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(54) **REDUCED VIBRATION TUBE BUNDLE SUPPORT DEVICE**


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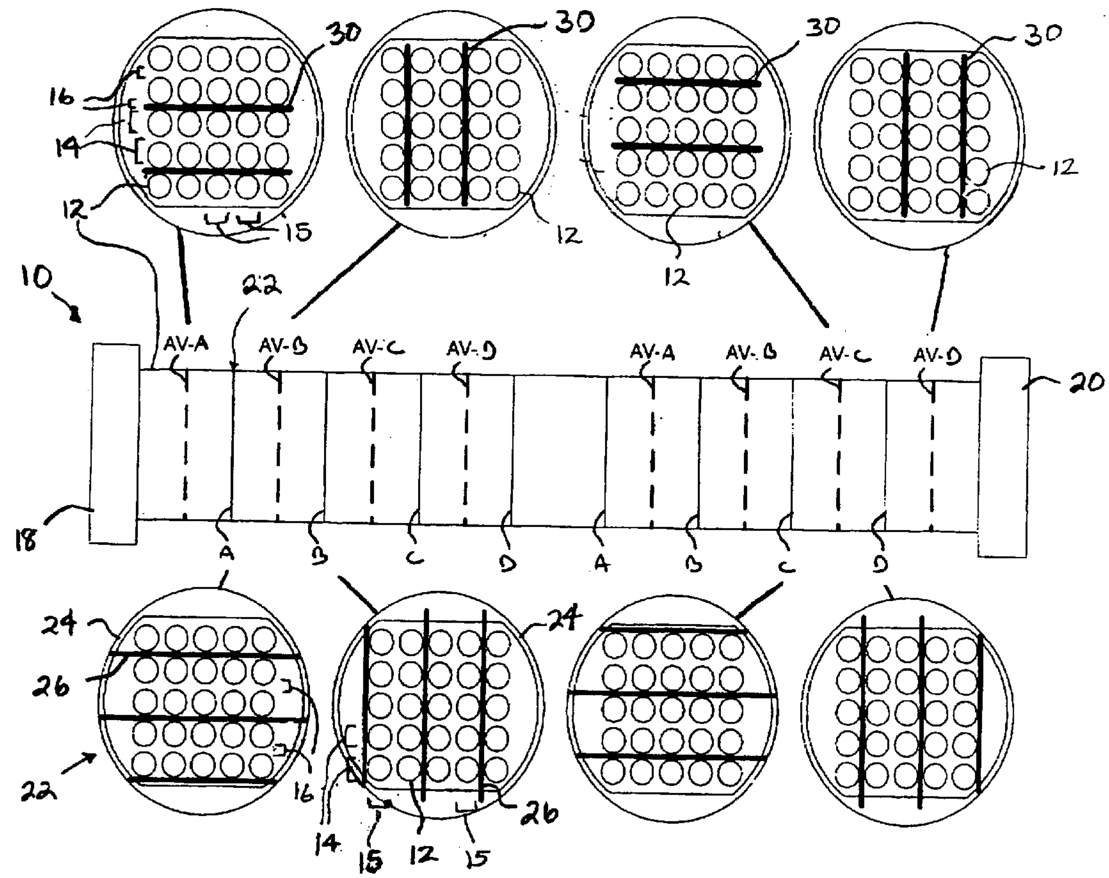
(57) **ABSTRACT**


A tube bundle for a shell and tube type heat exchanger has a support system that allows simple fabrication and provides a secure support of the tubes to mitigate vibration and problems associated with vibration. The tube bundle is composed of tubes that are supported by spaced cages having support rods sized to allow ample clearance with the adjacent tubes and configured in alternating positions and alternating orientations so that sets of four widely spaced cages form a complete support network. To ensure secure support to avoid vibration, sets of support stakes are inserted adjacent to (or in between) the cages to bias the tubes against the support rods of the cages. By this, fabrication is simplified, but a secure support system is maintained.

