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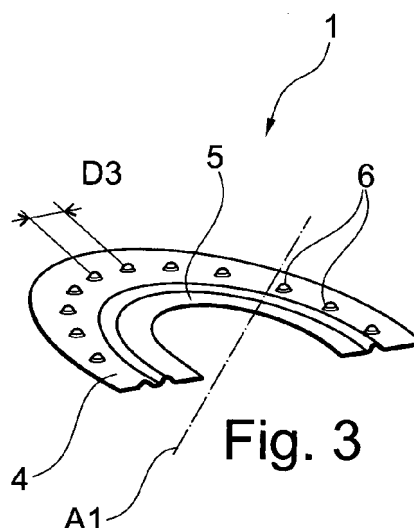
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(54) **Tube heat exchanger with optimized thermo-hydraulic characteristics**

(57) A tube heat exchanger (1) comprising at least a tube extending along a certain axial direction (A), each tube being provided with heat exchange fins (4) spaced apart from one another along said axial direction (A) and extending radially from said tube, each fin (4) being relief structured to form a groove/rib (5) arranged at a first distance from the tube and dimples (6) arranged in at least one line at a second distance from said tube, said second distance being greater than said first distance.



Description

Field of the invention

[0001] The invention relates to a tube heat exchanger comprising at least a tube extending along a certain axial direction, each tube being provided with heat exchange fins spaced apart from one another along the axial direction and extending radially from the tube, each fin being relief structured to form a groove/rib arranged at a first distance from the tube.

[0002] More specifically, the invention applies to a tube heat exchanger employing air as secondary exchange fluid such as air cooled heat exchangers used for the cooling or condensing of fluids in the oil and gas, power, petrochemical industries.

Background of the invention

[0003] Generally speaking, such equipment comprises a main heat exchanger provided with a bundle of finned tubes in which the fluid to be cooled or condensed circulates. These heat exchangers are generally equipped with 50 to 300 finned tubes and have as geometrical characteristics a length of 8 to 18 m and width of 0.3 to 5 m. These heat exchangers are supported by a steel structure. The cooling or condensing of the internal fluid is ensured by a forced circulation of ambient air crossing the external fins. The air circulation is generally ensured by fans that are located either below (forced draft) or above (induced draft) the finned tube of the heat exchanger. In order to optimize the cooling, the internal fluid circulation can be divided into passes, the heat exchanger comprising generally between three to eight rows of tubes.

[0004] The finned tubes consist of bare tubes or inner grooved tubes, having a diameter between 15 and 55 mm, generally composed of steel or steel alloy with aluminum fins on the outside of the tube. The selection of the bare tube material is a function of the internal fluid in respect to corrosion and safety issues.

[0005] The aluminum fins around for example the bare tubes have the advantage of increasing the external heat exchange surface by a factor between 15 and 25 compared to the bare tube external surface. This surface increase allows the increase of the heat transfer but generates pressure losses that are overcome by performing fan system. Aluminum fins can be realized through different manufacturing processes. In most of the known configurations, the fin profile along the tube is helicoidal. Moreover, the fins are independent from one tube to the other, each tube being therefore equipped with its own fin that is spirally wound around it.

[0006] In general, the air is blown on the outside of the finned tubes at a face velocity between 1 and 4 m/s. At such velocities and for the geometric configurations considered (particularly air passage sections, space between two fins or two consecutive tubes), the air flow

regime is overall laminar with some local turbulences, and characterized by relatively low heat exchange coefficients with the external fins.

[0007] The areas of high heat exchange coefficients are the leading edge of the fins and the tube to fins junctions in the upstream zone. Thus, due to the structure of the flow and the heat exchanger, the downstream areas of the tubes located behind the tubes in the flow direction show very poor heat transfer capacities. Said downstream areas, known as recirculation zones of the heat exchanger, are characterized by a recirculation of the air, which generates pressure drops and which does not enable a good cooling of the fins.

[0008] Some tube heat exchangers are provided with serrated fin with partial cutting performed along the fin periphery and enabling to locally increase the heat transfer through local turbulences created in the air flow. The Patent documents EP 0 854 344 and US 2010/0 282 456 disclose such serrated fins in which the cut parts are bent to allow higher heat transfer rate and guidance of the air flow. However this fin design shows a very poor resistance to fouling phenomena.

