Tray Specification

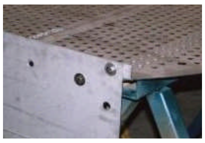
OVERVIEW

Conventional absorption, distillation or fractionating trays consist of vapour/liquid contacting decks or trays with segmented liquid downflow areas. Columns can contain any number of trays installed vertically above each other. Each set of trays needs to be individually designed for the specific process and mechanical requirements anticipated within the column.

The design and manufacture of trays to meet the requirements the major operating companies and engineering contractors is restricted to a small number of specialist international vendors such as HAT who have acquired and developed the experience and design tools to deliver a reliable and competitive product. Likewise, assembly and inspection of the trays inside the column should ideally be undertaken by specialist tray installers, like ourselves, or otherwise under our supervision.

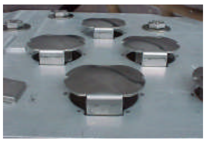
HAT manufactures a comprehensive range of **AlphaTRAY™** standard and high performance mass transfer trays as listed below.

Standard Types:



ST
Sieve Trays

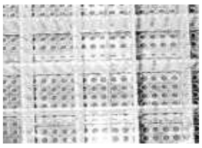
FV
Fixed Valve Trays



MV
Moving Valve Trays

BC
Bubble Cap Trays

High Performance Types:



HST
Highspeed Sieve Trays

HSC
Highspeed Swirl Cyclone Trays

Tray Specification

GENERIC TRAY TYPES

Sieve Trays - have tray deck areas uniformly perforated with round holes. Tray designs with perforations as small as 6mm or as large as 25mm are common with 13mm/19mm being the most frequently used. Vapour flow through the tray deck to contact the liquid is controlled by the number and size of the perforations. For efficient operation, the hole velocity must be sufficient to balance the head of liquid on the tray deck and thus prevent liquid from passing through the perforations to the tray below. On the other hand high hole velocities may cause severe liquid entrainment to the tray above. Consequently Sieve Trays have a narrow operating range, no more than 2:1.

To overcome this weakness, HAT has exclusively licensed the **Highspeed**™ sieve tray technology from Germany which offers both significantly improved capacity and turndown.

Valve Trays - have perforated tray decks fitted with moveable discs (valves) to vary the tray open area with changing vapour load. There are numerous valve types which may either have legs fitted to the valve disc to restrict upwards movement or alternatively the valve disc movement is restricted by a "cage" fitted to the tray deck.

At very low vapour rates, the valve discs rest on the tray deck to almost close off completely the tray deck perforations thus minimising tray open area. As the vapour rate rises, the valve discs are lifted from the tray deck which increases the open area for vapour flow between the valve disc and the tray deck.

The effective operating range of valve trays is dependent on specific service conditions as well as pressure drop limitations and can be as high as 10:1.

Fixed Valve Trays - the fixed valve tray is manufactured by punching and forming integral valves over the tray deck. By punching the fixed slots in a parallel to liquid flow arrangement, the fixed valve tray gives higher capacity than the sieve tray with a greater availabilty for turndown.

Bubble Caps - consist of bell shaped caps fixed to cylindrical risers through which the vapour passes the tray deck. The caps divert the vapour flow below the level of liquid on the tray deck where it is jetted into the liquid either through slots at the bottom of the cap or else between the skirt of the cap and the tray deck.

Swirl Cyclone Trays - also under exclusive licence, HAT's **Highspeed**™ swirl trays offer a high performance solution to many large column situations and can also be retrofitted to provide additional processing capacity relatively easily. Phase mixing, mass transfer and phase separation occur rapidly within swirl elements, achieving both high efficiency and high capacity.

