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(54) **IMPROVED HEAT EXCHANGER**  
**VERBESSERTER WÄRMETAUSCHER**  
**Échangeur thermique amélioré**

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## Description

### Technical Field

[0001] The present invention relates to an improved heat exchanger according to the preamble of claim 1. EP 1 533 586 discloses such a heat exchanger.

[0002] The invention further relates to production of such improved heat exchangers according to claim 5 and the use of such heat exchangers according to claims 6 and 7.

### Background Art

[0003] There exists already a broad range of heat exchangers, most of them using metal fins. The heat exchanging capacity of these fins is optimised in such a way that further improvements are expected to be minimal, but even minimal improvements would be highly appreciated.

[0004] A disadvantage of finned heat exchangers is their dependency on the flow direction of the fluid passing the fins, therefore it was proposed in the art to use open cell porous media instead of finned structures as open cell porous media in heat exchangers. Such open cell porous media heat exchangers are described in e.g. FR2738625, WO2003/100339 and WO2006/059908. However, still further improvements of the heat exchanging capacity of heat exchangers are desired.

### Disclosure of Invention

[0005] The object of the present invention is to provide an improved heat exchanger with which a more efficient heat exchange can be realised.

[0006] An aspect of the claimed invention provides a heat exchanger comprising a plurality of flat heat-conducting conduits for passage of a first medium and open cell porous medium layers, for passage of a second medium. Preferably, the heat-conducting conduits are flat tubes which are provided with internal fin structures. The heat-conducting conduits are joined together by said open cell porous medium layers thereby forming a heat exchanging stack. The open cell porous medium layers have a volume porosity ranging between 90 to 98%, and are further defined by a wire thickness ranging from 100 $\mu$ m to 600 $\mu$ m.

[0007] The heat exchangers as known from WO2003/100339, have a thermally conducting porous structure, preferably metal foam, wherein the metal foam has a volume porosity greater than or equal to 90%. However, the wire thickness of the porous structure lies preferably between 15 and 90 $\mu$ m. These heat exchangers are described particularly suitable for exposure to relatively low flow speeds up to 20 m/s and whereby the flow rate of the second medium through the heat exchanger is also up to 20 m/s.

[0008] However, extended experiments proved that

the wire thickness between 100 $\mu$ m and 600 $\mu$ m increase the heat exchange capacity of the heat exchanger substantially, amongst others for low flow speeds of the second medium, being flow speeds of 2,5 to 30 m/s. There is more transferred heat of the heat exchanger compared to heat transfer of a comparable finned heat exchanger, for comparable pressure losses. It was surprisingly noticed that wire thickness combined with the porosity of the open cell porous medium are the dominant characteristic in heat exchanging capacity combined with the inevitable pressure drop due to flow through the open cell porous medium.

[0009] The heat exchangers as known from WO2006/059908, have a thermally conducting porous structure, preferably metal foam, wherein the wire thickness of the porous structure lies between 15 and 500 $\mu$ m, but the volume porosity of the porous structure lies between 50 and 90%. These heat exchangers are described particularly suitable for exposure to relatively high flow speeds of the second medium from approximately 30 m/s to approximately 310 m/s. The same experiments as described above, revealed that for use of wire thicknesses between 100 $\mu$ m and 600 $\mu$ m, a volume porosity of the heat exchange enlarging structure ranging between 90 and 98% provides a far better heat transfer than volume porosities ranging between 50 and 90%, also for high flow speeds.

[0010] The volume porosity of the heat exchange enlarging structure ranging between 90 and 98%, means the volume porosity can be 90,1%, 90,2%, 90,3%, 90,4%, 90,5%, 90,6%, 90,7%, 90,8%, 90,9%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 97,9% or any porosity in between the described percentages. In a preferred aspect, the volume porosity of the thermally conductive open cell porous medium is ranging between 91,5% and 96,5%, more preferably between 92% and 96%, most preferably between 92,5% and 95,5%. This porosity provides an even more improved direct and immediate heat exchange of the heat conducting conduits. The porosity of the open cell porous medium can be tuned depending on the medium used as known by the person skilled in the art, e.g. in the case of an open cell metal foam reference is made to EP 1604756.