[0009] The Patent document KR 2010/0 102 937, discloses a tube heat exchanger with fin provided with holes formed on the downstream side of the fins to minimize the flow separation and increase the heat transfer coefficient. Nevertheless, this fin design does not solve the issues related to the low heat transfer that occurs in the downstream area of the finned tubes due to recirculation. In addition, the effective exchange surface area for transferring heat is decreased because of the holes.

[0010] Patent document US 7,743,821 discloses a tube heat exchanger with fin having on its surface a relief with dimples or grooves formed by mechanical deformation of the fins. Such dimples or grooves make it possible to increase the heat exchange between the air and the fin thanks to the creation of turbulences while increasing the pressure drop.

[0011] Patent document FR 2 940 422 discloses a tube heat exchanger with fin provided with grooves having different dimensions that progressively decrease on moving radially away from the tube so as to form a guide for a fluid around the tube.

[0012] Even though the fin patterns of the two previous patent documents improve the heat transfer, improved performances are still targeted.

Summary of the invention

[0013] An object of the invention is to provide a tube heat exchanger with optimized thermo-hydraulic characteristics enabling to reach an increase in heat exchanges between the air and the fluid circulating in the tube, without deteriorating the pressure drop and with good resistance to fouling phenomena.

[0014] To this end, the invention provides a tube heat exchanger comprising at least one tube extending along a certain axial direction, each tube being provided with

heat exchange fins spaced apart from one another along the axial direction and extending radially from the tube, each fin being relief structured to form a groove/rib arranged at a first distance from the tube, **characterized in that** each fin further comprises dimples arranged in at least one line at a second distance from the tube, the second distance being greater than the first distance.

[0015] The main advantage of such a design is that the dimples placed on the outside of the groove/rib create local turbulences in the air flow, that, by guidance of the air flow and in particular in the downstream area of the finned tube to prevent air recirculation, contribute to the heat transfer increase coefficient with reasonable pressure losses increase.

[0016] The tube heat exchanger of the invention may have the following features :

- the groove/rib has a depth along the axial direction greater than the depth of the dimples ;
- the groove/rib has a depth between 0.6 and 1.6 mm and preferably between 0.8 and 1.4 mm, and the dimples has a depth between 0.4 and 1.4 mm and preferably between 0.6 and 1.2 mm;
- the fins have a disc shape and are each provided with an annular groove/rib and an annular line of dimples ;
- the fins have a helicoidal shape and are provided with a helicoidal groove/rib and a helicoidal line of dimples ;
- the dimples have a shape chosen in the group comprising at least hemispherical, pyramidal, truncated shapes ;
- in a certain axial plane, the width of the groove/rib is between 1.2 and 3.2 mm, the width of the dimples is between 1.2 and 2.4 mm and the pitch between the middles of two adjacent dimples is between 4 and 10 mm and preferably between 5 and 8 mm ;
- in a certain axial plane, the distance between the tube and the groove/rib is between 3 and 7 mm and preferably between 4 mm and 6 mm, and the distance between the tube and the dimples is between 8.5 and 12.5 mm and preferably between 9.5 mm and 11.5 mm ;
- the groove/rib and the dimples are arranged on both sides of said fin.

Brief presentation of the drawings

[0017] The present invention will be better understood and other advantages will become apparent upon reading the following detailed description by way of non-limiting examples and illustrated by the accompanying drawings in which :

- figure 1 is a schematic side view of a heat exchanger according to the invention ;
- figure 2 is a perspective view of a tube of the heat exchanger of figure 1, provided with fins according

to the invention ;

- figure 3 is a partial perspective view of a single fin according to the invention of the heat exchanger of figure 1, this fin called compound fin being provided with a groove and a line of dimples according to the invention ;
- figure 4 is a partial axial section view of the fin of figure 3 ;
- figures 5 and 6 schematically illustrate the velocity field of the air circulating between the tubes respectively for a heat exchanger of the prior art and for the heat exchanger of the invention ;
- figures 7 to 9 are graphs representative of the heat transfer coefficient as a function of the ventilation power, respectively for conventional plain fin versus compound fin, for grooved fin versus compound fin, and for non optimized compound fin versus optimized compound fin.