Tray Specification

TRAY FUNCTION

Mass transfer columns in general operate with countercurrent vapour and liquid flow with the tray decks used to provide stagewise contact between the vapour and liquid resulting in light component-rich overhead product and heavy component-rich bottoms product. The basic flow pattern on a cross-flow tray is liquid phase continuous and vapour phase dispersed through the liquid. This ensures maximum vapour contact with the liquid but at the expense of creating a barrier to vapour flow that can result in a substantial pressure loss across the tray.

The sketch shown in Fig.1 illustrates the operating principle of conventional 1-pass and 2-pass fractionating trays. In each case, clear liquid enters the tray deck area from under the downcomer apron. Simultaneously, vapour from the tray below passes through the open area (perforations, valves or bubble caps) where it must bubble through the liquid forming a 2-phase froth in which mass transfer takes place whilst the froth moves horizontally across the tray deck. Vapour continuously disengages from the froth and flows to the tray above. The froth discharges over the outlet weir into the tray downcomer which acts as a settling zone where vapour disengagement takes place thus allowing clear liquid to flow to the tray below.

Proper and efficient functioning of trays for each specific service requires a unique design configuration based on a careful balance and optimisation of a number of interrelated and often opposing factors which in turn requires an accurate and reliable profile of the flowrates and properties of the internal column traffic.

TRAY CONFIGURATION

Listed below are the key tray design parameters which impact on column operation:

Active Area (or Bubble Area) - is the deck area of the tray which may either be perforated or fitted with valves or bubble caps and is the area available for vapour/liquid contacting. The vapour handling capacity of a tray is proportional to the active area (i.e. inversely proportional to the approach to Jet Flood).

Downcomer Area - is the area available for the transport of liquid from one tray to the next tray below. Also a very important function of the downcomers is to allow for the disengagement of vapour from the liquid which is a function of both residence time of the liquid in the downcomer. Undersized downcomers will result in downcomer flood.

Open Area (or Hole Area) - is the aggregate area available for vapour passage through the tray deck via perforations or valve and bubble cap slots. This is a critical factor in the tray operating range since high vapour velocity through the open area (hole velocity) will induce heavy liquid entrainment (as well as high pressure drop), but low hole velocity may allow liquid to "weep" or even "dump" through the tray deck to the tray below. The influence of open area on pressure drop also impacts on the liquid back-up in the downcomer.

Tray Spacing - is the vertical distance between adjacent tray decks. This effects both the height of spray that may be generated on the tray deck before liquid carryover and also the allowable head of liquid in the downcomers.

Downcomer Clearance - is the space below the downcomer apron allowing liquid to flow from the downcomer to the tray deck below. This must be sized to provide a balance between the minimum head loss required for good liquid distribution across the tray deck and avoiding excessive downcomer back-up.

Outlet Weir Height - The outlet weir is used to maintain a head of liquid on the tray deck as well as to ensure a positive vapour seal to the bottom of the downcomer.

Flow Path Length - is the span of tray deck between the downcomer inlet and the outlet weir and is the shortest path that the liquid takes in crossing the active area from one downcomer to the next. This has a big influence on tray efficiency, particularly in small columns as well as trays with large or multiple downcomers.

Number of Flow Paths - Larger diameter trays may be fitted with multiple downcomers to reduce the liquid load across each active area section. This reduces the weir load and liquid head on the tray deck resulting in higher vapour capacity, lower pressure drop and improved operating turndown range.

