March 14, 1967 H. F. MADDOCKS 3,308,879

HEAT EXCHANGERS

Filed June 10, 1954 4 Sheets-Sheet 1

Fig. 1.

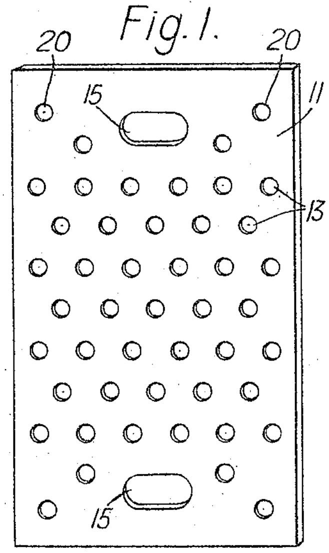


Fig. 2.

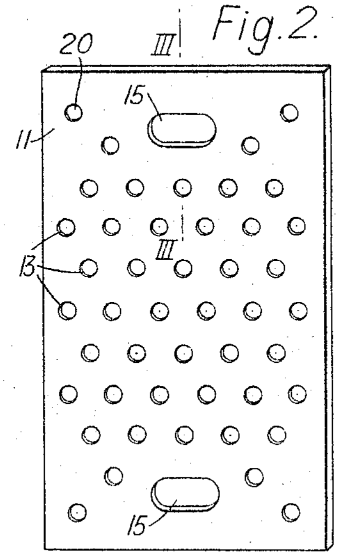


Fig. 3.

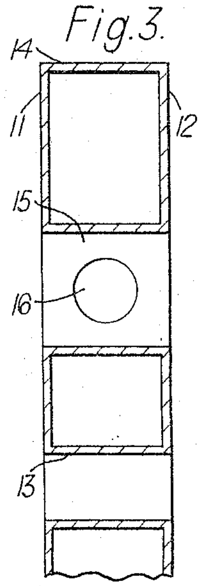
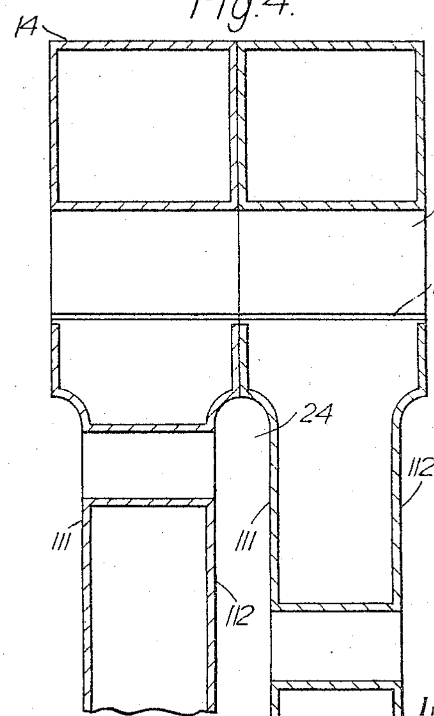


Fig. 4.



Inventor
Herbert F. Maddocks

By Watson, Cole, Grindle & Watson
Attorneys

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HEAT EXCHANGERS

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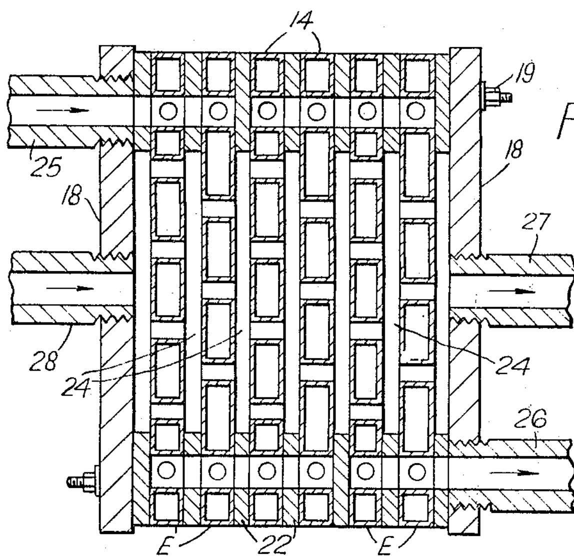


Fig.5.

