May 11, 1948. H. J. DE N. McCOLLUM 2,441,279

HEAT EXCHANGE METHOD AND APPARATUS

Filed June 12, 1942 2 Sheets-Sheet 1

Fig. 1.

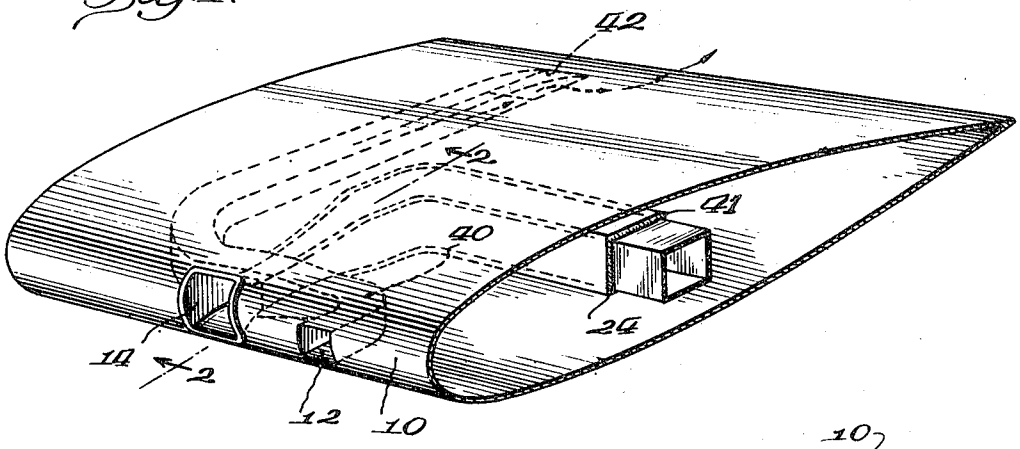
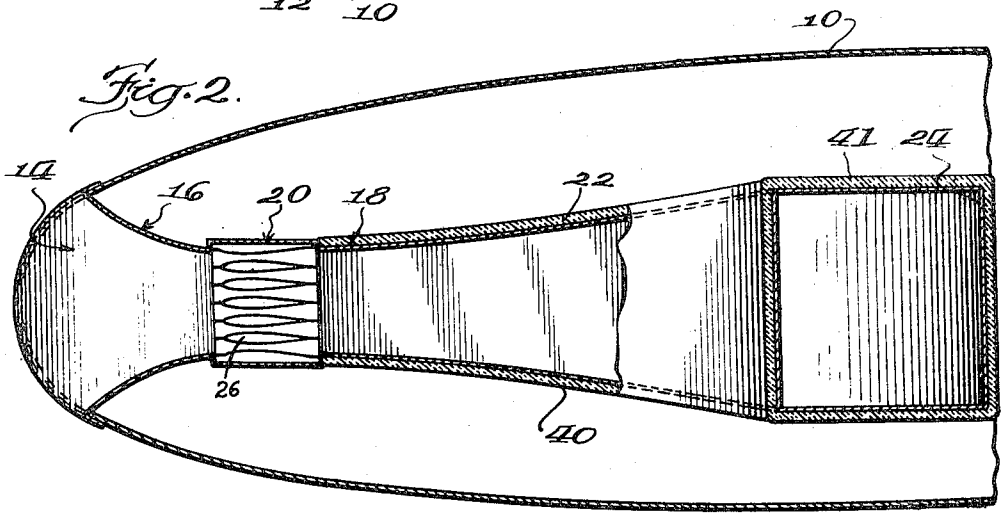


Fig. 2.



