

Sept. 24, 1963

W. C. MARCHAND
HEAT EXCHANGER

3,104,955

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2 Sheets-Sheet 1

FIG. 1.

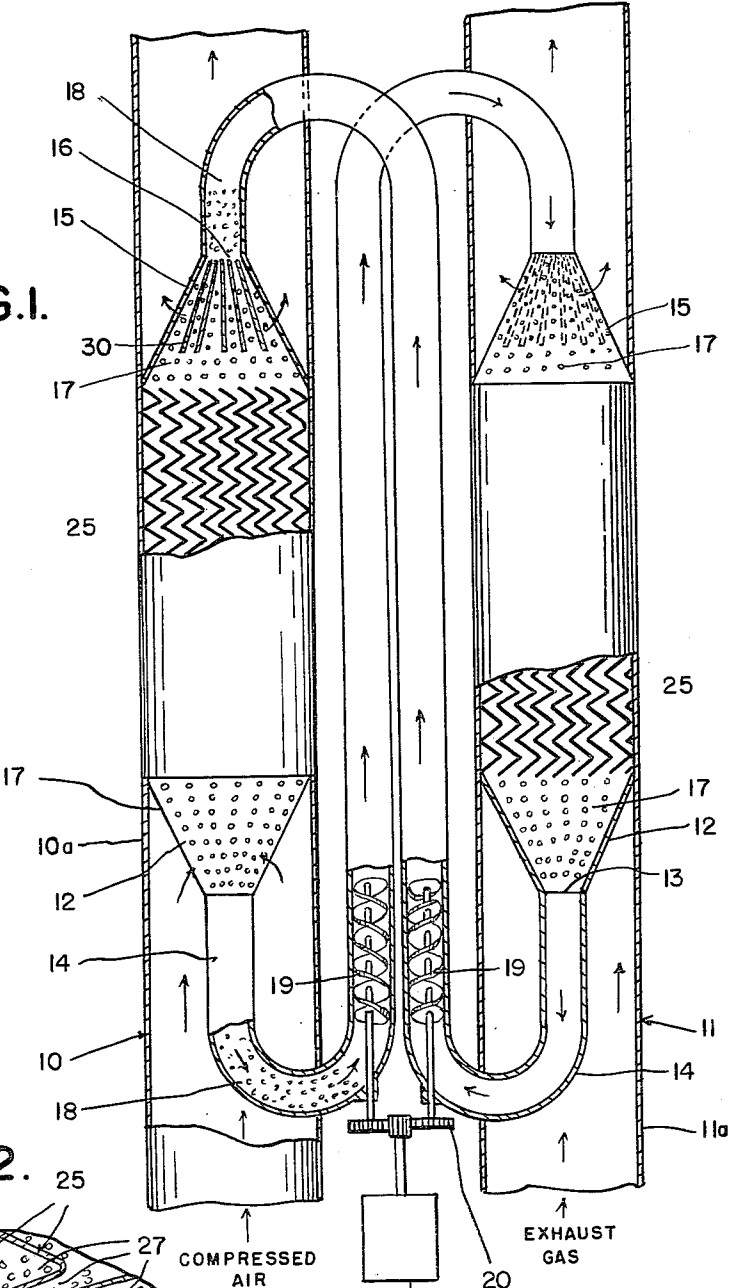
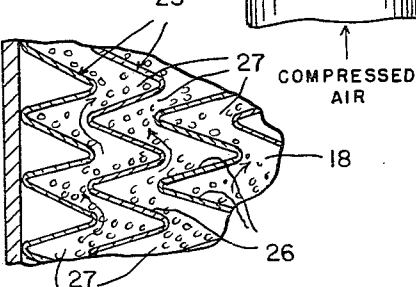


FIG. 2.



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FIG. 3.

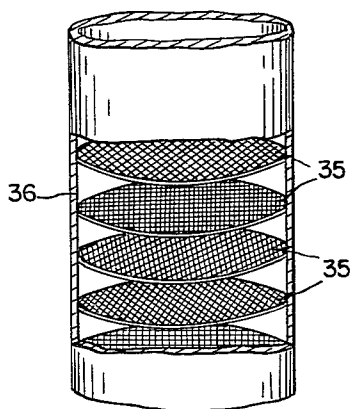


FIG. 4.

