

June 12, 1951

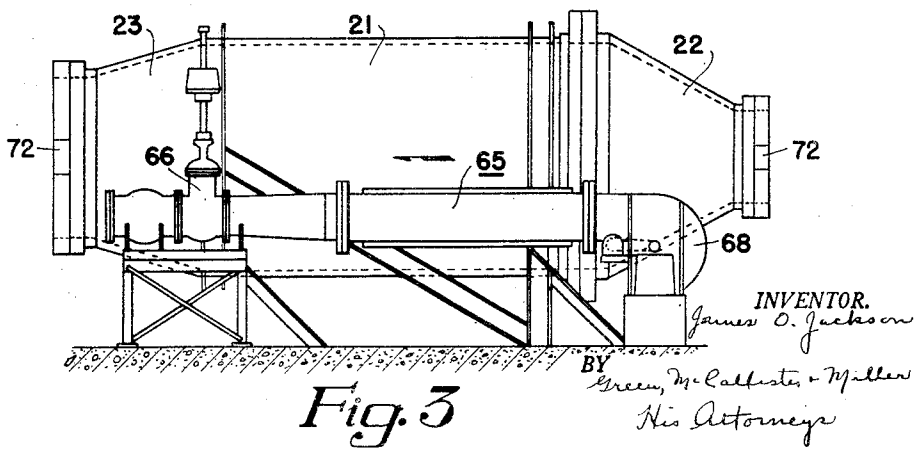
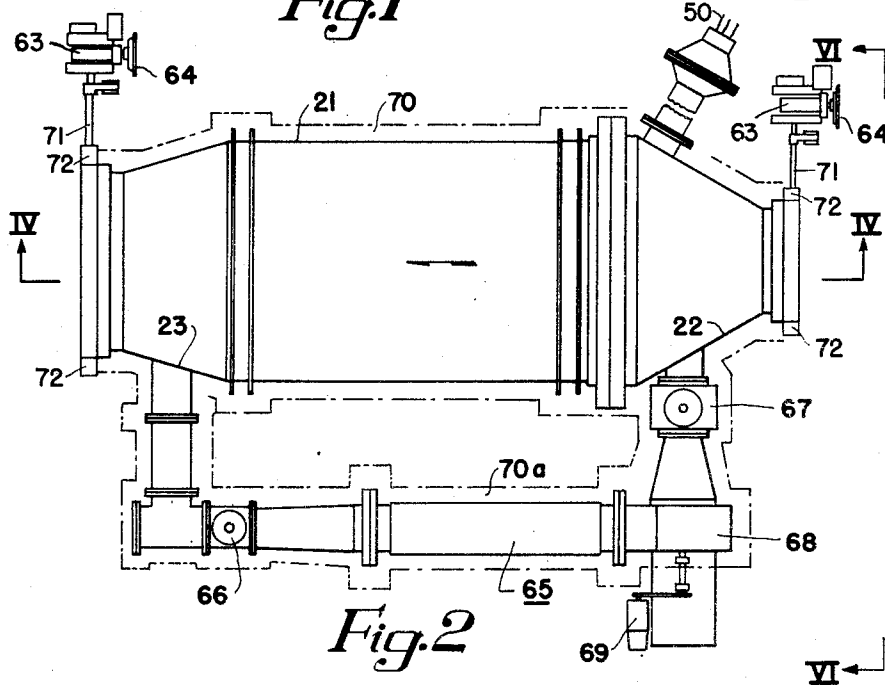
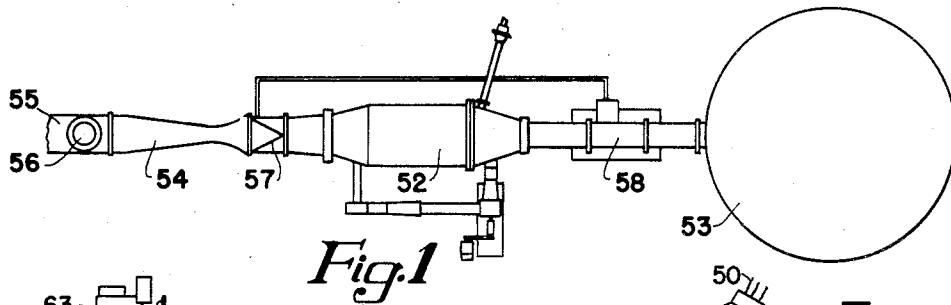
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2,556,498

HEAT ACCUMULATOR AND EXCHANGER

Filed Feb. 21, 1948

4 Sheets-Sheet 1



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HEAT ACCUMULATOR AND EXCHANGER