Description

[0018] In figure 1, the heat exchanger 1 according to the invention is represented comprising a bundle of tubes 2 of circular section with a diameter between 15 and 55 mm. The tubes 2 are arranged in several substantially parallel superimposed rows extending in an axial direction A and in which a fluid to be cooled circulates between an inlet B and an outlet C of the fluid, and around which circulates a flow of drafted ambient air drawn from the bottom upwards in the direction indicated by the arrows D, in a transversal manner to the tubes 2, by fans 3 positioned above the heat exchanger 1. A heat exchanger 1 generally comprises between three and eight rows of superimposed tubes 2 laid out in a staggered manner, six in the illustrated example. The tubes 2 may be composed of steel, for example stainless steel or carbon steel or a highly alloyed steel, such as Incoloy, the choice of the material of the tubes 2 being dependent on the transported fluid, which may be aggressive, and the operating conditions. The external fins 4 are generally made of aluminum, but can also be made of stainless steel, or any other heat conducting material. The fins 4 are attached to the bare tube 2 by any commonly known manufacturing process.

[0019] As shown on figure 2, each tube 2 is provided with external radial fins 4 substantially perpendicular to the tube 2 and substantially parallel to each other favoring heat exchange between the ambient air and the fluid, as well as guiding the flow of air towards the rear of the tubes 2, as will be described hereafter. The pitch between two fins 4 is usually between 2 and 3.5 mm and preferably between 2.3 and 3 mm. In the range of velocities concerned by the application (between 1 and 4 m/s), this distance allows for a maximal ratio between the heat transfer and the associated pressure losses on the air side. For better clarity, several fins 4 spaced apart from each other on a tube 2 are shown on figure 1. It is obvious that the fins 4 are arranged preferably along the whole

length of all of the tubes 2. Moreover, the shape and the dimension of the external fins 4 may vary from one tube 2 to the next tube 2. The configurations of tube 2 with external fins 4 are not necessarily uniform within a bundle of tubes 2, particularly the diameters of the tubes 2 can vary. In the example shown, the fin 4 is helicoidally wound around the tube 2. The fins may also have disc shapes, the discs being independent and arranged parallel to each other. In both case, viewed in the axial direction A, the fins 4 have a height between 8 and 20 mm and preferably between 12 and 18 mm.

[0020] As shown on figure 3, the fin 4 according to the invention is relief structured to form a groove/rib 5 and a line of dimples 6. The groove/rib 5 and the line of dimples 6 are concentric and radially spaced apart from each other with the line of dimples 6 surrounding the groove/rib 5. The groove/rib 5 and the line of dimples 6 are manufactured by mechanical deformation of the fins 4.

[0021] The groove and the rib of the groove/rib 5 are corresponding to each other, the groove being visible on one side of the fin 4, the rib being visible on the other side of the fin 4. As shown on figure 4, the groove and the rib of the groove/rib 5 have a depth, along the axial direction A, between 0.6 and 1.6 mm and preferably between 0.8 and 1.4 mm. In an axial plane P, the distance D1 between the tube 2 and the groove/rib 5 is between 3 and 7 mm and preferably between 4 mm and 6 mm. In the same axial plane P, the width of the groove/rib 5 is between 1.2 and 3.2 mm. The groove/rib 5 preferably has, in the axial plane P, a round shape.

[0022] As shown on figure 4, the dimples 6 are aligned to each other at a distance D2 from the tube 2 between 8.5 and 12.5 mm and preferably between 9.5 mm and 11.5 mm. Distances D1 and D2 are measured from the outside diameter of the tube 2 to the middle of the groove/dimple 6. The dimples 6 can be equally spaced along the line with a pitch D3 between of two adjacent dimples 6 between 4 and 10 mm and preferably between 5 and 8 mm. Each dimple 6 can have a hemispherical, a pyramidal, a truncated shape or any similar suitable smooth shape. The dimples 6 have a depth P2 between 0.4 and 1.4 mm and preferably between 0.6 and 1.2 mm. The width L2 of each dimple 6 is between 1.2 and 2.4 mm. As shown on figure 3, the pitch D3 between two adjacent dimples 6 is between 4 and 10 mm and preferably between 5 and 8 mm. In the example shown, the dimples 6 have the same orientation than the groove/rib 5. It is also possible to provide dimples 6 following an opposite orientation or have dimples 6 located on both sides of the fin 4 and following two opposed orientations.