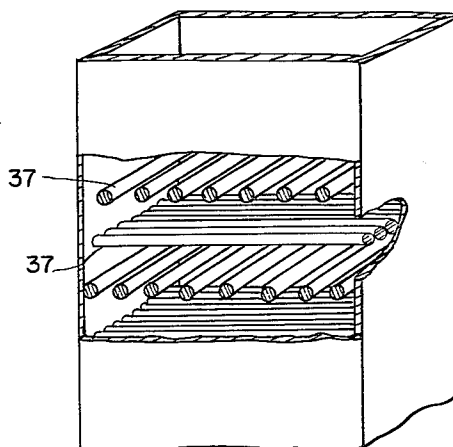
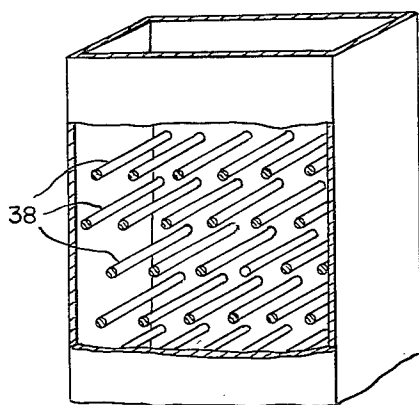


FIG. 5.

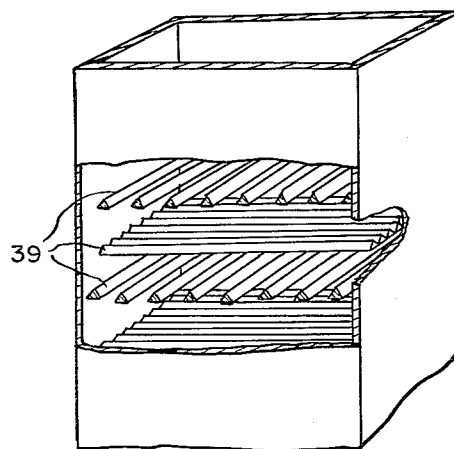


FIG. 6.

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3,104,955

HEAT EXCHANGER

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6 Claims. (Cl. 34-163)

My invention relates to heat exchangers and more particularly to small pellet type counterflow heat exchangers applicable for use with gas turbines in transferring exhaust gas heat to the intake compressed air.

To improve the fuel economy of gas turbines, particularly the part load economy, it has for some time been the goal of engineers to perfect a more efficient heat exchanger. The purpose of the heat exchanger, sometimes called a regenerator or recuperator, is to extract heat energy from the exhaust gases and to add this heat energy to the air charge after compression of the air and before the burner, usually called the combustor. The transference of this heat which otherwise would be wasted, allows the attainment of the desired temperature of the gases entering the turbine nozzle with a lesser expenditure of fuel in the combustor.

The fuel economy of gas turbines can be improved by increasing the pressure ratio of the machines but this increases cost, weight, bulk, and complexity and does not give the desired economy gain when the machine is operated at part load as is required for vehicular applications.

The most simple type of heat exchanger is the stationary type, consisting of a multiplicity of thin walled tubes with the low pressure hot gases flowing on one side, and the cooler compressed air flowing on the other side of the tube walls. To achieve the desired heat transfer requires a large bulk and weight of the exchanger which defeats the principal advantage of the gas turbine, its low bulk and weight. Furthermore, this type of exchanger usually requires a large pressure drop which is detrimental to the power and economy of the basic turbine, it is susceptible to leakage from the large number of welded or brazed joints, and is susceptible to clogging from dust in the consumed air.

The rotary type of heat exchanger consists of a disc or drum constructed of matrix which may be wire screens, a bundle of thin wall tubes or crinkled sheet metal. The drum or disc revolves slowly through two parallel ducts, one carrying the flow of exhaust gas and the other compressed air charge, the matrix allowing the gases to flow therethrough, the matrix being alternately heated by the exhaust gas and cooled by the compressed air. This type of heat exchanger overcomes several of the disadvantages of the stationary type. It is lower in bulk and weight, it has a low pressure drop, it has high effectiveness; that is, a large percentage of the exhaust heat is transferred to the compressed air, and it is not as susceptible to dust clogging as the stationary type.

The principal disadvantage of the rotary type is its leakage loss. Unless an effective seal can be made between the rotary element and the stationary ducts, compressed air is spilled either to atmosphere or to the exhaust duct. Since power is expended in compressing the air, this leakage causes loss in efficiency, which can overcome the advantage of the heat exchanger. Much effort has been expended to develop an effective seal and at the present state of the art, this is still an unresolved problem.

