(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 4 417 920 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
21.08.2024 Bulletin 2024/34

(21) Application number: **24156383.2**

(22) Date of filing: **07.02.2024**

(51) International Patent Classification (IPC):
F28D 1/04 *(2006.01)*

(52) Cooperative Patent Classification (CPC):
F28D 1/04; F28F 2210/08

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC ME MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA
Designated Validation States:
GE KH MA MD TN

(30) Priority: **09.02.2023 US 202318107843**

(71) Applicant: **RTX Corporation**
Farmington, CT 06032 (US)

(72) Inventors:
- **SNYDER, Jacob C.**
  East Haddam, 06423 (US)
- **SOBANSKI, Jon E.**
  Glastonbury, 06033 (US)
- **WIEDENHOEFER, James F.**
  Windsor, 06095 (US)
- **KIRSCH, Kathryn L.**
  East Haddam, 06423 (US)

(74) Representative: **Dehns**
St. Bride's House
10 Salisbury Square
London EC4Y 8JD (GB)

(54) TUBE HEAT EXCHANGER WITH VARYING DIAMETERS

(57) A tube bundle heat exchanger (10) includes a flow space for a first heat exchange medium; and a plurality of heat exchange tubes (38, 40) for a second heat exchange medium, wherein the plurality of heat exchange tubes (38, 40) extends at least partially across the flow space, wherein the plurality of heat exchange tubes (38, 40) comprises at least a first plurality of tubes (38) having a first diameter and a second plurality of tubes (40) having a second diameter different from the first diameter.

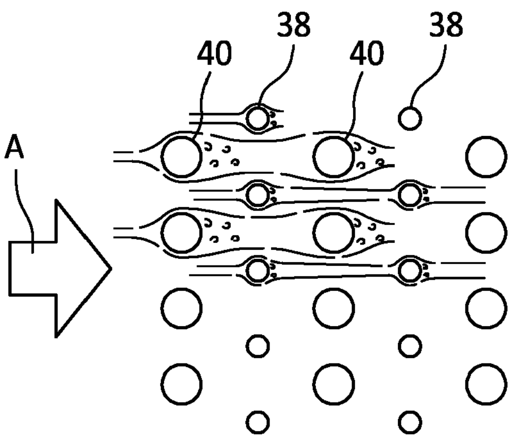

FIG. 5

EP 4 417 920 A1

Description

BACKGROUND OF THE DISCLOSURE

[0001] This disclosure relates to heat exchangers and, more particularly, to tube heat exchangers and configurations of tubes of tube heat exchangers.

[0002] Tube heat exchangers typically have a bundle of tubes which can include many rows of tubes in a cross-flow setup. The tubes carry one heat exchange medium and the other flows across the tubes.

[0003] Tube bundle heat exchangers are effective at heat exchange, but can encounter challenges in resonance driven by wakes being shed from the tubes due to flow past the tubes.

[0004] In some flow regimes, the wake can oscillate and the oscillating wake can generate a force function on the tubes generating the wake as well as tubes downstream being hit with the incident wake.

[0005] In some instances, wake frequency can be similar to the natural frequency of the tube, and resonance can occur which negatively impacts the high cycle fatigue (HCF) life.

[0006] In addition, certain conditions of oscillation as well as resonance can lead to noise at potentially undesirable levels, for example for humans working and/or otherwise in the vicinity of the heat exchanger.

[0007] Also, when the heat exchanger is used, for example for heat exchange in an engine, the environment generally is a highly vibratory environment and, therefore taking steps to mitigate additional vibration or resonance is of interest.

SUMMARY OF THE DISCLOSURE

[0008] In accordance with one non-limiting embodiment, a tube bundle heat exchanger comprises a flow space for a first heat exchange medium; and a plurality of heat exchange tubes for a second heat exchange medium, wherein the plurality of heat exchange tubes extends at least partially across the flow space, wherein the plurality of heat exchange tubes comprises at least a first plurality of tubes having a first diameter and a second plurality of tubes having a second diameter different from the first diameter.

[0009] In a non-limiting configuration, the second plurality of tubes are positioned relative to the first plurality of tubes such that, during expected flow conditions through the flow space, wake shedding frequency exhibited by the plurality of heat exchange tubes does not match natural frequency of the plurality of heat exchange tubes.

[0010] In another non-limiting configuration, the second diameter is larger than the first diameter.

[0011] In still another non-limiting configuration, the second plurality of tubes are positioned in alternating rows relative to the first plurality of tubes, the rows extending transverse to flow direction through the flow space.

[0012] In a further non-limiting configuration, the first set of tubes are not aligned with the second set of tubes in the flow direction.