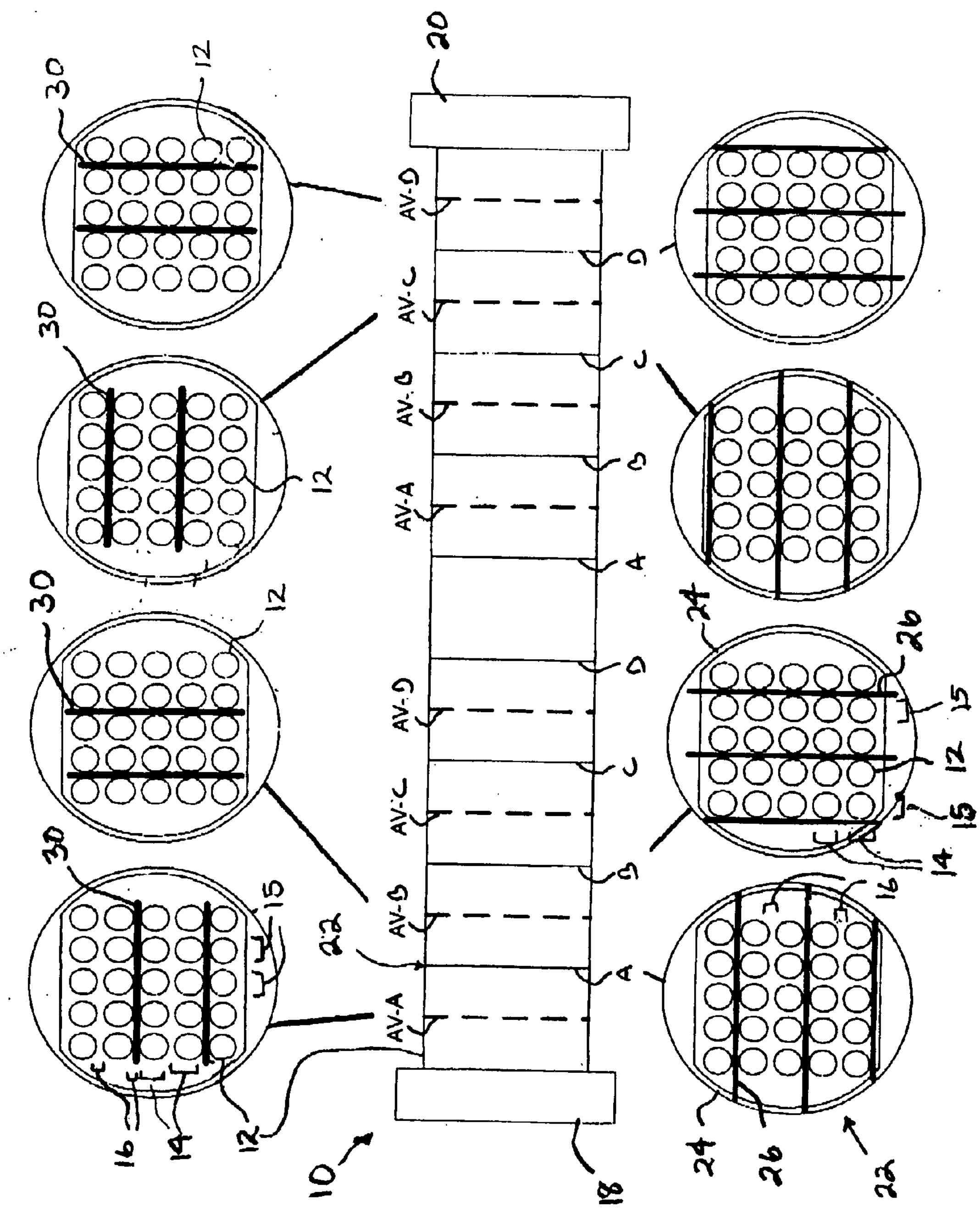


FIG. 1

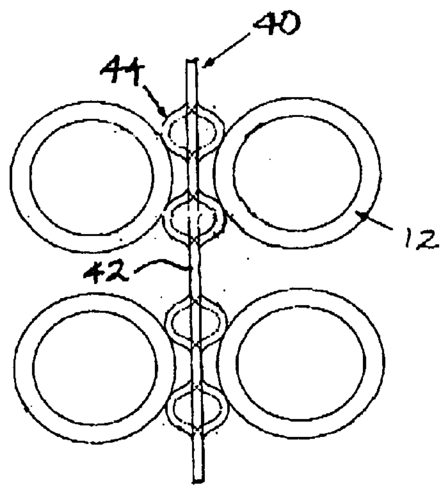



FIG. 2

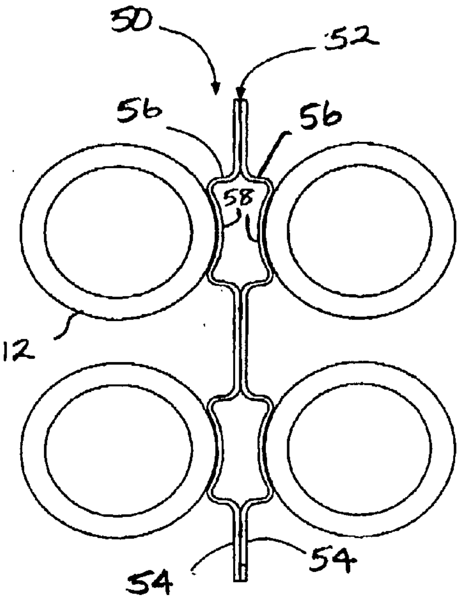



FIG. 3

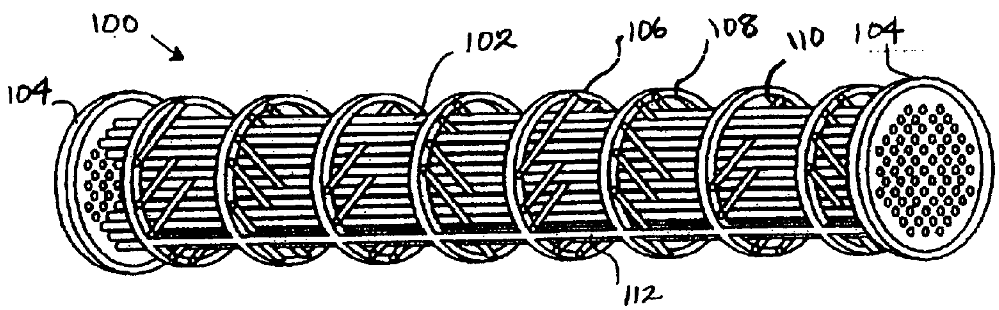



FIG. 4

PRIOR ART

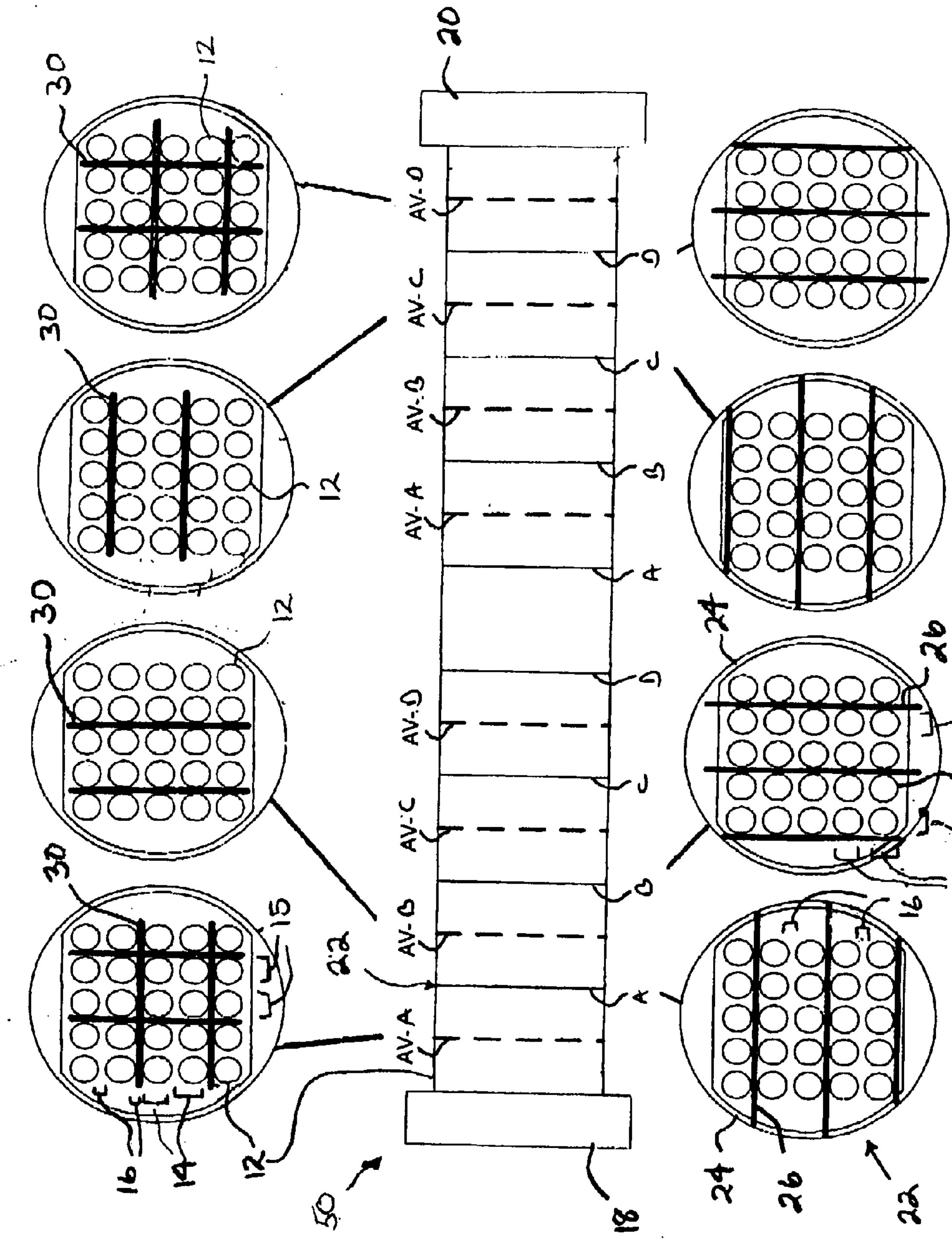



FIG. 5

# REDUCED VIBRATION TUBE BUNDLE SUPPORT DEVICE

## FIELD OF THE INVENTION

**[0001]** This invention relates to tube bundle devices such as heat exchangers, condensers and similar fluid-handling equipment with collections of tubes or rod-like elements, for example, in devices such as nuclear reactors, electrical heaters, or any collection of parallel cylindrical shapes that has a fluid flow passing over the tubes or other elements.