[0023] When the fins 4 have disk shape, the groove/rib 5 and the line of dimples 6 are annular. When the fins are helicoidally wound, the groove/rib 5 and the line of dimples 6 are helicoidal. The distance D1 between the tube 2 and the groove/rib 5 and the distance D2 between the dimples 6 and the tube are preferably constant. For simplicity of manufacture, each tube 2 has fins 4 of the same configuration over its whole length. But tubes 2

may also be provided with different configurations of fins 4.

[0024] This fin 4 design allows a subsequent increase of the global heat transfer and is associated with reasonable increase of the air side pressure loss. Indeed, the groove/rib 5 close to the tube 2, allows for guidance of the air flow and in particular in the downstream area of the finned tube 2 which is known to be inefficient. The depth P1 of the groove/rib 5 is optimized to get the maximum effect of the air flow guidance. Such guidance effect is visible on figures 5 and 6 on which the velocity fields in the plane located between two adjacent fins 4, 40 is illustrated. These figures clearly show the modifications on the air flow due to the new design between conventional plain fins 40 (figure 5) compared to a compound fin 4 according to the invention (figure 6), in particular the reduction of the recirculation area (non effective for heat transfer) behind the tubes 2 (compared to the tubes 20 of the conventional plain fin 40) and the local increase of the air velocity (acceleration) on the fins 4. The groove/rib 5 is judiciously located in such a manner that it still allows the development of the horseshoe vortex structure that naturally develops at the fin 4/tube 2 junction and account for high heat transfer coefficients.

[0025] The dimples 6 placed on the outside of the groove/rib 5 create local turbulences in the air flow, which contribute to the heat transfer increase coefficient with reasonable pressure losses increase. If there are only grooves 5, the heat exchange is mainly improve in the downstream area of the tubes 2. If there are only dimples 6, the heat exchange is improved all around the fins 4 except in the downstream of the tubes 2. That is why the combination of the groove 5 and the dimples 6 is efficient because the heat exchange is improved all around the tubes 2 thanks to the guidance of the air done with the groove/rib 5.

[0026] The previously detailed dimensions have been found to be optimal for the application concerned by the invention. The depth P2 of the dimples 6 is optimized to increase the heat transfer without important increase of the pressure losses on the air side. Such fin 4 design is optimized in regards to different phenomenon impacting the air flow topology such as the creation of local turbulences and air guidance. To this regards, the dimples 6 depth P2, smaller than the groove/rib 5 depth P1, allows the creation of local horseshoe vortices accounting for high heat transfer coefficients in the upstream part of the tube 4. If the pitch D3 between two dimples 6 is too small, the dimples 6 have a negative impact on each others. Indeed, behind each dimple 6, a small recirculation area is created. If the dimples 6 are too close to each others, the recirculation areas will combine together and obstruct the air flow. If the distance between two dimples 6 is too important the local contribution of each dimple 6 will not sufficiently increase the heat transfer.

[0027] The graph of figure 7 shows the heat transfer coefficients reached with a compound fin 4 according to the invention and a conventional plain fin, as a function

of the ventilation power used to push or pull the air flow through the tube heat exchanger 1. The heat transfer coefficient is clearly increased by the new fin 4 design. This new fin 4 design also increase the pressure drop on the air side. As the fan power consumption is directly proportional to the air flow multiplied by the air pressure losses, the air side pressure drop increase results in a higher power consumption of the fan system if the comparison is done for the same air flow rate. The new fin 4 design can also be performing at lower air flow rates and compared to conventional fin designs at the same fan power consumption. In that case, the heat transfer coefficient between the fin 4 and the air can be increased by up to 30% for the same power consumption of the fan system as shown in figure 7.

