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Description

This invention relates to an atmospheric vaporizer suitable for vaporizing cryogenic liquids on a substantially continuous basis at greatly improved operating efficiency.

Atmospheric gases such as oxygen, nitrogen and argon find wide use in a variety of applications. These gases are typically produced by means of air separation plants. Users of large quantities of such gases may have air separation units at the site of gas usage, while users of small quantities of such gases generally find it convenient to purchase their requirements in cylinders. Users of intermediate or moderate amounts of such gases generally do not have sufficient usage to justify an on-site air separation plant, but generally their requirements are large enough to make purchasing of gas in cylinders uneconomical. Typically, moderate users of gases will find it convenient to maintain on-site cryogenic liquid storage tanks and vaporize the liquid as requirements dictate. The gas is then piped to the use locations. The usage requirements may be intermittent or continuous.

An atmospheric vaporizer is a device which vaporizes cryogenic liquids by employing heat absorbed from the ambient air. Atmospheric vaporizers have been employed by users of intermediate quantities of gases as means of vaporizing the stored cryogenic liquid when the user's gas requirements are intermittent, but generally not when the user's gas requirements are continuous. The reason why atmospheric vaporizers are not generally used for continuous service is because ice and frost build up on the outside surfaces of the atmospheric vaporizer, rendering the unit inefficient after a sustained period of use.

Typically (FR-A-1 239 402 and US-A-2 322 341), an atmospheric vaporizer is comprised of one or more passes vertically positioned and piped together. The passes are comprised of a center tube through which the liquid passes, and the tube generally has one or more fins attached to it to increase the heat transfer area. The passes e.g. may be spaced about 23.5 cm, centerline to centerline, from each other. The cryogenic liquid enters at the bottom of one pass, passes up through it and then through a connection to the top of another pass through which it descends. This flow pattern is repeated through other passes as conditions such as usage and ambient temperature dictate. As the cryogenic liquid passes through the atmospheric vaporizer, the liquid is vaporized and the gas then further heated by heat transferred from the ambient air to the fluid through the vaporizer. The gas exits the atmospheric vaporizer at the required flow rate and exit temperature.

Furthermore JP-Y-73 032 064 discloses an apparatus for continuously vaporizing a cryogenic liquid by employing heat absorbed from the ambient air comprising at least three vertically positioned passes which are piped together, each pass being comprised of a center tube provided with 8 fins substantially equally spaced around said tube, each fin having a radial length of about 1.5 times the outside diameter of said tube and extending longitudinally along substantially the entire length of said tube, wherein the ratio of the distance between adjacent fin tips to radial fin length is about 1.2.

Besides, several vaporizers for continuously vaporizing a cryogenic liquid by employing heat absorbed from the ambient air have become prior art by public use, which vaporizers each comprise more than three substantially vertical positioned passes which are piped together, each pass being comprised of a center tube provided with eight fins substantially equally spaced around the center tube and extending longitudinally along substantially the entire length of the center tube. These vaporizers (designed A to D) are dimensioned as indicated in the table below:

Vaporizer	center tube outside diameter (cm)	radial fin length to center tube outside diameter	pass length (m)	vertical distance from ground (m)	tip distance of adjacent fins of adjacent passes to radial fin length
A	2.8	1.6	2.0	0.35	1.38
B	2.8	1.6	4.2	1.05	1.34
C	2.8	1.6	4.2	1.05	1.34
D	2.6	1.8	2.1	0.67	1.35

As the fluid passes through the vaporizer and as heat is exchanged from the ambient air, the moisture in the air condenses and freezes on the surfaces of the vaporizer. This frost and ice continues to build up during operation of the vaporizer resulting in decreasing efficiency until a steady state condition is attained. As the efficiency of the atmospheric vaporizer decreases, either the exit flow rate or the exit temperature or both must be decreased. Depending on the relative importance of these parameters, one or both of them are decreased until the steady state condition is achieved. Typically, this steady state condition is achieved at about 20 percent of the capacity of the vaporizer without the frost buildup.

When the user's requirements are intermittent, the frost buildup is generally not a problem because whatever frost build up does occur during operation melts off or can be easily removed while the unit is not in operation. Under these conditions, the vaporizer is operating efficiently, and the above-mentioned low efficiency steady state is generally not encountered.

However, when the atmospheric vaporizer is operating in the continuous mode, the frost and ice do not get a chance to melt, and the vaporizer is soon operating inefficiently. For this reason, atmospheric vaporizers are generally not preferred for continuous vaporization of stored cryogenic liquids. Instead, a vaporizer is employed which utilizes a source of heat other than or in addition to ambient heat. This source of heat or energy is normally obtained from steam or electricity. Due to the escalating cost of energy, it is desirable to reduce or eliminate the need for a supplementary heat source of the vaporizer. It would be desirable to vaporize stored cryogenic liquid continuously without encountering the heretofore unavoidable drastic decrease in operating efficiency characteristic of atmospheric vaporizers of the prior art.