## BACKGROUND OF THE INVENTION

**[0002]** Tube bundle equipment such as shell and tube heat exchangers and similar items of fluid handling devices such as flow dampers and flow straighteners utilize tubes organized in bundles to conduct the fluids through the equipment. In such tube bundles, there is typically fluid flow both through the inside of the tubes and across the outside of the tubes. The configuration of the tubes in the bundle is set by the tubesheets into which the tubes are set. One common configuration for the tubes is a rectangular or square formation with the tubes set in aligned rows with tube lanes (the straight paths between the tubes) between each pair or rows, aligned orthogonally to one another. In this formation, each tube is adjacent to eight other tubes except at the periphery of the tube bundle and is directly opposite a corresponding tube across the tube lane separating its row from the two adjacent rows. In a triangular tube formation, the tubes in alternate rows are aligned with one another so that each tube is adjacent to six other tubes (the two adjacent tubes in the same row and four tubes in the two adjacent rows).

**[0003]** Increases in throughput in existing exchangers are often desired either to reduce capital cost by reducing equipment size or to increase productivity factors. A common limiting factor experienced when evaluating the increase of rates in an exchanger is the potential for flow-induced vibration damage of the tubes. Fluid flow patterns around the tubes may give rise to flow-induced vibrations of an organized or random oscillatory nature in the tube bundle.

**[0004]** In the case of devices such as heat exchangers in which heat transfer takes place between the tubes and the surrounding fluid, the changes in the temperature and density of the fluid as it circulates and flows around the tubes may increase the likelihood of vibration. If these vibrations reach certain critical amplitudes, damage to the bundle may result. Tube vibration problems may be exacerbated if heat exchange equipment is re-tubed with tubes made of a different material than the original tubes, for example, if relatively stiff materials are replaced with lighter weight tubes. Flow-induced vibration may also occur when equipment is put to more severe operating demands, for example, when other existing equipment is upgraded and a previously satisfactory heat exchanger, under new conditions, becomes subject to flow-induced vibrations. Vibration may even be encountered under certain conditions when a heat exchanger is still in the flow stream but without heat transfer taking place, as well as in other tube bundle devices with collections of rods or rod-like elements in a flow stream with or without heat transfer.

**[0005]** Vibration damage is a very expensive event for most situations in an operating plant. While a heat exchanger may have thousands of tubes, failure of a single tube could lead to shutdown of a process unit, thus causing substantial economic loss. Thus, reducing or eliminating vibration is a very desirable goal. Another advantage of minimizing the risk of vibration is to allow the use of axial shellside flow in circuits with gas compressors since compressor power consumption can be decreased drastically leading to substantial savings in energy costs.

**[0006]** A number of different equipment designs have evolved to deal with the problem of tube vibration. One example is the rod baffle design. Rod baffle heat exchangers are shell and tube type heat exchangers utilizing rod baffles to support the tubes and secure them against vibrations. Additionally, rod baffles can be used to reduce shell-side flow maldistribution and to create a more uniform shell-side flow. The term “rod baffle” refers to the annular rings, placed every 15 cm or so along the length of the tube bundle, in which the ends of a plurality of support rods are connected to form a cage-like tube support structure.

**[0007]** Rod baffle exchangers, however, tend to be approximately 20 to 40% more expensive than conventional shell-and-tube exchangers. Moreover, there have been situations where tube bundle devices of this kind have failed owing to flow-induced vibrations. A significant problem with rod baffles is the difficulty in loading the tubes between the rods. In order to provide a secure support and minimize vibration, the spacing between rods is very close to the diameter of the tube. In some arrangements, the diameter of the rod is approximately the same size of the lane between tubes. This requires very careful threading of the tubes through the cages and greatly increases the difficulty and time involved in installation. Rod baffle heat exchangers are described, for example, in U.S. Pat. Nos. 4,342,360; 5,388,638; 5,553,665; 5,642,778.

**[0008]** As explained in U.S. Pat. No. 5,553,665, certain applications of the rod baffle design such as surface condensers and power plant applications may benefit from longitudinal-flow, with shell-side pressure losses to be minimized. Reduction in shell-side pressure losses may be accomplished by increasing rod baffle spacing, thereby reducing the number of rod baffles, or by decreasing the number of tubes by increasing the tube pitch dimension, i.e., the distance between two adjacent rows of tubes as measured from the center of the tubes. Increasing baffle spacing is usually not an attractive option, since increased baffle spacing increases the likelihood of flow-induced tube vibration occurrence. Decreasing the tube count by increasing tube pitch dimension produces decreased shell-side pressure loss for longitudinal-flow between rod baffles, but requires oversized support rod diameters, leading to increased rod baffle pressure losses, which may offset any decrease in longitudinal-flow, shell-side pressure loss resulting from the reduced tube count. This would also lead to a more expensive exchanger owing to the increased shell diameter for a specified tube count. The rod baffle design described in U.S. Pat. No. 5,553,665 represents an attempt to deal with the pressure drop problems of the rod baffle configuration. Another example of a design intended to avoid a significant increase in the longitudinal-flow, shell-side pressure loss is described in U.S. Pat. No. 5,642,778.

**[0009]** Alternative designs are the “Eggcrate” and “Square One” designs. These, however, can be even more expensive than the rod baffle design, and they do not eliminate tube chatter that could lead to tube failure. Chatter is the motion of a tube hitting the tube supports because of the gap between the support and the tube outside diameter. The gap is required to allow for inserting the tubes through the eggcrate or square one support when the bundle is being constructed. From economic and operational viewpoints, therefore, the rod baffle design represents a more hopeful starting point.

**[0010]** Besides good equipment design, other measures may also be taken to reduce tube vibration. Tube support devices, or tube stakes as these support devices are commonly known (and referred to in this specification), may be installed in the tube bundle in order to control flow-induced vibration and to prevent excessive movement of the tubes. A number of tube supports or tube stakes have been proposed and are commercially available. U.S. Pat. No. 4,648,442 (Williams), U.S. Pat. No. 4,919,199 (Hahn), U.S. Pat. No. 5,213,155 (Hahn) and U.S. Pat. No. 6,401,803 (Hahn), for example, describe different types of tube stakes or tube supports which can be inserted into the tube bundle to reduce vibration. Improved tube stakes are shown in U.S. Pat. No. 7,032,655 and U.S. Publication No. 2005/0279487, both to Wanni et al., and the contents of which are incorporated herein by reference.