[0028] The graph of figure 8 shows the heat transfer coefficients reached with a compound fin 4 according to the invention and a fin equipped with two grooves and no dimple, as a function of the ventilation power used to push or pull the air flow through the tube heat exchanger 1. The grooved fin has similar dimensions as the compound fin 4. The groove of the grooved fin close to the tube is the same as the one of the compound fin 4 (same position, depth and width), and the other groove of the grooved fin and close to the fin tip has the same position, depth and width than the dimples 6 of the compound fin 4. The heat transfer coefficient is clearly increased by the new fin 4 design due to the dimple 6 contribution for optimized geometrical range of parameters.

[0029] The graph of figure 9 shows the heat transfer coefficients reached with a compound fin 4 having dimensions as detailed previously and a compound fin 4 having dimensional parameters out of the range described. Optimal heat transfer coefficient is clearly reached thanks to the optimized dimensions.

[0030] The result of the performance increase of the Air Cooled Heat Exchanger can be turned in two different ways ; either a global increase of the system performance to which the tube heat exchanger 1 is connected to, or a reduction of the tube heat exchanger 1 size. The latter will result in less material used for the same service as for conventional design.

Claims

1. Tube heat exchanger (1) comprising at least one tube (2) extending along a certain axial direction (A), each tube (2) being provided with heat exchange fins (4) spaced apart from one another along said axial direction (A) and extending radially from said tube (2), each fin (4) being relief structured to form a groove/rib (5) arranged at a first distance (D1) from said tube (2), **characterized in that** each fin (4) further comprises dimples (6) arranged in at least one line at a second distance (D2) from said tube (2), said second distance (D2) being greater than said first distance (D1).

2. Tube heat exchanger (1) according to claim 1, wherein said groove/rib (5) has a depth (P1) along said axial direction (A) greater than the depth (P2) of said dimples (6).

3. Tube heat exchanger (1) according to claim 2, wherein said groove/rib (5) has a depth (P1) between 0.6 and 1.6 mm and preferably between 0.8 and 1.4 mm, and said dimples (6) has a depth (P2) between 0.4 and 1.4 mm and preferably between 0.6 and 1.2 mm.

4. Tube heat exchanger (1) according to claim 1, wherein said fins (4) have a disc shape and are each provided with an annular groove/rib (5) and an annular line of dimples (6).

5. Tube heat exchanger (1) according to claim 1, wherein said fins (4) have a helicoidal shape and are provided with a helicoidal groove/rib (5) and a helicoidal line of dimples (6).

6. Tube heat exchanger (1) according to claim 1, wherein said dimples (6) have a shape chosen in the group comprising at least hemispherical, pyramidal, truncated shapes.

7. Tube heat exchanger (1) according to claim 1, wherein in a certain axial plane (P), the width (L1) of said groove/rib (5) is between 1.2 and 3.2 mm, the width (L2) of said dimples (6) is between 1.2 and 2.4 mm and the pitch (D3) between the middles of two adjacent dimples (6) is between 4 and 10 mm and preferably between 5 and 8 mm.

8. Tube heat exchanger (1) according to claim 1, wherein in a certain axial plane (P), the distance (D1) between said tube (2) and said groove/rib (5) is between 3 and 7 mm and preferably between 4 mm and 6 mm, and the distance (D2) between said tube (2) and said dimples (6) is between 8.5 and 12.5 mm and preferably between 9.5 mm and 11.5 mm.

9. Tube heat exchanger (1) according to claim 1, wherein said groove/rib (5) and said dimples (6) are arranged on both sides of said fin (4).

