

**March 2, 1971**

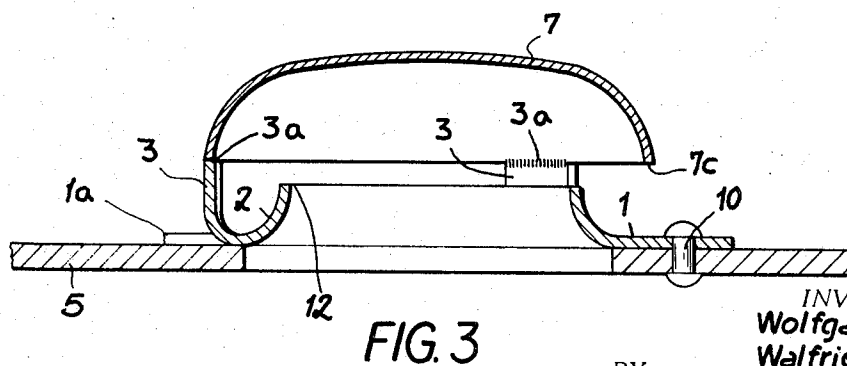
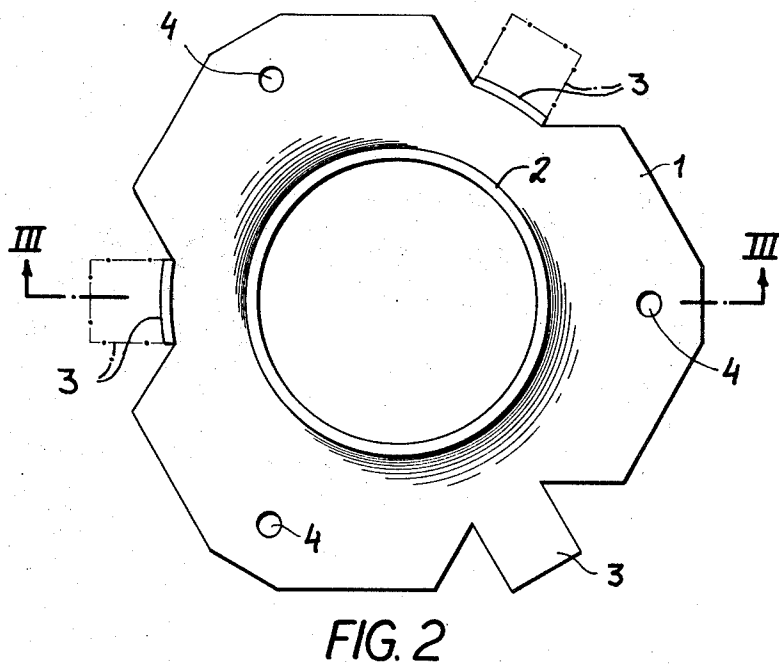
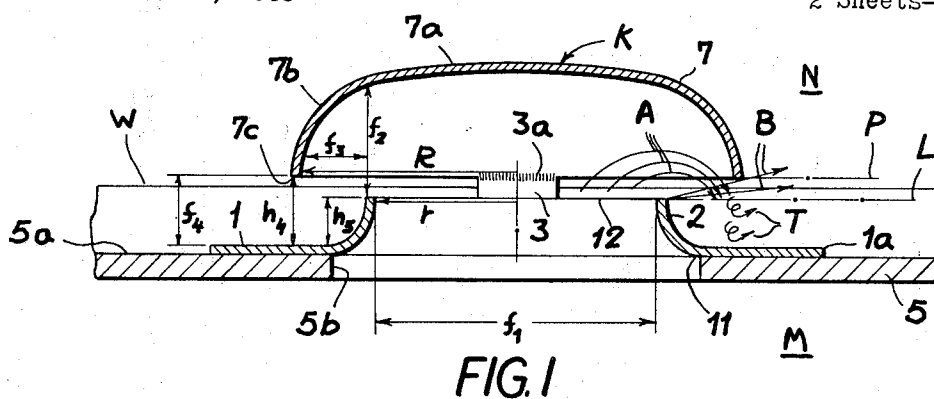
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**3,567,193**