**[0011]** A tube bundle device, which is believed to be more effective, more reliable, easier to fabricate and less expensive than a conventional heat exchanger of the rod baffle type, has been developed and is disclosed in U.S. Pat. No. 7,073,575 and U.S. Pat. No. 7,219,718, the contents of which are incorporated herein by reference. In that device, a tube support cage similar to a rod baffle is placed at extended locations along the length of the tubes, e.g. every 50-200 cm apart, and in most cases about every 60-150 cm, thereby making fabrication of such a tube bundle much easier and less expensive, as compared to conventional rod-baffle devices, in which the rod-baffle supports are typically placed no more than approximately 15 cm apart. The tubes are supported by rods or flat bars in each tube lane at the cage locations, compared to the cages provided in every other tube lane in the rod baffle design. The tube bundle is stiffened by inserting tube stakes between the tube support cages, preferably at the midpoint of the tube span between the cages. While this system is effective, it would be desirable to provide an alternate design that can be produced with simple fabrication while still ensuring vibration mitigation.

## SUMMARY OF THE INVENTION

**[0012]** Aspects of the invention are directed to a tube bundle device comprising tubes arranged parallel to one another and defining a tube bundle with a longitudinal axis, wherein the tubes are arranged in rows and columns with an x-tube lane separating adjacent rows and a y-tube lane separating adjacent columns. The tube bundle device comprises a first tube support cage comprising a baffle frame with a plurality of parallel tube support members secured to the baffle frame in a plane substantially perpendicular to the longitudinal axis, each tube support member extending in a first orientation in alternating x-tube lanes, a second tube support cage comprising a baffle frame with a plurality of parallel tube support members secured to the baffle frame in a plane substantially perpendicular to the longitudinal axis, each tube support member extending in a second orientation at an angle to the first orientation in alternating y-tube lanes, a third tube support cage comprising a baffle frame with a plurality of parallel tube support members secured to the baffle frame in a plane substantially perpendicular to the longitudinal axis, each tube support member extending in the first orientation in alternating x-tube lanes that are offset by one lane from the first tube support cage, and a fourth tube support cage comprising a baffle frame with a plurality of parallel tube support members secured to the baffle frame in a plane substantially perpendicular to the longitudinal axis, each tube support member extending in the second orientation in alternating y-tube lanes that are offset by one lane from the second tube support cage. At least one set of tube support stakes is inserted in the tube bundle adjacent to and spaced from one of the tube support cages substantially parallel to and offset in alternating lanes from at least some of the tube support members of the adjacent tube support cage. The first, second, third and fourth tube support cages form a set that together defines a grid of tube support members disposed in each x-tube lane and each y-tube lane. The tube support members have a thickness that is between 80-98% of the width of an x-tube lane or a y-tube lane, thus defining free space between each tube and an adjacent tube support member. The tube support stakes bias the tubes against adjacent tube support members.

**[0013]** A set of tube support stakes can be disposed adjacent to each tube support cage. A set of tube support stake can be disposed between adjacent tube support cages in the set.

**[0014]** Aspects of the invention are also directed to a tube bundle device comprising tubes arranged parallel to one another and defining a tube bundle with a longitudinal axis, wherein the tubes are arranged in rows and columns with an x-tube lane separating adjacent rows and a y-tube lane separating adjacent columns. The device further comprises a first tube support cage comprising a baffle frame with a plurality of parallel tube support members secured to the baffle frame in a plane substantially perpendicular to the longitudinal axis, each tube support member extending in a first orientation in alternating x-tube lanes, and a first set of tube support stakes inserted in the tube bundle adjacent to and spaced from the first tube support cage substantially parallel to and offset from at least some of the tube support members. A second tube support cage comprises a baffle frame with a plurality of parallel tube support members secured to the baffle frame in a plane substantially perpendicular to the longitudinal axis, each tube support member extending in a second orientation at an angle to the first orientation in alternating y-tube lanes, and a second set of tube support stakes is inserted in the tube bundle adjacent to and spaced from the second tube support cage substantially parallel to and offset from at least some of the tube support members. A third tube support cage comprises a baffle frame with a plurality of parallel tube support members secured to the baffle frame in a plane substantially perpendicular to the longitudinal axis, each tube support member extending in the first orientation in alternating x-tube lanes that are offset by one lane from the first tube support cage, and a third set of tube support stakes is inserted in the tube bundle adjacent to and spaced from the third tube support cage substantially parallel to and offset from at least some of the tube support members. A fourth tube support cage comprises a baffle frame with a plurality of parallel tube support members secured to the baffle frame in a plane substantially perpendicular to the longitudinal axis, each tube support member extending in the second orientation in alternating y-tube lanes that are offset by one lane from the second tube support cage, and a fourth set of tube support stakes is inserted in the tube bundle adjacent to and spaced from the fourth tube support cage substantially parallel to and offset from at least some of the tube support members. The first, second, third and fourth tube support cages form a set that together defines a grid of tube support members disposed in each x-tube lane and each y-tube lane. Each tube support cage is spaced apart at least a distance of 300 mm measured along the longitudinal axis. The tube support stakes bias the tubes against adjacent tube support members thereby stiffening the tubes to resist flow-induced vibration potential.

**[0015]** Additional tube support stakes may be provided adjacent the entrance and exit of the tube bundle to provide additional support for the tubes in these regions. The tube support stakes can have a plurality of spaced dimples and corrugations.

**[0016]** The invention is additionally directed to a heat exchanger having a tube bundle for transporting fluids for heat exchange comprising tubes arranged parallel to one another and defining a tube bundle with a longitudinal axis, wherein the tubes are arranged in rows and columns with an x-tube lane separating adjacent rows and a y-tube lane separating adjacent columns. The tube bundle includes a set of four tube support cages. Each tube support cage comprises a baffle frame with a plurality of parallel tube support bars secured to the baffle frame in a plane substantially perpendicular to the longitudinal axis. The set of four tube support cages are axially spaced along the longitudinal axis such that the tube support bars of two tube support cages extend in a first orientation in alternating x-tube lanes and the tube support bars of the other two tube support cages extend in a second orientation at an angle to the first orientation in alternating y-tube lanes. At least one set of tube support stakes is inserted in the tube bundle adjacent to and spaced from at least one of the tube support cages substantially parallel to and offset from at least some of the tube support members of the adjacent tube support cage in a woven configuration. The tube support stakes are formed with seats to support the tubes. The set of four tube support cages together define a grid of tube support bars disposed in each x-tube lane and each y-tube lane, and each tube support cage is spaced apart from another tube support cage in the set at least a distance of 300 mm measured along the longitudinal axis. The tube support bars have a thickness that is at most 98% of the width of an x-tube lane or a y-tube lane, thus defining free space between each tube and an adjacent tube support bar. The tube support stakes support the tubes in the seats and bias the tubes against adjacent tube support bars.