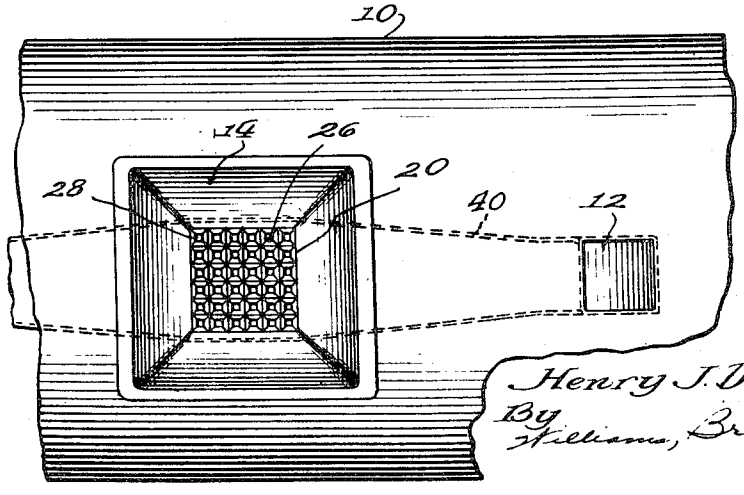


Fig. 3.

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Fig. 4.

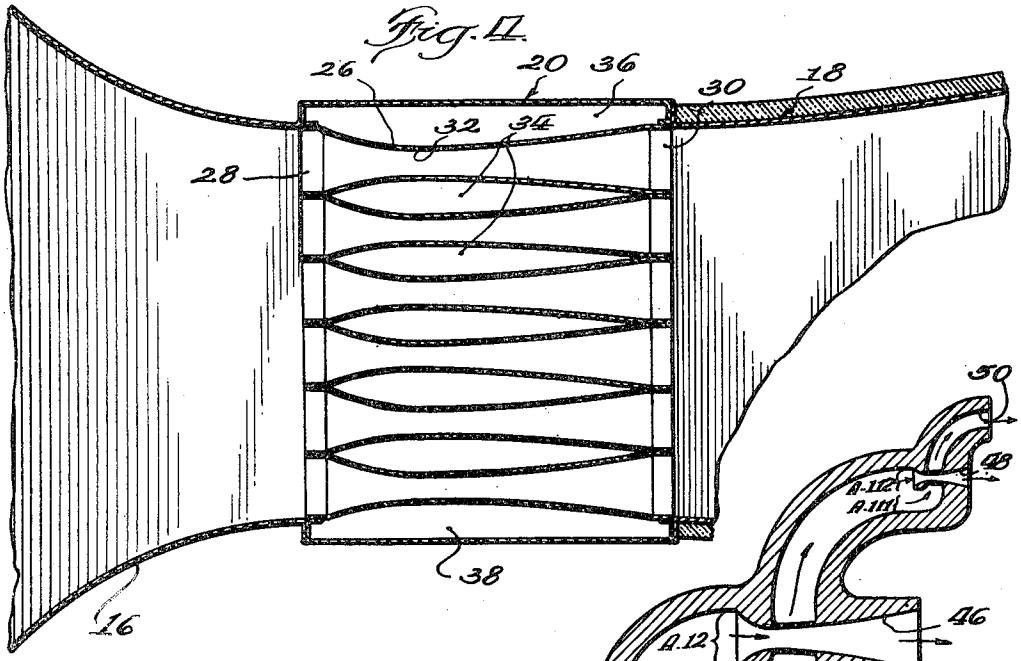


Fig. 5.

