

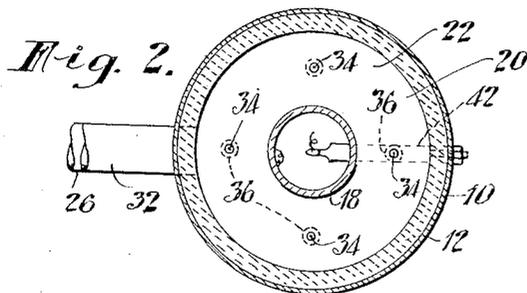
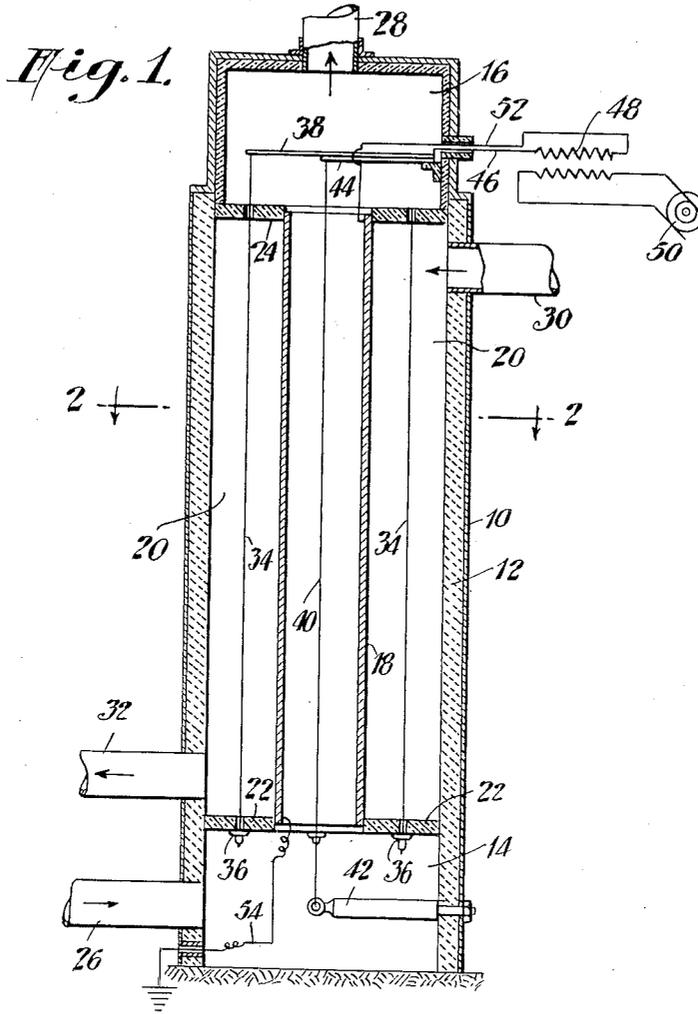
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HEAT TRANSFER

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HEAT TRANSFER

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The present invention relates to improvements in heat transfer, and more particularly to a method of and apparatus for increasing the rate at which heat transfer normally takes place between a solid surface and a body of gas in contact therewith.

Many industrial processes are concerned very directly with the problem of securing efficient utilization of heat, and particularly in securing ready transfer of heat from one body of fluid to another through the medium of a solid metal or refractory diaphragm. It is well known that in heat exchange apparatus designed to effect the transfer of heat between a solid surface and a fluid such as gas in direct contact therewith, considerable resistance is offered to the passage of heat. For instance, very low rates of heat transfer are normally obtained in the common type of heat recuperator applied to the preheating of air, steam or gas. The gas to be heated is passed through one section of the recuperator in indirect heat transferring relationship with hot products of combustion or other gaseous or liquid heating medium passed through another section of the recuperator, the transfer of heat between the two bodies of gas taking place through the medium of a refractory or metal diaphragm which separates the two sections.