CAP OR BELL FOR BUBBLE-CAP PLATE OR TRAY COLUMNS

Filed Nov. 18, 1968

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

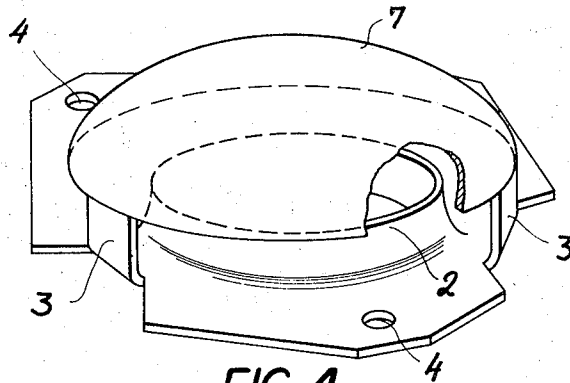


FIG. 4

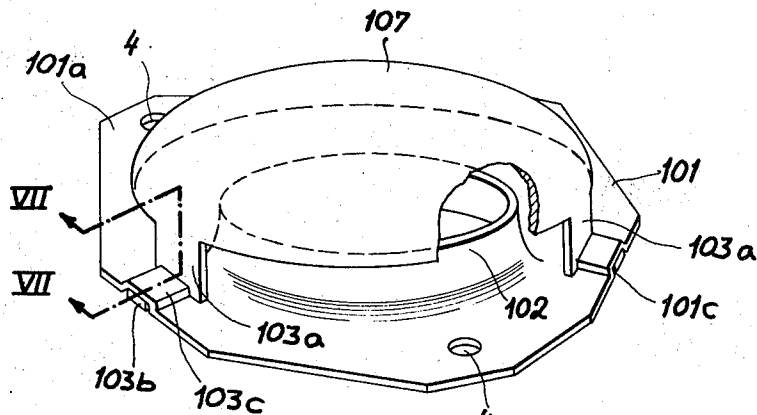


FIG. 5

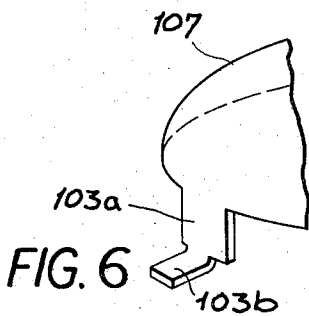


FIG. 6

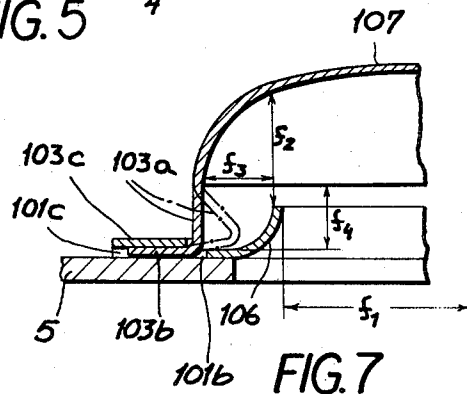


FIG. 7

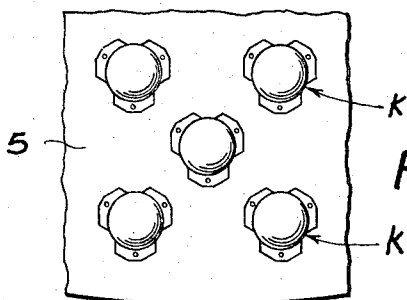


FIG. 8

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3,567,193

## CAP OR BELL FOR BUBBLE-CAP PLATE OR TRAY COLUMNS

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12 Claims

### ABSTRACT OF THE DISCLOSURE

A bubble-cap assembly for a tray of a rectification column, a washing column or a distillation column. The assembly consists of a chimney plate mounted upon the tray with its chimney registering with an opening in the latter and covered by a cap or bell spaced thereabove. A number of angularly spaced tongues extend at right angle to the tray and connect the chimney plate with the bell.

Our present invention relates to a bell or cap for multi-stage tray or plate columns for the intimate mutual contact of a gas and a liquid, especially for gas-washing columns, for distillation columns and for heat-exchange columns of the type used in gas (especially air) rectification in accordance with, for example, the Linde-Frönl low-temperature air-rectification system adapted to recover nitrogen and oxygen from air.