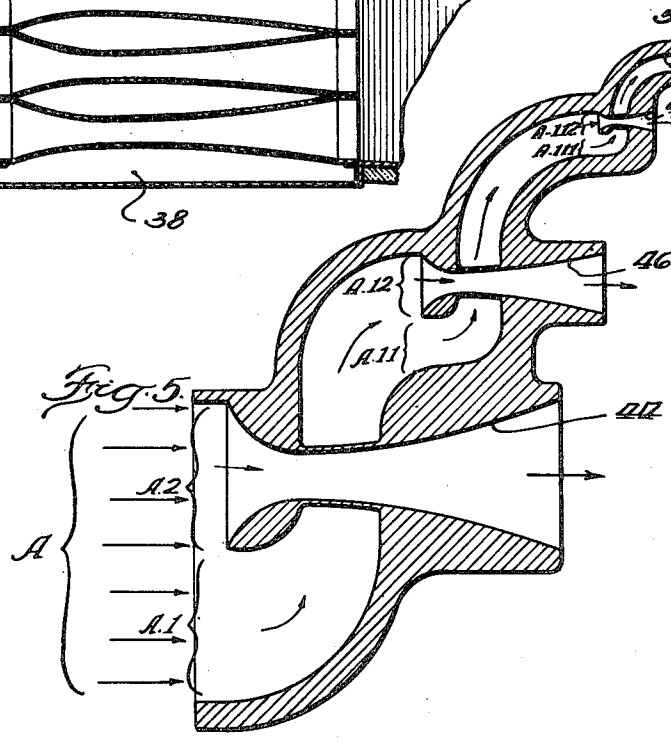
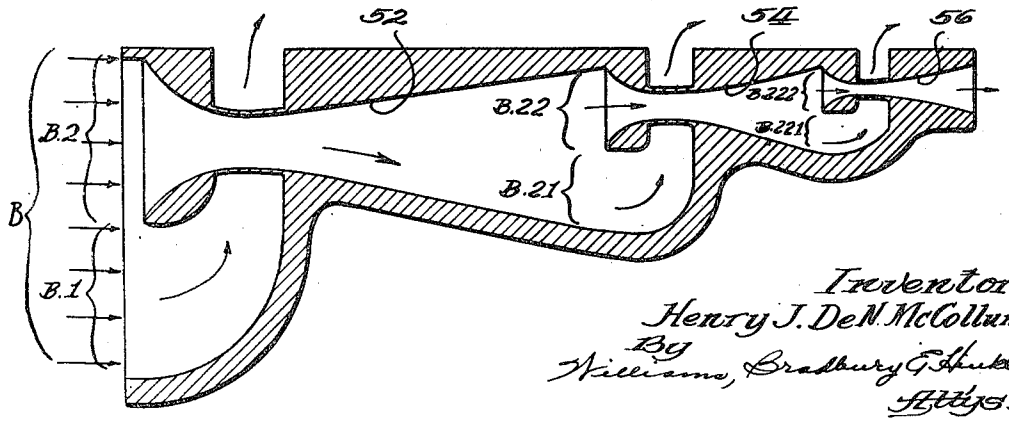


Fig. 6.



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2,441,279

HEAT EXCHANGE METHOD AND APPARATUS

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7 Claims. (Cl. 257—9)

1

My invention relates generally to heat exchange apparatus, and more particularly to apparatus especially usable upon high speed aircraft for heating or cooling the ventilating air of the aircraft or component parts thereof.

Considerable difficulty is encountered in providing heat in high speed and high altitude airplanes, for heating the ventilating air for the cabins, and for heating parts of airplanes, such as the carburetor, gun mountings, etc., and to prevent the frosting and icing of windshields and wing surfaces. Usually, equipment for supplying the amount of heat necessary to accomplish these heating functions adds considerable weight to the airplane, utilizes some of the fuel carrying capacity of the plane, and includes relatively complicated controls, which, due to enemy action or other factors, may become inoperative.

It is thus an object of my invention to provide an improved heating system for airplanes, which does not add materially to the weight of the plane, which may have but very few or no moving parts, which does not require a fuel supply, and which will operate effectively under varying operating conditions.

A further object is to provide an improved apparatus and method for heating the leading edge of airplane wings to inhibit formation of ice thereon.

A further object is to provide an improved heat exchange apparatus.

A further object is to provide an improved apparatus and method for utilizing the heat contained in one portion of a stream of compressible fluid to raise the temperature of another portion of that stream, or, similarly, to reduce the temperature of one portion of a stream of compressible fluid by transferring heat therefrom to another portion of the stream.

A further object is to provide an improved apparatus and method whereby a stream of a gaseous medium may have the heat energy contained therein transferred from one portion of the stream to another portion thereof, with resultant lowering of the temperature of the first portion and raising of the temperature of the second portion.

A further object is to provide an improved heat exchanger in which the reduction in temperature of a gaseous medium due to increasing its velocity of flow is utilized to provide a heat gradient permitting transfer of heat energy to the medium from a heat source at a relatively low temperature.