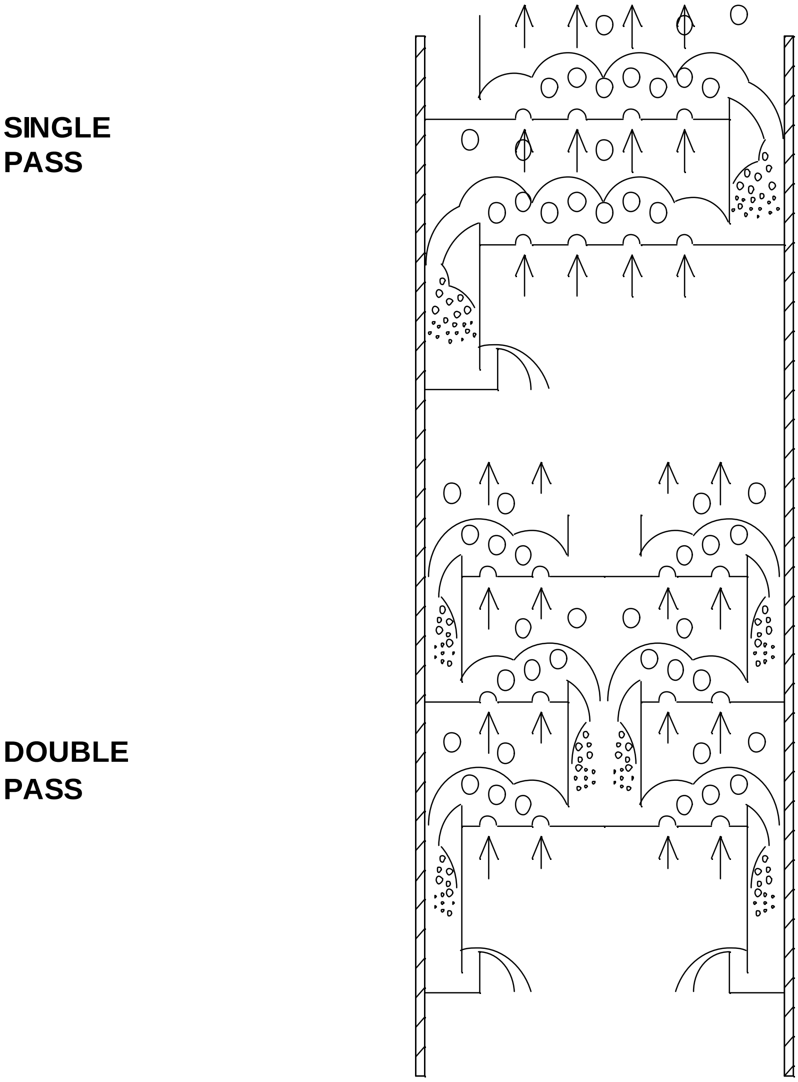


Figure 1

TRAY VAPOUR AND LIQUID FLOWPATHS

TRAY FEEDS & DRAWS

All columns in commercial operations will have process streams feeding to the column as well as product draw points. However any interference with the normal vapour and liquid flows on well designed trays can easily cause tray malfunction so the location and configuration of column feeds and draws is critical to overall column performance.

Tray feeds may be liquid, vapour or mixed.

The generally preferred arrangement for liquid feed between trays is a perforated pipe which directs liquid onto the vapour side of the downcomer apron so that the feed liquid mixes with the reflux from the tray above at the downcomer outlet. If the feed liquid is hotter than the liquid on the tray, an insulation baffle (or target plate) should be fitted to the vapour side of the downcomer apron to prevent vaporisation of liquid in the downcomer. A good rule-of-thumb (except for large size feed pipes) is that the perforated pipe should have a 200mm clearance above the tray deck and a 50mm clearance from the downcomer apron.

The preferred arrangement for liquid feed to the top tray is to feed into a "false downcomer". Typically the false downcomer would be 300mm high with half the normal downcomer clearance (minimum 25mm) to ensure sufficient head in the downcomer for good lateral distribution of liquid across the tray deck. Alternatively, an inlet weir may be installed in place of the "false downcomer".

In most cases an open nozzle is adequate for vapour feeds between trays which should be located to provide at least 400mm disengagement space from the tray above (therefore increase tray space by at least 50%) and oriented perpendicular to the liquid flow on the tray deck.

The reboiler return should be located at least 300mm above the liquid level and must also avoid any interference with liquid flowing from the bottom tray seal pan.

