Oct. 13, 1953 R. W. CORBITT ET AL 2,655,346

HEAT EXCHANGER WITH TUBE MATRIX

Filed July 7, 1950 2 Sheets-Sheet 1

Fig.1.

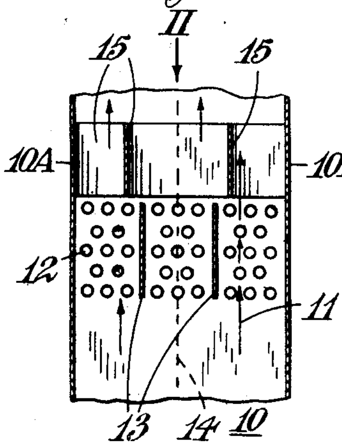


Fig.3.

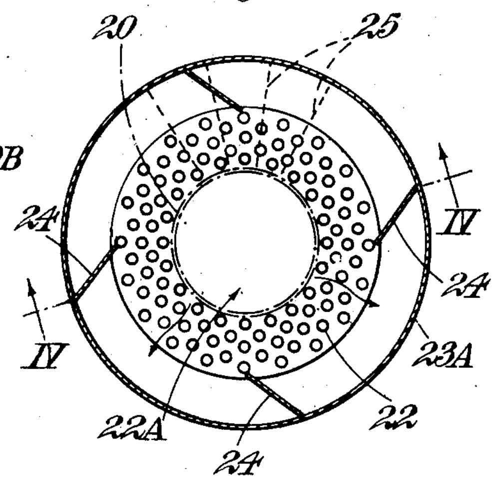


Fig.2.

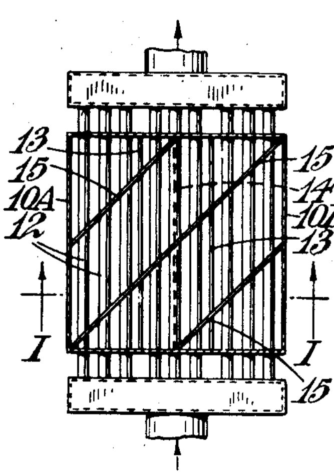
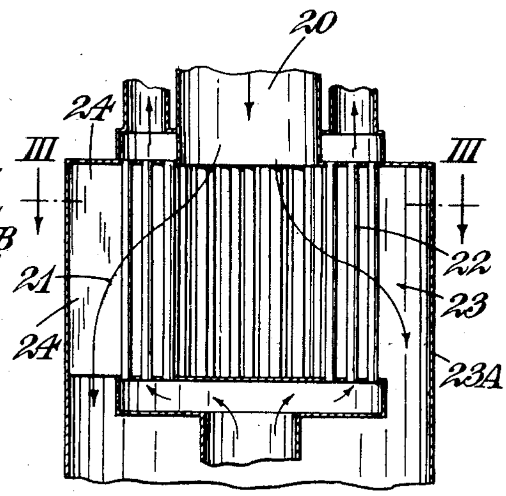


Fig.4.