Even with an effective seal, the rotary exchanger has another leakage loss, the so-called carry-over loss. The full air volume of the matrix is exposed alternately to the high pressure and low pressure ducts, and will therefore spill this volume of high pressure gas to the low pressure duct once each revolution of the rotor.

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To overcome the disadvantages of the above mentioned types of heat exchangers, the so-called pellet type of heat exchanger has been proposed. Small pellets of metal or refractory material are introduced into the top of a vertical exhaust duct with the exhaust gases flowing upward to atmosphere. The pellets move downward by gravity or other means and absorb heat from the hot gases. The pellets are collected at the bottom of the exhaust duct and are propelled by some means to the top of a second duct also vertically disposed. Compressed air from the compressor flows upward through this duct before entering the combustor. The hot pellets move downward through this second duct in the same manner as through the first duct and transfer their heat energy to the compressed air. The pellets are collected in the bottom of this second duct and propelled by some means to the top of the first duct, thus completing the heat cycle.

For a properly effective pellet type heat exchanger, it has been observed that the following requirements must be met:

(1) The pellets must be of sufficient size so that they will not become entrained in the compressed air or exhaust gases and be carried through the turbine and/or exhaust duct to be lost overboard.

(2) All the pellets must remain in contact with hot and cold gases for a sufficient length of time to attain nearly the same temperature as the gases.

(3) All portions of the gas streams must nearly equally contact the pellets.

(4) The rate of flow of pellets must be such that the temperature of the discharged exhaust gas is nearly as cool as the temperature of the incoming compressed air, and the temperature of the compressed air leaving the exchanger must be nearly the same as that of the entering exhaust gas.

(5) The gas velocity through both ducts of the heat exchanger must be low enough to avoid excessive pressure drop.

(6) The gas velocity through both ducts of the heat exchanger in relation to the pellet size must be low enough to avoid flotation of the pellets. Flotation would prevent downward flow of the pellets and would also produce excessive pressure drop.

(7) The bulk and weight of the heat exchanger must be a minimum.

Heretofore in pellet type heat exchangers, either the pellets fall freely through the gas column, or the pellets are closely packed and are propelled by gravity, as in the hour glass, or by some other mechanical means through the exchanger.

With the free falling system for a typical heat exchanger requirement either the pellets would be required to be nearly as fine as dust to heat quickly enough, or the height of the exchanger would need to be measured in tens or hundreds of feet to obtain adequate heating time.

With the closely packed system for the same typical requirement, the cross sectional area of the exchanger would be required to be measured in terms of many square feet to avoid excessive pressure drop of the flowing gases.

An object of the present invention is to improve pellet-type heat exchangers by providing a duct of short length and operable to materially increase the average time of descent of individually gravitating heat exchange particles.

Another object of the invention is to improve pellet-type heat exchangers by providing a rising fluid duct and utilizing the full flow of fluid therein to agitate and decrease the average velocity of descent of individually gravitating heat exchange particles.

A further object of the invention is to provide for

improved short length pellet-type heat exchangers by constructing a fluid duct coacting with the counterflowing fluid therein to intermittently interrupt and agitate the gravitating individual heat exchange particles to provide an increased period of heat exchange between the fluid and the particles.

A still further object of the invention is to improve pellet-type heat exchanger capability by constructing a fluid duct comprising one or more tortuous passages operable to repeatedly interrupt the descent of every individually gravitating heat exchange particle and to coact with the counterflowing fluid to produce agitation of each particle, thereby materially lengthening the average time during which the heat exchange process occurs in a relatively short space.

For a clearer understanding of the invention, reference may be had to the accompanying drawing illustrating a preferred embodiment of the invention in which like reference characters refer to like parts throughout the several views and in which:

FIG. 1 is a side view partially in cross-section of a preferred construction of the heat exchanger.

FIG. 2 is an enlarged fragmentary cross-sectional view illustrating the interior construction of the counterflow duct,

FIG. 3 is a fragmentary perspective view of a modified heat exchanger duct,

FIG. 4 is a fragmentary perspective view of another modified duct,

FIG. 5 is a fragmentary perspective of yet another modified duct, and

FIG. 6 is a fragmentary perspective of still another modified duct.