[0011] Preferably, the open cell porous medium layers have a thickness between 2 and 20 mm, which means that also the space between two succeeding heat conducting conduits is ranging between 2 and 20 mm.

[0012] Preferably, the open cell porous media are thermally conductive open cell porous media. This can be a carbon or graphite foam; a carbon or graphite containing metal foam; metal foam as described e.g. in EP1227908; a woven or knitted 3D textile in metal, graphite or carbon; a 3D wire structure made of metal, graphite or carbon, such as e.g. the Kagome structure or similar 3D-structures as described in WO2005/04483.

[0013] In a preferred aspect, the open cell porous medium is made of a heat conducting metal, preferably of nickel, copper, magnesium, aluminium or alloys thereof.

**[0014]** Preferably, the open cell porous medium is open cell metal foam with pores per inch (ppi's) ranging between 5 and 40 ppi. More preferably, the ppi's are ranging between 10 and 30 ppi, even more preferably ranging between 15 and 25ppi. Most preferably, the open cell metal foam is 20 ppi.

**[0015]** In a further preferred aspect, the open cell metal foam is made of aluminium or an aluminium alloy. In another preferred aspect, the metal foam is made of copper or a copper alloy. In a more preferred aspect the metal foam is made of graphite or comprises graphite.

**[0016]** In a further preferred aspect, the open cell porous media are thermally attached to the heat conducting conduits by sintering, or via a thermally conductive means. The thermally conductive means can be formed by thermally conductive glue, thermally conductive epoxy-layer, (soldering) paste, thermally conductive metal layer, e.g. brazing foil, and so on. Alternatively, the open cell porous media can be attached by means of a co-casting method. Such method is described in DE19650613, second method. In a further alternative, the heat exchanging stack is produced integrally by casting the open cell porous media together with the heat conducting tubes or by a method of rapid manufacturing. Every one of these attachment methods, reduce the thermal contact resistance and thus improves the thermal conductivity between the open cell porous media and the heat conducting conduits.

**[0017]** Another aspect of the present invention provides a method to produce the heat exchanger according to the present invention.

**[0018]** This method comprises the following steps: first a plurality of heat-conducting conduits and a plurality of layers of open cell porous media are provided. Thereafter the open cell porous media are thermally attached to the heat conducting conduits so as to obtain a stack of alternating conduits and open cell porous media. Then two collecting tanks are provided. These collecting tanks are then joined to both ends of the heat exchanging stack. Preferably, the collecting tanks are also thermally attached to the heat exchanging stack. In alternative method the heat conducting conduits and the open cell porous media layers are thermally attached, e.g. by brazing, in 1 step. In a more preferred method, the collecting tanks are also attached in this 1 step.

**[0019]** Another aspect of the present invention provides a use of the heat exchanger according to the present invention in heat exchange applications, such as e.g. boilers, radiators, air-conditioning, ...

**[0020]** Another aspect of the present invention provides a use of the heat exchanger as obtained by the method for producing a heat exchanger according to the present invention for heat exchange applications, e.g. boilers, radiators, air-conditioning, ...

#### Definitions

**[0021]** The term "wire thickness  $Wt$ " is to be understood

as the equivalent diameter of the wires making up the open cell porous media. The equivalent diameter of a particular wire is to be understood as the diameter of an imaginary wire having a circular radial cross section, which cross section having a surface area identical to the average of the surface areas of cross sections of the particular wire. In case the open cell porous medium is open cell foam, the wire thickness is the equivalent diameter of the strut evaluated in the middle of such a strut. In the majority of cases, such struts have an equilateral triangle shape.