2

Other objects will appear from the following description, reference being had to the accompanying drawings, in which:

Fig. 1 is a diagrammatic perspective view of a portion of an airplane wing with the improved heat exchange apparatus of the invention installed therein;

Fig. 2 is a longitudinal sectional view of the heat exchange apparatus taken on the plane represented by the line 2—2 of Fig. 1;

Fig. 3 is a front elevational view of the leading edge of the wing shown in Fig. 1;

Fig. 4 is an enlarged sectional view showing the throat section of the heat exchanger shown in Fig. 2;

Fig. 5 is a diagram illustrating a method and apparatus for lowering the temperature of a portion of a stream of air; and

Fig. 6 is a diagram illustrating an apparatus and method for heating a portion of a stream of air.

The invention herein disclosed is based upon the well known thermodynamic principle that as the velocity of the flow of a gaseous medium (hereinafter referred to as air, for convenience) increases, its pressure and temperature decrease. Thus, by dividing a stream of air into two portions, causing the velocity of one portion to increase materially while passing through a heat exchanger, heat from another portion of the same stream of air may be utilized in the heat exchanger to supply heat to the high velocity portion of the air stream.

In Figs. 1 to 4, the invention is illustrated as applied to the heating of ventilating air for an airplane. In these figures, the airplane wing 10 has two ram openings 12 and 14 in its leading edge. The opening 14 forms the inlet of the mouth portion 16 of a Venturi tube 18 having a throat portion 20 and a flaring outlet portion 22. The outlet end of the flaring portion 22 is connected to a conduit 24, which is utilized to convey heated air to the cabin of the airplane or to any other part thereof which is to be supplied with heat.

As best shown in Figs. 3 and 4, the throat portion 20 of the main Venturi tube 18 is divided into

a plurality of Venturi-shaped passageways formed by secondary Venturi tubes 26. These tubes, as well as the tube 18, are preferably square in cross-section and are arranged in rows and tiers so as to occupy substantially completely the cross-sectional area of the throat portion 20 of the main Venturi tube 18. The tubes 26 are preferably made of sheet metal having good heat conducting properties, such as copper or aluminum, and the walls being as thin as is compatible with their necessary strength and durability.

The inlet mouths 28 and the outlet ends 30 of the tubes 26 are contiguous, as best shown in Fig. 3, while the remaining portions of these tubes, particularly their throat portions 32, are spaced from one another to provide transverse passageways 34. The transverse passageways 34, as well as passageway 36 above the uppermost tube 26, and passageway 38 below the lowermost tube 26, form part of a conduit 40 which connects the ram inlet 12 with an outlet opening 42, preferably formed in the lower surface of the wing 10 near its trailing edge. The conduit 40 is preferably of substantially uniform cross-sectional area except as it is flared to encompass the throat portion 20. The passageways 34, 36, and 38 collectively are substantially the same area as that of the ram inlet 12 so that the air will flow through the latter passageways at substantially the same velocity as the air enters the ram 12.

On the other hand, the air entering the ram inlet opening 14 has its velocity greatly increased as it flows through the mouth portion 16 of the main Venturi tube 18 and has its velocity further increased as it flows through the secondary Venturi tubes 26. As a result, the pressure, and hence the temperature, of the air as it flows through the secondary Venturi tubes 26, is substantially lower than the atmospheric pressure and temperature, and heat may thus be transferred from the air flowing through the passageways 34, 36, 38 to this air of reduced pressure and temperature, by passing through the thin walls of the secondary Venturi tubes 26, which are of high heat conductivity. The changes in pressure of the air flowing through the main Venturi tube 18 is adiabatic except at the throat portion, namely, as the air passes through the secondary Venturi tubes 26.