Side draw liquid product is drawn from trays by locating draw nozzles in tray draw sumps normally placed below downcomers. Both the draw nozzle and sump must be sized to avoid drawing vapour. Typically the draw nozzle would be sized to restrict liquid velocity to below 1m/s and the depth of the draw sump would exceed 2.5 x nozzle diameter with the draw nozzle flush with the sump floor. The depth of the draw sump should not exceed 30% of normal tray spacing.

Large volume draws and total draws may require chimney trays.

A draw pan located below a seal pan may be used to draw liquid from below the bottom tray.

Tray Specification

TRAY OPERATING LIMITS

The tray operating envelope shown in Fig. 2 illustrates the relationship between liquid and vapour rates and the normal tray operating limits. The absolute locations of the envelope boundaries are a function of the tray layout and so each tray design will result in a unique set of operating limits. An ideal tray design would have the full range of expected column operation located within the envelope.

The normal tray operating limits are defined as follows:-

Jet Flood - is the criteria used to predict the point at which massive liquid carryover will occur due to the height of spray on the tray deck exceeding the available tray space. It is normal practice to limit tray design to a maximum of 80% of jet flood to allow a safety margin on tower control, possible discrepancies of VLE data and also the limitations of the flooding correlation used.

Entrainment Limit - is reached when the velocity of vapour through the tray open area is high enough to project liquid droplets to the tray above.

Weeping - occurs when the velocity of the vapour through the tray open area is too low to prevent liquid from leaking through the open area thus by-passing contact area to the tray below. Most valve and sieve trays will weep in normal operation. Weeping is considered excessive when it is sufficient to cause loss of efficiency - usually 10 to 20%.

Blowing Flood - occurs at low liquid rates at which the tray operates in the spray regime resulting in massive entrainment of liquid to the tray above to the extent that the tray deck is essentially blown dry.

Downcomer Flood- occurs at high liquid loads when the downcomers are too small to allow effective vapour disengagement (either because the downward velocity or "inlet velocity" of the liquid is too high or else insufficient residence time) causing vapour entrainment to the tray below. The resulting increased aeration of the liquid in the downcomer may also cause premature downcomer back-up flood.

Downcomer Back-up Flood - occurs when the head of liquid in the downcomer backs up onto the tray deck. The head of clear liquid in the downcomer is a balance of the pressure drop across the tray plus the head loss through the downcomer clearance. However an aeration factor must be applied to estimate the actual height of aerated liquid in the downcomer.

Tray Pressure Drop - may also be a limiting criteria particularly in low pressure services. The operating tray pressure drop is the sum of the dry pressure drop caused by the resistance to vapour flow through the tray open area and the head of clear liquid on the tray deck. The head of clear liquid on the tray deck is a function of weir height and weir length (as well as liquid and vapour rates and physical properties) and so pressure drop may be reduced by increasing the number of flowpaths in high liquid rate services.

Tray Specification

PROCESS DESIGN

HAT have developed design software to provide rapid, consistent and reliable tray designs and ratings. This ensures that all tray design parameters can be fully evaluated to ensure optimum performance over the complete range of anticipated operation. Input data should preferably be generated from a commercial column simulation package that should include stage-by-stage liquid and vapour loads, densities and transport properties. This is essential to ensure that the tray design takes account of the full range of loads across the each set of trays.

HAT tray design software is an extensive compilation of a multiplicity of flow and flood correlations to check tray design for:

- Jet flood
- Entrainment limits
- Pressure drop
- Downcomer back-up
- Downcomer inlet velocity
- Weir loadings
- Downcomer residence time
- Weeping

In addition, flagging of tray design parameters such as flow path length, valve count, and balanced designs in trays with multiple flow paths ensure a tray design which is efficient and practical.

Design Input

Accurate prediction of column internal traffic is essential to the evaluation of tray design layout and prediction of tray performance. The following is the minimum input data required by HAT for tray design and evaluation:

- Vapour & liquid flowrates
- Vapour & liquid densities
- Liquid viscosities & surface tensions.