Accordingly, it is an object of this invention to provide an improved atmospheric vaporizer for cryogenic liquids that is suitable for continuous operation while substantially avoiding the drastic reduction in operating efficiency characteristic of prior art atmospheric vaporizers.

The above and other objects which will be apparent to those skilled in the art are achieved by the present invention which comprises an apparatus for continuously vaporizing a cryogenic liquid by employing heat absorbed from the ambient air, said apparatus comprising at least three substantially vertically positioned passes which are piped together, each pass being comprised of a center the provided with a plurality of fins substantially equally spaced around said tube, each fin having a radial length of at least 1.5 times the outside diameter of said the and extending longitudinally along substantially the entire length of said tube, wherein the ratio of the distance between the tips of the most adjacent fins of adjacent passes to radial fin length is above 1,3, said apparatus being characterized in that each center tube has an outside diameter of from 1.27 to 1.81 cm and is provided with 3 to 8 fins, each fin has a radial length of about 3.5 times the outside diameter of said tube, each pass has a length of from 1.52 to 6.08 m and a vertical distance from the ground or other support platform to the bottom edge of the fins from 0.3 to 1.2 m, and the ratio of the distance between the tips of the most adjacent fins of adjacent passes to radial fin length is from 2 to 5.

Accordingly, the vaporizer of the present invention employs relatively wide spaces between each vertical pass. The wide spaces would be thought, under conventional thinking, to hinder efficient heat transfer. However, the combination of the wide space with the above defined fin length, tube diameter, tube length and vertical distance from the ground or other support platform to the bottom edge of the fins (shortly called ground clearance) serve not only to compensate for the expected loss of heat transfer efficiency, but surprisingly work together to actually provide improved overall heat transfer over the conventional design.

Preferred embodiments of the invention are described in detail below with reference to the drawings in which

Figure 1 illustrates a typical atmospheric vaporizer pass;

Figure 2,

Figure 3, and

Figure 4 are each a plan view of a vaporizer pass, wherein Figure 2 illustrates a pass having four fins, Figure 3 illustrates a pass having eight fins, and Figure 4 illustrates a pass having three fins;

Figure 5,

Figure 6, and

Figure 7 are each a plan view of a vaporizer pass array, wherein Figure 5 illustrates a square array of four-finned passes, Figure 6 illustrates a triangular array of four-finned passes, and Figure 7 illustrates a square array of three-finned passes;

In Figures 1 to 4 and 8 the diameter of the center tubes and the radial fin length are not drawn to scale.

Figure 8 illustrates one embodiment of the atmospheric vaporizer of this invention, and

Figure 9 is a graphical representation of steady state flow rate versus spacing ratio.

The atmospheric vaporizer of this invention is comprised of three or more finned passes piped together and arranged in an array having defined spacing in between individual passes.

Figure 1 illustrates a typical pass 10 comprising a center tube 11 and fins 12. The center tube has an outside diameter of from 1.27 to 3.81 cm, preferably about 2.54 cm, and is of sufficient thickness to contain the fluid at the requisite supply pressure. The cryogenic fluid passes through the center tube as it passes through the vaporizer. The fins 12 extend from the tube in radial fashion and extend longitudinally along the tube for substantially the entire length of the tube. The fins normally have a radial length of about 3.5 times the diameter of the tube. The fin thickness is not critical, and is generally sufficient to obtain adequate mechanical strength to permit support of the unit in an upright position with suitable brackets and leg supports. Generally, the fin thickness is from 0.16 to 0.32 cm; a convenient thickness is 0.25 cm. The number of fins can range from 3 to 8 fins per pass. Figure 1 illustrates a four-fin arrangement. The fins are spaced substantially equidistant around the center tube. Thus, for the four-finned tube 20 shown in Figure 2 the fins 22 are arranged around the center tube 21 at about 90° from each other. For the eight-finned tube 30 shown in Figure 3, the fins 32 are arranged arrund the center tube 31 at about 45° from each other. And for the three-finned tube 40 shown in Figure 4, the fins 42 are arranged around the center tube 41 at about 120° from each other.

Each pass has a length of from 1.52 to 6,08 m, preferably from 2,44 to 4.88 m, most preferably about 3,66 m. The fins extend along the length of the center tube substantially from end to end; however, there is a small length at both the top and bottom of the tube where the fins do not extend so as to permit connecting of the passes together. The passes are connected together in any suitable manner; a convenient method of connecting is by use of U-bend joints.