INVENTORS

R. W. CORBITT

+ J. H. DALE

By Wilkinson + Mawhinney

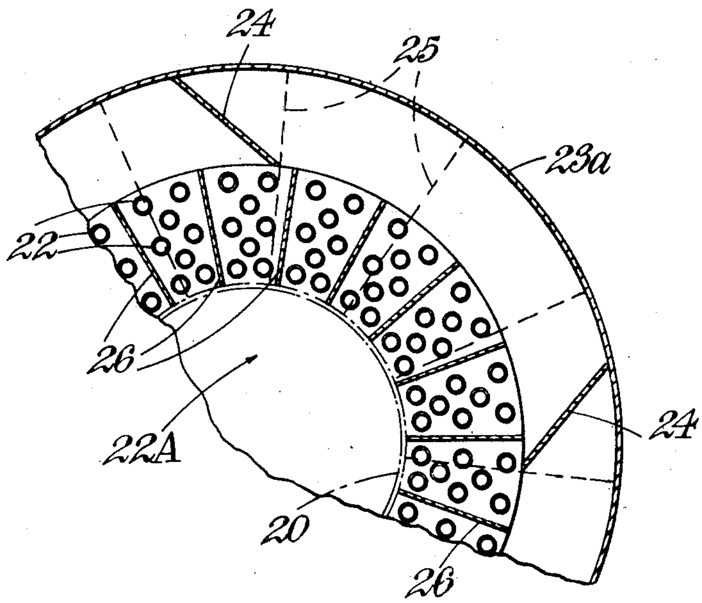
ATTORNEYS

Oct. 13, 1953 R. W. CORBITT ET AL 2,655,346

HEAT EXCHANGER WITH TUBE MATRIX

Filed July 7, 1950 2 Sheets-Sheet 2

Fig.5.



INVENTORS
ROBERT WILLIAM CORBITT &
JOHN HUGH DALE
BY
Wilkinson & Mawhinney
ATTYS.

Patented Oct. 13, 1953

2,655,346

UNITED STATES PATENT OFFICE

2,655,346

HEAT EXCHANGER WITH TUBE MATRIX

Robert William Corbitt, Tunstall, Sittingbourne, and John Hugh Dale, Darley Abbey, England, assignors to Rolls-Royce Limited, Derby, England, a British company

Application July 7, 1950, Serial No. 172,436
In Great Britain July 25, 1949

9 Claims. (Cl. 257—16)

1

This invention relates to heat-exchange apparatus of the kind (referred to hereinafter as heat-exchange apparatus of the kind specified) in which a first fluid medium flows over the outer surfaces of a bank or matrix of tubes, through which tubes a second fluid medium passes, whereby heat is transferred from the first fluid medium to the second fluid medium or vice-versa.

It has been observed in the use of heat exchanger apparatus of the kind specified, that an audible whistle occurs and we have found that the whistle is caused by the flow of the first fluid medium across the bank of tubes. The whistle is not only objectionable in itself, but also the vibrations set up in the fluid medium cause an increase of resistance to flow of the first medium and may also cause vibrational failure of the tubes and/or fixing joints due to vibrational fatigue. The object of the present invention is to prevent or reduce the magnitude of the whistle and the other disadvantages mentioned.

It is well known that when a fluid, particularly a gas, flows across a wire or tube and the flow is turbulent, then vortices are shed in the stream alternately from the sides of the wire or tube. The rate of the shedding of vortices is approximately of the order given by:

$$N=\frac{V}{5D}$$

where:

N=Vortices per second.
V=Stream velocity (ft. per second) and
D=the diameter, tube or wire (feet).

This relationship is independent of the rigidity of the wire, and gives rise to cyclic pressure changes in the fluid flow, which pressure changes may, if the value of V is sufficiently high, be of audible frequency.

We have concluded from a consideration of this formula (*a*) that, if the length of the tube or wire is finite and extends between end walls (as in a heat exchanger), each vortex may be shed simultaneously along the whole length of the tube; (*b*) that, if a number of like tubes are arranged in a bank (e. g. to form a heat exchanger matrix), similar vortices may be shed simultaneously from all the tubes, and (*c*) that, if similar vortices are shed from all the tubes to the same side of each tube, a resonant condition must exist to maintain vortex shedding from the tubes in step. We have also concluded that such a resonant condition and vortex shedding causes the loud audible whistle which occurs in the operation of tube matrix heat exchangers.

According to the present invention in a heat exchange apparatus of the kind specified, there is provided in association with a tube bank, baffle means arranged parallel to the direction of flow of the first medium, the baffle or each baffle of the baffle means being so located with respect to or so spaced from a side wall of the heat exchange apparatus or adjacent baffles or both that the fluid column therebetween is incapable of resonant vibration at the frequency of vortex shedding from heat exchange tubes due to the passage of the first medium across them.

2

According to a feature of the invention baffle means are provided in the form of plates which are located in the tube bank or downstream thereof parallel to the tubes so that the spacing of adjacent plates or of a plate and a side wall of the heat exchanger is less than half the wavelength of a note having a frequency corresponding to the frequency of vortex shedding from the tubes.