Fig.6.

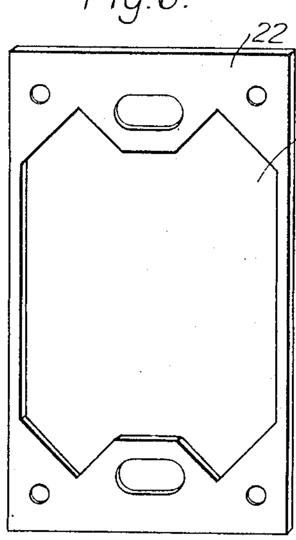
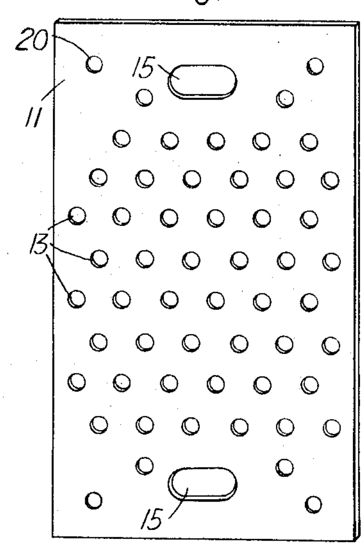


Fig.7.



Inventor
Herbert F. Maddocks
By Watson, Cole, Grindle & Watson
Attorneys

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HEAT EXCHANGERS

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Fig. 8.

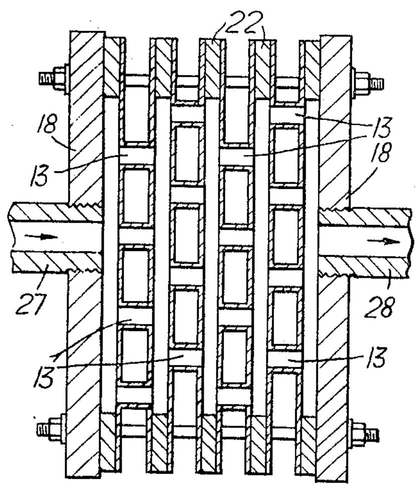


Fig. 9.

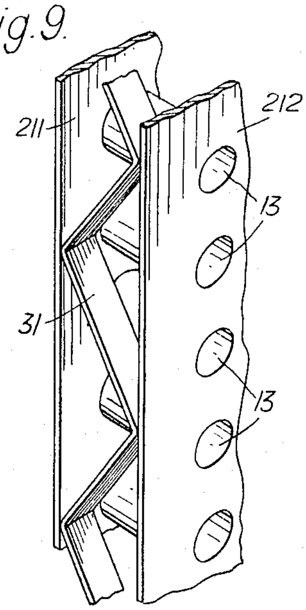


Fig. 14.

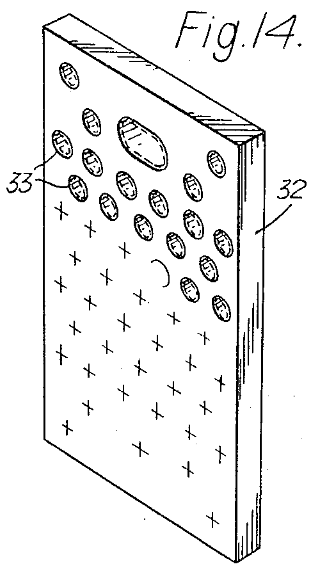
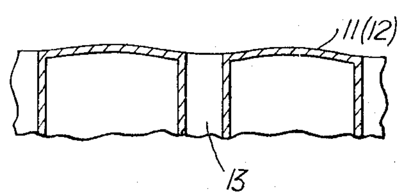


Fig. 10.