The passes may be constructed from any material having good heat transfer characteristics. Aluminum is the preferred material. When high pressure is required, the center tube may be fabricated from stainless steel or monel and fitted with the aluminum fins.

The passes are usually set on the ground, positioned vertically and held in place by suitable leg supports. Normally, the passes have a ground clearance of from about 0.3 to 1.2 m, preferably from about 0.46 to 0.92 m. By ground clearance it is meant the vertical distance from the ground, or other platform such as a concrete pad, to the bottom edge of the radial fins. The higher ground clearances would be better suited for climates having significant accumulations of snow so that the vaporizer can clear the level of snow.

The passes may be piped in series or in a combination of series and parallel configurations. The top of one pass is piped to the top of an adjacent pass, and the bottom of a pass is piped to the bottom of an adjacent pass. Thus, cryogenic fluid enters one pass at the bottom, travels up the pass and over through the connection to an adjacent pass, down that pass arid over through the connection to another pass, and so on until it exits as a gas at the temperature appropriate for the end use. The number of passes the fluid flows through, and the path of the fluid, i.e. series or combination series and parallel, will depend on various factors, such as end use temperature and flow rate requirements, ambient temperature,heat transfer characteristics, pressure drop factors and other considerations which are known to those skilled in the art.

The passes of the atmospheric vaporizer of this invention are spaced apart from one another such that the ratio of the distance between fin tips to the fin length, herein also called the spacing ratio, is from 2 to 5.

Preferably the spacing ratio is from 2 to 4 and most preferably it is about 3. There is a further increase in the operating efficiency of the atmospheric vaporizer at the lower end of the defined spacing ratio range. The efficiency gradually increases and then evens out as the upper limit of the range is approached and attained. This phenomenon is shown more clearly in Figure 9 and in the Examples.

Heretofore, it was felt that atmospheric vaporizers would operate at better efficiency, i.e., better heat transfer could be attained, when the passes were closer together. This invention comprises the discovery that moving in accordance with the teaching of the invention the individual passes further apart than heretofore thought prudent will result, surprisingly, in an increase in efficiency when the spacing ratio is increased to 2, and that the efficiency continues to increase until the spacing ratio is increased to 5.

The passes of the atmospheric vaporizer of this invention are arranged in a square, rectangular or triangular array. Figure 5 illustrates an array 50 of four-finned passes. Here one square array is demarcated by individual passes 51, 52, 53 and 54 at the corners of the square. Figure 6 illustrates an array 60 of four-finned passes. Here one triangular array is demarcated by individual passes 61, 62 and 63. Another triangular array is demarcated by individual passes 62, 63 and 64. Figure 7 illustrates an array 70 of three-finned passes. Here one square array is demarcated by individual passes 71, 72, 73 and 74.

Figure 5 may be used to illustrate some typical modes of operating for the atmospheric vaporizer of this invention. For example, a cryogenic liquid may enter the bottom of pass 51, travel up through it and over to pass 52, down this pass and so on down the line until it is discharged as a gas from pass 55. This illustrates operation in series. Similarly, the fluid may enter pass 53 and exit pass 56, or enter pass 58 and exit pass 57. Alternatively, the inlet fluid could be combined so that the inlets of pass 51, 53 and 58 would be combined and connected to the liquid source and the outlet of pass 55, 56 and 57 would be combined so that the exit gas would all be combined for the end use. This illustrates operation in combined series and parallel flow patterns. Those skilled in the art will readily seeadditional ways of operating the atmospheric vaporizer of this invention by altering the fluid path simply by appropriate piping and valving.

Figure 8 illustrates a typical atmospheric vaporizer of this invention. The front supports are shown in broken view in order to more clearly show the inlet and outlet connections. As shown in Figure 8, liquid cryogen enters the vaporizer through inlet 81, travels up pass 82 and across piping connection 83 to pass 84, down pass 84 and across piping connection 85 to pass 86, up pass 86 and across piping connection 87 to pass 88, and down pass 88 and out outlet 89 in the form of a gas.

The passes which comprise the atmospheric vaporizer of this invention may be deployed in any suitable spatial configuration consistent with the spacing ratio defined previously. It is expected that the array of three or more passes will define an enclosed air space between them, i.e. that the passes will not all be in a straight line. Preferred arrays are rectangular or square arrays as shown in Figures 5 and 7 and triangular arrays as shown in Figure 6.

The atmospheric vaporizer of this invention may also be provided with one or more control devices. One such device is to control the flow rate of the fluid. By regulating the flow of fluid, one can compensate for changes in ambient air temperature and/or system heat transfer efficiency in order to keep the exit gas temperature constant. Such an arrangement is most useful when the particular usage to which the gas is put requires a specific gas temperature or temperature range.