**[0017]** These and other aspects of the invention will become apparent in view of the following detailed description, especially when taken with the drawings.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0018]** FIG. **1** is a simplified schematic of a tube bundle with the tubes supported by tube support cages and tube stakes according to the invention showing enlarged details of the tube support cages and the tube stakes;

**[0019]** FIG. **2** is an enlarged view of a tube stake for use with the tube bundle of FIG. **1**;

**[0020]** FIG. **3** is an enlarged view of another tube stake for use with the tube bundle of FIG. **1**;

**[0021]** FIG. **4** is a side perspective view of a conventional rod baffle bundle; and

**[0022]** FIG. **5** is a simplified schematic of a variation of the tube bundle of FIG. **1** having additional tube stakes at the end portions of the tube bundle.

**[0023]** Like elements in the drawings are designated with the same reference numerals.

## DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

**[0024]** In this specification and claims, the terms "vertical" and "horizontal" are used in the relative sense with respect to the orientations of the elements of the tube support cages and of the stakes, that is, to designate a relative orientation of the support cage elements or of the stakes with respect to one another and the axis of the device. Thus, references to the "vertical" orientation mean that the orientation is orthogonal to a specified "horizontal" orientation, without implying that the orientations are true vertical or true horizontal. This applies especially when the axis of the heat exchanger itself is vertical or horizontal, so that all the support cages and stakes will be at true horizontal. Thus, the references to "vertical" and "horizontal" in relation to the orientation of the elements of the tube support cages and of the stakes are to be taken on the assumption that the longitudinal axis of the tube bundle device is itself true horizontal and that the specified orientations are relative to one another not true. For example, in a heat exchanger with a true horizontal longitudinal axis, the elements of the tube support cages may be at angles of 45° to the true horizontal/vertical but still be "vertical" and "horizontal" with respect to each other. In a heat exchanger with a vertical longitudinal axis, all the elements of all the tube support cages will be at true horizontal but are nevertheless to be considered to be "vertical" and "horizontal" if their orientations relative to one another about the longitudinal axis are orthogonal.

**[0025]** This invention is explained with reference to a shell and tube type heat exchanger in which a bundle of heat exchanger tubes is secured between tubesheets within a shell and liquid is directed through and around the tubes to effect heat exchange. This type of tube bundle could be used in a heat exchanger as described or in a condenser, nuclear fuel rod device or any other type of ordered arrangement of parallel tubes with fluid flowing over them. For convenience and brevity the invention will be described with reference to the device as a heat exchanger although other tube (or rod) bundle devices may also be constructed according the present principles. The tube bundle will be fitted into the surrounding shell in a conventional manner, for example, with two fixed tubesheets if the exchanger is to operate with only a small temperature differential or, more commonly, with one stationary tubesheet and one floating tubesheet, or with a U-tube bundle having only one (stationary) tubesheet.

**[0026]** FIG. **4** shows a conventional heat exchange tube bundle **100** that uses a rod baffle support system. The bundle **100** is composed of a plurality of elongated heat exchanger tubes **102** disposed in parallel and secured at each end by tubesheets **104**, as is known. The tubes **102** are spaced from each other by tube lanes. Disposed along the length of the heat exchanger tubes **102** are a plurality of rod baffles **106** about every 150 mm. Each rod baffle **106** is formed as an annular ring **108** that supports the ends of support rods **110** that extend across the ring **108**. As seen, the support rods **110** extend transversely across the bundle in the lanes between the tubes **102**. By this arrangement, vibrations induced by the flow of liquid through the bundle can be reduced. In this system, the size tolerance of each support rod **110** must be carefully designed. To closely support the tubes **102**, only a small clearance is provided to load the tubes **102** in place through the baffle **106**, which causes difficult loading and increases fabrication costs. However, undersizing the rods **110** to provide easier tube loading causes the bundle to lose the ability to avoid vibration damage, particularly at the shell inlet and outlet.

**[0027]** FIG. **1** shows a tube bundle **10** that is designed to address these problems. As will be explained below, the tube bundle **10** is designed to accommodate a greater throughput and be smaller than existing exchangers. These conditions lead to higher velocities experienced in the tube bundle and can lead to greater tendency for vibration.

**[0028]** The tube bundle **10** comprises a number of parallel tubes **12** in a rectangular configuration, that is, with rows **14** of tubes **12** and columns **15** of tubes **12** extending in two directions with x-tube and y-tube lanes **16** defined between the tube rows **14** and tube columns **15**, respectively. As seen in the figures, only several rows, columns and lanes are labeled for purposes of simplicity, but it should be understood that these reference numerals are intended to refer to each row, column and lane, respectively. The tubes **12** are connected to the tubesheets **18**, **20** at each end of the tube bundle in a conventional manner. The tubesheets **18**, **20**, in turn, will be installed into the shell of the exchanger. Of course, other configurations of the tubes **12** within the bundle **10** are possible, including for example a triangular configuration. The lane space **16** would need to be adjusted accordingly to fit the tube support members **26**.

**[0029]** The tubes **12** are supported by tube support cages **22** that are disposed at intervals along the length of the tubes **12**. The tube support cages **22** are of four different types that repeat throughout the bundle and designated in the drawings as A, B, C and D. Each tube support cage **22** is formed of a ring **24** or plate baffle with a central cut-out window. A plurality of tube support members or rods **26** extend across the central open area and are secured at their ends to the ring **24**. The cages **22** can be prefabricated for more efficient and less expensive assembly.

**[0030]** The rods **26** can be any configuration, but are preferably in the form of flat bars welded to the baffle. Of course, the rods **26** may be any shape, including circular, rectangular, or square cross-section, and referred to herein as “rods” for convenience and brevity regardless of their cross-sectional shape. The rods **26** may be directly welded to the sides of the ring **24** (across its wall thickness) or, with a more complicated construction, received in recesses or apertures in the annular ring **24**, shaped appropriately to the cross-section of the rods formed by drilling with the rods secured in the recesses or apertures by welding, brazing or other securing expedients.

**[0031]** The thickness of the rods **26** is preferably undersized in relation to the tube lanes **16**. To provide ample clearance around the rods **26** for insertion of the tubes **12**, the thickness of the rods can be 98% of the width of the lane, preferably in a range of 90% to 98%. In the case of the rods **26** configured as flat bars, the thickness refers to the width of the bar. For example, the rods **26** may be about 95% as wide as the tube lane **16**. In particular, if a tube lane measured as the spacing between two adjacent tubes is 6.35 mm, the rod is sized with a thickness of 6.0 to 6.2 mm. This allows the tubes **12** to be readily inserted into the prefabricated cages **22**, which makes bundle loading a fairly easy task. On large diameter bundles, small rods may be deflected by flow and for this reason, it may be desirable to use flat bars as the rods **26** for a greater modulus, resulting in greater axial strength. It is also contemplated that several crossbars may be used to stiffen the primary bars. The absence of complete support from the rods **26** does not, however, diminish the effectiveness of the overall support system because additional support is provided by the tube stakes which are inserted into the tube bundle, as explained below.

**[0032]** As noted above, there are four different configurations of cages **22**. The four types A, B, C, D are seen in FIG. **1** extending from left to right across the bottom of the figure. The different configurations relate to the orientation of the cage **22** when installed in the bundle **10**. The terms “horizontal” and “vertical” used herein are used for descriptive purposes to indicate relative position between adjacent elements. It should be appreciated that the entire assembly could be turned thus changing the orientation, while the relative orientations between elements will remain the same.