A pair of heat exchangers 10 and 11 are utilized in the present invention illustrated, applicable for use with a gas turbine, the heat of the exhaust gas flowing through a duct 11a being transferred to the cooler compressed air flowing through a duct 10a. It will be apparent that the principles herein described may be used with other fluids in other applications. The ducts 10a and 11a are vertically disposed, the fluids flowing from bottom to top.

Within each duct is a lower funnel-shaped member 12 which has a centrally disposed outlet 13 connected with a transfer duct 14, and an upper inverted funnel-shaped member 15 having a centrally disposed inlet 16 connected with the transfer duct 14 as shown in FIG. 1 such that the upper inlet 16 and lower outlet 13 in opposite ducts are connected. Each funnel member is provided with a plurality of perforations 17 so that the fluids flowing through the respective ducts 10a and 11a may continue in substantially uninterrupted flow from bottom to top. The funnel members 12 and 15 and the transfer ducts 14 provide for a continuous closed-cycle flow of heat exchange particles 18, which are preferably small metal pellets, preferably spherical in form, being transferred from one side to the other by any suitable means such as stoker-type screw lifts 19 operated through gear drives 20 by an electric motor 21 or other means. The pellets 18 may also be hollow for more rapid heating and cooling characteristics.

The heat exchange particles 18 are of a larger size than the perforations 17 so that they will not escape past the funnel members 12 and 15. The particles 18 are thus collected by the lower funnel members 12 and pass through the outlets 13 into the ducts 14, raised by the screws 19 and fed or introduced into the upper funnel member 15 through the inlets 16 to gravitate through the fluid to the lower funnel members 12. The particles being lifted through the ducts 14 will of course be closely packed above the screws 19, whereas in the ducts 10a and 11a, the gravitating particles are separated.

The axial distance separating the funnel members 12 and 15 is preferably quite short, and in the present embodiment is only about one to two feet. It is apparent

that normal free fall of the pellets or particles 18, even when deterred to some extent, by the counterflowing fluids, would be of extremely short duration. An obvious expedient would be to provide particles of extremely small size such that the deterrent effect of the fluid flow would be greater. However, for the practical reason that it is too difficult to prevent fine particles from passing through the perforations 17, and since perforations of very fine size are difficult to provide, a practical limit of about $\frac{1}{16}$ inch diameter is imposed on the particles 18, and under the normal gas turbine exhaust and air intake flow, particles of this size will still fall at a rapid acceleration. In order to provide the most efficient practical heating of the particles with the least practical resistance to the flow of fluids, two factors need to be maintained; one, that the area of any lateral cross section at any moment across the duct 10a or 11a between the funnel members 12 and 15 preferably includes less than 50 percent heat exchange material to more than 50 percent fluid; and second, that the average time of exposure of each particle to the fluid be at least about ten seconds.

In order to accomplish this result, since the distance is so short, a means is provided for intermittently interrupting each particle 18 in its path of descent, and coincidentally for coacting with the fluid flow to effect agitation of each particle, thus increasing the average time period during which each particle remains in contact with the fluid. Such a means which operates satisfactorily is illustrated in the drawings as comprising a plurality of corrugated partitions 25 extending the length of the ducts 10a and 11a between the funnel members 12 and 15. Each partition 25 is provided with a plurality of inclined upper faces 26 as shown in FIG. 2, and the partitions 25 are closely spaced, these providing a plurality of tortuous passages 27 through which both the gravitating particles 18 and the counterflowing fluids pass. Each particle 18 is forced to travel an irregular path, its descent being repeatedly interrupted as it rolls and drops from face to face of the corrugated partitions 25. In addition, the rising fluids produce additional agitation, so that the particles in total average effect descend very slowly. By choosing the proper construction for the partitions 25 relative to the mass of the particles, the rate they are introduced from the upper inlets 16, and the velocities of the fluids, the effective heat exchange period may be greatly increased for full efficiency without causing any appreciable pressure drop of the fluids.

In addition to the other advantages mentioned above, the present system is much lighter than these using a packed mass of heat exchange particles, and also the individually gravitating and agitated particles offer their total surfaces for heat exchange purposes during substantially the entire time of descent.

Diffuser vanes 30 or any suitable device may also be provided in the upper funnel members 15, as shown in FIG. 1, for scattering or distributing the particles 18 to provide substantially uniform dispersion over the total lateral cross-section area of the ducts 10a and 11a.