This information should be generated on a stage-by-stage (or tray-by-tray) basis using a commercial column simulation package (eg. Process, Hysim or Aspen).

If an evaluation of existing trays is required then the following additional information should be provided either in the existing tray arrangement drawings or in tabulated form:

- Tray diameter
- Tray spacing
- Downcomer inlet and outlet widths
- Weir heights and downcomer clearances.
- Number and type of valves or perforations.

Any other process limitations which need to be taken into account should be provided such as:

- Pressure drop limitations
- Foaming tendency of the system
- Possible fouling (eg solids, sludge, coking, scale or polymer build-up)

Design Output

All good tray manufacturers such as HAT have developed design software to evaluate the effect of all tray design criteria and provide a reliable and optimised tray design.

The software is a useful tool in assessing the performance of existing trays and evaluating viable options for modifying the trays to improve performance (eg. increasing open area by fitting new tray decks or moving the downcomer apron to modify balance between active area). The evaluation may also indicate that column capacity is restricted by tray design limitations in which case it may be necessary to consider alternative options such as replacing the trays with high performance trays or packings or replacing the column.

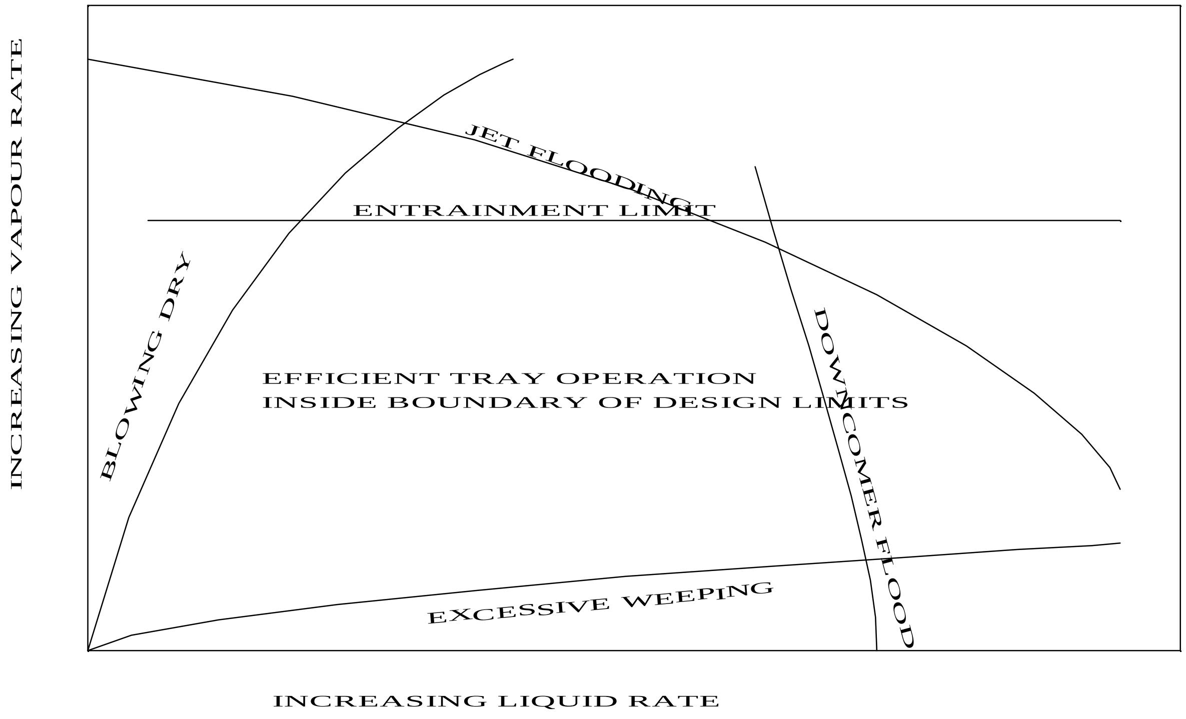


Figure 2

TYPICAL TRAY OPERATING ENVELOPE

TRAY DESIGN - MECHANICAL

HAT have developed a comprehensive design standard for the mechanical design of trays which, along with the tray geometry specified in the tray rating, is used as a basis for the tray CAD input except where more stringent requirements are specified by the client. Generally, the HAT design standards comply with the design requirements of most major oil companies.