The mouth portion 16 is designed for an adiabatic pressure change, whereas, the outlet portion 22 of the main Venturi tube 18 is likewise designed for an adiabatic change in temperature except that allowance is made for the increased amount of heat in the air as it leaves the outlet ends of the secondary Venturi tubes 26. By proper design of the shapes of the mouth portion 16 and outlet portion 22 of the main Venturi tube 18, a high degree of efficiency may be obtained. The secondary Venturi tubes 26 are designed to secure the highest possible velocity of flow under the differential pressures available to cause such flow so as to secure the maximum possible temperature difference between the air flowing through the secondary tubes 26 and that flowing through the passageways 34, 36, 38. In order to prevent dissipation of the heat from the air as its temperature rises in the flaring outlet portion 22 of the main Venturi tube 18, as well as in the conduit 24, these may be covered with a layer 41 of suitable heat insulating material.

The arrangement shown in Figs. 1 to 4 is designed to supply heated air to the cabin, etc., but it will readily be understood that to the extent

that the temperature of the air discharged through the conduit 24 is raised, that discharged from the conduit 40 is lowered, so that if it is desired to cool the cabin, etc., of the plane, suitable conduit connections may be provided to conduct the air from the conduit 40 to the cabin, etc., while permitting the air flowing through the conduit 24 to be discharged to the atmosphere. In some instances, it may be desirable to utilize the apparatus alternatively for cooling or heating, in which event, suitable valve means may be provided so that either the heated or the cooled air may be conducted to the cabin while at the same time the cooled or heated air (respectively) is discharged overboard.

By cascading heat exchange units of the type heretofore described, a very substantial increase in temperature of the air may be obtained, or a very substantial reduction in temperature may be obtained. In Fig. 5, there is illustrated diagrammatically, an apparatus for cooling a portion of an air stream to a very low temperature. In this figure, the heat exchangers at the throats of the Venturi tubes are not illustrated in detail, but these may be of a construction similar to that shown in Fig. 4. In Fig. 5, an air stream A is divided into two substantially equal portions A1 and A2, the portion A2 flowing through a Venturi tube 44, over the throat of which the air stream A1 passes. Heat from the air stream A1 is thus transferred to the air stream A2, with resultant reduction in temperature of the stream A1. The air stream A1 is divided into two portions, A11 and A12, the latter stream flowing through a Venturi tube 46, the throat of which is in heat exchange relationship with the stream portion A11 so as to withdraw heat from the latter and thus further reduce its temperature. The stream A11 is again divided into two stream portions A111 and A112, the latter air stream flowing through a Venturi tube 48, the throat of which is in heat exchange relationship with the stream portion A111. Thus, heat is again extracted from the air stream A111, with the result that air discharged from the outlet port 50 is at a much lower temperature than that of the air stream A. This method of dividing and cascading a number of stages of the apparatus may be carried further to any extent required for obtaining air of a desired temperature.

In a somewhat similar manner, a very substantial increase in the temperature of a portion of a stream of air may be obtained by the apparatus and method diagrammatically illustrated in Fig. 6, wherein, an air stream B is divided into two streams, B2 and B1, the portion B2 passing through a Venturi tube 52, the throat of which is in heat exchange relationship with the stream B1. After supplying some of its heat to the stream B2, the stream B1 may be discharged to the atmosphere or be utilized as a stream of air for supplying an air cooling system of the type represented by Fig. 5, if it should be desired to have available a stream of air at a temperature below that of the supply as well as a stream having a temperature above that of the supply. The stream of air B2 passing through the Venturi tube 52 is divided into two streams, B21 and B22, the stream B22 flowing through a Venturi tube 54, the throat of which is in heat exchange relationship with the stream B21, so that the stream B22 has additional heat supplied thereto, further to raise its temperature. The stream B22 is again divided into two streams, B222 and B221. The stream B22 flows through

a Venturi tube 56, the throat of which is in heat exchange relationship with the stream B221 so that the temperature of the stream B22 is raised still further to a relatively high value.

By successively cascading the heat exchange units in two, three, or more stages, a portion of the air stream may be raised to a very high temperature.