**[0022]** The term "second medium" is to be understood in the light of this invention as meaning a gaseous substance. In the light of this invention "first medium" can be gaseous, but also liquid substances.

**[0023]** The term "pore size" is to be understood in the light of this invention as an equivalent diameter of the pores making up the open cell porous media. The equivalent diameter of a particular pore is to be understood as the diameter of an imaginary sphere having a spherical cross section, which sphere having a volume area identical to the volume area of the pore or unit cell of the open cell porous medium.

**[0024]** The term "open cell metal foam" is to be understood as metal foam with interconnecting porosity. Such metal foams are e.g. described in EP1227908.

#### **Brief Description of Drawings**

**[0025]** Example embodiments of the invention are described hereinafter with reference to the accompanying drawings in which

Figure 1 shows drawings of an automotive heat exchanger. Figure 1a is a prior art conventional heat exchanger with conventional louvered fins.

Figure 1b shows a comparable foamed heat exchanger according to the present invention.

Figure 2 is a graph showing the results of heat exchanging capacity test performed on the heat exchangers of figure 1.

Figure 3 is a graph showing the heat transfer capacity of an open cell porous medium, more in particular open cell metal foam, as a function of the pore size and as a function of the wire thickness of the foam struts.

#### **Mode(s) for Carrying Out the Invention**

**[0026]** Examples of a heat exchanger according to the invention will now be described with reference to Figures 1 to 3.

**[0027]** Figures 1a and 1b show flat heat exchangers with one entry and one exit of fluid to be heat exchanged, i.e. the first medium. The heat exchanger of figure 1a is a conventional louvered finned heat exchanger; the heat exchanger of figure 1b is the same conventional finned heat exchanger wherein the louvered fins are replaced

by open cell aluminium foam of 20 ppi, with struts with wire thickness ranging between 300 and 400  $\mu\text{m}$ .

[0028] The heat exchanger of figure 1b was produced by following subsequent steps. First a plurality of heat-conducting conduits and layers of open cell 20 ppi aluminium foam, with struts with wire thickness ranging between 300 and 400  $\mu\text{m}$ , were provided. This metal foam has a volume porosity of 94,5%. Thereafter the open cell metal foam layers were thermally attached, via brazing, to the heat conducting conduits so as to obtain a stack of alternating conduits and metal foam. Then two collecting tanks are provided. These collecting tanks are then joined to both ends of the heat exchanging stack. Preferably, the collecting tanks are also thermally attached to the heat exchanging stack.

[0029] The heat exchangers of figure 1a and 1b were tested in a wind tunnel with cooling air speeds ranging between 4 and 30 m/s at an angle of 90° (frontal) and hot water at 80°C at a speed of 0,75m/s flowing through the heat conducting pipes of both heat exchangers.

[0030] The measured absolute heat exchanging power (UA) of the metal foam flat heat exchanger of figure 1b proved to be better performing for flow speeds ( $v_A$ ) of the cooling medium up to 25 m/s compared to the conventional finned flat heat exchanger of figure 1a, as shown in figure 2 wherein a ( $\diamond$ ) are the results of the heat exchanger as depicted in fig. 1a and b ( $\blacktriangle$ ) are the results of the heat exchanger as depicted in fig. 1b. This result is subject to the pressure build up over the fins and over the open cell metal foam limiting the better performance of the metal foam to relatively low flow speeds ranging between 4 and 20 m/s. Below 20m/s the flow through the louvered fins is initially duct flow, meaning the louvers are bypassed. This blocks heat transfer in louvered fins up to approximately 12m/s (depends on the fin geometry). From approximately 12 to 25 m/s (again depending on fin geometry), the flow transits from laminar to turbulent and thus heat transfer with fins increases. Above 25 m/s, the flow through the fins is fully turbulent with substantial heat transfer as a result. Due to its structure, flow through foam is almost directly turbulent (above approximately 3m/s), having immediately a high heat transfer rate.

