weight in the stack gas.) Above 500° F. the inherent conductivity of most of these available materials becomes quite high. It is for these reasons that their maximum resistivity is at the intermediate temperatures just given.

The fly ash, on account of its relatively high moisture content, will have a low resistivity at temperatures below about 180° F., and will have its maximum resistivity at intermediate temperatures, in the neighborhood of 275° F. to 300° F.

As stated above, it is desirable to locate the high-voltage electrode in a zone where both the fly ash and the granular material have maximum resistivity. With this location it is possible to apply maximum voltage to the high-voltage electrode, thus making economical use of electric current.

We have just noted that at temperatures in the neighborhood of 275° to 300° F. both the fly ash and the available granular materials are at their maximum resistivities. A zone which is maintained substantially at these intermediate temperatures during both phases of operation can be found intermediate the hot and cool faces of the combination material. This zone will usually be near the middle position between these two faces.

With the use of some particular granular material this zone of intermediate temperatures may be closer to one face than the other. Under these circumstances consideration must also be given to the fact that the high-voltage electrode should be so located that the current from the electrode to both faces is approximately equal.

These two factors, optimum temperature for maximum resistivity and equal current flow to both faces, must both be taken into account in locating the high-voltage electrode. In a typical installation this location will be in the zone located intermediate between the two gas-receiving faces of the bed of granular material.

It will be clear from the above that the present invention provides for the efficient collection of fly ash by reason of the combination of the following features:

(1) Separation of charging and collection sections.

By separating the charging and collecting sections it is possible to so locate the charging section that it receives the furnace gas directly from the furnace, at its top temperature, approximately 600° F. At this high temperature the fly ash has a low electrical resistivity and it is therefore possible to apply an efficient ionizing voltage without causing trouble from "back corona."

(2) Use of a bed of granular material for the collecting section.

The use of a bed of granular material compensates for the absence of corona current because the irregular pockets formed between pieces of the granular material form pockets which are quite effective in trapping and holding the collected dust.

(3) Subjecting the bed of granular material to reverse flow of hot gas and cool air.

By using the bed of granular material as a heat-interchanger, it is possible to maintain in this bed a zone which is maintained at approximately 275° to 300° F. Within this range of temperatures both the fly ash and the granular material have maximum resistivity. By locating the high-voltage electrode in this zone it is possible to apply maximum voltage, thus providing for economical use of electric current.

This combination of features provides optimum conditions for charging the dust particles, and for their collection.

In this way the present invention provides not only for improved heat efficiency, but for improved efficiency of dust removal.

Location of fans and dilution of ingoing combustion air

From the standpoint of power required to drive the fans, the fans should be located on the cool gas side of the interchanger. (For a given pressure, the fan power is proportional to gas volume and therefore inversely proportional to absolute temperature.) This arrangement is also desirable from the standpoint of gas leakage. It is assumed that large valves in hot dusty gases will have some leakage. It is undesirable to have any combustion gas leakage into the ingoing air since this would dilute the oxygen and reduce the combustion temperature. With the fans **103** in the incoming air, the outlet from these fans is the point of highest pressure. Thus leakage causes some increase in volume of gas handled and therefore some increase in fan power but this leakage does not dilute the ingoing combustion air.

In some cases it may be preferable to place the fans **103** in the outlet ducts adjacent to the stack.

Design features

FIG. 1 shows some useful characteristics of a design for moderate dust densities. As discussed in Patent 3,026,-964, space charge imposes an upper limit on the size of open spaces between the ionizer and the collector. A large ionizer is used which will collect a considerable fraction of the entering dust. By using dampers to isolate a section during rapping, dust can be efficiently transferred from the collecting electrodes to the hopper. Thus with a moderate dust load entering and with a considerable fraction removed by the ionizer, a 2 ft. wide open space is permissible.

This design contemplates combination units **19** to **22** of a size approximately 24 to 30 inches thick and 30 ft. long x 20 ft. high. At a face velocity of 100 ft. per minute this gives a throughput of 60,000 c.f.m. per unit. The velocity through the ionizer should be as low as possible. The arrangement shown allows each ionizer to be operating at all times except for rapping periods. Valves or dampers allow a given ionizer to serve either of two adjacent interchange units.

In the design of the combination units **19** to **22**, one side of the bin is always hot and so there is no serious corrosion problem with ordinary steel. The other side is cool and the combustion gases are relatively corrosive at this low temperature. This side of the bin may be of stainless steel or may be coated with materials such as electrically conducting rubber. (The degree of conductivity needed is small.) The insulating bushings and the lead to the power supply are in the entering air duct, where the air is clean and non-corrosive.

