Tray Design Techniques at Low Liquid Load Conditions

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We (as an industry) have a difficult time describing criteria for minimum liquid load in many trayed distillation applications. At present most people look at two criteria for standard downcomers: minimum weir loading and spray (blowing) factor. For truncated downcomers a third factor deals with keeping the downcomer sealed against vapor by-pass. The problem is that the first two are ill defined and little is understood about them.

Specific services including wash sections of towers, upper sections of low pressure distillation towers and separation of high boilers all can lead to tray designs that have very low liquid loads. Today many of these applications use random or structured packings as the preferred tower internal. However, as engineers, our job is to find economical solutions to problems. Many times the economical solution may still be trays. This paper is intended to address this issue and help define a design approach with Picket Fence outlet weirs that can accommodate low liquid load tray design.

Previously, we stated(5), there are low liquid rates that result in trays operating in the spray and/or blowing regime. "Lack of Liquid on the tray may seem difficult to understand, as the outlet weir keeps a liquid pool on the tray. How could the tray not have enough liquid?" Many people have a difficult time describing exactly what minimum liquid load is for trayed towers. As the authors understand it, there are two criteria at present: minimum weir loading and spray (blowing) factor. The addition of picket fence weirs to retain more of the liquid droplets over the tray is the most common method to extend a tray's operating range. This paper is intended to address this issue and to provide a definition of how to design Picket Fence outlet weirs that can accommodate low liquid load tray design.

According to FRI sieve tray observations(9), when reducing the liquid rate on a tray, below approximately 2.0 gpm/inch of weir loading, the vapor capacity must be reduced to maintain the same entrainment rate. This has been repeated many times at FRI and they have observed this phenomenon for many devices other than sieve trays. FRI has gone to "great lengths" of making their vapor capacity correlations have lower maximum values at very low liquid loads. It is believed that this is a jet flood phenomenon and the maximum vapor capacity equation is treated as such. This is really a misinterpretation on FRI's part and that what is being observed, in reality, is a transition between the spray and froth regime as Kister and Haas pointed out in 1988(10).

To better understand what is happening on a tray at low liquid loads you need to understand what is happening at the outlet weir. As liquid rate drops on a tray, the froth height reduces. There is the famous Francis Weir Formula for froth on a tray deck(6):

$$H_{froth} = 1.04\ (Q_L/(1-\varepsilon_w)\ C_d\ Bw)^{2/3}/g^{1/3} \qquad \text{Eq.(1)}$$

Where,

H_{froth}	=	Height of Froth flowing over weir, m
ε_w	=	volume of vapor in 2 phase dispersion (fraction)
Q_L	=	liquid load, m^3/sec
Bw	=	weir length, m
g	=	gravitation acceleration = 9.8066 m/sec^2
Cd	=	Discharge Coefficient (typically = 0.6)

This equation was used quite heavily through the 1970's and 1980's*. There have been modifications to it because people noticed that it breaks down at low weir loading. One modification was that the full weir height should not be employed. Many people use weir height adjustors such as:

1. Weir heights are limited to 2" regardless of the true weir height.
2. Weir heights applied in equation (1) are 1/2 the true weir height.

By making these adjustments, people were unknowingly adjusting the clear liquid height on the tray for froth aeration and spray carryover into the downcomer. As a tray operates closer and closer to the spray regime, the droplet throw over the outlet weir becomes very significant until all the flow over the weir is in droplet form. People have discovered that there are minimum liquid loads such that once a tray has less than a certain weir loading, all the liquid is in droplet form.

It wasn't until the mid 1980's that people realized the Francis Weir height approach was having too many "fudge factors" added to it and that it should be replaced with an equation that simply calculated (what each tray designer wants anyway) the froth height. Colwell's equation(4) came out in the early 1980's and has basically replaced the Francis Weir Formula, even gaining acceptance at FRI(7).

Many people have discussed observations where they discovered that, at times, their trays (both in the simulators and in the real towers) were blowing "dry" at low liquid loads. What they were observing was the transition of the frothy regime on the tray (liquid with jets of bubbles passing through it) to the spray (or blowing) regime on the tray. The spray (blowing) regime is defined here as a vapor continuous phase with liquid droplets "dancing" on the tray.

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* Most tray designers used this equation up to and through the mid 1980's. Colwell's equation came out in the early 1980's and replaced it, even gaining acceptance at FRI.

The observation of when this phenomenon occurred has always been recorded by simulator operators as when they could "see through the froth" and observe the tray deck. Armed with an enormous amount of data, Union Carbide Corporation (UCC) came up with a vapor momentum force equation that helped define when the vapor would "lift" the liquid from the tray deck. This work is NOT to be confused with the system limit that FRI has established. What UCC had discovered is that hole velocity, hole size and height of calculated clear liquid on the tray, all affect this transition. Equation 2.25 in Lockett's book was thus developed[(8)] for sieve trays. This equation has been successfully applied at Sulzer Chemtech many times, see equation 2 below. The applicable minimum Spray Factor to be used in this equation is 2.78. The addition of the K term came about through data evaluation at Sulzer and also feedback from actual tower operation. The value of the K term in Equation 2 for valve trays indicates that devices where the vapor enters the tray horizontally actually reduce entrainment significantly at low liquid rates.