Inventor
Herbert F. Maddocks
By Watson, Cole, Grindle & Watson
Attorneys

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Fig. 11.

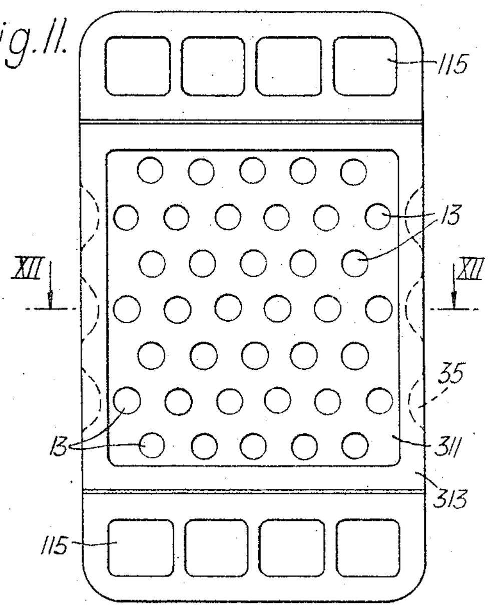


Fig. 12.

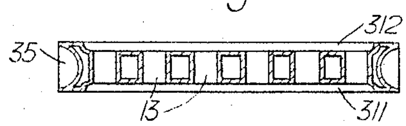
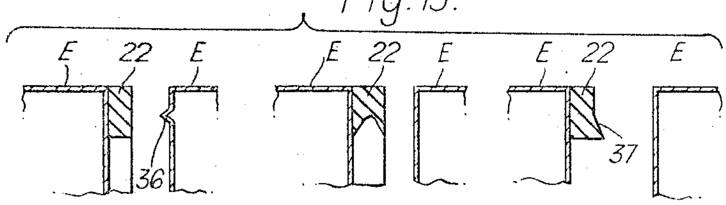


Fig. 13.



Inventor
Herbert F. Maddocks

By Watson, Cole, Grindle & Watson
Attorneys

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HEAT EXCHANGERS
Herbert Fernyhough Maddocks, 26 Garth Drive, Liverpool Road, Chester, England
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4 Claims. (Cl. 165—167)

The present invention relates to improvements in heat exchangers, which term is intended to include all types of apparatus for transferring heat energy between two fluids, which may be both gases or both liquids, or one of which may be a gas and the other a liquid, including radiators, boilers, evaporators, economisers, chemical reaction equipment, and the like.

More particularly the present invention is directed to the construction of a heat exchanger element adapted to be assembled with other similar elements to form a complete unit, and said unit may include means for admitting a first fluid to the unit and for providing for the collection of said fluid after it has passed through the unit, and also admission and withdrawal means for a second fluid.

In its simplest form the present invention may be used for transferring heat energy to or from a fluid to the surrounding air, this type of equipment being of the type generally referred to as radiators, for example for space heating by means of a heated fluid or for cooling a fluid by the circulation of air through the heat exchanger.

The primary object of the present invention is to provide a construction of heat exchanger element capable of permitting high rates of heat transfer to be obtained thereby permitting highly efficient heat exchangers of small dimensions to be produced.

The present invention comprises broadly a heat exchanger element of integral metal construction having very thin walls adapted to separate one fluid from the other and is arranged to provide a high measure of turbulence, so far as at least one of the fluids is concerned, so as to permit a high transfer ratio to be maintained under operating conditions, which factor coupled with the possibility of using very thin metallic walls separating the two fluids further provides for high heat exchange rates to be obtained.