[0031] Figure 3 is a graph showing the heat transfer capacity of an open cell porous medium, more in particular open cell metal foam, as a function of the pore size in pores per inch (ppi's) and as a function of the wire thickness of the foam struts. In this example, heat transfer was measured for 10,5 m/s of a cooling air flow as a second medium flowing through the open cell metal foam. From this graph we learn that there is an optimum in the heat transfer for a given wire thickness. Now pore size is a remaining degree of freedom which can be tuned according the application requirements, like pressure drop. The chosen pore size and wire diameter results in a porosity ranging between 90 to 98%.

[0032] An example of a heat exchanger according to the present invention is made of flat tubes, as conven-

tionally available in the automotive cooling field, in combination with a Kagome structure. The Kagome structure has a wire thickness of 250 $\mu\text{m}$  and the layers of Kagome structures in the heat exchanging stack are 15 mm. The Kagome structure has a porosity of 96,5%. Another example of a heat exchanger stack comprises flat tubes, with height of 0,8mm and width of 30mm, combined with 20 mm layers of 3D- octet truss structures in the heat exchanging stack. The 3D-octet truss has a wire thickness of 300 $\mu\text{m}$  and has porosity of 93%.

[0033] Another example of a heat exchanging stack comprises flat tubes with height of 10 mm and width of 40mm, combined with 10 mm thick layers of 3D spacer material, made of aluminium wires with a thickness of 600 $\mu\text{m}$ . The porosity of this 3D spacer material is 90,1 %.

[0034] Thus there has been described an improved heat exchanger. This heat exchanger comprises a stack of alternating heat conducting conduits for passage of a first medium, combined with open cell porous media which are interconnected in a material tight way. The volume porosity of the open cell porous media ranges between 90 and 98% and the wire thickness of the open cell porous media ranges from 100 to 600 $\mu\text{m}$ . The invention further relates to a method for producing such a heat exchanger and use of such a heat exchanger.

#### Claims

1. A heat exchanger comprising:

- a plurality of heat-conducting flat conduits for passage of a first medium, and open cell porous media for passage of a second medium;

- said heat-conducting conduits being joined together by said open cell porous media thereby forming a heat exchanging stack; **characterised by**

- said open cell porous media having a porosity ranging between 90 and 98%, and in that said open cell porous media has a wire thickness ranging from 100 $\mu\text{m}$  to 600 $\mu\text{m}$ .

2. A heat exchanger according to claim 1, wherein said open cell porous medium is open cell metal foam.

3. A heat exchanger according to claim 2, wherein said open cell foam is defined by pores per inch (ppi) ranging between 5 and 40 ppi.

4. A heat exchanger according to any of the claims 1 to 3, wherein said layers of open cell porous media in said stack have a thickness between 2 and 20 mm per layer.

5. Method of manufacturing a heat exchanger according to any of the claims 1 to 4, said method compris-

ing:

- providing a plurality of heat-conducting flat conduits for passage of a first medium, and
- providing open cell porous media for passage of a second medium;
- said open cell porous media having a porosity ranging between 90 and 98 and having a wire thickness ranging from 100 $\mu$ m to 600 $\mu$ m;
- joining together said heat-conducting conduits by said open cell porous media thereby forming a heat exchanging stack.

6. Use of the heat exchanger as described in any of the claims 1 to 4.
7. Use of the heat exchanger as obtained in the method of claim 5.