When the apparatus is utilized on high speed airplanes, it constitutes a reasonably high efficiency means for transforming the kinetic energy of the air stream (or, more correctly, the kinetic energy of the airplane) into heat at a temperature higher than that of the atmosphere. When the apparatus is used to raise the temperature of the air, a large proportion of the energy lost in friction of the air along the surface of the Venturi tubes and conduits, as well as the energy lost in internal friction of the air, is recovered in the form of heat, so that the frictional losses do not constitute an appreciable factor lessening the efficiency of the system.

Since the apparatus need not have any moving parts except possibly a damper valve to control the rate of egress of the heated air into the space to be heated, it will be apparent that the apparatus may be very durable and reliable in operation. Furthermore, because it is not necessary to provide a separate fuel source, a combustion apparatus, and the attendant air circulating and control means, the apparatus may be made light in weight. Under circumstances in which it is desirable not to have the air ram openings 12 and 14 affect the operation of the airplane when the heating apparatus is not to be used, suitable closures may be provided for these openings, such closures preferably conforming to the air foil shape of the leading edge of the wing, and thus may be in the form of shutters which slide longitudinally over the leading edge of the wing to cover the air ram openings 12 and 14.

As an illustrative theoretical quantitative example of the operation of the apparatus of Figs. 1 to 4, let it be assumed that the plane is traveling at an air speed of 300 M. P. H. at sea level, with the atmosphere at a temperature of 32° F. The pressure at the inlet opening of the main Venturi tube would be 1.63 lbs./in.^{2} and, assuming proper design of the Venturi tube, would be approximately .31 lb./in.^{2} at the throat. The temperature at the throat of the Venturi would thus tend to drop to approximately 4° F., and, assuming that the heat transfer at the throat were 100% efficient, the temperature of air at the outlet of the main Venturi tube would rise to about 60° F. Of course the heat transfer through the walls of the secondary Venturi tubes cannot be 100% efficient, but, by careful design and selection of materials, a very high degree of efficiency may be attained.

It will thus be seen that a substantial rise in the temperature of the ventilating air may be obtained by the use of a very simple and lightweight apparatus. In the design of the secondary Venturi tubes located in the throat of the main Venturi tube, to obtain maximum efficiency, it is desirable that the flaring outward portions of these tubes be so shaped that the air flow therethrough will be at a nearly constant velocity. Such constant velocity condition may be approached because of the fact that heat may be added to the air at a rate which substantially compensates for the increasing cross-sectional areas of the outward portions of these secondary Venturi tubes.

By cascading the Venturi tube heat exchangers

in the general manner illustrated in Fig. 5 or Fig. 6, the temperature of the ventilating air may be decreased or increased substantially to any value required by the expected conditions of operation. Such cascade systems are especially useful for carburetor deicing, windshield defrosting, and gunner's compartments (such as the small tail gunner's compartment of a bomber), in which cases it may be preferable to supply a small volume of air at high temperature rather than a larger volume at a lower temperature.

The heating apparatus is of particular utility for carburetor deicing since the tendency toward ice formation in the carburetor increases with increased speed of operation of the airplane. Likewise, the delivery of heat by the above described apparatus (whether of the single stage or multiple stage type) will increase with increased speed of the airplane and thus deliver heat to the carburetor at a rate varying generally with the heat requirements at different speeds of operation.

While I have shown and described particular embodiments of my invention, it will be apparent to those skilled in the art that numerous modifications and variations may be made without departing from the underlying principles of the invention. I therefore desire, by the following claims, to include within the scope of my invention all such modifications and variations by which substantially the results thereof may be obtained by the use of substantially the same or equivalent means.

I claim:

1. In a heating apparatus, means for compressing an expansible fluid above atmospheric pressure, a nozzle element of the Venturi type having a heat conducting throat portion, and having inlet and outlet openings of substantially equal size, and means to direct some of the fluid supplied by said compressing means through said nozzle and other fluid from said compressing means around the throat portion only of said nozzle, the means for directing part of the fluid around the throat portion comprising a passageway of substantially the same cross-sectional area around the throat portion and at its inlet and outlet ends.

2. The method of heating a portion of a supply of a gaseous medium under pressure, which comprises, adiabatically expanding a portion of the gaseous medium by increasing its flow velocity, maintaining it while expanded in heat exchange relation with another portion of the gaseous medium, and thereafter adiabatically reducing its velocity of flow.