This invention, by employing the critical pass spacing ratio and the other defined features provides an atmospheric vaporizer which is capable of vaporizing cryogenic liquids on a continuous basis at an efficiency considerably higher than is achievable by the use of atmospheric vaporizers of the prior art.

The following examples serve to further illustrate preferred embodiments of the atmospheric vaporizer of this invention, and the greatly improved results attainable by its use over those obtained with conventional atmospheric vaporizers. The examples are intended to illustrate the invention, and are not intended to limit the scope of the invention.

<u>Examples 1-4</u>

An atmospheric vaporizer having four passes in a square array was employed to vaporize liquid oxygen and was evaluated to determine its flow capacity at steady state. The evaluation was conducted in a climate control house so that ambient temperature and humidity were relatively constant throughout the evaluation. The vaporizer passes were

2.29 m in height, each had a ground clearance of

0.46 m, each had a center tube diameter of

2,54 cm and each was provided with eight fins. Each fin had a radial length of 8.89 cm and a thickness of 0.25 cm. In a comparative example the pass spacing, centerline to centerline, was 33.66 cm between adjacent passes and the spacing gap, i.e. the space from fin tip to fin tip was 13.34 cm. Thus, the spacing ratio was 13.34 cm/8.89 cm = 1.5.

The ambient temperature was kept at about 1.7°C throughout the evaluation and the relative humidity was kept about 100 percent. The gas exit temperature was maintained relatively constant throughout the evaluation at about -15°C by periodically adjusting the flow through the vaporizer. As the ice and frost blanket continued to increase, the flow was adjusted downward to maintain the gas exit temperature essentially constant. After about six days of operation the vaporizer operating conditions reached steady state and the flow rate was measured. The results appear in Table 1 under Example 1.

The procedure described above was repeated except that the distance between adjacent passes was increased to

45.7 cm giving a spacing gap of 25.4 cm and a spacing ratio of 2.9. The vaporizer was evaluated for steady state flow rate and the results are shown in Table 1 under Example 2.

The above-described procedure was repeated a third time. The pass spacing again was 45.7 cm. However, in this example the number of fins used on each pass was four instead of eight. The vaporizer was evaluated for steady state flow rate. The results are reported in Table 1 under Example 3.

For further comparative purposes the above-described procedure was repeated with a vaporizer identical to the eight-fin vaporizer described above except that the pass spacing was only 23.5 cm. The spacing gap was only 3.2 cm and the spacing ratio was only 0.4. This vaporizer was also evaluated for steady state flow rate and the results are also reported in Table 1 under Example 4.

TABLE 1

Example	1	2	3	4
Number of Fins	8	8	4	8
Pass spacing (cm)	33.66	45.7	45.7	23.5
Spacing Gap (cm)	13.3	25.4	25.4	3.2
Spacing Ratio	1.5	2.9	2.9	0.4
Flow Capacity (m^3/hr)	10.9	13.2	9.9	6.9

As shown in Table 1 there is an increase in steady state flow rate when the atmospheric vaporizer of this invention is employed over that obtained in the comparative examples wherein the atmospheric vaporizer of this invention was not employed. This increase in steady state flow rate is indicative of the increase in operating efficiency.

Comparison of Example 2 with Example 1 demonstrates that the increase in pass spacing ratio from 1.5 to 2.9 results in an increase in steady state flow capacity of 21 percent. Comparison of Example 2 with Example 4 demonstrates that the increase in pass spacing ratio from 0.4 to 2.9 results in an increase in steady state flow capacity of 90 percent. Comparison of Example 3 with Comparative Example 4 demonstrates that even though the fin number per pass was reduced from 8 to 4 resulting in a decrease in the heat transfer area of about 50 percent, an increase in pass spacing ratio from 0.4 to 2.9 results in an increase in steady state flow capacity of 43 percent.

The results of these examples are shown graphically in Figure 9; one curve represents the results employing the vaporizer provided with 8 fins per pass and the other curve represents the results employing the vaporizer provided with 4 fins per pass.

Claims

1. An apparatus for continuously vaporizing a cryogenic liquid by employing heat absorbed from the ambient air comprising at least three substantially vertical positioned passes (10, 51 to 58, 61 to 64, 71 to 74,

82, 84, 86, 88) which are piped together, each pass being comprised of a center tube (11, 21, 31, 41) provided with a plurality of fins (12, 22, 32, 42) substantially equally spaced around said tube, each fin having a radial lenght of at least 1.5 times the outside diameter of said tube and extending longitudinally along substantially the entire lenght of said tube, wherein the ratio of the distance between the tips of the most adjacent fins of adjacent passes to radial fin lenght is above 1.3, characterized in that each center tube (11, 21, 31, 41) has an outside diameter of from 1.27 to 3.81 cm and is provided with 3 to 8 fins, each fin (12, 22, 32, 42) has a radial length of about 3.5 times the outside diameter of said tube, each pass has a lenght of from 1,52 to 6.08 m and a vertical distance from the ground or other support platform to the bottom edge of the fins from 0.3 to 1.2 m, and the ratio of the distance between the tips of the most adjacent fins of adjacent passes to radial fin lenght is from 2 to 5.