It was formerly believed that any heat given up by the hot products of combustion passing through a recuperator of this kind must first pass by convection directly to the outside of the surface of the diaphragm, thence by conduction through the diaphragm and thence by convection directly to the gas or air which is taking up heat, and that accordingly the resistance offered by the system to heat transfer must be due chiefly to the poor heat conductivity of the diaphragm and/or to the low velocity of the gas passing over the surface of the diaphragm which in turn would adversely affect the rate at which heat is transferred by convection. By actual tests,

however, it can be demonstrated that the above system offers much more resistance to the transfer of heat than can be accounted for by the heat resistance of the diaphragm and/or by the reduction in heat transfer by convection caused by retarded rate of gas flow past the diaphragm.

It has now been fairly well established that the greatest factor in the resistance offered to the flow of heat from solids to gas and vice versa is due to the presence of a film of the gas adhering to the surface of the solid through which heat must be transmitted by straight-forward conductance. Thus in a heat recuperator in which air is being preheated by heat exchange with hot products of combustion one surface of the recuperator diaphragm will be insulated by a substantially quiescent film of the heating gas (products of combustion) from direct contact with the main stream of the heating gas passing through the recuperator. Likewise the opposite surface of the diaphragm will be insulated by a film of dead air from direct contact with the main current of cold air undergoing preheat. These adhering dead gas films prevent the direct transfer of heat by convection between the two surfaces of the recuperator diaphragm and the main bodies of hot and cold gases flowing past the diaphragm through the two sections of the recuperator. As it is well known that heat passes very slowly by conduction through any body of gases, the heat conductivity of these dead gas films must always be relatively low, and accordingly their presence on the surface of the diaphragm must greatly increase the resistance to heat transfer between the diaphragm and the moving cores of hot and cold gases passing through the recuperator. In general the heat conductivity of the recuperator diaphragm will be found to be many times as large as the conductivity of the films of dead gas adhering to the surfaces of the diaphragm and producing what is called "skin

effect." Heat passing between the diaphragm and the main body of gas flowing through either section of the recuperator must first pass by conduction toward or away from the solid surface of the diaphragm through the quiescent film of gas adhering thereto, and thence by convection between the outer surface of this dead gas film and the moving molecules of the main body of gas which come in contact therewith. Obviously any means or method which can be devised for decreasing the thickness or entirely disrupting these dead gas films will correspondingly increase the rate of heat transfer between the surface of the solid and the main body of gas scrubbing such surface and will greatly benefit any industrial process in which heat exchange apparatus of the indirect heat transfer type is employed.

One object of the present invention is to provide a method of and apparatus for improving the transmission of heat between a solid surface and a body of dielectric fluid in contact therewith.

Another object of the invention is to provide a method of and apparatus for increasing the rate at which heat is transmitted to or absorbed from a body of dielectric fluid in heat exchange apparatus of the indirect heat transfer type per unit area of solid diaphragm.

Another object of the invention is to provide a simple and relatively inexpensive method for increasing the rate at which heat is normally transferred from one body of gas to another through the medium of a heat conductant recuperator diaphragm.

In general the less turbulence there is in the gas flow the thicker is the film of gas adhering to the solid surface and the greater is the "skin effect." One obvious way of decreasing this skin effect and of increasing the heat transfer is to increase the rate of flow of gas past the solid surface or to increase the violence of motion of the gas by a baffle so introduced as to have a churning action on the gas flow. In this way the gas can be made to scrub the solid surface more effectively and thus to decrease the thickness of the heat resistant gas film.

The method above suggested has been tried and has proven more or less effective in decreasing the thickness of the adhering gas films, but it has not been found effectual to fully destroy these films nor has it proven completely satisfactory from the economical standpoint in increasing the rate of heat transfer.

One of the principal features of the present invention contemplates the use of inexpensive means for breaking down or at least partially destroying the films of dead gas which normally adhere to a recuperator diaphragm so as to facilitate the transmission of

heat from one body of gas to another through the medium of the diaphragm.

With these and other objects and features in view the invention consists in the method of and apparatus for improving the transmission of heat between a solid surface and a gas hereinafter described and particularly defined in the claims.