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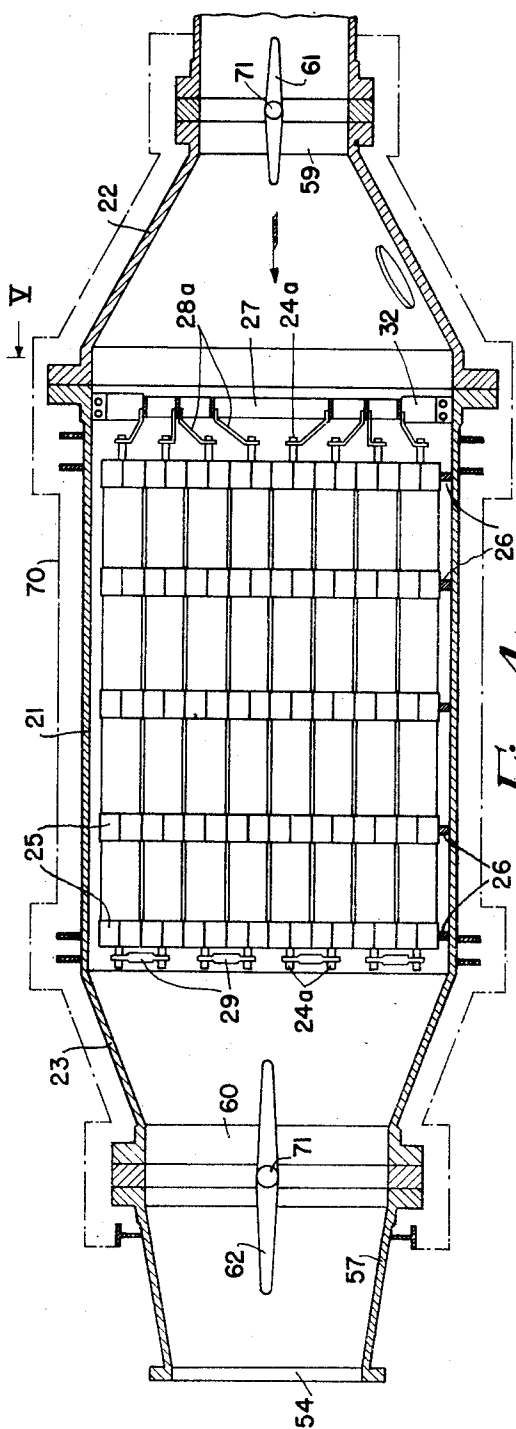