The CAD/CAM system for tray design and manufacture developed by HAT is necessary to ensure good fit up of all tray parts. An added benefit from the accuracy of this system is that it allows for tray design with through-bolted panel joints that results in a more rigid structure than can be achieved by clamping tray panels together with friction washers. Tray drawings are produced from computer generated three-dimensional models of trays assembled in the vessel and include tray attachments and internal piping where relevant. The CAD models are subsequently used to program CNC machines for accurate fabrication of individual components.

STANDARD MECHANICAL DESIGN FEATURES

Trays for columns larger than about 900mm diameter are manufactured in sections sized to fit through vessel manways and are assembled inside the vessel to form complete trays which conform to the required specific tray layout. The installed trays are therefore removable for maintenance purposes with one panel on each flow path designed as an inspection or access manway.

The trays are clamped or bolted to attachments welded to the vessel wall. Except where clients' own design standards mandate otherwise, HAT design and manufacture fractionating trays to a set of design standards that includes the following features:

Tray Support Ring Size

Trays can normally be designed to suit existing tray attachments in existing columns. For new columns, the trays are designed for attachment to support rings as follows:

COLUMN DIAMETER	SUPPORT RING WIDTH
1500mm and less	40mm
1501 to 2500mm	50mm
2501 to 3500mm	60mm
3501 to 4500mm	80mm
4501 to 6000mm	90mm
6001 to 9000mm	100mm
9001mm and greater	Case by case

The minimum recommended thickness for support rings, downcomer bars and other welded attachments is 10mm for carbon steel and 6mm for stainless steel and non-ferrous alloys. For columns where a corrosion allowance is applicable for the shell, the minimum thickness given above should be increased by adding twice the corrosion allownace.

Tray Specification

Tray Diameter

To allow for column diameter tolerance and out of roundness, trays are designed with a wall clearance on the following basis:

COLUMN DIAMETER	TRAY-VESSEL WALL CLEARANCE
900 - 2000mm	20mm
2001 - 3500mm	25mm
3501 - 6000mm	30mm

Structural Design

Tray deck and downcomer panels are fabricated from 2mm (+ C.A.) thick alloy steel or 3mm (+ C.A.) carbon steel. Where appropriate, panels are folded to form integral trusses (box section) designed for a deflection of less than 3mm (5mm in columns larger than 3500mm) under a uniform live load of 1.5 kPa and to withstand a concentrated load of 1.5kN under assembly and maintenance conditions. The depth of the box sections is generally restricted to 20% of the normal tray space for both process and access reasons. In larger diameter columns where box section depth would be excessive, separate major beams are used. All major beams are through bolted to support brackets welded to the column wall.

The upper sections of downcomers generally functions as beam supporting tray deck panels and is therefore through bolted to the downcomer bolting bars. Lower downcomer sections may be clamped to the downcomer bolting bar.

In some services the trays may need to be designed to withstand higher downwards or in some cases upwards loads. Heavy duty tray design may incorporate some or all of the following features to increase mechanical strength:

- Manufacture from heavier gauge material
- Larger box/beam sections
- Increased number of major beams
- Tied-in box sections (ie bolted to wall cleats)
- Closer spacing of bolting and clamping.

Tray Manways

All tray decks are designed with one tray manway panel per pass to allow for inspection and maintenance access. Tray manway clearance is normally a minimum of 380mm x 470mm provided that the tray manway panels and adjacent tray deck panels are able to pass through the vessel manway. The tray manway panels are clamped in position using fasteners which are designed to allow the manway panels to be removed from either above or below.