The various features of the invention are illustrated in the accompanying drawings, in which:—

Fig. 1 is an elevation in diametrical section of a standard type of heat recuperator fitted up with the simple added equipment for increasing its heat transfer efficiency in accordance with the preferred apparatus arrangement of the present invention;

Fig. 2 is a horizontal sectional view of the same recuperator taken on the line 2—2 of Fig. 1.

Broadly the method of improving heat transfer between a solid surface and a body of gas flowing past said surface which constitutes the preferred form of the present invention comprises producing a silent electrical discharge in the body of gas which is giving heat to or receiving heat from a solid to break down and at least partially destroy the film of gas adhering to the surface of the solid and thereby facilitate the transfer of heat directly by convection between the solid surface and the main body of gas scrubbing that surface. As applied specifically to heat exchange apparatus the invention consists in mounting an electrical conductor connected to one terminal of a static transformer on one side of a recuperator diaphragm in such position as to be entirely surrounded by the stream of gas passing through the recuperator and spaced from the surface of the recuperator diaphragm (preferably using metal or other good electrical conductor for the diaphragm or as a lining for the diaphragm and grounding the other terminal of the transformer through the diaphragm or the metal lining thereof) and setting up a silent electrical discharge of high potential and low current density between the conductor and the metal surface. By this method of operation when the gas is at normal pressure the intensity of the electric field set up at the point where discharge is occurring causes the rapid movement of the ions (which are present in every gas to some extent) toward or away from the point of discharge. The energy imparted to these ions is sufficiently great to cause the formation of additional ions by impact with the gas molecules. In this way a large number of ions are formed, many of which attach themselves in additional gas molecules and thus a condition is established in which an appreciable percentage of the total gaseous particles are electrified. This results in the rapid movement of the body of the gas toward or

away from the surface where the discharge is taking place and the result of this action in turn is to disrupt the gas films existing at the surface of the solid. It is not certain whether this rupture of the gas film is caused by the rapid motion of the ions and charged molecules through the film, or whether it is caused by the effects of churning up of the gas stream en masse or whether it is a combination of both these or other causes, but from whatever cause the rupture takes place there is no question, as demonstrated by numerous experiments, that in almost every case heat transfer is facilitated.

The method for improving heat transfer between a solid body and a gas comprising the preferred form of the present invention may be applied with advantage to almost any standard form of heat exchange apparatus by simply altering the apparatus so as to include the addition of the active and passive electrodes with their connections, a source of high potential, and the insulation required to make the whole conform in a general way to the apparatus outlay embodying the preferred form of the invention as illustrated in the drawings. The new features of heat exchange apparatus which together go to make up the improved apparatus embodying the preferred form of the invention are believed to be clearly illustrated in the drawings, which are intended to show the principles of the invention as they are applied to a standard form of recuperator having upright metal heating flues. The apparatus outlay shown in the drawings is intended merely to illustrate the principles of the invention as applied to one form of recuperator, and as almost any other type of recuperator or other heat exchange apparatus may be readily fitted up with the electrodes and connections necessary for effecting the disruption of non heat conductant gas films by silent electric discharge it is not the intention to limit the application of the invention to any specific type of heat exchange apparatus.

The simple apparatus arrangement illustrative of the principles of the invention, as shown in the accompanying drawings, comprises essentially a standard form of recuperator housing 10, preferably lined with refractory or other heat and/or electrical insulating material 12. A distributing chamber 14 at the base of this housing communicates with a collecting chamber 16 at the top of the housing through the hollow core of a metal heating flue 18. The flue 18 extends through the center of a long heating chamber 20, which comprises the main interior chamber of the housing 10 and is sealed off from the chambers 14 and 16 at bottom and top respectively by annular header sheets 22 and 24. In operation cold air or other gas which is to be preheated enters distributing chamber 14

through an inlet 26 and after passing upwardly through the hollow core of flue 18 and taking on preheat therein passes into collecting chamber 16 and finally exits from the apparatus through an offtake 28. At the same time hot products of combustion or other gaseous heating media enter chamber 20 through an inlet 30, and after giving up heat to the outer surface of flue 18 during the downward passage through chamber 20 the thus cooled gas exits from the apparatus through an outlet 32. Flue 18 is supported in the chamber 20 by the two headers 22 and 24, and the joints between the ends of the flue and the corresponding cores in the headers are calked or otherwise treated to make them gas-tight, in order to prevent contact between the heating medium passing through chamber 20 and the medium taking up heat during its passage through chamber 14, flue 18, and chamber 16.