2. An apparatus as claimed in claim 1 wherein said ratio is from 2 to 4.

3. An apparatus as claimed 1 wherein said ratio is about 3.

4. An apparatus as claimed in claim 1 wherein said passes (51 to 58, 71 to 74) are arranged in a square array.

5. An apparatus as claimed in claim 1 wherein said passes (61 to 64) are arranged in a triangular array.

6. An apparatus as claimed in claim 1 wherein said passes (71 to 74) are provided with 3 fins (42).

7. An apparatus as claimed in claim 1 wherein said passes (10, 51 to 58, 61 to 64, 82, 84, 86, 88) are provided with 4 fins.

8. An apparatus as claimed in claim 1 wherein said passes are provided with 8 fins (32).

9. An apparatus as claimed in claim 1 wherein said passes have a vertical distance from the ground or other support platform to the bottom edge of the fins (12, 22, 32, 42) of from 0.46 to 0.92 m.

10. An apparatus as claimed in claim 1 wherein said center tube outside diameter is about 2.54 cm.

11. An apparatus as claimed in claim 1 wherein said pass length is from 2.44 to 4.88 m.

12. An apparatus as claimed in claim 1 wherein said pass length is about 3.66 m.

Patentansprüche

1. Vorrichtung zum kontinuierlichen Verdampfen einer kryogenen Flüssigkeit unter Verwendung von aus der Umgebungsluft absorbierter Wärme, mit mindestens drei im wesentlichen lotrecht angeordneten Zügen (10, 51 bis 58, 61 bis 64, 71 bis 74, 82, 84, 86, 88), die durch Rohrleitungen untereinander verbunden sind, wobei jeder Zug ein zentrales Rohr (11, 21, 31, 41) aufweist, das mit mehreren Rippen (12, 22, 32, 42) versehen ist, die in im wesentlichen gleichen Abständen um das Rohr herum verteilt sind, wobei jede Rippe eine radiale Länge von mindestens dem 1,5-fachen des Außendurchmessers des Rohres hat und sich in Längsrichtung entlang im wesentlichen der vollen Länge des Rohres erstreckt, und wobei das Verhältnis des Abstandes zwischen den Spitzen der einander am nächsten liegenden Rippen benachbarter Züge zu der radialen Rippenlänge größer als 13 ist, dadurch gekennzeichnet, daß jedes zentrale Rohr (11, 21, 31, 41) einen Außendurchmesser von 1,27 bis 3,81 cm hat und mit 3 bis 8 Rippen versehen ist jede Rippe (12, 22, 32, 42) eine radiale Länge vom etwa 3,5 fachen des Außendurchmessers des Rohres hat, jeder Zug eine Länge von 1,52 bis 6,08 m und einen lotrechten Abstand von dem Boden oder einer anderen Trägerplattform bis zum unteren Rand der Rippen von 0,3 bis 1,2 m hat, sowie das Verhältnis des Abstandes zwischen den Spitzen der einander am nächsten liegenden Rippen von benachbarten Zügen zu der radialen Rippenlänge zwischen 2 und 5 beträgt.

2. Vorrichtung nach Anspruch 1, wobei das Verhältnis zwischen 2 und 4 liegt.

3. Vorrichtung nach Anspruch 1, wobei das Verhältnis bei etwa 3 liegt.

4. Vorrichtung nach Anspruch 1, wobei die Züge(51 bis 58, 71 bis 74) in einer quadratischen Gruppierung angeordnet sind.

5. Vorrichtung nach Anspruch 1, wobei die Züge (61 bis 64) in einer dreieckförmigen Gruppierung angeordnet sind.

6. Vorrichtung nach Anspruch 1, wobei die Züge (71 bis 74) mit 3 Rippen (42) versehen sind.

7. Vorrichtung nach Anspruch 1, wobei die Züge (10, 51 bis 58, 61 bis 64, 82, 84, 86, 88) mit 4 Rippen versehen sind.

8. Vorrichtung nach Anspruch 1, wobei die Züge mit 8 Rippen (32) versehen sind.

9. Vorrichtung nach Anspruch 1, wobei die Züge einen lotrechten Abstand von dem Boden oder einer anderen Trägerplattform bis zum unteren Rand der Rippen (12, 22, 32, 42) von 0,46 bis 0,92 m haben.