In the art of gas/liquid intimate contact for treatment of a gas with a liquid or vice versa and for low-temperature rectification of gases and their liquefaction products into components of different boiling points and in processes for the distillation of liquids wherein a rising gas stream is brought into intimate contact with a descending liquid, it has been a common practice to provide generally upright columns with a multiplicity of distillation, rectification or washing stages, the resolving power or efficiency of the system being proportional to the number of such stages.

The stages generally are constituted by vertically spaced generally horizontal trays on which the liquid layer is maintained by weirs or the like rising above the upper horizontal surface of the tray. It may be noted also that such trays are referred to variously as "stages," as "plates" and as "bottoms," in addition to the usual descriptive designation as "trays."

When the term "bottoms" or "plates" are used herein, therefore, it is to be understood that the expressions are used interchangeably with the word "trays," which has recently been used to a greater degree than heretofore.

Above the liquid layer retained on each generally horizontal tray, there is provided a gas chamber which opens upwardly into the next higher chamber via one or more passages in the tray. One prior-art-type of tray of this general character is the so-called "bubble-cap" tray which is formed with a multiplicity of openings establishing communication between the gas chambers on opposite sides of each tray. In such systems, each opening is overhung by a downwardly concave and generally upwardly convex bell or cap which acts to deflect the gases rising through the corresponding opening downwardly and outwardly into intimate contact with the liquid layer. As a consequence, bubbling of the gas through the liquid occurs. Because of the downwardly concave configuration of the member overlying the opening in the tray, the member is generally referred to either as a "cap" or as a "bell." These expressions also may be used interchangeably hereinafter. The bell or cap serves to partially enclose a gas compartment above the surface of the respec-

tive tray which is in communication with the next-lower gas chamber through the opening.

In recent times, attempts have been made to replace the early relatively deep bells, with their correspondingly high compartments, with so-called "flat bells" which require less material and labor for their construction and which allow a greater number of stages to be built into the column.

Earlier flat bells have generally comprised caps with slots or tongues, prongs, teeth and scallops adapted to promote turbulence in the vapor, thereby increasing the efficiency of the corresponding stages of the column. However, a difficulty arises since the very flatness of the bell, because of its reduced height, is capable of providing relatively small slotted areas with limited turbulence-inducing effect; moreover, since the flow cross-section of the bells for the gases is relatively small, the pressure drop at each bell is proportionately high and the capacity of the device is limited.

Other proposals whereby the bell compartments are formed with chimneys or stacks which are higher than the upper edges of the slots have been found to be unsatisfactory because with relatively low gas velocities, liquid cannot pass over the upper edge of the chimney or weir onto the next-lower bottom or tray. The result is an increase in the pressure drop.

There is also the danger, in this system, that contaminants or polymerization products may be deposited to obstruct the passages of the bell. In such cases, the bell must be removed at considerable expense, cleaned and replaced. Another disadvantage of earlier bell systems resides in the fact that the bells are difficult to mount and center with respect to the opening, difficult to remove and replace, and sensitive to deformation stresses in handling or in use. Attempts to avoid these difficulties by making the chimneys or weir surrounding the opening unitary with the cap have proved to be unsatisfactory. Another characteristic difficulty of the earlier systems is that they often become deformed or otherwise misshapen so that nonuniform liquid levels are encountered on the trays.

It is an object of the present invention to provide an improved bell construction for a bubble-cap tray, bottom or plate which has a wide load or capacity range and affords excellent operating efficiency.

Another object of our invention is the provision of a bubble-cap structure for a multistage gas rectification, washing or distillation column which has a high flow cross-section, low pressure drop and a substantially better resistance to contamination and blockage by contaminants than earlier systems.

A further object of the instant invention is the provision of an improved flat bell or cap for a bubble-cap tray which is of low cost and can be mounted on the tray or bottom with relatively small labor cost.

Still another object of our invention is the provision of a bubble-cap structure of flat configuration but which can be quickly, inexpensively and easily mounted upon the bubble-cap tray.