Headers 24 and 22 are preferably constructed of electrical insulating material, which must also be resistant to the corrosive action of combustion gases or whatever form of heating medium is intended to be passed through chamber 20. Also each header (see Fig. 2) is preferably bored for high tension wire electrodes 34, a number of which may be mounted the required distance from the outer surface of flue 18 to permit the establishing of an electric discharge between each of said electrodes and the surface of the flue at the potential which it is contemplated to employ. These electrodes 34 are preferably mounted in chamber 20 to extend through its whole length at regular intervals around the periphery and parallel to the outer surface of flue 18. Insulators 36 mounted on the underside of header 22 serve, together with a circular bus bar 38 in chamber 16, as anchors for each of electrodes 34. In the drawings four of these electrodes 34 are illustrated as mounted at intervals of 90° around the periphery of flue 18. These wire electrodes 34 may be replaced by a single thin metal cylinder entirely surrounding the surface of flue 18 and spaced therefrom the required distance to maintain the electric discharge at the potential which it is contemplated to employ. A bare high tension wire 40 is suspended in the axial center of flue 18 and forms the active electrode of that part of the system on the inside of flue 18. Wire 40 is anchored at the bottom by means of an insulator 42 in chamber 14 and at the top by a radial member 44 of the bus bar 38 in chamber 16. The bus bar 38 is in turn connected to one terminal wire 46 of a source of high electrical potential, illustrated diagrammatically in the drawings as comprising a transformer 48 and a generator 50. The other terminal 52 of the transformer is grounded through the metal walls of flue 18 and ground wire 54.

In the operation of the recuperator a current of cold air or other gas to be preheated is continuously passed into the distributing chamber 14 through the inlet pipe 26 and after taking on preheat during its passage through flue 18 the hot air is continuously passed out from collecting chamber 16 at the top of the recuperator through the outlet 28. A continuous stream of hot products of combustion or other heating gas enters at the top of heating chamber 20 through the inlet 30 and after giving up a substantial portion of its sensible heat to the outer surface of the diaphragm during its downward passage through chamber 20 the cooled stream of combustion products continually exits from chamber 20 through the offtake pipe 32.

As previously pointed out one terminal (46) of the transformer unit (48) in the high potential supply circuit is directly connected through the bus bars 38 and 44 at the top of the preheater to the electrodes 34 and 40, and the other terminal 52 of the transformer is grounded through the metal heating surfaces of the flue 18 and through ground wire 54. An annular film of dead air is continuously in process of attaching itself to the inner surface of flue 18 and the insulating effect of this film to heat transfer between the walls of flue 18 and the main body of air is continuously counteracted by the high potential discharge taking place between the electrode 40 and the inner heating surface of flue 18 for the reason that this electrical discharge sets up an electric wind which continuously disrupts the dead film of air and thus breaks down its resistance to heat transfer. By thus breaking down the resistance of one of the gas films the heat transferring efficiency of each unit area of the recuperator diaphragm is considerably increased. In the recuperator construction illustrated in the drawings the film of heating gas which is continually in process of formation around the outer wall of flue 18 can also be continuously broken down and at least partially disrupted by the silent discharges set up between conductors 34 and the outer surface of the flue. Consequently since the gas films on both surfaces of the flue are at least partially disrupted the resistance normally offered to heat transfer is to the same extent reduced, and as these films are by far the greatest factors in the heat transfer resistance offered by the system, it is apparent that the rate of heat transfer through the system will be materially increased.

In case the apparatus is employed in effecting heat exchange between a liquid and a gas through the medium of the walls of flue 18, the electrodes which would normally be suspended in the chamber of the recuperator through which the liquid is to pass may be dispensed with, for any liquid is a relatively

good conductor of electric current (as distinguished from a gas) and accordingly it would not be feasible to attempt breaking down the films of such a liquid tending to adhere to the surface of the diaphragm by means of a silent electric discharge.