More specifically the present invention provides a heat exchange element comprising opposed parallel walls and a plurality of integrally formed tubular elements extending between said walls and interconnecting them, said tubular elements being open on the two faces of said walls to provide passageways between the outer faces of the two walls, so that a first fluid is capable of being passed over the outer surfaces of said walls and through said tubular elements and a second fluid is adapted to be passed through the space between the two walls and around the tubular elements to provide for interchange of heat between the two fluids

The present invention further relates to a heat exchanger element comprising a substantially closed unitary casing of heat-conductive material comprising opposed walls and a plurality of integrally formed tubular elements extending between said walls, means being provided for admitting a first fluid to the inside of said casing and for causing a second fluid to pass over the outside of said casing

This casing may be a closed hollow casing having parallel walls the spacing between which is substantially less than the facial dimensions of said walls and having integrally formed tubes extending between said walls and opening on the outer sides of said casing.

The opposed walls are preferably smooth and flush on the outer faces of the opposed walls and the ends of the tubes are preferably flush with the said outer faces,

and openings in the said faces are formed by the terminal ends of the said tubes.

Each element may be formed integrally and in one piece of a thin highly conductive metal selected from copper and silver optionally with a surface of another protective metal such as nickel, the whole of the outer casing and the connecting elements between parallel walls thereof being formed as integral elements by an electroforming process.

The present invention also relates to a heat exchanger assembly or unit comprising heat exchanger elements of the character referred to above, said elements being located between end plates, with chambers formed between adjoining walls of adjacent elements, means being provided for admitting a first fluid to the inside of all said elements so as to sweep over the tubular elements between the opposed walls of each element and for admitting a second fluid to the successive chambers between adjacent elements so that said second fluid flows from one chamber to the other through the tubular elements extending between the parallel walls of each exchanger element in turn.

In the case of a heat exchanger assembly in the nature of a radiator where air is one of the fluids, each element may be open around the whole or part of one edge for direct admission of atmospheric air to the space between the walls of each element, and a heat exchanger assembly may comprise a plurality of said elements assembled or fixed in place between end plates.

The heat exchanger elements according to the present invention are preferably produced by an electro-forming process, an electrolytic deposit being produced on a matrix consisting of a rectangular plate-like element having a plurality of apertures therein. The matrix may be formed of a low melting point metal or of a non-metallic material, either of which is capable of being removed from the electroform by melting out or by other suitable procedures.

The electroform may be produced mainly from a highly conductive metal such as silver or copper, and it may be provided with an initial or final additional deposit of a protective metal such as nickel. The matrix may be coated with a release layer consisting for example of graphite applied in an organic solvent for the purpose of promoting release of the matrix material from the matrix electroform layer produced thereon.

Various embodiments of the present invention are illustrated by way of example on the accompanying drawings in which:

FIGS. 1 and 2 are perspective views illustrating heat exchanger elements according to one embodiment of the present invention,

FIG. 3 is an enlarged sectional detail view on the line III—III of FIG. 2,

FIG. 4 is a view corresponding to FIG. 3 illustrating an alternative embodiment of the invention, two contiguous elements being shown,

FIG. 5 is a view illustrating a heat exchange unit embodying elements according to FIGS. 1 to 3 as well as spacer elements,

FIG. 6 is a perspective view illustrating the spacer elements shown in FIG. 5,

FIG. 7 is a perspective view illustrating an alternative form of element,

FIG. 8 is a sectional view showing a form of heat exchange unit where one of the fluids is atmospheric air,

FIG. 9 is a perspective view illustrating the elements used in the embodiment of FIG. 8,

FIG. 10 is a detail view illustrating a heat exchanger element having a corrugated face,

FIG. 11 is a general view from one face showing the construction of another form of heat exchanger element,

FIG. 12 is a cross-section of FIG. 11 on the line XII,

FIG. 13 shows view illustrating various forms of spacer elements or gaskets between adjacent elements, applicable to the arrangement shown on FIG. 5, and

FIG. 14 is a view illustrating a matrix for use in the production of the heat exchanger elements shown in FIGS. 1 and 2 of the drawings.

Referring to the accompanying drawings, it will be understood that heat exchanger elements are employed which provide the basic feature of the present invention, being adapted to be assembled into units, typical arrangements of which are shown on FIGS. 5 and 8 of the drawings.