3. The method of producing a temperature difference in two portions of an air stream which comprises, dividing the air stream into two portions, adiabatically expanding a primary portion by increasing its velocity of flow, passing it while expanded in heat exchange relationship with the other or secondary portion of the air stream, and thereafter adiabatically increasing the pressure of said primary portion of the air stream by decreasing its velocity of flow, whereby, the temperature of said primary portion of the air stream is raised and the temperature of said secondary portion of the air stream is lowered.

4. The method of producing a temperature difference between different portions of a substantially homogeneous stream of a compressible gaseous medium which comprises, separating said stream into two portions A1 and A2, adiabatically expanding the portion A2 by increasing its veloc-

ity of flow, and, while it is thus expanded, bringing it into heat exchange relationship with the portion A1, separating the portion A1 into two streams A11 and A12, adiabatically expanding the stream A12 by increasing its flow velocity, and, while it is expanded, bringing it into heat exchange relationship with the stream A11, whereby, the portion A1 will transfer heat to the portion A2 and the stream A11 will transfer heat to the stream A12 to cause a substantial reduction in the temperature of the stream A11 relative to the initial temperature of the portion A1.

5. The method of securing substantial transfer of heat from one portion to another portion of a substantially homogeneous and uniform temperature stream B of a gaseous medium which comprises, separating the stream B into two streams B1 and B2, adiabatically expanding the stream B2 by increasing its velocity, bringing the stream B1 in heat exchange relationship with the stream B2 while the latter is expanded, causing adiabatic compression of the stream B2, separating the stream B2 into streams B21 and B22, adiabatically expanding the stream B22 by increasing its velocity of flow, bringing the stream B21 into heat exchange relationship with the stream B22 while the latter is in expanded condition, and adiabatically compressing the stream B22 by decreasing its velocity of flow, whereby, said stream B2 derives heat from said stream B1 and said stream B22 derives heat from said stream B21 and thus causes said stream B22, after it is compressed, to be at a temperature substantially higher than that of the intial stream B.

6. In a heating system for airplanes, the combination of a pair of rams, a primary Venturi tube connected to receive air from one of said rams, said primary Venturi tube having a throat portion formed by a plurality of secondary Venturi tubes occupying substantially all of the throat portion of said primary Venturi tube and having walls of heat conducting material, means for conducting air from the other of said rams at substantially constant velocity past and between said secondary Venturi tubes, and means for conducting air from the outlet of the primary Venturi tube to a space to be heated.

7. In an airplane heating system, the combination of two air rams, a primary Venturi tube having a mouth inlet opening of substantially the same cross-sectional area as the inlet opening of the ram, a plurality of secondary Venturi tubes located in the throat portion of said primary Venturi tube and having their inlet openings of aggregate area substantially equal to that of the inlet end of the throat portion of said primary Venturi tube, said secondary Venturi tubes having thin walls of heat conducting material, means for insulating the flaring outlet portion of said primary Venturi tube against the transfer of heat therefrom, and means for supplying a heating fluid to the throat portion of said primary Venturi tube, thereby to cause transfer of heat from the heating fluid to a gaseous medium flowing through said secondary Venturi tubes, whereby, the temperature difference between the heating fluid and the gaseous medium is increased by the reduction in temperature of the gaseous medium as its pressure is lowered while it flows at high velocity through said secondary Venturi tubes.

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REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
1,580,177	Suczek	Apr. 13, 1926
1,781,062	Houston	Nov. 11, 1930
1,821,920	Andrew	Sept. 8, 1931
1,906,370	Darrow	May 2, 1933
1,965,733	Chamberlain	July 10, 1934
2,101,782	Kuhner	Dec. 7, 1937
2,214,053	Gwinn, Jr.	Sept. 10, 1940
2,310,771	Franz	Feb. 9, 1943
2,325,036	Case	July 27, 1943

FOREIGN PATENTS

Number	Country	Date
754,609	France	Nov. 10, 1933