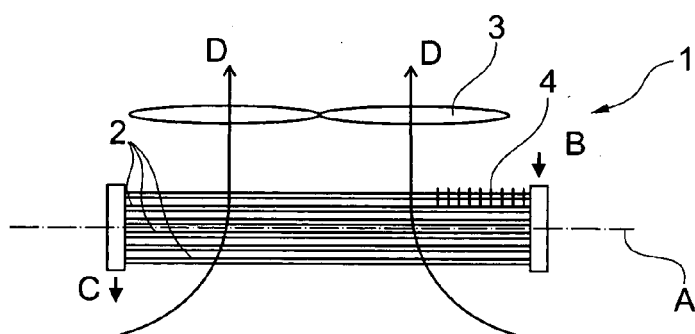


Fig. 1

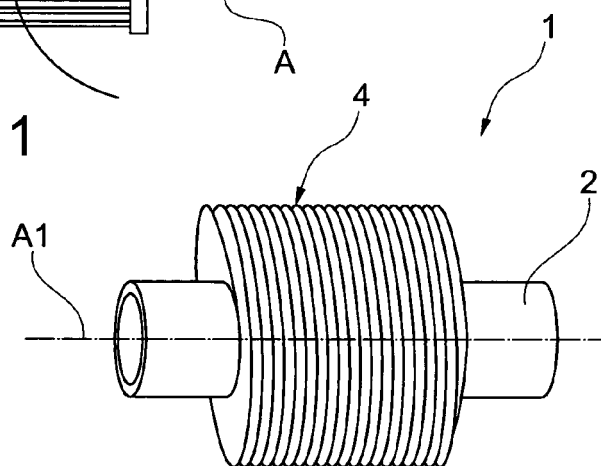


Fig. 2

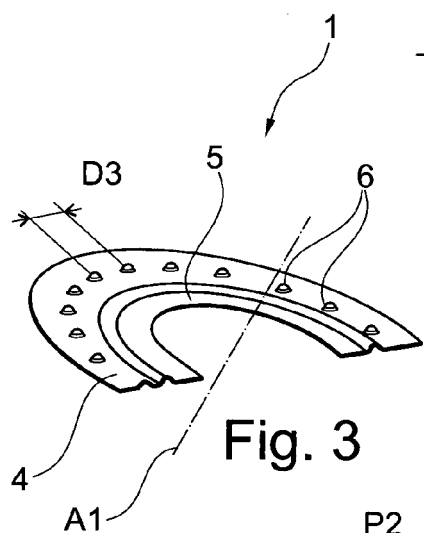


Fig. 3

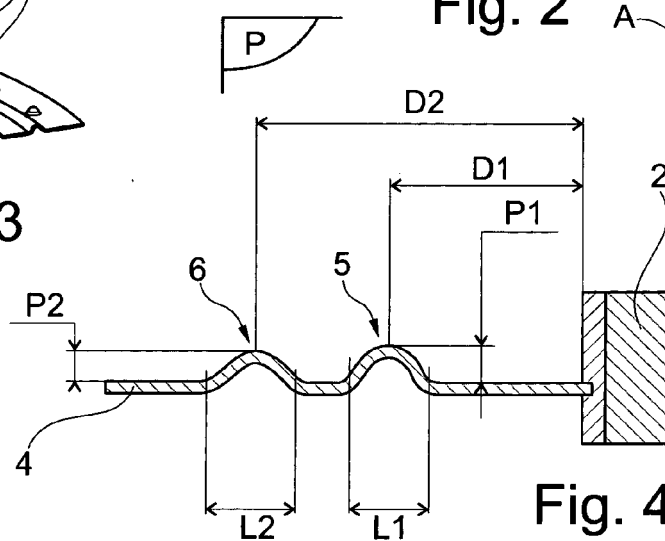


Fig. 4

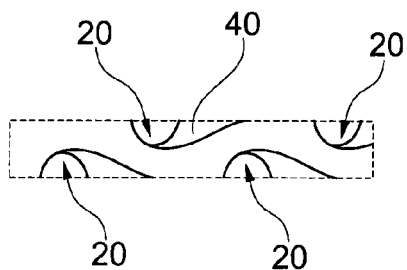


Fig. 5

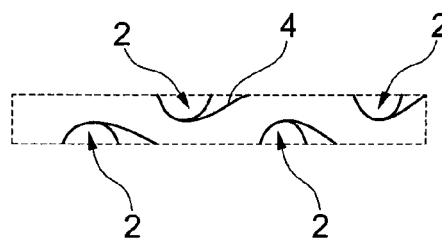


Fig. 6

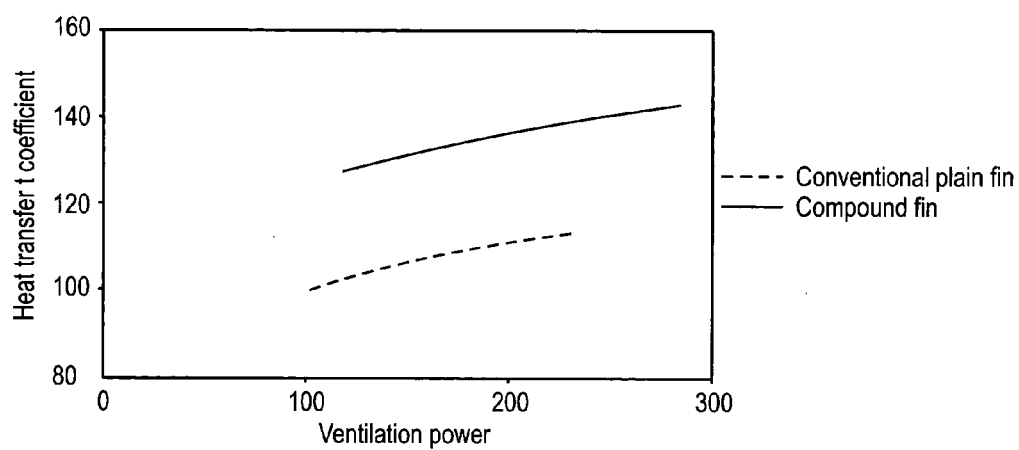


Fig. 7

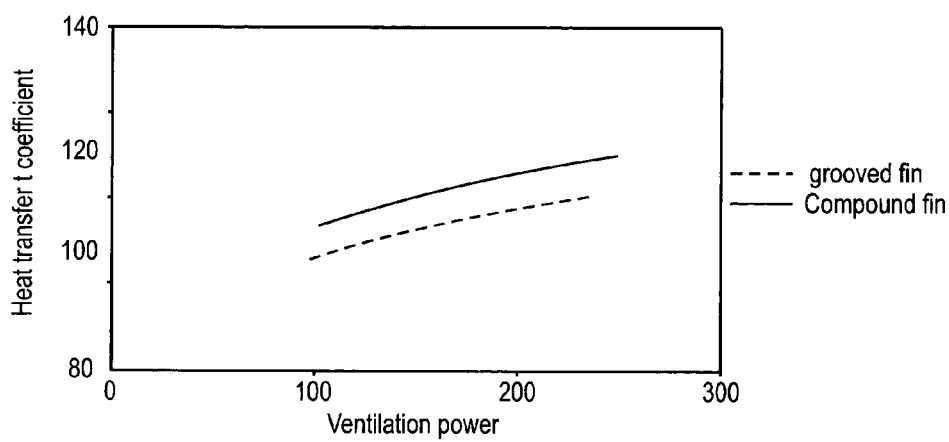


Fig. 8