Fig. 4

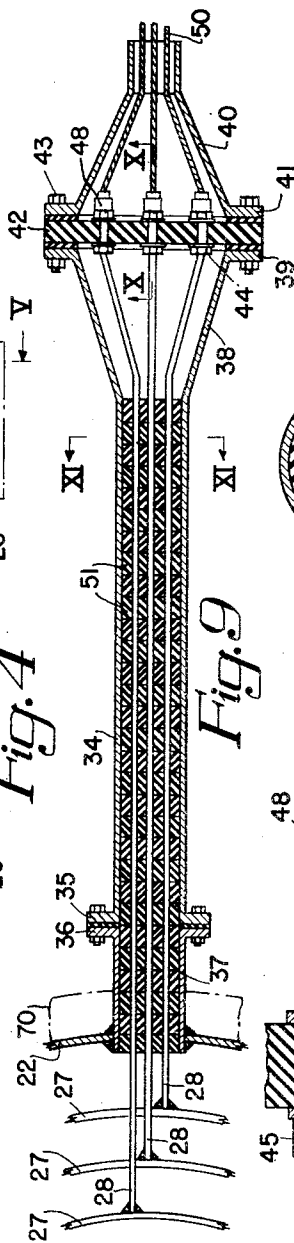


Fig. 9

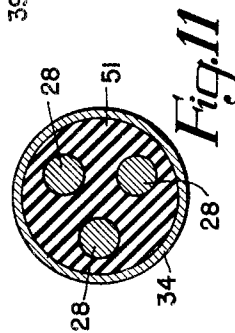


Fig. 11

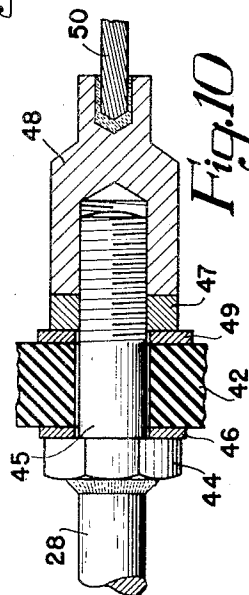


Fig. 10

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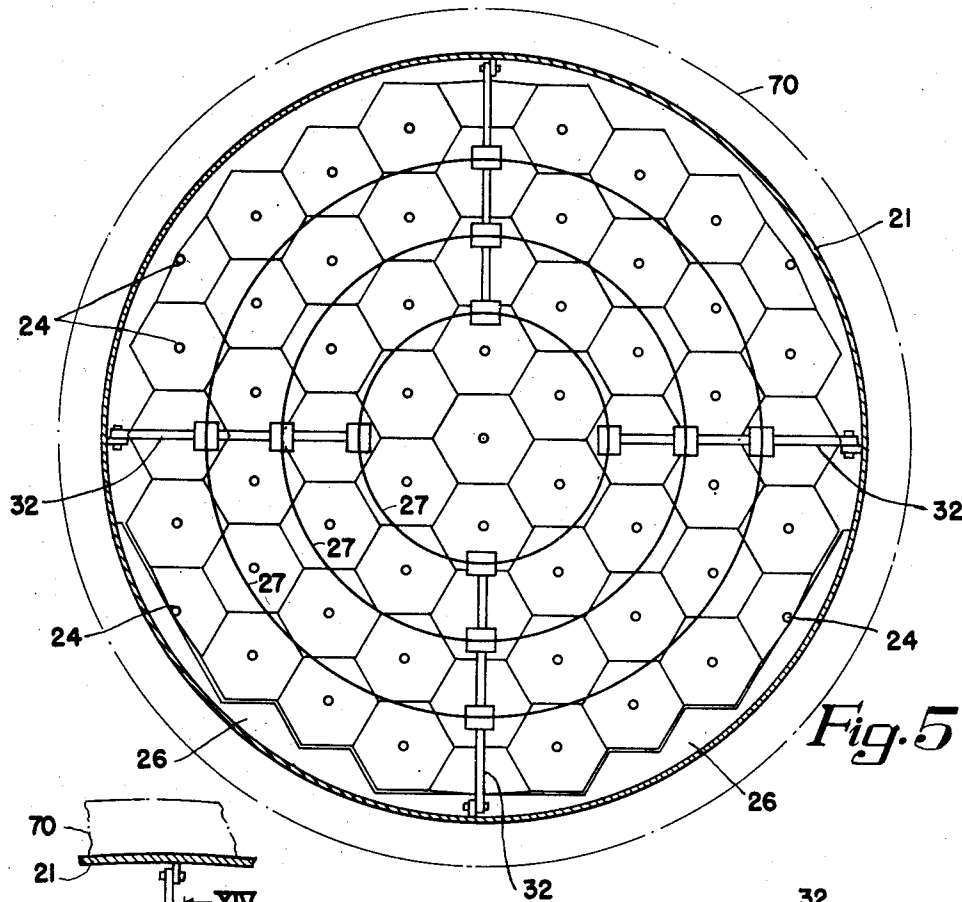


Fig. 5

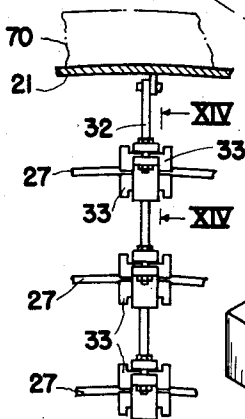


Fig. 12

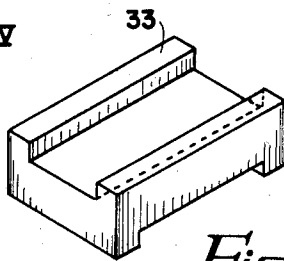


Fig. 13

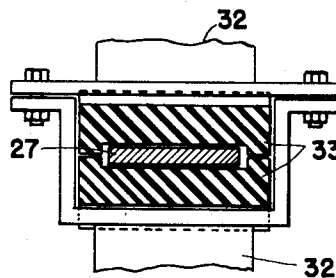


Fig. 14

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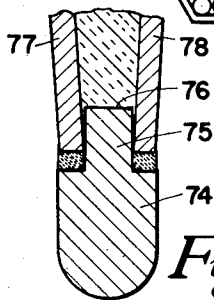
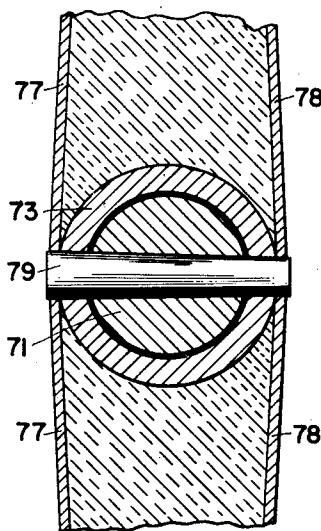
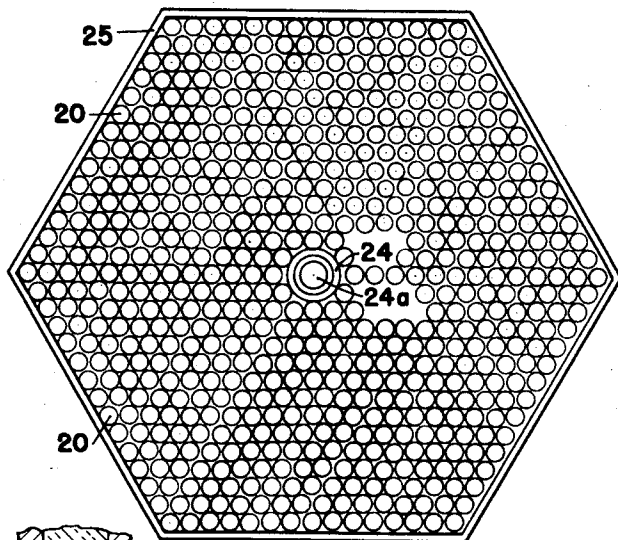
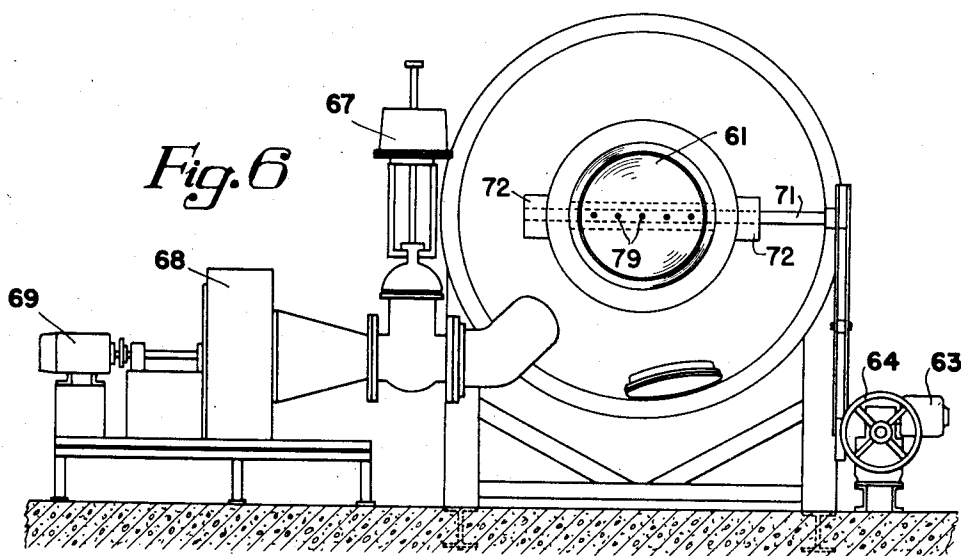