According to an important feature of this invention, a rectification column for the low-temperature separation of the components of a fluid in accordance with its boiling point, a column for the washing of gases with liquid or a distillation column is provided with a stack of vertically spaced trays of the bubble-cap type, the trays being provided with respective discharge weirs over which the liquid passes from one tray to the next-lower tray but maintains a liquid layer on the trays. A rising stream of gas, introduced into the column or formed in situ therein, passes upwardly through the trays which are provided with respective openings interconnecting the gas chamber above each tray with the gas chamber therebelow, the

gases rising through these openings being turbulently deflected into the layer of liquid carried by the corresponding tray by a flat-bell bubble-cap structure surmounting the opening. According to the present invention, the bell, hood or cap is downwardly concave and of flattened cross-section with, however, a circular configuration in plan view, the downwardly turned rim or edge of the bell being unbroken.

A key characteristic of this invention resides in our discovery that a wide load or capacity range with high gas/liquid contact efficiency can be obtained without the danger of obstruction by contaminants when the upper edge of the an upwardly rising generally cylindrical chimney or annular weir surrounding the opening and converging upwardly and inwardly from the border of this opening, has its upper edge below the lower edge or rim of the bell-shaped cap. Such a system avoids the need for slotting the bell or scalloping the cap.

As a consequence of such a relationship and the cross-sectional relationships discussed in greater detail below, two distinct gas flows appear to be obtained. One of these gas flows, arising predominantly from the gases passing through the inner or central portions of the cross-section of the chimney or opening is deflected downwardly by the bell-shaped bubble cap and thus is directed substantially downwardly through the layer of liquid retained upon the bubble-cap tray. However, the gases passing through the chimney at the region of its upper edge (which, it has been noted, terminates below the horizontal plane of the lower rim or edge of the downwardly concave bell) appear to flow outwardly substantially across the upper edge of the chimney and perpendicularly to the downwardly deflected streams.

As a consequence of the interaction of these two more distinct gas flows, the turbulence of the gas contacting the liquid is increased sharply by comparison with earlier systems, thereby increasing efficiency at the same time that the flow cross-section is increased. Moreover, even at low gas velocities, the turbulent conditions in the region between the rim of the bell, which lies outwardly of the chimney (which it surrounds with an annular clearance), precludes passage of liquid beneath the bell and over the chimney walls to the opening. The reduced height of the chimney affords a considerable load or capacity range.

Since the bell circumferentially overhangs the chimney, the outlet cross-section of the bell can be considered to be the imaginary right-circular cylinder defined between the downwardly turned outer rim of the bell and the surface of the tray juxtaposed therewith, this cross-section ( $f_4$ ) being, of course, equal to the product of the altitude ( $h_4$ ) of the rim and the circumference  $C$  of the outer rim of the bell. This circumference  $C$  is, of course, equal to  $2\pi R$  where  $R$  is the radius of this rim.

Most desirably, this outlet cross-section of each bell should be approximately equal to the flow cross-section provided between the chimney and the outlet cross-section, the latter cross-section ( $f_2$ ) being the area of the imaginary right-circular cylinder with vertical axis defined above the upper edge or rim of the chimney and having an altitude ( $h_2$ ) equal to the vertical distance between the upper edge of the chimney and the bell; the cross-section can then be considered the product of the altitude  $h_2$  and the circumference  $c$  of the chimney, this circumference being, of course, equal to  $2\pi r$  where  $r$  is the radius of the chimney.

According to a further feature of this invention, the upper edge of the chimney from which the gases of a lower chamber emerge into the bell compartment of one of the bell caps, is so low or of such reduced height as to lie below the upper edge of the discharge weir of the tray. The high turbulence generated at the outlet of the bubble cap thus precludes liquid from passing through the chimneys onto the next-lower trays and confines such movement to a flow over the weirs.

It has also been found to be an important feature of

this invention that the chimney lies above the openings cut into the tray and constituted by a drawn, pressed or stamped sheet metal plate affixed to the upper surface of the tray. The chimneys are inwardly and upwardly convergent with a Laval-nozzle configuration, the inlet side of the chimney being rounded. Such rounding at the inlet or wider side of the chimney has been found to further reduce pressure drop as the gases traverse the bells. The openings for the chimneys can be punched from sheet metal while the marginal portions thereof are pressed transversely to the plane of the sheet to simultaneously form the upwardly converging funnel configuration of the chimney and produce the rounded inlet side in a single step.