In all cases the heat exchanger elements comprise flat box-like casings having front and rear parallel faces which are spaced apart by an amount which is much less than any dimension of the faces. These faces are formed of very thin and preferably highly conductive metal or alloy and they may if desired be formed from superposed thin layers of different metals according to the operating conditions. Thus, conveniently, the casings may be formed of copper because of the well-known high heat conductivity of this metal, and this metal may be provided with a coating on one or both faces of a metal having a protective action, for example nickel.

The parallel faces shown at **11** and **12** in FIGS. 1 to 3 are interconnected at a large number of points by tubular elements **13** providing a series of ductways extending from the outside of the face **12** to the outside of the face **11**, and it is an important feature of the present invention that these tubular elements **13** are formed integrally with the faces **11** and **12** and are substantially flush with said outer faces as is clearly indicated on FIG. 3 of the drawings.

Thus, each element comprises a box-like casing formed of very thin metal and provided with a large number of tubular elements **13** extending between the front and rear faces, giving a stiff and strong construction for each unit despite the fact that the walls are very thin. This arrangement permits high heat conductivity between fluids flowing in the space between the faces **11** and **12** and around the tubular elements **13**, on the one hand and a fluid medium passing over the outer surfaces of the faces **11** and **12** and through the tubular element **13**.

In the embodiments shown in FIGS. 1 to 7 of the drawings, each heat exchanger element is in the form of a closed casing, the space around the periphery of the faces **11** and **12** being closed by an edge wall **14** so that each unit is a substantially closed unit, fluid being capable of being admitted to the interior of said unit by means of an entry or exit duct **15** which is generally similar to, although substantially larger than the tubular element **13** and may be either of circular shape or of elongated slot-like shape, as indicated on FIGS. 1 and 2 of the drawings. This ductway is apertured as indicated at **16** or is partly cut away on the side facing the centre part of the element as indicated at **17** in FIG. 4, so that fluid admitted to the duct **15** at the upper end of the unit is capable of flowing into the space within the element and being withdrawn therefrom at a similar ductway **15** at the lower end of the element.

Such elements are adapted to be assembled to form a heat exchanger unit in the manner shown in FIG. 5 of the drawings wherein a plurality of such elements E are assembled one beside the other between terminal casing walls **18** held in assembly by fastening bolts **19** extending through additional apertures **20** in the elements, these apertures being also indicated on FIGS. 1 and 2 of the drawings.

Each element **3** may be spaced from its neighbour by means of a spacer element **22** having the configuration shown on FIG. 6 of the drawings. Each of these spacer elements is similar in external configuration to the elements E and is provided with a central open area **23** providing a series of turbulence chambers **24** between adjacent elements E. The spacer elements **22** may be formed of a sufficiently deformable material, such as a plastics material to form a fluid-tight joint, or they may be formed of metal, with the joint face coated with a suitable sealing compound.

It will be seen that all the ductways **15** of the elements E come into alignment and provide a continuous header passage which lies in line with an inlet pipe **25** and, at the other end of each element E, with an outlet pipe **26**. It will be seen that a fluid gas or liquid admitted to the pipe **25** will flow into the aligned ductways **15** and will pass therefrom through the openings **16** into the spaces within all the elements E and will sweep over the internal surfaces of the faces **11** and **12** and around the tubular elements **13**, the fluid being carried away through the pipe **26**. A second fluid is admitted through a feed pipe **27** into the first turbulence chamber **24** and it then sweeps over the outer surface of the first element E, then through the ducts **13** into the next turbulence chamber and so on until the fluid reaches the outlet pipe **28** fixed to the other end plate **18**.