**[0033]** As seen, the first type, A, has horizontally disposed rods **26** that begin at the bottom portion of the ring **24** and are spaced to be disposed in x-tube lanes **16** between alternate horizontal rows **14**. The second type, B, has vertically disposed rods **26** that begin at the left portion of the ring **24** and are spaced to be disposed in y-tube lanes **16** between alternate vertical columns **15**. The third type, C, has horizontally disposed rods **26** that begin at the top portion of the ring **24** and are spaced to be disposed in x-tube lanes **16** between alternate horizontal rows **14**. The fourth type, D, has vertically disposed rods **26** that begin at the right portion of the ring **24** and are spaced to be disposed in y-tube lanes **16** between alternate vertical columns **15**. So, each cage **22** has rods **26** that are oriented in only one direction. By this, each set of four cages **22** of the types A, B, C, D will provide a rod **26** in every lane **16** between each row **14** and each column **15** of tubes **12** fully supporting the bundle.

**[0034]** Each tube support cage **22** is positioned at a spaced interval along the length of the bundle **10**. In this arrangement, the spacing is wider than conventional support cages, for example at least 300 mm between cages **22**. The spacing can be as much as 600 mm (for 19.05 mm diameter tubes) and 1200 mm (for 25.4 mm diameter tubes) between cages **22**. If desired, the distance between support cages/stakes may be increased in the middle portion of the exchanger because the axial velocity in the middle portion of the bundle **10** is parallel to the tubes and therefore is less likely to cause vibration. The cages **22** are secured to each other, as seen for example in FIG. **4**, by tie bars or tie rods **112**.

**[0035]** Due to the decreased size of the rods **26**, the use of fewer cages **22** and the alternate arrangement of rods **26**, loading of the tubes **12** through the cages **22** can be easily accomplished. After the tubes **12** are loaded, additional anti-vibration support is provided by the insertion of tube support stakes **30** to stiffen the tubes **12** disposed in the bundle.

**[0036]** Referring to the top row in FIG. **1**, four different configurations of anti-vibration (AV) tube support stakes **30** are shown from left to right as AV-A, AV-B, AV-C, and AV-D. The tube support stakes **30** at each location are disposed in the same direction and are disposed in a lane between alternate rows or columns. Configuration AV-A utilizes two tube support stakes **30** that are both disposed horizontally and are disposed in a lane **16** between two adjacent rows **14** that is offset from the lane **16** in which the rod **26** of the adjacent cage **22** is positioned. This can be appreciated by comparing the configuration of the A cage **22** with the AV-A stake configuration in FIG. **1**.

**[0037]** Similarly, configuration AV-A utilizes two tube support stakes **30** that are disposed vertically in a lane **16** between columns **15** beginning at the left portion of the bundle. Configuration AV-B utilizes two tube support stakes **30** that are disposed horizontally in a lane **16** between rows **14** beginning at the top portion of the bundle. Configuration AV-D utilizes two tube support stakes **30** that are disposed vertically in a lane **16** between columns **15** beginning at the right portion of the bundle. Similar to the cages **22**, by this configuration each set of the four configurations provide a tube support stake **30** in every x-tube and y-tube lane **16** between the rows **14** and columns **15**, respectively. Of course, if the bundle is composed of more tubes **12**, more rods **26** and more tube support stakes **30** would be used at each position. As long as the rods **26** and corresponding tube support stakes **30** are disposed in alternating lanes **16**, each row **14** and each column **15** will be fully supported. All of the tube support stakes **30** may be tied together at each location, for example, by circumferentially wrapped braided cables and/or clamps.

**[0038]** As seen in FIG. **1**, the locations of the cages **22** and tube support stakes **30** also alternate. Each adjacent cage **22** type and tube support stake **30** configuration is oriented in the same manner. For example, cage type A has horizontally oriented rods **26** that are disposed in alternate lanes as the horizontally oriented tube support stakes **30** of configuration AV-A. This is true for each adjacent, matched pair: B and AV-B; C and AV-C; D and AV-D.

**[0039]** In the rectangular tube arrangement, the alternating vertical/horizontal disposition of the support rods **26** will result in the tube support stakes **30** in each set being parallel to the support rods **26** of one of the adjacent cages **22** so that the tubes **12** are held by the support stakes **30** firmly against the support rods **26** to which they are parallel. In the triangular tube arrangement, it is preferable for the orientation of the support stakes **30** at a given location to be parallel to the support rods **26** of one of the adjacent cages **22** in order to hold the tubes firmly against the rods **26** of that cage **22**. Of course, in a triangular arrangement, the spacing between the tubes will increase slightly and the alternate orientation of the cages and stakes may be at an angle that is not 90 degrees. So, the shape created by the rods and stakes in each set may be a rhombus rather than a square.

**[0040]** The alternating configuration provides a benefit in terms of permitting freer fluid flow through the bundle. The parallel alignment of the tube support stakes **30** with the support rods **26** of an adjacent cage **22** and offset configuration has the effect of urging every tube **12** against a support rod **26** or stake **30** to give the final bundle the rigidity it requires for satisfactory operation. The insertion of the tube support stakes **30** into the tube bundle forces the tubes **12** away from the surface of the support stakes **30** and biases them toward the rods **26**. The effect is similar to a woven basket. In this way, the tubes **12** are slightly (up to 2 mm) deflected so as to provide tube support not only at the tube support stake locations but also at the tube support cage stations as well.

**[0041]** It is noted that no tube supports stakes are provided at the longitudinal center of the bundle between the two sets of cages because the tube support stakes **30** are not needed at every span between cages **22**. This is especially true near the mid-region(s) between the inlet and outlet nozzles because the shell flow is mostly axial and has a very small tendency to cause vibration damage. It is possible to dispense with the tube support stakes **30** at other positions, as well, depending on the particular bundle configuration and vibration analysis. The particular design will be application specific.

**[0042]** A variation of the present invention is illustrated in FIG. **5**. In this variation, the tube bundle **50** includes additional tube support stakes **30** located at AV-A' and AV-AD' in order to provide additional bundle stiffening of the tubes at the entrance and exit regions of the bundle to ensure that all of the tubes of the bundle are well supported. It is contemplated that in the event the tube bundle has a U-bend configuration (i.e., entrance and exit regions on are the same side of the bundle) then additional tube support stakes would only need to be provided at one location (i.e., AV-A' or AV-AD').

**[0043]** The tube support stakes **30** can have any configuration provided that they are dimensioned to impart the increased tube separation on insertion into the tube bundle to hold the tubes firmly against the support rods of the cages. Thus, for example, the tube stakes described in U.S. Pat. No. 4,648,442 (Williams), U.S. Pat. No. 4,919,199 (Hahn), U.S. Pat. No. 5,213,155 (Hahn) and U.S. Pat. No. 6,401,803 (Hahn) might be used provided that their dimensions are satisfactory to the purpose. The preferred type of tube stake is, however, the type shown in U.S. Pat. No. 7,032,655 (Wanni et al.), to which reference is made for a description of these preferred tube stakes, which are called dimple tube supports. Another preferred form of tube stake which may be used in the same manner is described in U.S. Pub. No. 2005/0279487, to which reference is made for a description of these preferred tube stakes, which are called saddle tube supports. A combination of these types may also be used. Full details of these types of supports are disclosed in the above patent and application, which have been incorporated herein, along with this type of support arrangement from U.S. Pat. No. 7,073,575, which has also been incorporated herein.