TRAY INSTALLATION

To minimise installation time, trays are designed using the minimum number of individual panels that can be installed through the vessel manway and other access (and mass transfer) limitations.

Fractionating trays are supplied in "completely knocked down" (CKD) form in crates for final assembly inside the column. Therefore it only becomes a proper functioning fractionating tray when it has been properly assembled. No matter how well a tray has been designed and manufactured, sloppy installation will result in a tray which does not conform to the design specification and which may therefore not perform. The following are just a few common installation faults that would impact adversely on tray performance:

- Incorrect panel location - eg similar shape panels with wrong number of valves
- Poor panel fit-up / adjustment - possible large gaps in panel joints
- Incomplete or insecure bolting
- Incorrect use of peripheral ledge clamps - not properly overlapping tray ring
- Missing seal plates
- Trays decks not installed level
- Incorrect downcomer clearances - could result in premature downcomer flood
- Incorrect / unlevel weir heights

A standard installation procedure for fitting most fractionating trays in columns should provide some methodology with which to avoid most of the above potential installation faults. However additional procedures may be required for major tray replacement work particularly where changes to flow paths are called for.

Standard practice is to ship fractionating trays with all like panels in the same crate. All tray parts are numbered according to the numbering system shown in the tray arrangement and assembly drawings, with all like parts having the same part number. A good ground crew would unpack the crates as part of the installation preparation and sort out the components on a tray by tray basis onto pallets each clearly marked with tray number and arranged in sequence of installation. The tray arrangement drawings are used as a reference document to ensure that the correct part numbers and quantities are allocated to each tray and any missing parts or unmarked parts can be identified and corrective action taken before installation takes place.

Working space inside columns is very limited and therefore for smooth installation in the shortest possible time it is best to place tray parts inside the column in assembly sequence. This requires good communication between the tray fitters and the ground crew.

Tray panel joints are engineered to provide plenty of adjustment inside the column in order to take up vessel and welded-in attachment tolerances. However this feature requires careful installation practice to avoid poor fit up. In particular, all tray panels should be located as shown in the arrangement drawings and loosely bolted (including the manway panels). They can then if necessary be adjusted to avoid excessive gaps or uneven and insufficient overlapping of the tray rings before torquing up.

Tray Specification

To provide for installation fit up and adjustment, oversize bolt holes are used at tray joints. HAT typically use one 12mm and one 20mm diameter hole with M10 bolting at each fixing position. Bolting and clamping is generally arranged around all tray panels on maximum 150mm centres. Small gaps between some tray panels may be unavoidable and are acceptable on the tray active area. Where the size of the gap is excessive, bolted down seal plates should be used to cover the gap. Gaps on downcomer panels must be avoided. Also tray panel joints on the downcomer floor should be minimised or eliminated because the higher liquid levels in the downcomers may result in substantial leakage.

Before clamping down the tray manways, a final inspection of the installed trays needs to carried out by a suitably experienced and responsible engineer. In our Installation Manual is a checklist which may be used to verify the installation of each tray.

TRAY DESIGN CRITERIA

The following design rules are valid for most systems and may be used to estimate valve tray design and predict hydraulic performance.

HAT have developed computer software to optimise the design of Trays which incorporate various design model to provide more rigorous designs as well as analysing all permutations of tray geometry. Included are correlations which consider the effects of system properties as well as indicating the requirement for tray features not listed below such as anti-jump baffles and notched weirs. This facility should therefore always be used to provide consistent, reliable and cost effective final designs.