When the rows of tubes in bank are staggered with respect to the adjacent rows, the spacing W of the baffle plates or of a plate and a side wall of the heat exchange apparatus may be estimated from the following approximate empirical formula:

$$W=\frac{0.6a\cdot D}{V\ \text{max.}}$$

where:

W=the spacing of the baffle plates (or between a baffle plate and side wall).
a=velocity of sound in the fluid of the first medium.
V max.=maximum fluid velocity between tubes.
D=tube diameter.

Alternatively tests may be carried out on the heat exchanger without baffles and a baffle spacing according to the frequency of the whistle experienced.

A further feature of the invention provides baffle means external to the tube bank and downstream thereof, which baffle means comprises baffle plates located in planes at an angle to the tubes, and thus at an angle to the planes in which nodes tend to occur during resonant vibration. The baffle plates of such external baffle means are not necessarily spaced from one another or from a side wall of the heat exchanger by a distance less than half the wave length of a note having a frequency equal to the frequency of vortex shedding, since, by virtue of their inclination to the planes in which nodes tend to occur they prevent the formation of such nodal planes on the downstream side of the tube bank.

When baffles are provided downstream of the tube bank, resonance may in the absence of internal baffles, occur in the tube bank itself, but the provision of baffles on the downstream side of the tube bank, either parallel to the tubes and spaced at less than half the wave length of the resonant frequency or at an angle to the tubes, prevents the nodal planes which exist in the tube bank, from developing downstream of the tube bank, and thus diminishes the resonant energy.

The invention is applicable to various forms of heat exchanger of the kind specified. For instance the invention is readily applied in a heat-exchanger which comprises a straight-through duct carrying the first medium and a matrix of heat-exchange tubes extending across the duct, so that the first medium flows over the surfaces of the tubes. Another common heat exchanger arrangement in which the invention can be readily applied, comprises a central cylindrical duct and an outer annular duct separated by an annular matrix of heat exchange tubes, so that, in use, the first medium flows transversely across the tubes; in this arrangement, when whistle in the heat exchanger is experienced, the presence of resonant nodal planes has been detected in the outer annular duct.

The application of the invention in these forms of heat exchanger is illustrated diagrammatically in the accompanying drawings, to which the following description refers.

In this drawing:

Figure 1 is a section parallel to the direction of flow of the first medium through a straight-through type of heat exchanger, the plane of the section being indicated at I—I of

Figure 2 which is a view in the direction of arrow II of Figure 1;

Figure 3 is a section at right angles to the axis of a heat exchanger having a matrix of heat exchanger tubes of annular form the section being taken on the line III—III of Figure 4 and Figure 4 is a section on IV—IV of Figure 3, and

Figure 5 illustrates a modification of the arrangement of Figure 4.

Referring to Figures 1 and 2, the heat exchanger diagrammatically illustrated comprises a duct passage 10 with side walls 10A and 10B, through which passage 10 the first medium flows in the direction of the arrow 11. A bank or matrix 12 of heat exchange tubes extends across the duct passage parallel to the side walls 10A, 10B; the first fluid medium flows through the spaces between the tubes and over the surfaces of the tubes and the second medium flows in the bores of the tubes.

With a heat exchanger of this type, it has been found that the flow of the first medium across the tube matrix 12 may give rise to an objectionable whistle having a node in a transverse plane as indicated by the dotted line 14, and we have found that if baffle plates such as baffle plates 13 are provided within the tube matrix 12 in planes parallel to the direction of flow of the first medium through the duct and to the tubes 12, the whistle can be avoided.

In the simple heat exchanger illustrated, two baffle plates 13 are provided within the matrix and the plates 13 divide up the space between the side walls 10A, 10B into three parts, so that the transverse dimension of each of these parts, either between adjacent baffles 13 or between a baffle 13 and a side wall 10A or 10B is less than half the wave length of a note having a frequency equal to the estimated freouency of vortex shedding in the manner described.