Preferably two different "sorts" of Elements E are provided, as indicated respectively on FIGS. 1 and 2 of the drawings, the ducts **13** being differently arranged on the two sorts of elements so that no duct **13** in one element lies directly opposite the duct **13** in a neighbour when the different sorts of element are assembled in alternating sequence, as shown on FIG. 5 of the drawings. This ensures a turbulent flow as the fluid from the pipe **27** passes through one set of ducts **13** and enters the next turbulence chamber **34** at a point otherwise than directly opposite a duct **13** in a neghbouring element so that the fluid is caused to pass in a circuitous path from one element to the next.

A substantially similar result may be obtained by providing identical elements E each comprising an arrangement of ducts **13** which is non-symmetrical about at least one axis, as shown on FIG. 7, for example the horizontal axis. With such an arrangement alternate elements may be assembled in inverted positions (that is to say inverted by turning around the horizontal axis); this gives the same result as with the elements of FIGS. 1 and 2, i.e. no duct **13** in one element lies immediately opposite a similar duct in an adjoining element.

FIG. 4 illustrates an alternative arrangement of elements E which are provided with dished face portions **111, 112**, the marginal portions of each element being of flat planar form so that successive elements can be assembled in facial contact at the edges, as indicated in FIG. 4, and without it being necessary to provide spacer elements **22** as in FIG. 5; the dished portions of adjoining faces **111, 112**, then provide the turbulence chambers **24** between them.

The construction of a heat exchanger unit or assembly shown in FIG. 5 is adapted to various uses where heat is to be exchanged between two different fluids capable of being supplied through pipes **25** to **27**, but the invention is not limited to constructions adapted to the case where both fluids are supplied from a piped supply, but it can also be applied to the case where one of the fluids is the surrounding air, for example in the case of radiators, whether air heating radiators or water cooling radiators, as for example in the case of internal combustion engine radiators.

An embodiment of this character is illustrated in FIG. 8 where a plurality of elements E are held in assembled condition between end plates **18**, and with spacer elements **22** between them in a manner generally similar to that shown on FIG. 5 of the drawings. The end plates **18** carry inlet and outlet pipe sections **27, 28** for admission of one fluid for example water.

Each unit E is constructed in the manner shown in FIG. 9 and comprises open edges between parallel front and rear plates **211, 212**, so that the space between the plates is freely open and accessible to the atmosphere. If desired, the assembly shown in FIG. 8 of the drawings may be open on all sides, or the elements may be closed on two opposite sides and open on two other opposite sides in order that air may be caused to circulate through the space between the parallel faces **211**, **212**.

If desired, the exposed edges of each element may be protected and strengthened by means of a sinuous or corrugated insert element **31** which may be formed integrally with the plates **211**, **212**, or may be a separate element inserted and either left loosely in position or fixed by adhesive or by soldering operations.

In some cases the faces **11**, **12**, **111**, **112**, **211**, **212** are not necessarily flat and they may be corrugated, as indicated for example on FIG. 10 of the drawings, thereby strengthening each face of the element and providing a greater area of contact between the two fluids and increased turbulence.

In the embodiment of the invention illustrated in FIGS. 11 and 12 a heat exchanger element is shown which is generally similar to the construction shown in FIGS. 1 and 2, but this embodiment is designed to provide the minimum resistance to the flow of fluid through each element. Each exchanger element comprises an integral flat box-like casing, one face being shown at **311**. This face may be a recessed surface framed by surrounding portions **313**, in the manner indicated on FIG. 4 of the drawings, as regards the depressed face portions **111**, **112** in the latter figure.

In the present embodiment, however, the entry or exit duct **15** of the previous embodiment is replaced by a row of square apertures **115**, the surfaces defining these apertures being co-planar with the frame portions **313** surrounding the depressed portion **311**.

Two different sorts of exchanger elements of the character indicated on FIG. 11 are provided, only one sort being shown on FIG. 11. The alternative sort may be provided with six ducts **13** in the top and bottom rows, in contrast to the arrangement shown on FIG. 11 where the top row and bottom row have five ducts. Thus, when the different sorts of elements are assembled in alternating sequence the apertures **15** come into alignment and form a continuous supply duct, each aperture incorporating a cut-away part similar to that shown at **17** in FIGURE 4 of maximum possible flow area to ensure that one fluid admitted through the aligned ducts can pass to the inside of each of the exchanger elements. Because different sorts of elements are arranged alternately—as also indicated on FIG. 4—a high measure of turbulence is obtained as regards the fluid flowing between the opposite faces of each element through the ducts **13**.