[0013] In a still further non-limiting configuration, the first set of tubes are arranged across the flow direction of the heat exchanger with gaps defined between each pair of adjacent tubes, and tubes of the second set of tubes are aligned in the flow direction with the gaps in the first set of tubes.

[0014] In another non-limiting configuration, the first set of tubes and the second set of tubes are aligned with each other in the flow direction.

[0015] In still another non-limiting configuration, the first plurality of tubes and the second plurality of tubes are arranged in staggered alternating rows extending in the flow direction.

[0016] In a further non-limiting configuration, a ratio of second diameter to the first diameter is greater than 1:1 and up to 3:1.

[0017] In a still further non-limiting configuration, the second set of tubes has a diameter that is at least 10% larger than the first set of tubes.

[0018] In another non-limiting configuration, the second set of tubes comprises between about 30 and about 70% by number of the plurality of heat exchange tubes.

[0019] In still another non-limiting configuration, the plurality of heat exchanger tubes are arranged at a transverse spacing (ST) such that a ratio of the transverse spacing to an average diameter (D) of the plurality of tubes (ST/D) is between 1.5 and 2.5.

[0020] In a further non-limiting configuration, the plurality of heat exchanger tubes are arranged at a longitudinal spacing (SL) such that a ratio of the longitudinal spacing to an average diameter (D) of the plurality of tubes (SL/D) is between 1.0 and 3.0.

[0021] In a still further non-limiting configuration, the second set of tubes comprises a row of the second set of tubes extending across the flow direction to reset any wake shedding flow conditions from upstream of the row.

[0022] In another non-limiting configuration, the first set of tubes are arranged in hexagonal patterns around each of the second set of tubes.

[0023] In a further non-limiting embodiment, in a method for operating a tube bundle heat exchanger comprising a flow space for a first heat exchange medium; and a plurality of heat exchange tubes for a second heat exchange medium, wherein the plurality of heat exchange tubes extends at least partially across the flow space, wherein the plurality of heat exchange tubes comprises at least a first plurality of tubes having a first diameter and a second plurality of tubes having a second diameter different from the first diameter, the method comprising flowing the first heat exchange medium through the flow space at flow conditions to generate vortex shedding frequency; and flowing the second heat exchange medium through the plurality of heat exchange tubes at tube flow conditions to generate natural frequency, wherein the second set of tubes are positioned such that there is no resonance between the vortex shedding frequency and the natural frequency.

[0024] In another non-limiting configuration, the flowing steps result in heat exchange between the first heat exchange medium and the second heat exchange medium.

[0025] In still another non-limiting configuration, the second diameter is at least 10% greater than the first diameter.

[0026] In a further non-limiting configuration, tubes of the plurality of heat exchanger tubes are arranged at a transverse spacing (ST) such that a ratio of the transverse spacing to an average diameter (D) of the plurality of tubes (ST/D) is between 1.5 and 2.5.

[0027] In a still further non-limiting configuration, tubes of the plurality of heat exchanger tubes are arranged at a longitudinal spacing (SL) such that a ratio of the longitudinal spacing to an average diameter (D) of the plurality of tubes (SL/D) is between 1.0 and 3.0.

[0028] The foregoing features and elements may be combined in various combinations without exclusivity, unless expressly indicated otherwise. These features and elements as well as the operation thereof will become more apparent in light of the following description and the accompanying drawings. It should be appreciated that the following description and drawings are intended to be exemplary in nature and non-limiting.

BRIEF DESCRIPTION OF THE DRAWINGS

[0029] A detailed description of non-limiting embodiments of the present disclosure follows, with reference to the attached drawings, wherein:

FIG. 1 schematically illustrates a conventional cross flow tube bundle heat exchanger;

FIG. 2 illustrates a series of different types of flow regimes that can occur due to flow past heat exchanger tubes;

FIG. 3 illustrates the relationship between natural frequency and wake shedding frequency for heat exchanger tubes by tube diameter;

FIG. 4 illustrates an offset pattern of heat exchanger tubes similar to that which is used in FIG. 1;

FIG. 5 illustrates a pattern of tubes with different diameters arranged in rows transverse to the flow direction in the heat exchanger;

FIG. 6 illustrates another pattern of tubes with different diameters arranged in offset rows parallel to the flow direction;

FIG. 7 illustrates a further non-limiting configuration similar to that of FIG. 5, but with first tubes and second tubes aligned along the flow direction;

FIG. 8 illustrates a further arrangement of tubes wherein a relatively larger plurality of tubes are surrounded in hexagonal patterns of relatively smaller tubes; and

FIG. 9 illustrates another non-limiting configuration wherein the larger and smaller diameter tubes are arranged diagonally across the flow space.