According to the provisions of the patent statutes, I have explained the principle of my invention and have illustrated and described what I now consider to represent its best embodiment. However, I desire to have it understood that, within the scope of the appended claims, the invention may be practiced otherwise than as specifically illustrated and described.

I claim:

1. In an industrial furnace installation the combination of:

(A) a furnace;

(B) a stack for discharging furnace gas to the atmosphere;

(C) an air inlet for the admission of cool air;

(D) a plurality of combination units connected between the furnace and the stack;

each combination unit comprising a bin having side walls electrically grounded, the bin being filled with a bed of granular material having low electrical conductivity, and a high-voltage electrode located within the bin and extending parallel to the side walls and in direct contact with the granular material and connected to impress a voltage on the granular material;

(E) a plurality of ionizing units connected between the furnace and the combination units;

(F) ductwork connected to the furnace, thence to the ionizing units, thence to the combination units, thence to the stack, whereby gas coming from the furnace is conducted directly from the furnace to an ionizing unit, thence to a combination unit and from the combination unit to the stack;

(G) ductwork connected to the air inlet, thence to the combination units and thence to the furnace, whereby cool inlet air is conducted from the air inlet through said combination units and from the combination units to the furnace; and

(H) dampers in the ductwork and so arranged that in one set of positions they will direct hot gas from the furnace through the ionizing units and the combination units as specified in subparagraph (F) and in another set of positions they will direct cool incoming air through the combination units as specified in subparagraph (G);

(I) whereby the combination units absorb heat and remove ionized dust from the furnace gases when connected as in subparagraph (F) and pre-heat incoming cool air for the furnace when connected as in subparagraph (G).

2. A system as recited in claim **1** in which the bin is of rectangular shape having elongated side walls.

3. A system as recited in claim **1** in which the bed of granular material is approximately 24 to 30 inches thick and the high-voltage electrode is located intermediate the two faces of the bed.

4. A system as recited in claim **2** in which the bed of granular material is approximately 30 inches thick and the width and length of the bed are at least several times the thickness, and with a high voltage electrode whose width and length are each less than the corresponding dimensions of the bed by an amount approximately equal to the thickness of the bed.

5. A system as recited in claim **1** in which the granular material is a material of irregular shape and averaging approximately ½ inch in diameter.

6. The method which comprises carrying out these steps in the order recited:

(A) treating hot gas coming from an industrial furnace by passing it directly to an ionizing unit to charge the dust particles in the hot gas with negative charges;

(B) passing the hot gas through a bed of granular material charged with a voltage gradient, and causing the dust to precipitate on the granular material while at the same time causing the granular material to absorb heat from the hot gas;

(C) cutting off the flow of hot gas to the bed of granular material after the granular material has reached a suitable temperature; and

(D) passing cool air through the heated bed of granular material to pre-heat the cool air prior to passing it to the furnace.

7. The method as specified in claim **6** wherein the ionizing units continuously receive hot furnace gas while the bed of granular material is alternately receiving hot gas from the ionizer or cool air.

8. The method as specified in claim **6** wherein the cool air is passed through the granular material in the direction reverse to that taken by the flow of hot gas.

9. The method as specified in claim **6** wherein the gas passing into the ionizer is at a high temperature approximately that at which it left the furnace, and the dust is precipitated in the bed of granular material at a lower temperature, approximately that at which both the dust and the granular material have maximum electrical resistivity.

10. The method as specified in claim **6** wherein the gas passing into the ionizer is at approximately 600° F., at which temperature the resistivity of the dust is low, and the dust is precipitated in the bed of granular material at a temperature of approximately 275° to 300° F., at which temperatures the resistivity of the dust and of the granular material is high.

11. The method as specified in claim 6 wherein after a number of cycles of use the bed of granular material is isolated from the flow of both hot gas and cool air and is agitated by a flow of cleaning air to remove accumulated dust.

12. The method of treating hot furnace gas containing fly ash which has an electrical resistivity greater than 2×10^{10} at approximately 250° F., which comprises; ionizing the gas at a temperature of approximately 600° F., at which temperature the resistivity of the fly ash is low, and precipitating the fly ash in a bed of granular material by applying a high voltage to the granular material in a zone where the bed has temperatures of approximately 275° to 300° F., at which temperature the resistivity of the fly ash and of the granular material is high.

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