FIG. 12 illustrates a cross-section through the heat exchanger elements of FIG. 11, and it will be seen that each element may be provided with spaced depressions **35** in the longer edge to promote distribution of fluid within the element.

FIGS. 11 and 12 relate to embodiments in which depressed face portions **311**, **312** are provided on the opposed faces of each element, but it should be understood that the construction described with reference to FIGS. 11 and 12 is also applicable to embodiments in which the faces **311** and the framing edge parts **313** are co-planar overall.

Elements having depressed face portions, as shown in FIG. 4 or 12, may be assembled in facial contact, with a suitable sealing medium between the faces. Elements having faces which are flat overall may be assembled with spacer elements such as are shown on FIGS. 5 and 8 of the drawings, and further details relating to such spacer members are shown in three embodiments in FIG. 13. In each case adjacent elements E are shown together with a deformable spacer element **22**. As shown on the left-hand side the part of each element which engages the spacer member **22** is provided with a rib-like portion **36** which effects deformation of the member **22** on assembly of the parts. In the centre section of FIG. 13 there is shown a spacer element **22** which is of approximately U-shape in cross-section so that deformation of the fin-like edge parts occurs on assembly of the elements. The right-hand section of FIG. 13 shows an arrangement in which the sealing member **22** has a widened edge part **37** which becomes deformed on assembly of several elements with the spacer members **22** between them.

An important feature of the present invention is that the two faces of each element and the ducts **13** between such faces are of integral construction and the ducts **13** are substantially flush with the outer face of said elements. Additionally, in some embodiments of the invention there may be peripheral walls **14** so that each element is of a closed box form. The present invention also relates to the production of these elements with integrally formed ducts **13**.

In accordance with this aspect of the present invention the heat exchanger elements are formed by electro-forming processes using a matrix such as is represented in typical form on FIG. 11 of the drawings as applied to a matrix for producing the element shown on FIG. 1 of the drawings. This matrix is formed of any material capable of being eliminated from the finished product after electro-forming by melting out, by evaporation, by chemical reaction or otherwise.

In one example a matrix such as is shown in FIG. 11 of the drawings may be produced from a metal alloy having a low melting point such as the alloy commonly known as Woods metal, or such as sold under the trademark Cerrobend. The matrix **32** shown may be produced by gravity or by die casting, permitting such matrices to be produced expeditiously and in the quantities necessary for mass production of the exchanger elements E. Alternatively, such matrices may be produced from non-metallic material such as paraffin wax of suitable grade or synthetic resin materials having a relatively low melting point. If non-metallic materials are utilised they may, if desired, be mixed with a conductive material such as graphite or they may be coated with a conductive layer which may be either of metal or may be graphite applied as a suspension in an organic solvent.

Preferably, whatever the nature of the matrix, even if it is formed of metal, it is coated with a layer of graphite in an organic solvent to assist in the subsequent removal of the matrix from the electro-formed product and to act as a parting agent or release agent, thereby assisting in complete elimination of the matrix material from the electro-forming product.

A matrix formed of non-conductive material may also be provided with a conductive layer, for example of metal, by any well-known reduction process so as to produce a thin conductive deposit of silver, nickel, or copper. The baths which must be employed for producing such a conductive deposit are well-known in the art, a typical example being a solution of silver nitrate containing formaldehyde, this bath being capable of depositing metallic silver on a non-metallic object placed therein.

The matrix, whether produced from a fusible metal alloy or from non-metallic material provided with a conductive coating, and preferably after treating with a layer of graphite to form a parting layer, is then subjected to an electro-forming process.