Fig. 7

Fig. 8

Fig. 15

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UNITED STATES PATENT OFFICE

2,556,498

HEAT ACCUMULATOR AND EXCHANGER

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Application February 21, 1948, Serial No. 10,139

14 Claims. (Cl. 219—39)

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This invention relates to heat accumulators and exchangers and one of its objects is to produce an improved device of this character.

Another object is to produce a heat accumulator and exchanger by means of which it is possible to heat to a substantially constant temperature a stream of air having a substantially constant pressure and decreasing temperature.

Another object is to produce a heat accumulator and exchanger having a much higher exchange coefficient than any of the prior art devices of this type with which I am familiar.

A further object is to produce a heat accumulator and exchanger having an exchange coefficient of at least about 150 B. t. u.'s per square foot per hour per Fahrenheit degree temperature difference between the mean temperature of the air being heated and the temperature of the surfaces of the exchanger with which such air contacts.

A further and more limited object is to produce a heat accumulator and exchanger capable of heating to the desired temperature, the air necessary for a single run of a blowdown supersonic tunnel, while such air is flowing from a storage container or reservoir to the nozzle of such tunnel during such run.

These as well as other objects which will readily appear to those skilled in this particular art, I attain by means of the structures described in the specification and illustrated in the drawings accompanying and forming part of this application.

In the drawings:

Figure 1 is a diagrammatic view in top plan of a supersonic wind tunnel of the blowdown type, in the make-up of which a heat accumulator and exchanger embodying this invention is utilized.

Fig. 2 is an enlarged top plan view of the heat accumulator and exchanger of Fig. 1;

Fig. 3 is a view in side elevation of the heat accumulator and exchanger of Fig. 2;

Fig. 4 is a sectional elevational view taken on line IV—IV of Fig. 2;

Fig. 5 is an enlarged sectional view taken on line V—V of Fig. 4. In both Figs. 4 and 5, the individual tubes are omitted, merely the outline of the tube bundles being shown.

Fig. 6 is a view looking toward Fig. 2, from line VI—VI but is on an enlarged scale;

Fig. 7 is an end view of one of the hexagonal tube bundles such as used in the make-up of the device of this invention;

Fig. 8 is a fragmentary sectional view of one

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of the two insulated end gates which are closed during the heat accumulating periods. These gates are shown open in Fig. 4 and closed in Fig. 6;

Fig. 9 is a view partly in elevation and partly in section of a pothead connection such as used in the heat accumulator and exchanger of this invention;

Figs. 10–14 inclusive are enlarged detail views of parts of such pothead connection; and

Fig. 15 is a fragmentary cross sectional view of a peripheral rim portion of the gate of Fig. 8.

The heat accumulator and exchanger of this invention in its preferred form comprises a large number of closely packed small diameter steel tubes with which the air or other fluid to be heated is caused to contact during its passage through the device. Such tubes are arranged in groups and each such group of tubes has an electric heating element located therein.

In the drawings, which closely follow one installation constructed in accordance with this invention, the tubes, which are numbered 20, are $\frac{1}{8}$ " nominal diameter, iron pipe size, steel tubes 10 feet long. 39,000 of these tubes, with their major axes lying parallel are housed within a steel casing having a cylindrical intermediate portion 21 having an internal diameter of 89 inches and a length of 12 feet and tapered or frusto-conical end portions 22 and 23.

Tubes 20 are arranged in groups or bundles, fifty-five of which, in cross section, are regular hexagons, and six are half hexagons as shown in Fig. 5. Each hexagonal bundle has a short diameter of about ten and one half inches and contains 624 tubes.