DETAILED DESCRIPTION

[0030] The disclosure relates to tube bundle heat exchangers. FIG. 1 schematically illustrates such a heat exchanger 10 wherein a duct 12 carries a first flow 14 of heat exchange medium that flows across a plurality of heat exchange tubes 16 carrying a second fluid exchange medium. In such heat exchangers, heat transfer is effectively conducted between the two heat exchange mediums. However, depending upon the mounting of the heat exchange tubes, as well as diameter, material and other factors, each of the heat exchange tubes will have a natural frequency induced by the flow. In addition, when fluid flows past a "blunt" object such as tubes 16, the flow regime passing and following the object can be significantly impacted.

[0031] FIG. 2 shows a series of different flows that can result due to flow past blunt objects like heat exchanger tubes. One basic flow regime is a regime of unseparated flow as illustrated at 18. In view 20, a flow regime is created which exhibits a fixed pair of oppositely rotating vortices in the wake. In view 22, two regimes are created wherein a vortex street is laminar. This flow pattern can be particularly disruptive as the aligned lateral flows can impact downstream tubes at the same frequency which, depending upon the specific application, can be in the range of 2-4 kHz. View 24 shows a transition to turbulence in the vortex, and the vortex street is fully turbulent. View 26 shows a flow regime wherein a laminar boundary layer has undergone turbulent transition, leading to a narrower wake that is disorganized. In the last view 28, a turbulent vortex street is reestablished.

[0032] In certain circumstances, any of the flow regimes illustrated in FIG. 2 can cause issues. This is due to the combination of natural frequency illustrated by all heat exchanger tubes, and flow shedding frequency caused by the wake as the flow passes a tube. FIG. 3 illustrates a plot of these frequencies versus tube diameter. As shown, natural frequency 30 steadily increases with tube diameter, while frequency of the vortex shedding 32 decreases with increase of tube diameter. Where these frequencies approach each other 34, resonance can occur that can cause damage to the tubes and related structures. Incorporating tubes of different sizes as well as different flow patterns can help to avoid resonance and thereby extend the useful life of the heat exchanger. Further, as will be discussed below, heat exchange efficiency can also be improved.

[0033] FIG. 4 shows another version of a conventional tube configuration wherein tubes all having the same diameter are arranged in a staggered configuration rather than the straight rows of FIG. 1. In the configuration of FIG. 4, vortex shedding can occur differently, but downstream can have an even greater influence on tubes that they impact. In consideration of FIG. 4 and the discussion of FIGS. 5-9 to follow, potential flow regimes are illustrated and discussed as well. These illustrations are shown only on selected portions of tubes, but are representative of the full flow field. The flow fields for each of the configurations shown will have some similarities. The first two rows of tubes will see relatively clean air. Depending upon Reynolds number, the flow separates on the aft or downstream side of the tubes, producing a vortex. The vortex is swept downstream to impinge on the next row of tubes. On subsequent rows, instead of clean air, the vortex strikes the tube. Flow in this configuration has some separation and also different relative speed. Flow immediately downstream of the tube can have vortices and is relatively slow flow, while the flow alongside the tubes and past the wake flow is faster. The flow is squeezed and expanded as it works its way through the tube bank. This aids with mixing the heated flow (that near the tubes) with the unheated, bulk flow. This can be considered as a steady-state depiction, but there will also be periodic vortex shedding. Referring back to the illustrations of FIG. 2, the effects of different Reynolds numbers is illustrated. For a relatively low Reynolds number, flow can be similar to image 20, with low Reynolds separation. At relatively higher Reynolds numbers, the vortex shedding becomes turbulent, for example as shown in image 26 of FIG. 2.

[0034] FIGS. 5-9 illustrate different configurations wherein the plurality of heat exchanger tubes are provided as a first set or plurality of tubes 38 having a first diameter and a second set or plurality of tubes 40 having a second diameter. Of course, this is a non-limiting configuration and it is possible to have arrays of tubes with more than 2, for example 3 or more, different diameters. While adding a further layer of complexity to the overall net result on flow, this can also be modeled and tailored to the specific environment to reduce the possibility of resonance. In one non-limiting configuration of these embodiments, the second diameter is larger than the first diameter.

[0035] When different size tubes are introduced, the local Reynolds number changes, since it is a function of the tube diameter and spacing. For the relatively smaller tubes, the Reynolds number is lower and should produce more of a fixed pair of vortices, similar to image 20 of FIG. 2. For the relatively larger tubes, at a higher Reynolds number, the shedding will be more periodic.