10. Vorrichtung nach Anspruch 1, wobei der Außendurchmesser des zentralen Rohrs etwa 2,54 cm beträgt.

11. Vorrichtung nach Anspruch 1, wobei der Zug eine Länge von 2,44 bis 4,88 m hat.

12. Vorrichtung nach Anspruch 1, wobei der Zug eine Länge von etwa 3,66 m hat.

Revendications

1. Appareil pour vaporiser en continu un liquide cryogénique en utilisant de la chaleur absorbée de l'air ambiant, comprenant au moins trois passages (10, 51 a 58, 61 à 64, 71 à 74, 82, 84, 86, 88) positionnés à peu près verticalement, qui sont raccordés entre eux, chaque passage comprenant un tube central (11, 21, 31, 41) portant plusieurs ailettes (12, 22, 32, 42) espacées de façon sensiblement équidistante autour dudit tube, chaque ailette ayant une longueur radiale d'au moins 1,5 fois le diamètre extérieur dudit tube et s'étendant longitudinalement, sensiblement sur toute la longueur audit tube, le rapport de la distance comprise entre les extrémités des ailettes les plus adjacentes de passages adjacent à la longueur radiale des ailettes étant supérieur à 1,3 caractérisé en ce chaque tube central (11, 21, 31, 41) présente un diamètre extérieur de 1,27 à 3,81 cm et comporte 3 à 8 ailettes, chaque ailette (12, 22, 32, 42) présente une longueur radiale d'environ 3,5 fois le diamètre extérieur dudit tube, chaque passage présente une longueur de 1.52 à 6,08 m et une distance verticale à partir du sol ou autre plateform de support jusqu'au bord inférieur des ailettes de 0,3 à 1,2 m, et le rapport de la distance comprise entre les extrémités des ailettes les plus adjacentes de passages adjacents à la longueur radiale des ailettes est de 2 à 5.

2. Appareil selon la revendication 1 dans lequel ledit rapport est de 2 à 4.

3. Appareil selon la revendication 1 dans lequel ledit rapport est d'environ 3.

4. Appareil selon la revendication 1 dans lequel lesdits passages (51 à 58, 71 à 74) sont agencés en un réseau carré.

5. Appareil selon la revendication 1 dans lequel lesdits passages (61 à 64) sont agencés en un réseau triangulaire.

6. Appareil selon la revendication 1 dans lequel lesdits passages (71 à 74) comportent 3 ailettes (42).

7. Appareil selon la revendication 1 dans lequel lesdits passages (10, 51 à 58, 61 à 64, 82, 84, 86, 88) comportent 4 ailettes.

8. Appareil selon la revendication 1 dans lequel lesdits passages comportent 8 ailettes (32).

9. Appareil selon la revendication 1 dans lequel lesdits passages ont une distance verticale du sol ou autre plateforme de support au bord inférieur des ailettes (12, 22, 32, 42) de 0,46 à 0,92 m.