We have also observed that there are some important relationships between the dimensions of the bell which must be observed if pressure drop is to be minimized and a wide load range maintained. To establish these relationships, we have determined the outlet cross-sectional area  $f_4$  of the bell to be:

$$f_4 \approx h_4 \times C = 2\pi R h_4 \quad (1)$$

where  $f_4$ ,  $R$ ,  $C$  and  $h_4$  have the meanings previously assigned.

The "transverse" cross-section  $f_2$  is defined then as the flow cross-section at which the rising air stream is deflected outwardly by the bell and may be considered in terms of the relationship:

$$f_2 \approx h_2 \times c = 2\pi r h_2 \quad (2)$$

where  $c$ ,  $r$  and  $h_2$  have the meanings previously given.

The inlet flow cross-section to the bell is defined as  $f_1$  and corresponds to the inner cross-section of the chimney at its upper edge:

$$f_1 \approx 2\pi r \quad (3)$$

disregarding the wall thickness of the chimney.

Finally, one can define the horizontal outlet flow cross-section  $f_3$  of the bell as the annular cross-section in the horizontal plane of the clearance by which the bell projects beyond the chimney so that

$$f_3 \approx 2\pi R - 2\pi r = 2\pi(R - r) \quad (4)$$

The relationships which have been found to apply for best results between these parameters are the following:

$$f_1 \approx f_3 \quad (5)$$

$$f_4 \approx 1.5 f_1 \quad (6)$$

$$f_2 \approx f_4 \quad (7)$$

$$f_2 \approx 1.5 f_1 \quad (8)$$

According to still another feature of this invention, the bell-shaped hood of this invention is secured to the tray via a chimney plate which, surrounding the chimney and the tray opening registering therewith, is formed with a flange lying parallel to the tray and surrounding this opening.

A plurality of angularly equispaced upstanding tongues (preferably three), which advantageously are perpendicular to the flange and to the tray, interconnect the rim of the bell with the flange outwardly of the chimney structure itself. The tongues may be unitarily integral with the chimney plate and can be bent upwardly from the flange in the same operation in which the chimney is stamped therefrom, the tongues being welded to the rim of the bell. Alternatively, the tongues may be formed unitarily integral with the bell and can project downwardly beyond the plane of the continuous rim thereof to engage the chimney plate. It has been found that attachment of the bell to the chimney plate in this latter case can be accomplished conveniently and effectively by providing the chimney flange with inwardly open radial pockets in the operation in which the chimney is formed, these pockets being angularly equispaced about the axis of the chimney corresponding to the tongues or legs. The tongues are formed with outwardly bent lugs or feet adapted to fit

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snugly into these pockets and thus to anchor the bell to the chimney plate and tray and also center the bell with respect to the chimney.

The flange of the chimney plate can be provided with a plurality of angularly equispaced holes for facilitating attachment of the chimney plate to the tray with rivets, bolts or by welding. When removal of the bell structures is not contemplated, spot-welding may be used to attach the chimney structure to the tray.

The lug-and-pocket structure has an important advantage in that the tongues can be deflected radially inwardly to release the bell and permit cleaning of the assembly when such is necessary. However, dismounting of the bell with the relationship of the cross-sections and positions of the edges of the bell and the chimney presented above can be carried out easily. The pocket and lug arrangement eliminates the need for welding of the bell to the chimney structure and thus allows the assembly to be made from materials which are normally difficult to weld, e.g. aluminum. This construction also decreases the assembly costs, permits removal and replacement of the bells, allows storage of the trays without the bells, facilitates transportation of columns and their components and, because it allows aluminum or aluminum alloys to be used, enables the system to be made with less weight. The bell portions are interchangeable and replaceable so that they may be disregarded in the event of contamination or corrosion. The tongues preferably are highly elastic so that they spring into the respective pockets, and can be deflected therefrom by hand and without special tools. It may be noted that synthetic resins as well as light-weight stainless steels and springy aluminum sheets may be used for this purpose.