A steel tube 24 having an outer diameter of one inch, an internal diameter of 78 hundredths of an inch and a length of ten feet serves as a housing or container for an electric heating element 24a of the metal sheathed type.

Tube 24 is located at the geometric center of each full hexagonal bundle and at the center of the wide side of each half bundle, as shown in Fig. 5. Each full bundle as well as each half bundle is firmly held in shape by five metal bands 25 which are six inches wide by one sixteenth inch thick and are evenly spaced throughout the length of the bundles as disclosed in Fig. 4. These bands are each preferably made in three parts. The bundles are made up in the shop, so that the tubes can be handled and transported as bundles. They are also installed or placed within the casing in the field as bundles.

The bundles are made by stacking the tubes

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in jigs. The one inch tubes 24 for the heating elements are placed in position at the center of the whole bundles during the stacking of the tubes, and in the case of the half bundles, toward the end of the stacking procedure.

After the tubes have been stacked in the jigs, they are forced into close contact with one another by tourniquet-like means which are used at intervals throughout the length of the tube bundles adjacent the positions which bands 25 are to occupy. The sections of bands 25 are first tack-welded in position and then permanently welded together. Cooling of the bands and the weld metal causes the bands to shrink tightly around the tube bundles holding the tubes firmly in place.

The tube bundles are supported in place within portion 21 of the casing by means of a cradle consisting of five semi-circular steel members 26, secured in position within the lower half of the casing in line with metal bands 25 of the tube bundles (Figs. 4 and 5). The inner peripheral edge of each cradle member 26 is shaped so as to conform to the adjacent faces of the full and half bundles of tubes located within the lower part of the casing (Fig. 5). While tubes 20 are omitted from Figs. 4 and 5, the tube bundles are indicated. Heater housing tubes 24, however, are indicated in Fig. 5.

All of the spaces between the shell of intermediate body portion 21 of the casing and the tube bundles above cradle members 26 are filled with individual or loose tubes (not shown) of the same diameter and length as tubes 20. The spaces between the tube bundles and the shell below the tops of the cradle members 26 are blocked off to air flow by such cradle members so that all of the air flowing through the casing is caused to contact with the tube surfaces.

Heating elements 24a are one half inch in diameter and 11 feet long—one foot longer than tubes 24—so that they project six inches beyond each end of such tubes. These six inch projecting portions are made as cold sections so that the electrical connections can be made to them.

Each heating element 24a has a power consumption of 3500 watts and is thus rated at 3½ kw., and since there are 60 such heating elements, the total heater load is 210 kw. on a 440 volt, 3 phase, 60 cycle A. C. source.

Electrical energy is supplied to the heating elements through a circuit which includes bus bars 27, lead-in conductors 28, connectors 28a, and jumpers 29, all preferably made from stainless steel of the 18-18 type. Lead-in conductors 28 are fed by copper conductors 50 through copper connecting lugs 48. Bus bars 27 are supported in position adjacent the inlet or upstream ends of the tube bundles by support brackets 32 which are secured to the intermediate cylindrical portion 21 of the casing. The bus bars are insulated from such brackets by means of insulators 33 (Figs. 12, 13 and 14).

Since the heat accumulator and exchanger of this invention operates at pressures of at least 100 pounds per square inch and temperatures of at least 500° F., the means for connecting bus bars 27 to the source of current supply becomes a problem.

Lead-in conductors 28, which are weld connected to bus bars 27, extend outwardly through an opening in the cone-shaped wall of upstream end 22 of the casing. Conductors 28 which are about 1¾ inches in diameter are straight and

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parallel for a distance of about six feet and are arranged in a triangular group as shown in Fig. 11. The straight portion of the triangular group is housed within a steel tube 34 (Fig. 9) about five inches in diameter. This tube at its inner end is provided with a welded on flange 35 which is bolted to a companion flange 36 welded to the end of a short tube section 37 which extends within the opening in the wall of cone-shaped end 22 and is welded in place within such opening. The outer or distal end of tube 34 is provided with a flared section 38 preferably welded thereto, and this member 38 at its outer end is provided with a flange 39. Member 38 forms one part of a pothead which comprises member 38, a corresponding member 40, having a flange 41, and a circular diaphragm 42 secured in place between flanges 39 and 41 by means of a circular row of bolts 43 which extend through openings in such flanges and such diaphragm.

Diaphragm 42 is preferably formed from a material such as Micarta and is approximately 18 inches in diameter and 1½ inches thick, since it is subjected to the pressure within the casing of the device.

The portions of conductors 28 located within the pothead are spread apart as shown in Figure 9 and each such conductor is welded to the head 44 of a bolt-like lug member 45 (Fig. 10) which extends through an opening formed for its reception in diaphragm 42. A flexible gasket 46 is interposed between head 44 and diaphragm 42. Each lug member 45 is threaded to receive a nut 47 and a threaded copper lug 48; a metal washer 49 being interposed between diaphragm 42 and nut 47. After nuts 47 clamp lug 45 to diaphragm 42, copper lugs 48 are tightened on lug members 45 and the lead-in cables 50 are then silver soldered to lugs 48.