10. Appareil selon la revendication 1 dans lequel le diamètre extérieur dudit tube central est d'environ 2,54 cm.

11. Appareil selon la revendication 1 dans lequel ladite longueur des passages est de 2,44 à 4,88 m.

12. Appareil selon la revendication 1 dans lequel ladite longueur des passages est d'environ 3,66 m.

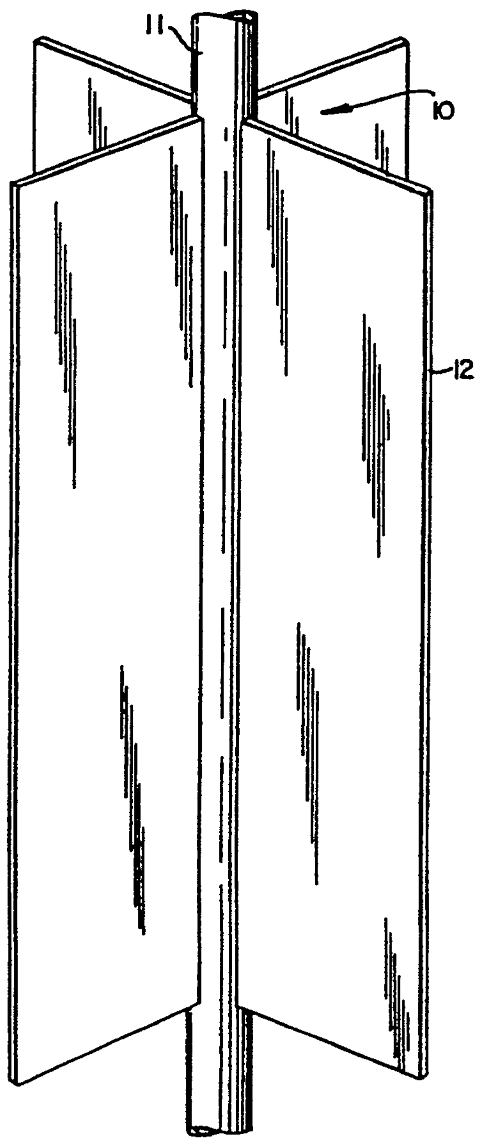


FIG. 1

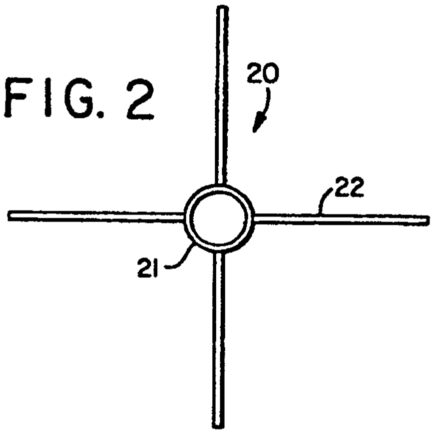


FIG. 2

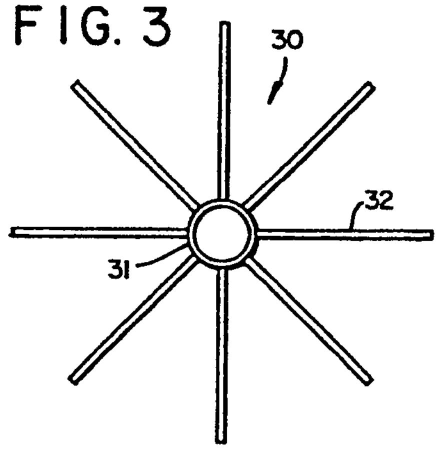


FIG. 3

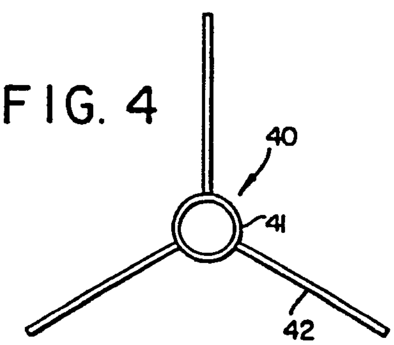


FIG. 4

FIG. 5

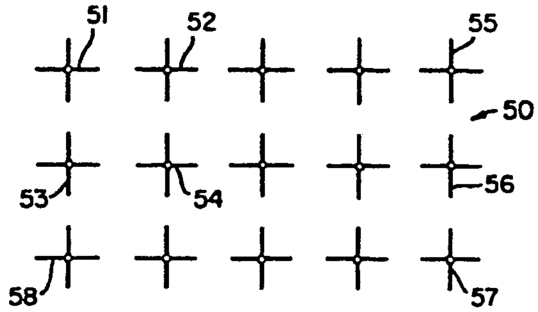
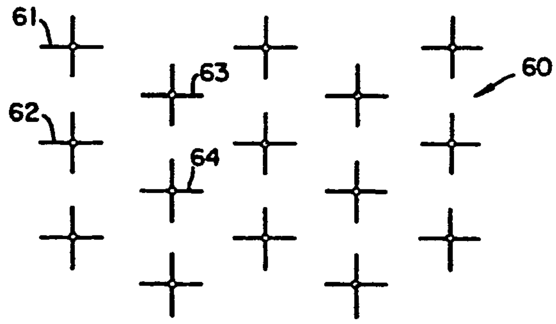