#### Patentansprüche

1. Wärmetauscher, umfassend:
- eine Vielzahl von wärmeleitenden flachen Rohren für den Durchgang eines ersten Mediums und von offenporigen Medien für den Durchgang eines zweiten Mediums,
  - wobei die wärmeleitenden Rohre durch die offenporigen Medien verbunden sind, wodurch ein Wärmetauschstapel gebildet wird,
- dadurch gekennzeichnet, dass**
- die offenporigen Medien einen Porenanteil zwischen 90 und 98 Prozent aufweisen und dass die offenporigen Medien eine Drahtdicke von 100  $\mu$ m bis 600  $\mu$ m aufweisen.
2. Wärmetauscher nach Anspruch 1, wobei es sich bei dem offenporigen Medium um offenporigen Metallschaum handelt.
3. Wärmetauscher nach Anspruch 2, wobei der offenporige Schaum durch Poren pro Inch (ppi) zwischen 5 und 40 ppi festgelegt ist.
4. Wärmetauscher nach einem der Ansprüche 1 bis 3, wobei die Schichten der offenporigen Medien in dem Stapel eine Dicke zwischen 2 und 20 mm pro Schicht aufweisen.
5. Verfahren zur Herstellung eines Wärmetauschers nach einem der Ansprüche 1 bis 4, wobei das Verfahren Folgendes umfasst:
- Bereitstellen einer Vielzahl von wärmeleitenden flachen Rohren für den Durchgang eines ersten Mediums und
  - Bereitstellen von offenporigen Medien für den

Durchgang eines zweiten Mediums,

- wobei die offenporigen Medien einen Porenanteil zwischen 90 und 98 aufweisen und eine Drahtdicke von 100  $\mu$ m bis 600  $\mu$ m aufweisen,
- Verbinden der wärmeleitenden Rohre durch die offenporigen Medien, wodurch ein Wärmetauschstapel gebildet wird.

6. Gebrauch des Wärmetauschers, wie er in einem der Ansprüche 1 bis 4 beschrieben ist.
7. Gebrauch des Wärmetauschers, wie er bei dem Verfahren nach Anspruch 5 gewonnen wird.

#### Revendications

1. Échangeur thermique comprenant :
- une pluralité de conduits plats de conduction thermique servant au passage d'un premier agent, et
  - un matériau poreux à cellules ouvertes servant au passage d'un second agent ;
  - lesdits conduits de conduction thermique étant raccordés les uns aux autres par le biais dudit matériau poreux à cellules ouvertes de façon à former ainsi un empilement d'échange thermique ;
- caractérisé en ce que**
- ledit matériau poreux à cellules ouvertes présente une porosité située dans la plage de 90 à 98 %, et
- en ce que** ledit matériau poreux à cellules ouvertes présente une épaisseur de fil située dans la plage de 100  $\mu$ m à 600  $\mu$ m.
2. Échangeur thermique selon la revendication 1, dans lequel ledit matériau poreux à cellules ouvertes est une mousse métallique à cellules ouvertes.
3. Échangeur thermique selon la revendication 2, dans lequel ladite mousse à cellules ouvertes est définie par un nombre de pores par pouce (ppi - pores per inch) situé entre 5 et 40 ppi.
4. Échangeur thermique selon l'une quelconque des revendications 1 à 3, dans lequel lesdites couches de matériau poreux à cellules ouvertes dans ledit empilement présentent une épaisseur comprise entre 2 et 20 mm par couche.
5. Procédé de fabrication d'un échangeur thermique selon l'une quelconque des revendications 1 à 4, ledit procédé comprenant :
- prévoir une pluralité de conduits plats de con-

duction thermique servant au passage d'un premier agent, et

- prévoir un matériau poreux à cellules ouvertes servant au passage d'un second agent ;

- ledit matériau poreux à cellules ouvertes présentant une porosité située dans la plage de 90 à 98 et présentant une épaisseur de fil située dans la plage de 100  $\mu\text{m}$  à 600  $\mu\text{m}$  ;

- raccorder lesdits conduits de conduction thermique les uns aux autres par le biais dudit matériau poreux à cellules ouvertes de façon à former ainsi un empilement d'échange thermique.