The above and other objects, features and advantages of the present invention will become more readily apparent from the following description, reference being made to the accompanying drawing in which:

FIG. 1 is a cross-sectional view, taken in a vertical plane, through a bell assembly according to the present invention;

FIG. 2 is a plan view of the blank for forming the chimney prior to welding the bell thereto and with one of the support tongues of the bell shown in its position prior to upward bending while the other support tongues have been bent upwardly;

FIG. 3 is a vertical cross-sectional view through the assembly taken along the line III—III of FIG. 2 but with the bell in place;

FIG. 4 is a perspective view, partly broken away of the assembly of FIGS. 1-3;

FIG. 5 is a view similar to FIG. 4 wherein, however, the bell is mounted upon the chimney plate without welding;

FIG. 6 is a fragmentary perspective view of one of the support tongues of the bell;

FIG. 7 is a cross-sectional view along the line VII—VII of FIG. 5; and

FIG. 8 is a fragmentary plan view, drawn to a reduced scale of a bubble-cap tray according to this invention provided with a number of bubble-cap assemblies according to the present invention.

Referring first to FIG. 1, in which we show some of the relationships previously described, it can be seen that a bubble-cap assembly K, a number of which may be formed on a tray 5 as shown in FIG. 8, comprises a chimney plate 1 overlying the upper surface 5a of the tray 5 which is formed with an opening 5b through which the gases may pass from a lower chamber represented at M to an upper chamber N of the stack of the trays forming the distillation, rectification or washing column.

The plate 1, comprises an annular horizontal flange 1a which overlies the surface 5a and frames the opening 5b while being formed with an upwardly and inwardly converging funnel-shaped chimney 2 in the form of a Laval-type nozzle by stamping, drawing or some other sheet-

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forming process. Rivets, bolts or welds may be used via three angularly spaced openings 4 in the flange 1a to affix the plate 1 to the tray 5. The rivet 10 shown in FIG. 3 represents the fastening means.

As can be seen from FIGS. 1 and 3, the inlet portion 11 of the chimney 2 has a diameter which is identical with the diameter of the opening 5b and registers perfectly with the latter. From this diameter 11, the chimney 2 is rounded inwardly through a quarter-round to the throat 12 of this chimney. The throat 12 has the approximate radius  $r$  and effective flow cross-section as represented at  $f_1$ .

Above the chimney 2, we provide a downwardly concave bell 7 having flattened central portions 7a of approximate radius  $r$  which merges into a quarter-round downwardly turned portion 7b which overhangs the chimney 2 and has a radius  $R$ , somewhat larger than the radius of opening 5b.

The plane P of the rim 7c of bell 7 is disposed above the plate 11 at the upper edge of the chimney 2 so that this upper edge is offset downwardly below the edge 7c of the bell. In other words, the height  $h_5$  of the chimney 2 is less than the altitude  $h_4$  of the rim 7c of the bell.

The gases, of course, flow upwardly through the chimney 2 and thence are deflected outwardly and downwardly by the bell (arrows A) through the transition flow cross-section represented at  $f_2$  between the generally flat portion of the bell and the downward portion which commences at the upper projection of the edge 12 on the bell. The gases are then passed through the horizontal annular overhanged section  $f_3$  prior to flowing through the outlet cross-section  $f_4$ .

The relationships given in Equations 5-8 (above) apply and, as a result a second gas flow occurs along the top or rim 12 of the chimney 2 (arrows B) to intersect the gas flow A at right angles and produce a high turbulence mixture of gas and liquid as represented by the arrows T. The liquid layer on trays 5 may reach the height of the weir W which, it will be seen, is above the rim 12 of the chimney.

As will be apparent from FIGS. 2-4, the stamping operation which forms the chimney plate 1 (FIG. 2) can punch generally wedge-shaped cutouts from opposite sides of tongue 3 which is bent upwardly at right angles to the flange 1a (FIGS. 3 and 4) and are welded at 3a to the rim 7c of the bell.

In FIGS. 5-7, we have shown a somewhat different system for supporting the bell 107 on the chimney plate 101 the flange of which is represented at 101a. Three angularly equispaced pockets 101c are formed in the flange 101a to receive feet 103b of downwardly extending tongues 103a of the bell 107. The chimney of the device is shown at 102 to have a rounded inlet side 106. A slot 101b transverse to the pocket 101c receives the radially extending feet 103b while shoulders 103c bear against the surface of flange 101a on opposite sides of this slot. The feet 103b are bent at right angles to the tongues and can be deflected rearwardly (dot-dash line in FIG. 7) to enable withdrawal of the bell from the chimney 2. If the portions of the assembly are of a substantially inelastic material, prior to assembly the tongues are positioned parallel to the axis of the bell and then are pushed into the slits 101b axially. The legs 103b are then bent up into the pockets. When the bell is of elastic material, the feet 103b are simply permitted to snap into the pockets from the position shown in dot-dash lines.