[0036] In the configuration of FIG. 5, tubes are arranged in alternating rows that are substantially transverse to the flow direction A. Further, these rows are themselves offset such that tubes 38 are not aligned with immediately upstream tubes 40. In this configuration, the vortex shedding from a large diameter tube 40 next encounters an offset pair of small diameter tubes 38, and thus disrupts the vortex street and helps to prevent resonance. The difference in diameter of the tubes 38, 40 disrupts the formation of a coherent set of vortices. For example, in the configuration of FIG. 5, wakes of neighboring tubes interfere with each other. In the configuration of FIG. 6, tubes 38, 40 are arranged in staggered rows arranged substantially parallel to flow direction A. In this configuration, vortex shedding from each tube encounters a spaced pair of different sized tubes downstream, and this also helps to disrupt any potential resonance.

[0037] Changing the position of large and small tubes from the position in FIG. 5 to that of FIG. 6 is believed to produce a different looking flow field. The impedance over the smaller tubes, with a relatively larger spacing is lower than that of the larger tubes. The flow rate is expected to be biased, even only a small amount, toward the rows of smaller tubes. As a result, their Reynolds numbers will rise while the decrease in flow rate on the large tubes lowers their respective Reynolds numbers. In the extreme case, with very large and very small tubes, flow over the larger tubes could be starved. Hence, the arrangement in FIG. 5 should have better thermal performance than that of FIG. 6.

[0038] In the configuration of FIG. 7, tubes can be arranged in alternating and aligned rows of tubes 40, 38 that are arranged substantially transverse to flow direction A. In this configuration, vortex shedding from any tube next encounters a tube of a different diameter immediately downstream, again serving to disrupt resonance. On the other hand, this configuration, known as an in-line arrangement, can be less efficient in heat exchange because flow can move directly along between the rows.

[0039] In the configuration of FIG. 8, relatively large diameter tubes 40 can be arranged in an offset pattern, with each tube 40 surrounded by a hexagonal pattern of smaller diameter tubes 38. In FIG. 8, lines show the actual hexagonal positioning, but these lines are only for further illustration and do not represent a structural component of the tube pattern. This results in a more complex interaction of vortex shedding interaction with lateral interference of the vortices which again serve to help disrupt the potential for resonance.

[0040] Specifically, the configuration of FIG. 8 should produce a blending of staggered and in-line arrangement. The larger tubes are staggered but the smaller tubes are in-line. The flow striking the larger tubes is always produced by the wake of the smaller tubes, with a low Reynolds vortex. The larger tube will have a larger Reynolds number and produce the relative cortex pattern, which now strikes the downstream, smaller tube. These large and small vortices can be expected to mix rather quickly and have a somewhat uniform size after the first few rows. Locally, right behind a given tube, the shedding will be similar to what is shown in FIG. 2, for example at 20.

[0041] In the configuration of FIG. 9, a further pattern can have the smaller diameter tubes 38 and the larger diameter tubes 40 arranged diagonally across the flow space as shown. In this configuration, each transverse row of tubes comprises alternating large and small diameter tubes, and although the tubes are also in line in the flow direction A, they alternate in the flow direction as well between small diameter and large diameter tubes. This configuration also helps to interrupt flow vortices at each level to help prevent an undesirable vortex street and resonance as discussed above.

[0042] The flow field that results in FIG. 9 can be somewhat different from the other tube configurations. Keeping with the vortex shedding pattern based on tube size, the smaller tubes produce a symmetric vortex pair. The larger tubes have more periodic shedding. As a result, the vortex wake of the larger tubes may encompass the smaller, downstream tube. In FIGS. 5 and 6, the flow striking the small tubes was rather smooth. Here, that only holds for the first row. After that, all the smaller tubes are in the wake of larger tubes. This is expected to produce a particularly chaotic flow field to the point of mimicking a higher Reynolds number vortex pattern. This in turn should result in higher Nusselt numbers and improved thermal performance.

[0043] In another configuration, the lateral or transverse spacing (ST), that is, the spacing between tubes in a direction transverse to the flow direction (See ST in FIG. 9), can be selected such that a ratio of the transverse spacing to an average diameter (D) of the plurality of tubes (ST/D) is between 1.5 and 2.5. Further, the longitudinal spacing (See SL in FIG. 9), or spacing between tubes in the longitudinal direction, or parallel to the flow direction A, can be selected such that a ratio of the longitudinal spacing to an average diameter (D) of the plurality of tubes (SL/D) is between 1.0 and 3.0. These spacings, which can be incorporated into any of the disclosed embodiments of FIGS. 5-9, can also help to break up any undesirable formation of a vortex street or resonance, and thereby enhance the useful lifetime of the tube bundle heat exchanger, and also help to reduce the noise from operating the heat exchanger.