6. Utilisation de l'échangeur thermique tel que décrit dans l'une quelconque des revendications 1 à 4.

7. Utilisation de l'échangeur thermique tel qu'obtenu par le procédé de la revendication 5.

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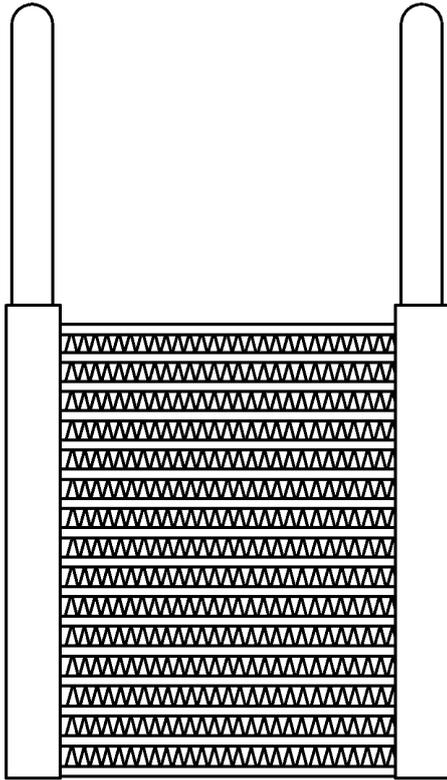