**[0044]** Referring to FIG. **2**, a dimple tube support stake **40** is shown disposed in a lane between tubes **12**. The dimple tube support stake **40** is formed as a stake or strip **42** having an elongated body with a series of raised portions, corrugations or dimples **44** that are spaced to form a seat for each adjacent tube **12**. FIG. **3** shows a saddle tube support **50** formed as a stake **52** formed of two sheets **54** of stiff material, each with an opposed raised section **56** or corrugation having a rounded central cup **58** that forms a seat for each adjacent tube **12**. Of course, different configurations and methods of forming the seats are possible. These configurations provide easy insertion while reliably locking the tubes in place. They are also economical to fabricate.

**[0045]** In these types of tube supports or stakes, the corrugations that face the tubes function to deflect the tubes slightly to provide resilient support for the tubes while, at the same time, enabling the support stakes to be readily inserted into the bundle. At its outer extremity, each tube support stake has dimples which deflect the tubes slightly in the same way but which lock more securely onto the outermost tubes so as to minimize the likelihood of undesirable dislocation of the tube support stakes during handling or in operation. The present invention is not intended to be used in connection with tube supports having dimples and/or corrugations. It is contemplated that other support devices may be used within the tube lanes to force or bias the tubes against the rods.

**[0046]** If desired, bypass shrouds can be provided at the top and bottom of tube bundle **10** to preclude longitudinal bypassing of the shellside fluid. These shrouds are known and are formed with a flat face that sits against the outermost tubes and a peripheral flange at each end. The flange is a chordal segment of a circle of diameter matching the internal diameter of the exchanger shell so that when the tube bundle is inserted into the shell, the flange conforms closely to the interior of the shell to preclude entry of shell side fluid into the shrouded region. The shrouds may be made in standard lengths and a number of them may be bolted (or otherwise fastened together end-to-end) through the flanges so as to extend over the tubes in all areas except at the inlet and outlet ends where flow to the shell inlet and outlet is required. The shrouds are fastened to the tube support cages for adequate rigidity, for example, by having the flanges bolted together with a tube support cage in between them.

**[0047]** In a triangular tube arrangement, a similar disposition of the tube support cages and tube support stake sets can be made, but in this case, the alignment of the support rods in the cages at each successive axial location is rotated by a multiple of 60° so that the original alignment is restored at the fourth location (i.e. the support rods are successively aligned at 0°, 60°, 120° and so on), with the stakes inserted in a similar alignment pattern. Given the desirability of having the tubes support stakes inserted parallel to the support rods of an adjacent support cage, a typical mode of insertion would be with the relative angular positions of the cage support rods and tube support stakes indicated at angular displacements of 0°, 60°, 120° relative to the first cage. In a triangular tube arrangement, the spacing between tubes **12** may be increased slightly over the conventional arrangement to accommodate the cage support rods.

**[0048]** During assembly, the tubes **12** are inserted through the cages **22** and into one or both tubesheets **18**, **20**. In the case of a tube bundle with U-shaped tubes received in one tubesheet, the cages **22** will be put onto the free ends of the tubes **12** and the tubes **12** then secured in the single tubesheet. In the case of a bundle with two tubesheets, the tubes **12** will normally be passed through the cages **22** and into one or both tubesheets, following which, the tubes **12** will be secured to one or both of the tubesheets, according to exchanger design, e.g. by welding or with an expanded joint.

**[0049]** The preceding description explains an arrangement in which the pitch and tube dimension are constant, but it will be recognized by those of ordinary skill in the art that assembly disclosed herein can be constructed to operate on rows of tubes having a variable pitch or variable tube dimensions. For example, the spacing or curvature of the seats of the tube supports could be easily modified. Moreover, those of ordinary skill in the art will recognize that various changes and modifications can be made to the arrangement herein and remain within the scope of the invention as defined in the appended claims.

The invention claimed is:

**1**. A tube bundle device, comprising:

tubes arranged parallel to one another and defining a tube bundle with a longitudinal axis, wherein the tubes are arranged in rows and columns with an x-tube lane separating adjacent rows and a y-tube lane separating adjacent columns;

a first tube support cage comprising a baffle frame with a plurality of parallel tube support members secured to the baffle frame in a plane substantially perpendicular to the longitudinal axis, each tube support member extending in a first orientation in alternating x-tube lanes;

a second tube support cage comprising a baffle frame with a plurality of parallel tube support members secured to the baffle frame in a plane substantially perpendicular to the longitudinal axis, each tube support member extending in a second orientation at an angle to the first orientation in alternating y-tube lanes;

a third tube support cage comprising a baffle frame with a plurality of parallel tube support members secured to the baffle frame in a plane substantially perpendicular to the longitudinal axis, each tube support member extending in the first orientation in alternating x-tube lanes that are offset by one lane from the first tube support cage;

a fourth tube support cage comprising a baffle frame with a plurality of parallel tube support members secured to the baffle frame in a plane substantially perpendicular to the longitudinal axis, each tube support member extending in the second orientation in alternating y-tube lanes that are offset by one lane from the second tube support cage; and

at least one set of tube support stakes inserted in the tube bundle adjacent to and spaced from one of the tube support cages substantially parallel to and offset in alternating lanes from at least some of the tube support members of the adjacent tube support cage,

wherein the first, second, third and fourth tube support cages form a set that together defines a grid of tube support members disposed in each x-tube lane and each y-tube lane,

wherein the tube support members have a thickness that is between 90-98% of the width of an x-tube lane or a y-tube lane, thus defining free space between each tube and an adjacent tube support member, and

wherein the tube support stakes bias the tubes against adjacent tube support members.

**2**. The tube bundle device of claim **1**, wherein each tube support cage is about 95% the width of an x-tube lane or a y-tube lane.

**3**. The tube bundle device of claim **1**, wherein each tube support cage is spaced apart at least a distance between 300 mm measured along the longitudinal axis.

**4**. The tube bundle device of claim **1**, wherein each tube has a diameter in a range of 12-22 mm and each tube support cage is spaced apart a distance of about 500-700 mm measured along the longitudinal axis.

**5**. The tube bundle device of claim **4**, wherein each tube has a diameter of approximately 19 mm and each tube support cage is spaced apart a distance of about 600 mm.

**6**. The tube bundle device of claim **1**, wherein each tube has a diameter in a range of 23-40 mm and each tube support cage is spaced apart a distance of about 1100-1300 mm.

**7**. The tube bundle device of claim **6**, wherein each tube has a diameter of about 25.4 mm and each tube support cage is spaced apart a distance of about 1200 mm.

**8**. The tube bundle device of claim **1**, wherein there is a set of tube support stakes disposed adjacent to each tube support cage.