Tube 34 is filled with disk-like electrical insulating members 51. These members are provided with three circular holes arranged to receive conductors 28; the insulating members 51 being slipped over the three conductors 28 and slid to position within tube 34 before such conductors are welded to the bus bars. Members 51 are preferably molded from some material which is a heat conductor as well as an electrical insulator; a material such as synthetic mica.

The distance from diaphragm 42 to the end 22 of the casing is at least six feet, so that the heat transmitted from the accumulator by tube 34 and conductors 28 is sufficiently dissipated by the time it reaches diaphragm 42 as not to be harmful to such diaphragm.

The heat accumulator and exchanger of this invention was primarily designed to be part of a supersonic wind tunnel of the blowdown type, and Figure 1 of the drawings as before pointed out is a diagrammatic top plan view of such wind tunnel.

In Figure 1, 52 represents the heat accumulator and exchanger, 53 represents the source of supply of stored air under pressure, 54 represents the expansion nozzle of the wind tunnel and 55 represents the test section of the tunnel. For the purposes of simplification, Figure 1 shows a window 56 in the top of the test section instead of windows in opposite sides of such section. 57 represents the section connecting the circular downstream end of the heat accumulator and exchanger to the square inlet to nozzle 54. This serves as the stilling section for the nozzle. 58 represents an automatic valve for maintaining, at a substantially constant

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pressure, the air delivered from source 53 (the storage tank or tanks) to the upstream end of nozzle 54.

The air to be heated enters the heat accumulator and exchanger through port 59 (Fig. 4) of the upstream end 22 and the heated air leaves through port 60 of the downstream end 23.

Because of the fact that the tubes nearest the electrical heating elements become hotter than those further away and also because of the fact that after each blowdown or each heat transfer period, there is a marked temperature difference between the opposite ends of the tube bundles; the upstream ends having the lowest temperature and the downstream ends having the highest, it becomes desirable to equalize the temperatures both transversely and longitudinally of the stack of tube bundles and loose tubes within the heat accumulator and exchanger.

In order to obtain this equalization of temperatures, I close end ports 59 and 60 of the device during each heat accumulating period and cause the air thus trapped within the casing of the accumulator and exchanger to circulate again and again preferably in the opposite direction to the normal flow. In order to do this, I employ a gate 61 for port 59 and a gate 62 for port 60. These gates are actuated either by motors 63 or by hand wheels 64. An air duct system, which as an entirety is numbered 65, connects conical end portions 22 and 23 of the casing and is provided with shut-off valves 66 and 67 and a blower 68 driven by a motor 69.

During a heat accumulation cycle, valves 66 and 67 are opened and blower 68 draws air from end portion 22 of the device and delivers such air to end portion 23. Because of this arrangement, the air trapped within the device by the closing of end gates 61 and 62 is caused to continually circulate through the stack of tubes as long as valves 66 and 67 are open and blower 68 operates.

Gate 61, which controls port 59 at the upstream end of the casing, is about 36 inches in diameter, while gate 62, which controls port 60 at the downstream end of the casing, is about 60 inches in diameter. These gates are of similar construction and a description of one, therefore, is deemed sufficient.

A shaft 71 which carries the gate is journaled in bearings indicated at 72 (Figs. 2, 3 and 6) and is surrounded by a hollow shaft 73 which forms part of what might be termed the gate frame as will later appear. The gate is provided with a bar rim 74 (Fig. 15) and the inner portion of this rim has its sides cut away forming a central flange 75. A number of parallel ribs (not shown) extending at right angles to the axes of shafts 71 and 73, have their inner ends welded to hollow shaft 73 and their outer ends welded to the inner peripheral edge 76 of flange 75.

Cover plates 77 and 78 which are preferably formed from $\frac{1}{8}$ inch steel plate bear against the side faces of flange 75 and are welded to rim 74, to hollow shaft 73 and to such ribs. Hollow shaft 73 and solid shaft 71 are secured together by five tapered pins 79 as shown in Figs. 6 and 8.

After one cover plate is thus secured in position, the interior of the gate is packed with suitable thermal insulating cement. After the cement is thoroughly dry, the other cover plate is welded in position, care being taken to allow any moisture within the gate to escape as the welding of

this second cover to the ribs, rim and hollow shaft progresses.

Openings are made in this second cover plate at different positions opposite the ribs and it is because of these openings that this cover plate can be welded to the ribs.

As shown in Figs. 4 and 5, the casing of the device is covered with a relatively heavy layer of heat insulating material 70. This and the insulating material for the circulating system 70a is indicated by dotted lines in Fig. 2.

Under some circumstances, it may be necessary to operate the accumulator and exchanger at a much higher temperature than 500° F. If it is to be used in heating the air for a supersonic wind tunnel of the blowdown type in which velocities much above a Mach number of 4.4 are to be used, it may be desirable or necessary to use refractory tubes or other refractory members instead of steel tubes as the heat absorbing elements. The necessary air temperatures may be well above 2000° F.