Fig. 1a

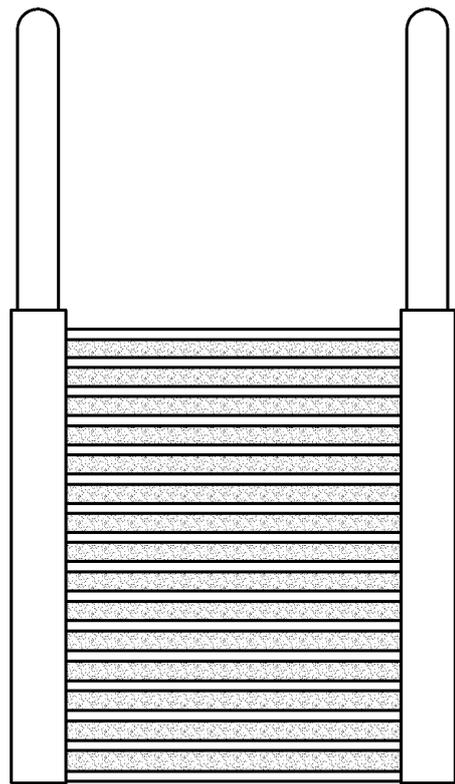


Fig. 1b

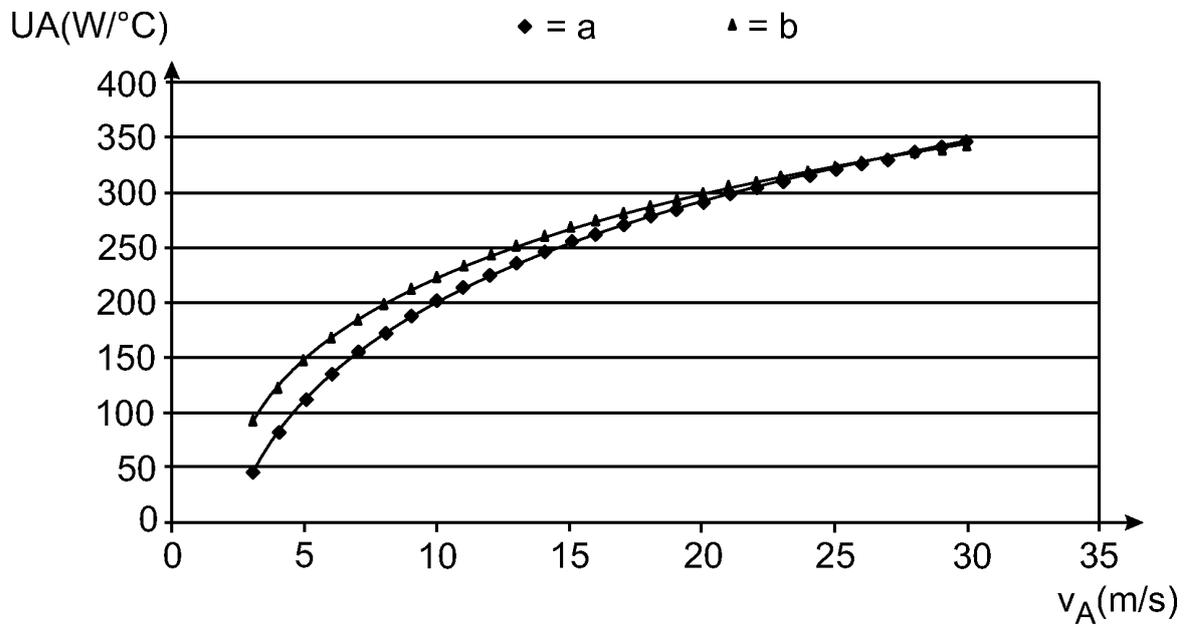


Fig. 2

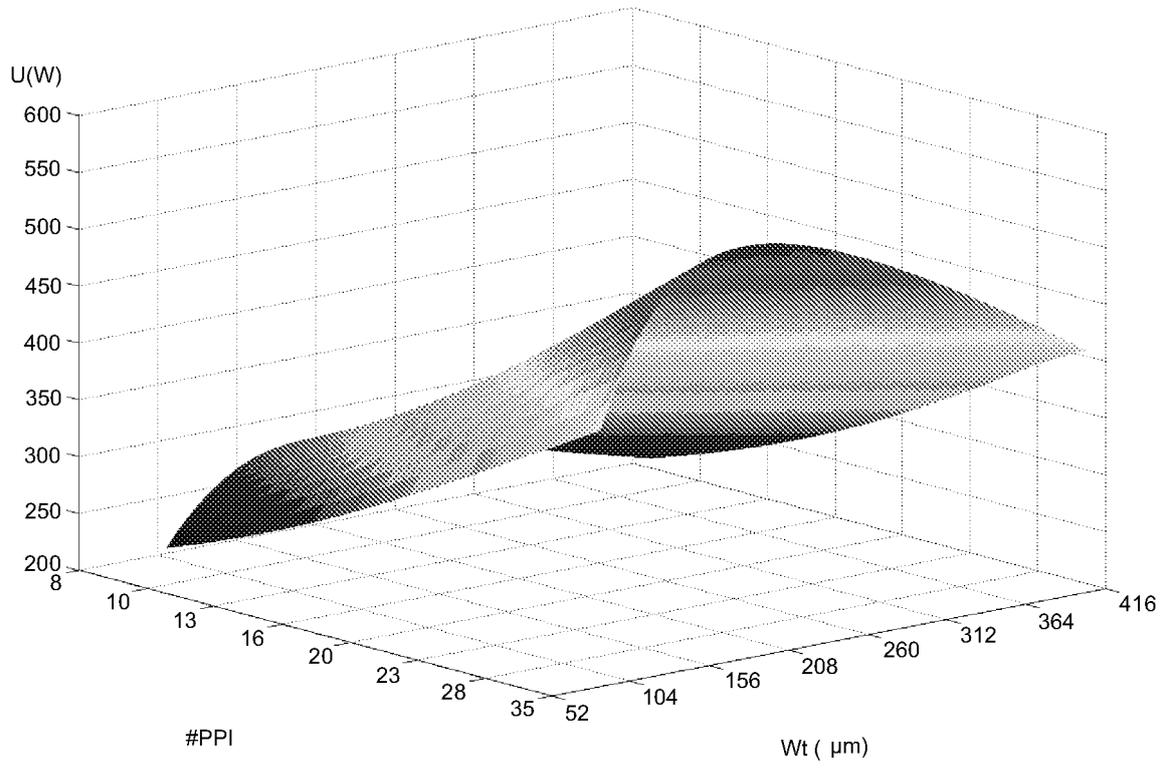


Fig. 3

**REFERENCES CITED IN THE DESCRIPTION**

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