**9**. The tube bundle device of claim **1**, wherein there is a set of tube support stake disposed between adjacent tube support cages in the set.

**10**. The tube bundle device of claim **1**, wherein the tube support stakes have a plurality of spaced projections, the projections forming a seat for an adjacent tube.

**11**. The tube bundle device according to claim **10**, wherein the spaced projections are one of spaced dimples and spaced corrugations.

**12**. The tube bundle device of claim **1**, wherein the tube support stakes have a plurality of spaced saddles, each saddle forming a seat for an adjacent tube.

**13**. The tube bundle device of claim **1**, wherein some of the tube support stakes have a plurality of spaced dimples and some of the tube support stakes have a plurality of spaced saddles, wherein the pairs of dimples and saddles form seats for adjacent tubes.

**14**. The tube bundle device of claim **1**, wherein at least some of the tube support stakes have a combination of dimples and saddles that form a seat for an adjacent tube.

**15**. The tube bundle device of claim **1**, wherein each tube support member is a flat bar.

**16**. The tube bundle device of claim **1**, wherein each baffle frame is formed of a plate with a central cut-out window.

**17**. The tube bundle device of claim **1**, wherein the tube bundle has a square cross section.

**18**. The tube bundle device of claim **1**, wherein the tube bundle has a triangular cross section.

**19**. The tube bundle device of claim **1**, further comprising a shell and a tubesheet connected to the shell that supports the tube bundle.

**20**. The tube bundle device of claim **1**, wherein the tube bundle having a first end forming an entrance region and a second end forming an exit region, wherein the tube bundle device further comprising at least one additional tube support stake inserted into the tube bundle adjacent one of the first end and the second end.

**21**. A tube bundle device, comprising:

tubes arranged parallel to one another and defining a tube bundle with a longitudinal axis, wherein the tubes are arranged in rows and columns with an x-tube lane separating adjacent rows and a y-tube lane separating adjacent columns;

a first tube support cage comprising a baffle frame with a plurality of parallel tube support members secured to the baffle frame in a plane substantially perpendicular to the longitudinal axis, each tube support member extending in a first orientation in alternating x-tube lanes;

a first set of tube support stakes inserted in the tube bundle adjacent to and spaced from the first tube support cage substantially parallel to and offset from at least some of the tube support members;

a second tube support cage comprising a baffle frame with a plurality of parallel tube support members secured to the baffle frame in a plane substantially perpendicular to the longitudinal axis, each tube support member extending in a second orientation at an angle to the first orientation in alternating y-tube lanes;

a second set of tube support stakes inserted in the tube bundle adjacent to and spaced from the second tube support cage substantially parallel to and offset from at least some of the tube support members;

a third tube support cage comprising a baffle frame with a plurality of parallel tube support members secured to the baffle frame in a plane substantially perpendicular to the longitudinal axis, each tube support member extending in the first orientation in alternating x-tube lanes that are offset by one lane from the first tube support cage;

a third set of tube support stakes inserted in the tube bundle adjacent to and spaced from the third tube support cage substantially parallel to and offset from at least some of the tube support members;

a fourth tube support cage comprising a baffle frame with a plurality of parallel tube support members secured to the baffle frame in a plane substantially perpendicular to the longitudinal axis, each tube support member extending in the second orientation in alternating y-tube lanes that are offset by one lane from the second tube support cage; and

a fourth set of tube support stakes inserted in the tube bundle adjacent to and spaced from the fourth tube support cage substantially parallel to and offset from at least some of the tube support members,

wherein the first, second, third and fourth tube support cages form a set that together defines a grid of tube support members disposed in each x-tube lane and each y-tube lane, and each tube support cage is spaced apart at least a distance of 300 mm measured along the longitudinal axis, and

wherein the tube support stakes bias the tubes against adjacent tube support members.

**22**. The tube bundle device of claim **21**, wherein the tube support members have a thickness that is between 90-98% of the width of an x-tube lane or a y-tube lane, thus defining free space between each tube and an adjacent tube support member.

**23**. The tube bundle device of claim **21**, wherein each tube support cage is spaced apart a distance of at least 600 mm measured along the longitudinal axis.

**24**. The tube bundle device of claim **21**, wherein each tube support cage is spaced apart a distance of at least 1200 mm measured along the longitudinal axis.

**25**. The tube bundle device of claim **21**, wherein the tube support stakes have a plurality of spaced projections, the projections forming a seat for an adjacent tube.

**26**. The tube bundle device according to claim **25**, wherein the spaced projections are one of spaced dimples and spaced corrugations.

**27**. The tube bundle device of claim **21**, wherein the tube support stakes have a plurality of spaced saddles, each saddle forming a seat for an adjacent tube.

**28**. The tube bundle device of claim **21**, wherein some of the tube support stakes have a plurality of spaced dimples and some of the tube support stakes have a plurality of spaced saddles, the dimples and saddles forming seats for adjacent tubes.

**29**. The tube bundle device of claim **21**, wherein at least some of the tube support stakes have a combination of dimples and saddles that form seats for adjacent tubes.

**30**. The tube bundle device of claim **21**, wherein each tube support member is a flat bar.

**31**. The tube bundle device of claim **21**, wherein each baffle frame is formed of a plate with a central cut-out window.

**32**. The tube bundle device of claim **21**, further comprising a shell and a tubesheet connected to the shell that supports the tube bundle.

**33**. The tube bundle device of claim **21**, wherein the tube bundle having a first end forming an entrance region and a second end forming an exit region, wherein the tube bundle device further comprising at least one additional tube support stake inserted into the tube bundle adjacent one of the first end and the second end.

**34**. A heat exchanger having a tube bundle for transporting fluids for heat exchange, comprising:

tubes arranged parallel to one another and defining a tube bundle with a longitudinal axis, wherein the tubes are arranged in rows and columns with an x-tube lane separating adjacent rows and a y-tube lane separating adjacent columns;

a set of four tube support cages, each tube support cage comprising a baffle frame with a plurality of parallel tube support bars secured to the baffle frame in a plane substantially perpendicular to the longitudinal axis,

wherein the set of four tube support cages are axially spaced along the longitudinal axis such that the tube support bars of two tube support cages extend in a first orientation in alternating x-tube lanes and the tube support bars of the other two tube support cages extend in a second orientation at an angle to the first orientation in alternating y-tube lanes; and

at least one set of tube support stakes inserted in the tube bundle adjacent to and spaced from at least one of the tube support cages substantially parallel to and offset from at least some of the tube support members of the adjacent tube support cage in a woven configuration, wherein the tube support stakes are formed with seats to support the tubes,

wherein the set of four tube support cages together define a grid of tube support bars disposed in each x-tube lane and each y-tube lane, and each tube support cage is spaced apart from another tube support cage in the set at least a distance of 300 mm measured along the longitudinal axis,

wherein the tube support bars have a thickness that is at most 98% of the width of an x-tube lane or a y-tube lane, thus defining free space between each tube and an adjacent tube support bar, and

wherein the tube support stakes support the tubes in the seats and bias the tubes against adjacent tube support bars.

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