In the installation above referred to, the air is delivered from the storage tanks at a diminishing pressure and temperature. Such air on its way to the heat accumulator and exchanger, passes through a valve which causes it to be delivered to the upstream end of the heat accumulator and exchanger at a constant pressure of about 117 pounds per square inch absolute.

The function of the heat accumulator and exchanger in such installation is to store about one million B. t. u.'s of heat energy in a four hour heat accumulating period and to deliver such heat energy to the air stream during a ten second operating period.

During such operating period, heat stored in the tubes is transferred to the air at a rate of 354,000,000 B. t. u.'s per hour. About 8460 pounds of dry air at an average temperature of 57° F. are heated during this ten second period to an average temperature of 508° F. The exchange coefficient, usually referred to as the "H" value, is 155 B. t. u.'s per square foot per hour per Fahrenheit degree temperature difference between the mean temperature of the tubes and the air being heated, as compared with a coefficient of from 5 to 15 as ordinarily obtained in commercial heat exchangers.

I obtain the extremely high exchange coefficient of 155 by taking advantage of the fact that a pressure loss in the air being heated, which would be prohibitive in commercial applications as uneconomical, is not objectionable in the operation of a supersonic wind tunnel of the blowdown type, because the air is stored at a pressure almost double that at which it is delivered to the nozzle of the tunnel.

In the installation above referred to, the air is stored at over 200 p. s. i. and is used in the tunnel nozzle at about 117 pounds per square inch absolute, while the pressure drop through the exchanger is only ten p. s. i. In other words, in order to store sufficient air for the operation of the tunnel, it is necessary to increase the pressure, and such increased pressure is advantageously used to obtain the very desirable high thermal exchange coefficient in the accumulator and exchanger.

Operation

When the heat accumulator and exchanger is first put in operation, it requires about nine hours to raise its temperature from around 70° F. to a required average temperature of about

546° F. However, due to the fact that the device in heating the proper amount of air to the desired temperature for a blowdown gives up but a small part of its stored B. t. u.'s, it takes a much shorter period of time for subsequent heatings.

When the heat storage tubes are heated to an average temperature of about 546° F., the required amount of air for a ten second blowdown can be heated to a temperature of from 500 to 510° F. during such ten second period.

In the installation above referred to, it is necessary to operate the air compressors about four hours in order to obtain a pressure of 205 pounds per square inch gauge in the storage tanks.

During this four hour period, the heating elements are energized for about the first hour and one half during which a little more than the total required amount of heat for one blowdown of the wind tunnel is delivered to the stacked tubes within the heat accumulator and exchanger. After this, the power is shut off.

While the heating elements are being energized, end gates 61 and 62 are closed, valves 66 and 67 are opened and blower 68 is operated by its motor 69 to circulate the air in the opposite direction to the normal direction of flow through the device during a blowdown.

The tubes nearest the heating elements of course become hotter than the other tubes in the bundles and I have found that in order to substantially equalize the temperature of the tubes, it is necessary to operate blower 68 for about four hours, which time can be made to coincide with the operation of the compressors.

The function of the air circulation is to transfer heat from the warmer to the cooler tubes and to equalize the temperature of the tubes both longitudinally and throughout the cross section of the accumulator and exchanger.

The action of the air passing through the accumulator and exchanger during a ten second blowdown is as follows:

The first air flowing through the heated accumulator and exchanger absorbs more heat from the upstream ends of the tubes than it does from the mid sections and very much more than it does from the downstream ends. In fact, the first air probably absorbs no heat whatever from the downstream ends of the tubes. As the flow continues, the temperature of the upstream ends of the tubes falls, while that of the mid sections is but slightly reduced.

In general, the longer the tubes are the longer the time and the greater the volume of air that may be passed through them for a given outlet temperature drop. I have found that for a ten second run in a tunnel having a velocity of Mach 2 and a throat area of five square feet, it is possible to maintain a constant exit temperature within + or - 5 Fahrenheit degrees.

At the end of a blowdown period, the upstream ends of the tubes are much colder than the downstream ends and for this reason, the air during the heating up period is circulated in a direction opposite to the normal direction of flow.

At the end of a ten second blowdown, the temperature of the upstream end of the tubes drops about 238 Fahrenheit degrees; the temperature midway between the ends of the tubes drops about 50 Fahrenheit degrees and the temperature adjacent the downstream ends drops only about 1 Fahrenheit degree.

As above pointed out, the length of the cylindrical portion of the exchanger, in the installation above referred to is twelve feet and its inside diameter is 89 inches. The cross sectional area, therefore is 43 square feet. The metal area of the tubes equals 45 percent of such 43 square feet. The tube hole area equals 40 percent and the area of the spaces between the tubes equals 15 percent of such 43 square feet. The average velocity of the air flowing through the device during a blowdown is 161 feet per second.

What I claim is:

1. In a heat accumulator and exchanger, a hollow casing having an intermediate portion and ported end portions adapted to be connected into a fluid line, a mass of heat absorbing material substantially filling such intermediate portion and having openings therethrough connecting such end portions, a number of tubes arranged in spaced positions within such mass and each extending from one such end portion to the other and an electric heating element located within each such tube and having an effective heating length which is substantially the same as that of such tube.