[0044] As set forth herein, it should be appreciated that heat exchanger tubes are arranged in various different patterns. Further, these different ranges of difference in size. In one non-limiting configuration, it may be desirable to have a ratio of size of the large diameter tubes to size of small diameter tubes of greater than 1:1 and up to about 3:1. Further, in another non-limiting configuration, it is desirable that the larger diameter tubes have a diameter that is at least about 10% greater than the diameter of the small diameter tubes.

[0045] In another non-limiting configuration, there is a prescribed range of ratio of the number of small diameter tubes to large diameter tubes. This range can suitably be between about 30 and about 70% by number of the plurality of tubes. This blend of small and large diameter tubes allows for effective arrangement of the tubes such that the wakes or vortices shed from each tube are cancelled out by other wakes or vortices shed from other (for example adjacent) tubes.

[0046] The tubes of different diameter can themselves carry a different flow volume of heat exchange medium, or they can have thicker walls, for example due to hoop stress. While this might reduce the difference in flow to some extent, generally, the larger diameter tubes will still have a larger inner diameter and therefore a larger flow area. This can also be compensated by having fewer large diameter tubes, for example, if it is desired to do so.

[0047] Heat exchange tubes of differing diameter are readily available and can be obtained and incorporated into heat exchangers using known techniques.

[0048] It should also be appreciated that although the drawings present the different flow patterns in terms of a relatively straight flow duct, the principles disclosed herein are readily applicable to other, potentially more complex, flow ducts and heat exchange tube patterns, all within the broad scope of the present disclosure.

[0049] As disclosed herein, use of different diameter tubes in tube heat exchangers can help to ensure that the wake frequency is not similar to the natural frequency of the tubes, and thereby avoid resonance that can negatively impact the useful life of the tubes and heat exchanger.

[0050] The foregoing description is exemplary of the subject matter of the invention disclosed herein. Various non-limiting embodiments are disclosed, however, one of ordinary skill in the art would recognize that various modifications and variations in light of the above teachings will fall within the scope of the appended claims. It is therefore to be appreciated that within the scope of the appended claims, the disclosure may be practiced other than as specifically described. Thus, the scope of the present claims is not specifically limited by the details of specific embodiment disclosed herein, but rather the claims define the full and reasonable scope of the invention.

Claims

1. A tube bundle heat exchanger (10), comprising:

   a flow space for a first heat exchange medium; and
   a plurality of heat exchange tubes (38, 40) for a second heat exchange medium, wherein the plurality of heat exchange tubes (38, 40) extends at least partially across the flow space, wherein the plurality of heat exchange tubes (38, 40) comprises at least a first plurality of tubes (38) having a first diameter and a second plurality of tubes (40) having a second diameter different from the first diameter.

2. The tube bundle heat exchanger (10) of claim 1, wherein the second plurality of tubes (40) are positioned relative to the first plurality of tubes (38) such that, during expected flow conditions through the flow space, wake shedding frequency exhibited by the plurality of heat exchange tubes (38, 40) does

not match natural frequency of the plurality of heat exchange tubes (38, 40).

3. The tube bundle heat exchanger (10) of claim 1 or 2, wherein the second diameter is larger than the first diameter.

4. The tube bundle heat exchanger (10) of claim 3, wherein the second plurality of tubes (40) are positioned in alternating rows relative to the first plurality of tubes (38), the rows extending transverse to flow direction through the flow space.

5. The tube bundle heat exchanger (10) of claim 4, wherein the first set of tubes (38) are not aligned with the second set of tubes (40) in the flow direction, wherein, optionally, the first set of tubes (38) are arranged across the flow direction of the heat exchanger (10) with gaps defined between each pair of adjacent tubes, and wherein tubes of the second set of tubes (40) are aligned in the flow direction with the gaps in the first set of tubes (38).

6. The tube bundle heat exchanger (10) of claim 4, wherein the first set of tubes (38) and the second set of tubes (40) are aligned with each other in the flow direction.

7. The tube bundle heat exchanger (10) of claim 4, wherein the first plurality of tubes (38) and the second plurality of tubes (40) are arranged in staggered alternating rows extending in the flow direction.

8. The tube bundle heat exchanger (10) of any of claims 3 to 7, wherein:

a ratio of second diameter to the first diameter is greater than 1:1 and up to 3:1; and/or
the second set of tubes (40) has a diameter that is at least 10% larger than the first set of tubes (38); and/or
the second set of tubes (38) comprises between about 30 and about 70% by number of the plurality of heat exchange tubes (38, 40).

9. The tube bundle heat exchanger (10) of any of claims 3 to 8, wherein the plurality of heat exchanger tubes (38, 40) are arranged at a transverse spacing (ST) such that a ratio of the transverse spacing to an average diameter (D) of the plurality of tubes (ST/D) is between 1.5 and 2.5.