The improvement described and illustrated is believed to admit of many modifications within the ability of persons skilled in the art, all such modifications being considered within the spirit and scope of the invention except as limited by the appended claims.

We claim:

1. A bell assembly for a bubble-cap tray of a gas-washing, distillation or rectification column or the like, said assembly comprising a chimney mounted on a tray and

registering with an opening provided therein for transfer of gas between a chamber below said tray and a chamber thereabove; and a downwardly concave bell above said chimney and radially overhanging same, the upper rim of said chimney lying below the lower rim of said bell, said chimney having a flow cross section  $f_1$  at said rim, said bell and said rim defining an intermediate flow cross section  $f_2$  between said rim and said bell along an imaginary right circular cylinder between said rim and said bell, said lower rim of said bell and said right circular cylinder defining in a horizontal plane an annular flow cross section  $f_3$  and said lower rim of said bell defining along a right circular cylinder extending from said lower rim to a surface juxtaposed therewith a discharge flow cross section  $f_4$ , said flow cross sections  $f_1$ ,  $f_2$ ,  $f_3$  and  $f_4$  being in the following relationship:

$$\begin{aligned} f_1 &\approx f_3 \\ f_4 &\approx 1.5f_1 \\ f_2 &\approx f_4 \\ f_2 &\approx 1.5f_1 \end{aligned}$$

2. The assembly as defined in claim 1 wherein said tray has an outlet weir for a liquid layer sustainable on said tray and said upper rim of said chimney lies below the upper edge of said weir.

3. The assembly defined in claim 1 wherein said chimney has an inlet side substantially co-extensive with said opening and converges upwardly and inwardly therefrom in the direction of said bell, said inlet side of said chimney being rounded convexly inwardly.

4. A bell assembly for a bubble-cap tray of a gas-washing, distillation or rectification column or the like, said assembly comprising a chimney mounted on a tray and registering with an opening provided therein for transfer of gas between a chamber below said tray and a chamber thereabove; a downwardly concave bell above said chimney and radially overhanging same, the upper rim of said chimney lying below the lower rim of said bell, said chimney being unitarily pressed from a chimney plate and provided with an outwardly extending flange parallel to said tray and affixed thereto; and a plurality of angularly equispaced tongues outwardly of said chimney and connecting said bell with said flange.

5. The assembly as defined in claim 4 wherein said tray has an outlet weir for a liquid layer sustainable on said tray and said upper rim of said chimney lies below the upper edge of said weir.

6. The assembly defined in claim 4 wherein said chimney has an inlet side substantially co-extensive with said

opening and converges upwardly and inwardly therefrom in the direction of said bell, said inlet side of said chimney being rounded convexly inwardly.

7. The assembly defined in claim 4 wherein said flange is provided with a plurality of angularly equispaced radially inwardly opened pockets, said tongues having feet removably received in said pockets.

8. The assembly defined in claim 7 wherein said tongues are unitarily integral with said bell.

9. The assembly defined in claim 8 wherein said feet are bent at right angles to said tongues and are received in slots provided in said flange adjacent the respective pockets.

10. The assembly defined in claim 4 wherein said tongues are welded to said bell along the lower rim thereof.

11. The assembly defined in claim 10 wherein said tongues are bent upwardly from said flange and are unitarily integral therewith.

12. The assembly defined in claim 4 wherein said chimney has a flow cross section  $f_1$  at said rim, said bell and said rim defining an intermediate flow cross section  $f_2$  between said rim and said bell along an imaginary right circular cylinder between said rim and said bell, said lower rim of said bell and said right circular cylinder defining in a horizontal plane an annular flow cross section  $f_3$  and said lower rim of said bell defining along a right circular cylinder extending from said lower rim to a surface juxtaposed therewith a discharge flow cross section  $f_4$ , said flow cross sections  $f_1$ ,  $f_2$ ,  $f_3$  and  $f_4$  being in the following relationship:

$$\begin{aligned} f_1 &\approx f_3 \\ f_4 &\approx 1.5f_1 \\ f_2 &\approx f_4 \\ f_2 &\approx 1.5f_1 \end{aligned}$$

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