2. In a heat accumulator and exchanger, a hollow casing having an intermediate portion and ported end portions adapted to be connected into a fluid line, a mass of heat-absorbing material substantially filling such intermediate portion and having openings therethrough connecting such end portions, a number of heating agents arranged at spaced positions within such mass, gates for controlling the ports of the end portions, a fluid duct independent of the openings in such mass for connecting such end portions, and means for circulating the heated fluid confined within such casing by the closing of such ports.

3. In a heat accumulator and exchanger, an elongated hollow casing having an intermediate portion and ported end portions adapted to be connected into a fluid line, groups of contacting metal tubes substantially filling such intermediate portion and providing multiple passages between such ported end portions, and an electric heating element located adjacent the center of a major portion of such groups, extending lengthwise of such tubes and having substantially the same length as the length of such tubes.

4. In a heat accumulator and exchanger, a casing having an intermediate portion and ported end portions adapted to be connected into a fluid line, multiple groups of metal contacting tubes located within, substantially filling such intermediate portion and connecting such end portions, and electric heating means located within, extending lengthwise of each such group tubes and having an effective heating length substantially equalling the length of such tubes; the tubes of each such group being bound together so that they can be handled as a unit.

5. In a heat accumulator and exchanger, a metal casing having an intermediate portion and end portions adapted to be connected into a fluid line, multiple hexagonal bundles of metal tubes of relatively small diameter located within, substantially filling such intermediate portion and connecting such end portions, and an electric heating element located within and extending lengthwise of each such bundle.

6. In a heat accumulator and exchanger, a casing having a cylindrical intermediate portion and tapered end portions, multiple bundles of

metal tubes of relatively small diameter located within and substantially filling such cylindrical portion and connecting such end portions, and an electric heating device associated with and extending lengthwise of each such bundle for heating the tubes thereof; the majority of such bundles being hexagonal in cross section.

7. In a heat accumulator and exchanger, a metal casing having a cylindrical intermediate portion and tapered end portions, multiple hexagonal bundles of metal tubes of relatively small diameter located within and substantially filling such cylindrical portion and connecting such end portions and an electric heating device associated with each such bundle and having an effective heating length substantially equal to the length of such tubes such heating device being located within and adjacent the center of a majority of such bundles; the tubes of each bundle being bound together so that they can be handled as a unit.

8. In a heat accumulator and exchanger, a casing having an intermediate portion and end portions having ports therein, gates controlling such ports, a mass of heat absorbing material substantially filling such intermediate portion and having openings therein connecting such end portions, electric heating elements distributed throughout such mass, a fluid duct connecting such end portions outside of such casing, and means utilizing such duct for circulating through such mass the heated air confined within such casing by the closing of such gates, for the purpose of equalizing the temperature throughout such mass.

9. In a heat accumulator and exchanger, a casing having an intermediate portion and end portions having ports therein, gates controlling such ports, a mass of heat absorbing material substantially filling such intermediate portion and having openings therein connecting such end portions, electric heating elements located at spaced positions within such mass, a fluid duct connecting such end portions outside of such casing, and means utilizing such duct for circulating through such mass the heated air confined within such casing by the closing of such gates, for the purpose of equalizing the temperature throughout such mass.

10. In a heat accumulator and exchanger, a casing having an intermediate body portion, end portions having ports therein adapted to be connected into a line leading from a source of air under pressure, gates controlling such ports, multiple groups of metal tubes of relatively small diameter located within and substantially filling such body portion and extending toward such end portions, electric heating elements associated with a majority of such groups for heating the

tubes thereof, a fluid duct independent of such tubes for connecting such end portions, and means within such duct for circulating the air confined within such casing by the closing of such gates, for the purpose of equalizing the temperature in the tubes of such groups.

11. A unit for use in making a heat accumulator and exchanger, comprising a bundle of metal tubes of relatively small diameter in contact with one another, grouped about an electric heating element, extending in the same direction and having an effective heating length which is substantially the same as that of such tubes.

12. A unit for use in making a heat accumulator and exchanger, comprising a hexagonal bundle of annular metal tubes of relatively small diameter, contacting with one another throughout their length and grouped about an electric heating element extending in the same direction and having an effective heating length which is substantially the same as that of such tubes.

13. A unit for use in making a heat accumulator and exchanger, comprising a hexagonal bundle of annular metal tubes of relatively small diameter grouped about a metal tube of larger diameter enclosing an electric heating element having an effective heating length which is substantially the same as that of such tubes and means for binding together the tubes of such bundle in metal to metal contact.

14. A unit for use in making a heat accumulator and exchanger, comprising a hexagonal bundle of annular metal tubes of relatively small diameter grouped about a metal tube of the same length but of larger diameter and which encloses a sheathed type electric heating element having an effective heating length which is substantially the same as that of the tubes of such bundle and has cold ends projecting beyond the ends of such tubes and bands spaced longitudinally of such bundle binding such tubes in contact with one another throughout their length.

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