Various other means for interrupting or delaying the descent of the heat exchange particles 18 may be utilized in the ducts 10a and 10b, and several modifications embodying the basic principle of the invention are illustrated in FIGS. 3-6.

In FIG. 3 a plurality of screens 35 are provided in a duct 36, the perforations in the screens being larger than the diameter of the heat exchange particles. The screens 35 should be so located relative to each other as to prevent any particle from falling directly through from one to another screen, thus imposing the desired delay in the descent of the particles.

FIG. 4 illustrates a further modification having a plurality of rows of spaced bars 37, the bars of each alternate row being angularly disposed with respect to each other, preferably closely spaced and each row preferably being staggered with respect to the other rows of bars

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running the same way so that no direct fall-through of particles is possible.

FIG. 5 illustrates yet another modified structure in which is provided a plurality of parallel rows of bars 38, the bars of each row parallel and staggered relative to the bars next above and below in such a manner that again direct fall-through is impeded.

FIG. 6 shows a still further modification of the invention in which a plurality of parallel rows of inverted V-shaped bars 39 are provided, preferably being so located that the rows are at right angles as shown.

Proper design of the foregoing modifications will result in obtaining any desired rate of descent within practical limits.

In summary, the present invention comprises a novel and practical construction of the heat exchanger passages which allow the combination of the following desirable characteristics:

- (1) A heat exchange particle size sufficiently large to avoid entrainment of the particles in the flowing gases.
- (2) A slow enough particle descent to allow adequate heating time in an exchanger of short length.
- (3) Nearly uniform spacing of the particles in the gas stream to accomplish a nearly uniform and complete heat transfer.
- (4) Low gas velocity and therefore low pressure drop in an exchanger of small cross sectional area because of a low density ratio of particle volume to gas volume. Expressed in other terms, the porosity ratio is high.
- (5) Low weight and bulk.
- (6) Very low leakage and carry over losses.

Although I have described only one preferred embodiment of the invention, it will be apparent to one skilled in the art to which the invention pertains that various changes and modifications may be made therein without departing from the spirit of the invention or the scope of the appended claims.

I claim:

1. A pellet type heat exchanger comprising a substantially vertical conducting means having a fluid intake, a fluid exhaust, a pellet inlet means, and a pellet outlet means spaced from and disposed at a lower level than said inlet means, said inlet means being constructed and arranged to introduce pellets into said conducting means intermediate the intake and exhaust thereof at a rate only at which each pellet is enabled to substantially individually gravitate in a free fall state through said conducting means and at which substantially little pressure drop is produced in flow of fluid from the intake to the exhaust, said outlet means being constructed and arranged to remove said pellets from said conducting means at least as fast as the pellets reach the outlet means whereby to prevent the massing of said pellets within said

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conducting means, and means interrupting the free-fall of each pellet intermittently throughout the descent thereby to decrease the average velocity of each pellet to attain an optimum effective heat exchange between said pellets and fluid.

2. The heat exchanger as defined in claim 1 and in which said interrupting means comprises a plurality of thin walled vertically disposed partitions each having a plurality of vertically spaced inclined surfaces disposed in the path of said surfaces being constructed and arranged to effect intermittent rebound of said pellets from each surface to a surface below throughout the free fall descent of each pellet.

3. The heat exchanger as defined in claim 1 and in which said interrupting means comprises a plurality of vertically disposed closely spaced partitions each having closely vertically spaced lateral corrugations providing tortuous passages through which the fluid and pellets pass, said corrugations having surfaces constructed and arranged to effect intermittent rebound of said pellets from each surface to a surface below throughout the free fall descent of each pellet.

4. The heat exchanger as defined in claim 1 and in which said pellets are of a predetermined size such that as introduced by said inlet means the area of any lateral cross-section through said conducting means at any moment includes less than fifty percent pellet to more than fifty percent fluid.

5. The heat exchanger as defined in claim 1 in which said fluid intake is disposed below said fluid exhaust, and in which said interrupting means coacts with rising fluid flow to effect agitation of said pellets uniformly laterally dispersing same throughout said conducting means.

6. The heat exchanger as defined in claim 5 in which the distance between the pellet inlet and outlet is approximately one to two feet and in which said interrupting means and the fluid flow are operable in combined effect to produce an average rate of descent of said pellets of not more than about two tenths of a foot per second.

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