10. The tube bundle heat exchanger (10) of any of claims 3 to 9, wherein the plurality of heat exchanger tubes (38, 40) are arranged at a longitudinal spacing (SL) such that a ratio of the longitudinal spacing to an average diameter (D) of the plurality of tubes (38, 40) (SL/D) is between 1.0 and 3.0.

11. The tube bundle heat exchanger (10) of any of claims 3 to 10, wherein the second set of tubes (40) comprises a row of the second set of tubes (40) extending across the flow direction to reset any wake shedding flow conditions from upstream of the row.

12. The tube bundle heat exchanger (10) of any of claims 3 to 11, wherein the first set of tubes (38) are arranged in hexagonal patterns around each of the second set of tubes (40).

13. A method for operating a tube bundle heat exchanger (10) comprising a flow space for a first heat exchange medium; and a plurality of heat exchange tubes (38, 40) for a second heat exchange medium, wherein the plurality of heat exchange tubes (38, 40) extends at least partially across the flow space, wherein the plurality of heat exchange tubes (38, 40) comprises at least a first plurality of tubes (38) having a first diameter and a second plurality of tubes (40) having a second diameter different from the first diameter, the method comprising:

flowing the first heat exchange medium through the flow space at flow conditions to generate vortex shedding frequency; and
flowing the second heat exchange medium through the plurality of heat exchange tubes (38, 40) at tube flow conditions to generate natural frequency, wherein the second set of tubes (40) are positioned such that there is no resonance between the vortex shedding frequency and the natural frequency.

14. The method of claim 13, wherein:

the flowing steps result in heat exchange between the first heat exchange medium and the second heat exchange medium; and/or
the second diameter is at least 10% greater than the first diameter.

15. The method of claim 13 or 14, wherein:

tubes of the plurality of heat exchanger tubes (38, 40) are arranged at a transverse spacing (ST) such that a ratio of the transverse spacing to an average diameter (D) of the plurality of tubes (ST/D) is between 1.5 and 2.5; and/or
tubes of the plurality of heat exchanger tubes (38, 40) are arranged at a longitudinal spacing (SL) such that a ratio of the longitudinal spacing to an average diameter (D) of the plurality of tubes (SL/D) is between 1.0 and 3.0.