In certain cases, however, it is inconvenient to construct the heat exchanger with baffle plates within the structure of the matrix 12, and an alternative arrangement is used, which consists in the provision of external baffle plates 15. The baffle plates 15 are located in planes parallel to the direction of flow of the first medium on the outlet side of the tube matrix 12 and inclined at acute angles to the tubes, and their function is to prevent the development of or extension of a nodal plane, such as plane 14, on the downstream side of the tube matrix 12. Where it is possible to employ baffles such as baffles 13 they may be used in combination with baffle plates 50.

It will be seen from Figure 2 that the external baffle plates 15 are at an acute angle to the nodal plane 14, thereby preventing the maintenance of this node (if formed) in the heat exchanger outlet. By inclining the baffles in this way it is unnecessary for them to be spaced less than half a wave length apart as described for baffle plates 13. If desired, baffle plates may be arranged downstream of matrix 12 in a manner similar to baffle plates 13.

In Figures 3 and 4, an alternative form of heat exchanger is illustrated in which the first medium flows, in the direction of the arrow 21, through an inlet duct 20 into the space 22A within an annular matrix of heat exchanger tubes 22, and through the matrix 22 into an annular outlet duct 23, the external wall of which is indicated at 23A.

With such an arrangement, it has been found that the flow of the first fluid medium across the heat exchanger tubes may give rise to a series of circumferentially distributed nodal planes some of which are indicated at 25. It will be noted that these nodal planes are not parallel to a side wall but are radial to the axis of the heat exchanger system; the number of the nodal planes 25 is determined by the circumferential dimensions of the matrix 22 and the frequency of vortex shedding. The vibrations which produce the nodal system give rise to the undesirable whistle effects previously mentioned.

In order to avoid this whistle effect, external baffles as indicated at 24 are provided, which due to their inclination to the radial planes serve to absorb vibrational energy and prevent the maintenance of the nodal system in the annual outlet duct 23. It is not necessary to space inclined baffles at a distance less than half the wavelength of the resonant frequency.

If desired, there may also be provided radially disposed baffles 26 (Figure 5) arranged within the matrix 22, to be spaced apart by a mean distance, which is less than half the wavelength of a note having a frequency corresponding to the frequency of the vibrations induced by the passage of the first medium. Such baffles will therefore be spaced apart at somewhat less distance than the dimension between the adjacent nodal planes 25.

It has been found that the present invention is particularly useful in its application to heat exchangers for gas-turbine engines where the desirability of designing the heat exchanger to have small tubes, combined with the comparatively high mass flow of exhaust gas (the first medium) gives rise to high gas velocities through the tube matrix and high frequency of vortex shedding.

Adoption of the invention not only reduces or avoids objectionable noise but also avoids losses arising from the production of wave energy.

We claim:

1. In heat-exchange apparatus of the class comprising a casing, a matrix of tubes arranged within said casing, an inlet connection to said casing, an outlet connection from said casing, said inlet and outlet connections being positioned to permit a first fluid medium in passing from said inlet connection to said outlet connection

to flow transversely across the tubes of said matrix of tubes, and inlet connection to the tubes of said matrix of tubes and an outlet connection from said tubes whereby a second fluid medium can flow in said tubes; the combination with said matrix of tubes of a plurality of baffle elements located within said casing between said matrix of tubes and said outlet connection from said casing thereby to be in the path of said first fluid medium on the downstream side of said matrix of tubes, each said baffle element being disposed at an acute angle to a plane containing both the direction of the flow of said first fluid medium through the matrix of tubes at a location adjacent said baffle element and also the lengthwise dimensions of the adjacent tubes, whereby the formation of nodal planes of resonant vibrations on the downstream side of said matrix of tubes is inhibited.

2. Heat-exchange apparatus as claimed in claim 1 comprising also internal baffle devices within said matrix of tubes, said baffle devices being arranged to be parallel both to the direction of adjacent flow of said first fluid medium through said matrix of tubes and to the longitudinal dimension of the tubes, and being spaced with respect to one another by a distance which is less than the distance between vibrational nodes liable to form in said matrix in planes parallel to said baffle devices.

3. Heat-exchange apparatus as claimed in claim 2 having said baffle devices spaced from a wall of said casing when adjacent a wall and from a next adjacent baffle device by a distance W given by the expression

$$W=\frac{0.6a\cdot D}{V\,\mathrm{max.}}$$

where a is the velocity of sound in said first fluid medium, D is the diameter of the tubes of said matrix of tubes, and V max. is the maximum velocity of said first fluid medium between the tubes.