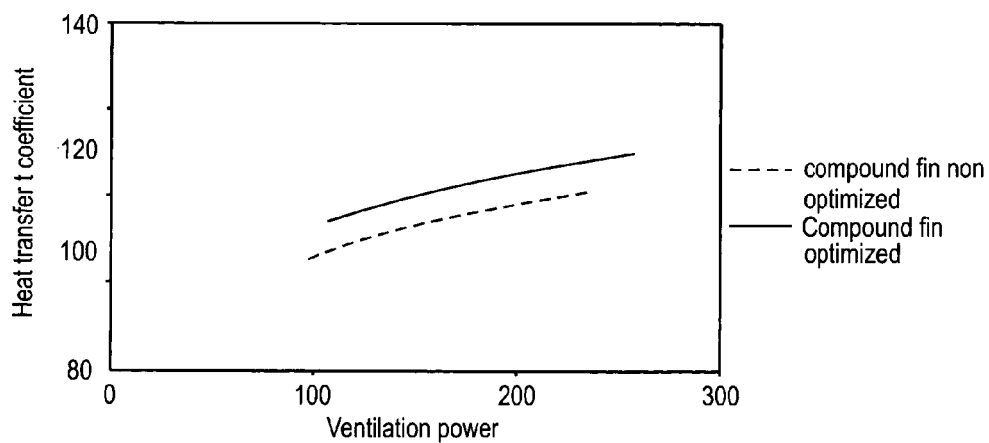


Fig. 9



EUROPEAN SEARCH REPORT

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 EP 13 16 1435

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The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 10 July 2013	Examiner Mendão, João
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**ANNEX TO THE EUROPEAN SEARCH REPORT
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