FIG. 6



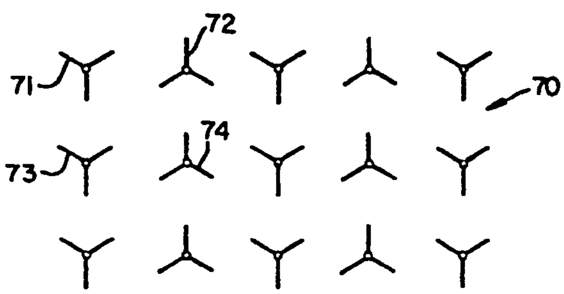
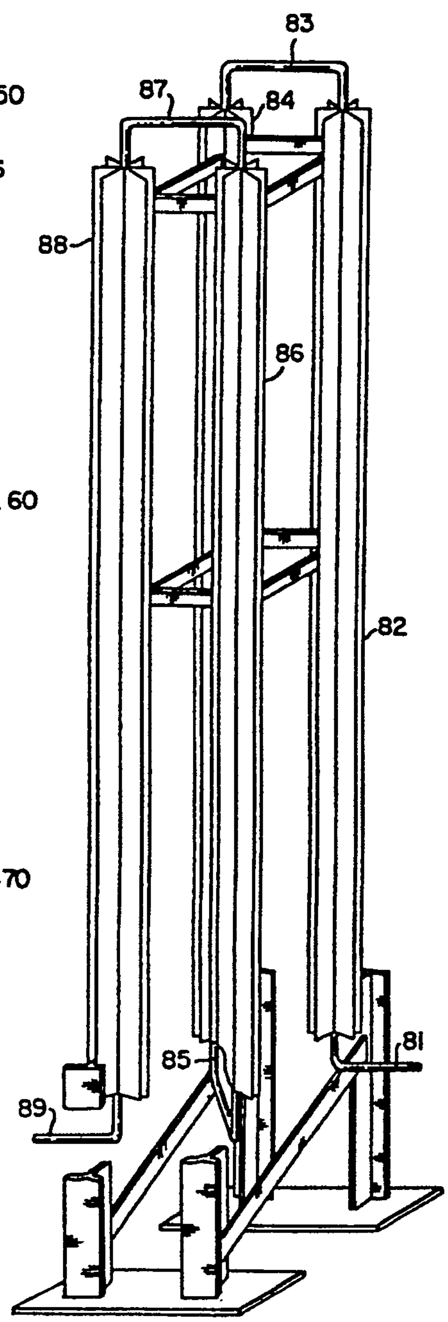


FIG. 7

FIG. 8



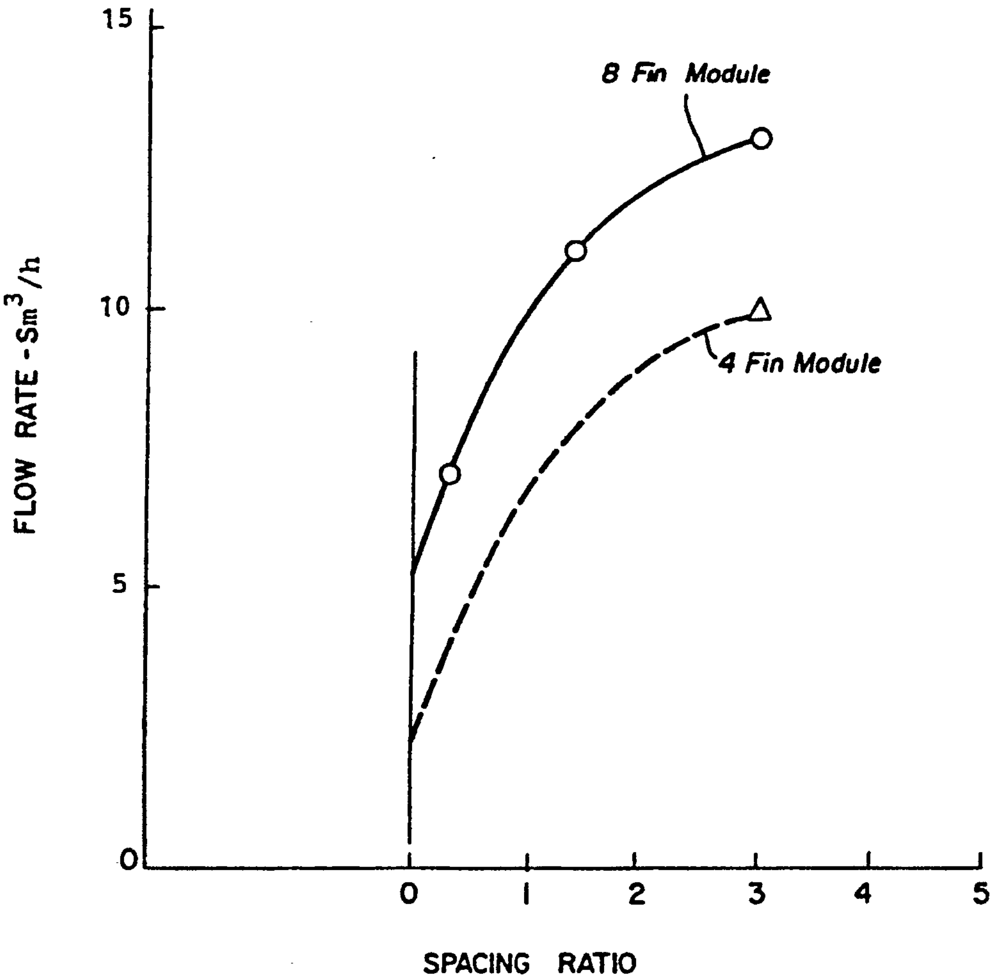

15
10
5
0
FLOW RATE - Sm^3/h
8 Fin Module
4 Fin Module
0
1
2
3
4
5
SPACING RATIO

FIG. 9