The precise nature of the electro-forming will depend on the required properties of the element and the conditions under which it is intended to be operated. A typical example comprises a first thin coating of nickel, followed by a coating of copper and finally by a further layer of nickel. Each nickel layer may be about 0.001 thick, while the copper layer may vary between 0.002 to 0.050, again according to the specification conditions to be met. The plating with nickel may be performed with any standard ickel plating bath, for example the following Watts type ath:

	Ozs. per gal.
Vickel sulphate	45
Vickel chloride	9
Ioric acid	5

H adjusted to 4 to 4.5.

This may be followed by a copper plating bath such as:

	Ozs. per gal.
Copper salt	3.6
'otassium pyrophosphate	24
'otassium oxalate	2.4
'otassium nitrate	0.8
Ammonia	0.15

H adjusted to 8.2 to 8.8.

The electro-forming techniques follow normal practice n the electro-forming art and do not form any part of the resent invention. The result is to produce a thin co-erent deposit on the matrix **32**, the deposit being effected lso in the apertures **33** in the matrix so as to form the ducts **13** between the flat faces **11** and **12** of the elements.

When electro-forming has been completed to produce leposits of the required thickness the matrix is melted out, or evaporated, according to the nature of the matrix and iny residues of the matrix material are eliminated by chemical cleaning operations, using, for example, cleaning acids which have no effect on the metallic deposit initially formed on the matrix. The resulting product is the hin-walled hollow box-like casings shown on the drawngs while, of course, appropriate modifications in the electro-forming procedure are adopted if open edged casings of the character shown in FIG. 9 are required. In the case of FIG. 9 the corrugated edge strengthening elements **31** may be also formed by electro-forming processes or they may be inserted after electro-forming and pressed or otherwise fixed in position.

What I claim is:

1. A heat exchanger comprising a plurality of heat exchanger elements each heat exchanger element comprising two spaced parallel walls having smooth marginal portions to permit adjacent elements to be assembled in peripherally sealed disposition and having a plurality of apertures in the faces thereof within said marginal portions, a corresponding plurality of tubular members having a length substantially equal to the distance between the outer faces of said parallel walls, the ends of each of said tubular members being secured in fluid-tight relationship to the periphery of each of said apertures, whereby the outer faces of said parallel walls have flush smooth faces, said elements being assembled such that the tubular members of adjacent elements are not axially aligned whereby sinuous flow paths are provided, clamp means to hold said exchanger elements in mutually spaced parallel order with chambers between adjacent elements defined by

the outer faces of the mutually facing parallel walls of exchanger elements, means to circulate a first fluid through said heat exchanger to flow in succession through all said tubular members and chambers in said successive sinuous paths, and means to circulate a second fluid through the interior of said exchanger elements causing said second fluid to flow within all elements between the parallel walls thereof and around the tubular members interconnecting said walls to provide for exchange of heat through the exchanger element structures between the two said fluids respectively.

2. A heat exchanger element as claimed in claim **1** wherein the faces of said two spaced parallel walls within said marginal portions of each of said exchanger elements are recessed.

3. A heat exchanger as claimed in claim **1** further comprising spacer members interposed between the smooth marginal portions of the walls of each set of exchanger elements each of said spacer members having a central aperture further defining the chambers formed between the outer faces of the walls of adjacent elements, and terminal end plates at opposite ends of said heat exchanger, said means to circulate a first fluid to said heat exchanger comprising admission and exit connections in said end plates, all said exchanger elements, spacer elements and end plates being fixed together in assembly by said clamp means.

4. A heat exchanger as claimed in claim **1** wherein said means to circulate a second fluid through the interior of said exchanger elements comprises aligned inlet and outlet ducts in each of said exchanger elements said ducts extending between said two spaced parallel walls in said marginal portions and having ports therein communicating with the interior of each of said exchanger elements.

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ROBERT A. O'LEARY, *Primary Examiner.*

T. W. STREULE, *Assistant Examiner.*