NUMBER OF FLOW PATHS

Design Criteria: Max Weir Load = 0.085 x Tray Space (m) - 0.02 $m^3/m.s$

Weir Load (U_d) = $\dfrac{\text{Liquid Rate } (m^3/s)}{\text{Numberof Flowpathsx Weir Length } (m)}$ $m^3/m.s$

Min. Flow Path Length = 430mm

Min. Weir Length = 0.6 x Column Diameter

ACTIVE AREA

Design Criteria: Max Jet Flood = 85 %

Where:

[1] Capacity Factor (CF_0) = $0.14 \times \left(\dfrac{\text{Tray Space (mm)}}{610}\right)^{\frac{1}{3}} - \left(\dfrac{\text{Tray Space (mm)}}{610}\right)\dfrac{\rho_g}{3724}$ m/s

[2] Vapour Load (C_{SA}) = $\dfrac{\text{Vapour Rate } (m^3/s)}{\text{Tray Active Area } (m^2)} \cdot \sqrt{\dfrac{\rho_g \text{ m/s}}{(\rho_L - \rho_g)}}$

[3] Jet Flood = $\dfrac{100}{FF \times CF_0 \times 0.79 \sigma^{0.1}} \cdot \left(C_{SA} + \dfrac{\text{Liquid Rate } (m^3/s)}{N_p \times W_{fp}}\right)$ %

N_p = Number of Flow Paths
W_{fp} = Flow Path Width (Active Area/Flow Path Length) m
FF = Foam Factor
σ = Liquid Surface Tension mN/m
ρ_g = Vapour Density kg/m^3
= Liquid Density kg/m^3

NUMBER OF TRAY VALVES

Design Criteria: Tray Pressure Drop within process limitations at maximum vapour load.

Orifice Vapour Velocity (V_o) above weep point at minimum vapour load.

Where:

[4] Dry Tray Pressure Drop = $\frac{175 \times V_o^2 \times \rho_g}{\rho_L}$ (valves full open) mm liquid

Dry Tray Pressure Drop = $\frac{105 \times V_o^2 \times \rho_g}{\rho_L} + \frac{800 \times M_v}{\rho_L \times A_v}$ (valves part open) mm liquid

V_o = Vapour Rate (m^3/s) / (0.0012 x Number Valves / Tray) m/s
M_v = Mass of each valve (0.04 for 16g valves) kg
A_v = Valve Disc Area (=0.0016) m^2

[5] Clear Liquid Height (H_c) = $406 \times \left(\frac{\text{Liquid Rate } (m^3/s)}{C_{SA} \times L_w \times N_p} \right)^{\frac{1}{3}} \times (H_w)^{\frac{2}{3}}$ mm

L_w = Weir Length m
H_w = Weir Height m

[6] Tray Pressure Drop = Dry Tray Pressure Drop (maximum) + H_c mm liquid

[7] V_o(weep point) = $\frac{4.413 \times H_d \text{(weep point)}}{1000} \times \left(\frac{\rho_L - \rho_g}{\rho_g} \right)^{\frac{1}{2}}$ m/s

DOWNCOMER AREA

Design Criteria: Maximum Downcomer Back-up (as clear liquid) = 0.4 x Tray Space

Maximum Downcomer Inlet Velocity (V_d) = 0.9 x DC Velocity Limit

Where:

[8] Downcomer Head Loss = $51 \times \left(\frac{\text{Liquid Rate} (m^3/s)}{N_p \text{ x } L_w \text{ x } H_i \text{ x } C_d} \right)^2$ mm liquid

[9] Downcomer Back-up = H_c + (Tray + DC Head Loss) x $\left(\frac{\rho_L}{\rho_L - \rho_g} \right)$ mm liquid

[10] DC Velocity (V_d) = $\frac{\text{Liquid Rate} (m^3/s)}{N_{dc} \times \text{Downcomer Inlet Area}}$ m/s

N_{dc} = Number of downcomers on tray.

[11] DC Velocity Limit = $0.008 \times \left(\text{Tray Space (m) x } (\rho_L - \rho_g) \right)^{\frac{1}{2}}$ x FF m/s