It has been found that the amount of electrical energy required to disrupt the films of gas adhering to one or both sides of the recuperator diaphragm is extremely slight, for the reason that under ordinary conditions of gas pressure and with a generating unit and transformer designed to deliver electricity at 10,000 to 50,000 volts the amount of current flowing in the silent electric discharge set up between the electrodes and the metal diaphragm of the recuperator is of the order of a milliampere or less.

The invention having been thus described, what is claimed as new is:

1. The method of improving heat transfer between a solid and a dielectric fluid which comprises setting up a silent electric discharge between the solid and the fluid to disrupt the heat resistant fluid films adhering to the surface of the solid.

2. The improvement in the art of transferring heat between a solid and a gas which consists in passing a stream of the gas over the surface of the solid and through an electric field set up between the solid and an active electrode suspended in the gas stream.

3. The improvement in the art of transferring heat between a dielectric fluid and an electrified solid conductor which comprises passing the fluid in contact with the solid and setting up a silent electric discharge in the fluid between the solid and another electrified conductor supported in the path of the fluid stream.

4. The method of improving heat transfer between two bodies of fluid through the medium of a solid diaphragm which comprises setting up a silent electric discharge between an active electrode mounted in one body of dielectric fluid and the surface of the diaphragm and utilizing the electric wind thus set up to disrupt the non-heat-conductant film of the fluid normally adhering to the solid surface.

5. The method of improving heat transfer between a body of hot and a body of cold gases through the medium of an electrically conductant recuperator diaphragm which comprises setting up silent electric discharges between active electrodes mounted in the respective bodies of hot and cold gases and the surfaces of the diaphragm exposed thereto and utilizing the electric winds thus created to break down the low heat conductant gas films normally adhering to both surfaces of the diaphragm.

6. The method of improving heat transfer between a stream of gas and a stream of liquid

flowing past opposite sides of a solid partition wall which comprises setting up a silent electric discharge between an active electrode mounted in the gas stream and the surface of the partition wall exposed to the gas to break down the low heat conductant film of the gas normally adhering to the surface of the partition.

7. The method of increasing the rate of heat transfer per unit area of heating surface in a solid-gas heat exchange system which comprises establishing a high difference of electric potential between the solid and the gas while the heat exchange is taking place.

8. In apparatus arranged for the transfer of heat between a solid and a gas, the improvement which comprises a grounded passive electrode attached to the solid, an active discharge electrode suspended in the gas and spaced from the solid and passive electrode, and means for setting up a silent electric discharge in the gas between the two electrodes.

9. In a recuperator arranged for the transfer of heat between two bodies of gas through the medium of a metal diaphragm, the improvement which comprises active electrodes suspended in both gas bodies together with means for establishing a high difference of potential and a silent electric discharge between each of said electrodes and the metal diaphragm.

10. Apparatus arranged for effecting the exchange of heat between a solid and a gas comprising a casing, a flue mounted in said casing, said flue serving as the solid and also as one electrode of a high potential electric circuit, a second electrode mounted in said flue and paralleling and spaced from the surface of said flue, an inlet and an outlet for gas on opposite ends of said flue, and a source of high potential having one of its terminals connected to one of said electrodes and its other terminal grounded through the other electrode.

11. In a recuperator designed for effecting the exchange of heat between two bodies of fluid through the walls of a metal flue, the improvement which comprises an electrode mounted in the central axis of the flue and spaced from its inner surface, means for passing one body of fluid through the flue, means for passing another body of fluid around the outside of the flue and means for setting up an electric wind in the fluid passing through the flue between the axially mounted electrode and the inner surface of the flue.

12. In a recuperator designed for effecting the exchange of heat between two bodies of fluid through the walls of a metal flue the improvement which comprises an electrode spaced from and paralleling substantially the whole length of the outer surface of the flue in the path of the fluid scrubbing said

surface, and means for setting up an electric wind in the fluid between said electrode and the outer surface of the flue.

In testimony whereof I affix my signature.
STEPHEN P. BURKE.

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