4. In heat-exchange apparatus comprising a tubular casing member having an inlet thereto and an outlet therefrom, a matrix of parallel tubes arranged within said casing in the flow path between said inlet and said outlet with their axes substantially at right angles to the flow path, there being an inlet connection to the tubes and an outlet connection from the tubes to provide a second flow path, the combination with said matrix of tubes of a plurality of plate-like baffles arranged in first said flow path between said matrix and said first outlet thereby to be downstream of the matrix, each said baffle being contained in a plane containing the direction of flow from said matrix to said first outlet and inclined at an acute angle to nodal planes tending to develop downstream of the matrix.

5. In heat-exchange apparatus comprising a cylindrical casing having an inlet thereto and an outlet therefrom, a plurality of tubes arranged within the casing with their axes parallel to one another and parallel to the casing axis and to form an annular matrix with its outer bounding surface spaced radially inwards from the casing wall so that fluid flowing from said inlet to said outlet flows substantially radially through the matrix of tubes, there being an inlet connection to said tubes and an outlet connection therefrom so that the bores of said tubes afford a second flow path; the combination with said casing and said matrix of a plurality of plate-like baffles located in said first flow path between said matrix and said first outlet thereby to be downstream of said matrix and circumferentially spaced in said flow path relative to said matrix, each said baffle being contained in a plane which is parallel to the casing axis and is inclined at an acute angle to adjacent radii from the casing axis.

6. In heat-exchange apparatus comprising a cylindrical casing having an inlet thereto and an outlet therefrom, a plurality of tubes arranged within the casing with their axes parallel to one another and parallel to the casing axis and to form an annular matrix with its outer bounding surface spaced radially inwards from the casing wall so that fluid flowing from said inlet to said outlet flows substantially radially outwards through the matrix of tubes, there being an inlet connection to said tubes and an outlet connection therefrom so that the bores of said tubes afford a second flow path; the combination with said casing and said matrix of a plurality of plate-like baffles located in circumferentially spaced relation in the annular space between said annular matrix and said casing wall thereby to be downstream of said matrix, each said baffle being contained in a plane which is parallel to the casing axis and is inclined at an acute angle to adjacent radii from said casing axis.

7. Heat-exchange apparatus as claimed in claim 6, comprising also baffles located in said matrix each said baffle being radially disposed with respect to the casing axis and being spaced from each next adjacent baffle by a distance which is less than half the wave length of a note covering a frequency equal to the frequency of vortex shedding from the matrix tubes.

8. In heat-exchange apparatus comprising a tubular casing having an inlet at one end and an outlet at its opposite end with a first flow path between said inlet and outlet which flow path is parallel to the casing axis, and a plurality of parallel tubes extending across said casing substantially at right angles to the casing axis and affording in their bores a second flow path, the combination with said casing and matrix of a plurality of plate-like baffles located parallel to one another within said casing between said matrix and first said outlet thereby to be on the downstream end of said tubes, each of which baffles is in a plane which is parallel to the casing axis but is inclined at an acute angle to the axes of the tubes.

9. Heat-exchange apparatus as claimed in claim 8, comprising also baffles within said matrix of tubes each said baffle being contained in a plane parallel to the axis of said casing and to the axes of the tubes and being spaced from each adjacent baffle by a distance which is less than half the wave-length of a note covering a frequency equal to the frequency of vortex shedding from the matrix tubes.

ROBERT WILLIAM CORBITT.
JOHN HUGH DALE.

References Cited in the file of this patent

UNITED STATES PATENTS

Number	Name	Date
1,641,999	Webster	Sept. 13, 1927
1,888,711	Bourne	Nov. 22, 1932
2,144,506	Potter	Jan. 17, 1939
2,155,278	Mautsch	Apr. 18, 1939
2,396,208	Serre et al.	Mar. 5, 1946
2,397,208	Saco, Jr., et al.	Mar. 26, 1946
2,479,165	Jackson	Aug. 16, 1949