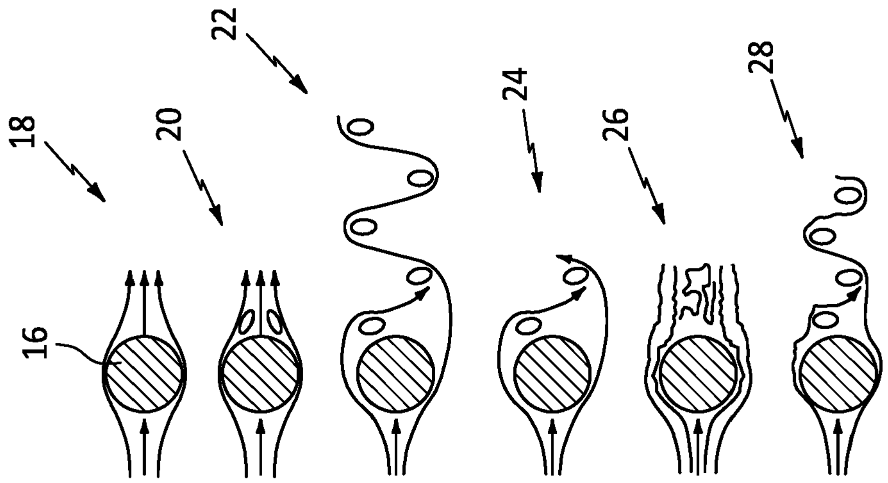

FIG. 2

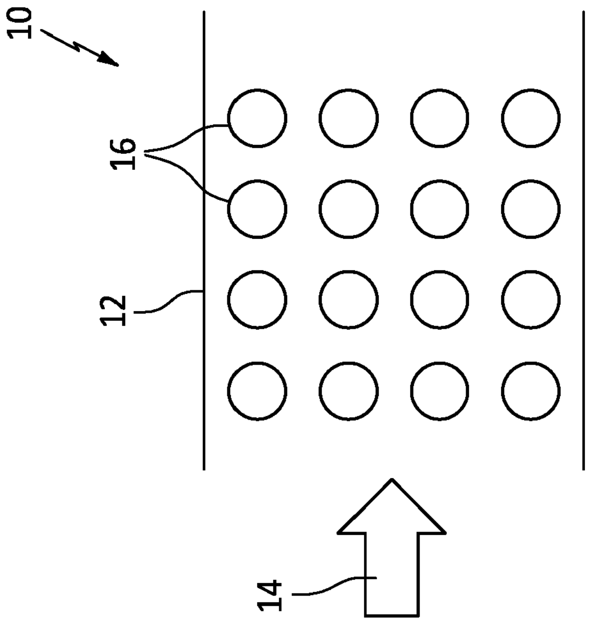

FIG. 1

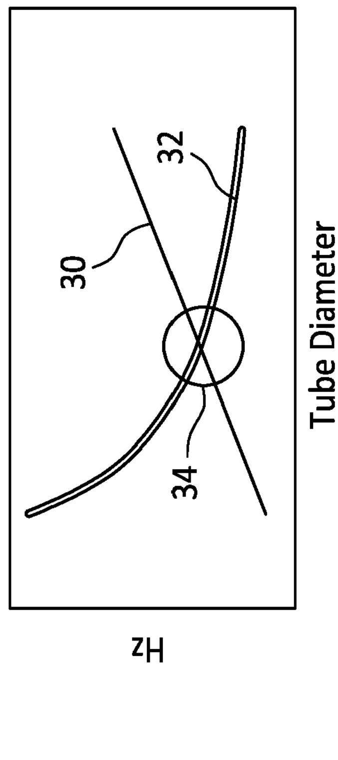

FIG. 3

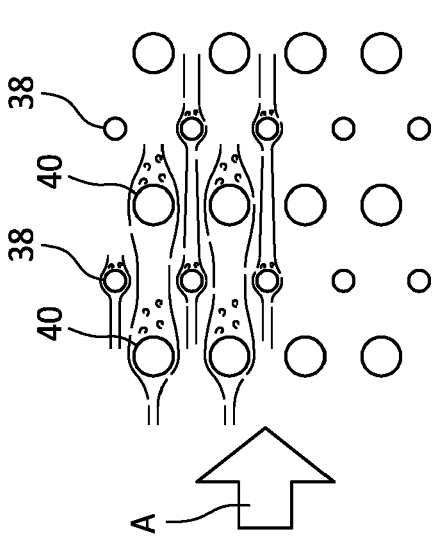

FIG. 5

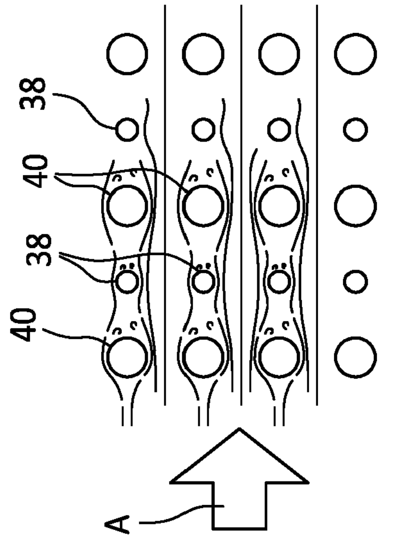

FIG. 7

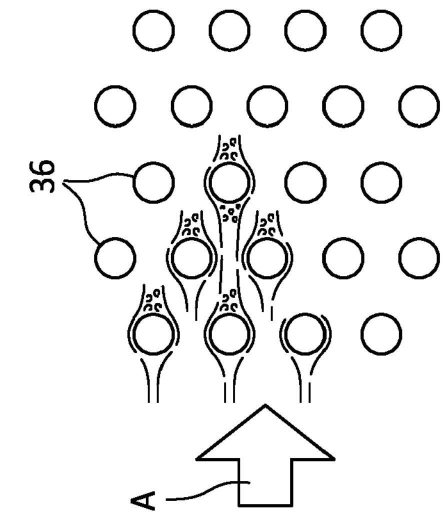

FIG. 4

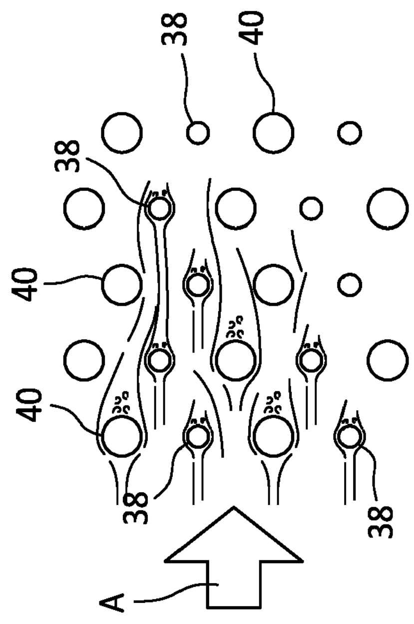

FIG. 6

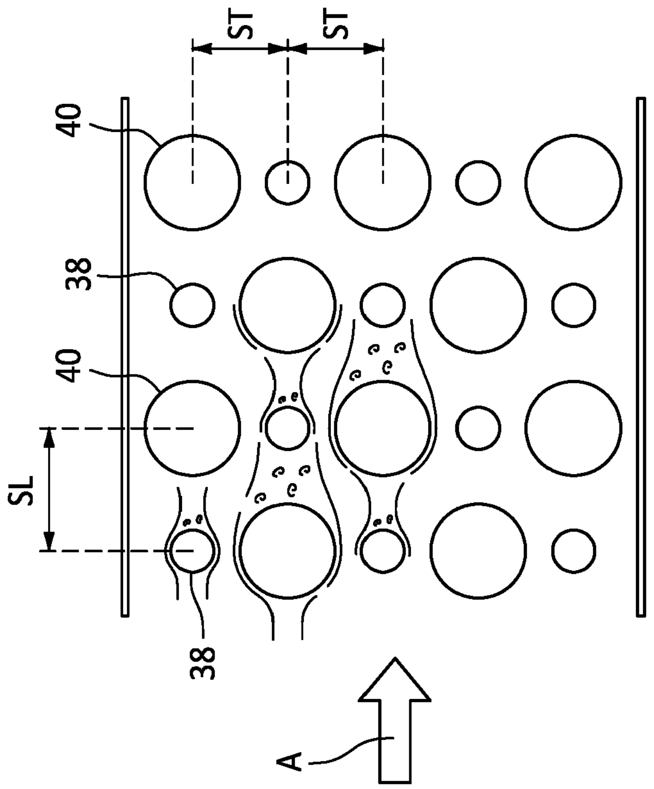

FIG. 9

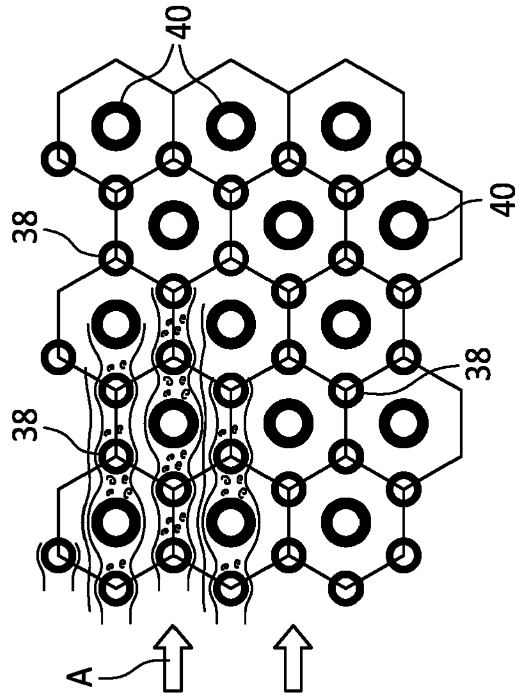

FIG. 8

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EUROPEAN SEARCH REPORT

Application Number
EP 24 15 6383

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	SOFIA G MAVRIDOU ET AL: "Numerical evaluation of a heat exchanger with inline tubes of different size for reduced fouling rates", INTERNATIONAL JOURNAL OF HEAT AND MASS TRANSFER, ELSEVIER, AMSTERDAM, NL, vol. 55, no. 19, 30 April 2012 (2012-04-30), pages 5185-5195, XP028399949, ISSN: 0017-9310, DOI: 10.1016/J.IJHEATMASSTRANSFER.2012.05.020 [retrieved on 2012-05-19] * figures 4-8 *	1-15	INV. F28D1/04
X	JP 2001 065801 A (HITACHI LTD; BABCOCK HITACHI KK) 16 March 2001 (2001-03-16) * figures *	1-15	
X	LAM K ET AL: "Experimental study and large eddy simulation of turbulent flow around tube bundles composed of wavy and circular cylinders", INTERNATIONAL JOURNAL OF HEAT AND FLUID FLOW, BUTTERWORTH SCIENTIFIC LTD, GUILDFORD, GB, vol. 31, no. 1, 1 February 2010 (2010-02-01), pages 32-44, XP026853202, ISSN: 0142-727X [retrieved on 2009-11-18] * figures 1,2 *	1-15	TECHNICAL FIELDS SEARCHED (IPC): F28D F28F
X	US 6 536 513 B1 (FONT-FREIDE JOSEPHUS JOHANNES [US] ET AL) 25 March 2003 (2003-03-25) * figure 3a *	1-15	

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The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	27 June 2024	Mellado Ramirez, J

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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page 1 of 2

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EP 24 15 6383

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	27 June 2024	Mellado Ramirez, J

CATEGORY OF CITED DOCUMENTS

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