$$\text{Spray Factor} = K * H_{CL} * \rho_L^{0.5} / (Dp\ U_H\ \rho_V^{0.5}) \qquad \text{Eq.(2)}$$

Where,

H_{CL} = Clear Liquid height, meters

K = 1.0 for sieve trays, 2.5 for movable or fixed valves

Dp = hole Diameter, meters

U_H = Vapor Hole Velocity, m/sec

ρ_V = Vapor Density, Kg/m^3

ρ_L = Liquid Density, Kg/m^3

Four things can be done to a tray to help increase the Spray Factor in this equation; increase weir height, increase open area, decrease opening size or decrease weir length. Of these four, the most effective method to increase Spray Factor is to decrease the weir length. The best way to do this is to picket the outlet weir. We have successfully applied picketing to many trays. The following are a few examples.

Examples

A client of Sulzer Chemtech indicated that the trays they have had for many years were experiencing large amounts of carryover from the overhead of the tower, low pressure drop and the trays had poor efficiency. At the same time they were not near a predicted maximum percent vapor flood. They were about to replace the trays with new higher capacity trays, but it was pointed out that if they did not understand what was going on with their current trays, that the new trays would not work as well as expected. After looking at current operating information, it was discovered that the weir loading was extremely low, 0.26 gpm/in. The spray (blowing) factor (equation 2) was too low as well, 1.45. We determined that they could simply add pickets to the outlet weir and the tower would work fine. This was enacted (we could have sold a full set of new trays with picket fence weirs – but we were too honest), and they discovered exactly how good the spray (blowing) factor equation really is. The rating sheets and weir layout is shown Appendix A. This proves beyond doubt that the spray factor is real and can be applied to our trays.

A second example comes from two existing stripper towers in a Caprolactam Plant where they are experiencing carryover in the overhead and poor tray performance in this slightly fouling service. We provided a design that reduced the weir length to only 5% of the chord length which is 95% picketing, see photo in Figure 7. After startup the trays are performing excellently. Appendix B shows the tray rating sheets after the revamp. The weir length was reduced such that the minimum weir loading is 1 gpm/inch and the Spray Factor is well above minimum.

Another current example has recently started up. We replaced the outlet weirs on the 2-pass SVG trays in a large 9.5 meter/13.1 meter diameter Oil Quench Tower. The client had complained that the existing trays were entraining excessively. They also noticed that if they raised the operating pressure, the entrainment went away. This led Sulzer to believe the trays were crossing over into the spray regime. A check of the spray factor in Appendix C shows that the existing trays have a value of 1.44 which is well below the allowable 2.78. Basically we used Lockett's equation to get more capacity from this tower. The spray (blowing) factor was very low and by adding 42% picketing (58% effective weir length) the tower got the desired 20% increase in capacity. Initial feedback is excellent from the client even though the Spray Factor was only increased to 2.99. Note that for these two pass trays picketing was added to both the side and center downcomer weir lengths. In addition, this reduction in weir length was not quite enough to eliminate the spray factor. We could not reduce the weir length any more because the client indicated that these trays have a tendency to foul. Subsequently, after checking the maximum allowable pressure drop across the trays, the outlet weir height was also increased to increase the spray factor to acceptable levels. Since the successful startup, it is important to note that the capacity of this low pressure Gasoline Fractionator was actually increased by adding obstructions to the outlet weirs.

Design Criteria

Typically, people will establish minimum allowable effective weir lengths. ExxonMobil typically has indicated that 70% blockages are acceptable and Dow has indicated that 80% blockages are acceptable. Many people however indicate that 55% blockage of the outlet weir length is the maximum allowable.

Therefore, this leads us to the proper design of picket fence outlet weirs. Picket fence weirs should be employed to equalize flow on 3 and 4 pass trays; this is well understood. However, they are also needed to provide a high enough weir loading on any tray to ensure good tray hydraulics and to keep the tray from going spray fluidized[1].

To ensure good tray hydraulics, the weir loading must stay above a certain minimum. Some people say 0.5 gpm/inch is the lowest value[2,3]. This is a good practice and should be abided by at turndown. This is not a value to be used at design however. Our recommended minimum is 0.5 gpm/inch at turndown. However, we also have to look very carefully at the spray (blowing) factor and sometimes this factor will tell us that we must design for a weir loading even higher than 0.5 gpm/inch at turndown. Another criteria that we may use (this one is very subjective) is to not go below a weir loading of 1.0 gpm/inch at design loadings.

Once a designer has established the weir loading value to satisfy spray and/or minimum weir loading criteria, then the minimum effective outlet weir length is established. This calculated weir length can range between 5% and 95% of the available chord length for picket fence weirs. If the application is a new design, every effort should be made to reduce the chord length of the downcomer (within reasonable geometric limitations). It is not the purpose of this discussion to address downcomer and chord length issues but simply the weir loading. Keep in mind that reducing the chord length to very low constriction factor values will require the use of Push Valves and/or other flow enhancing devices to ensure good liquid hydraulics and efficiency on the tray. Constriction factor, for one pass trays, is the ratio of the outlet weir chord length divided by the tower diameter. For revamps, the designer does not typically have the flexibility to easily adjust the chord length on the tray (except perhaps with the use of Z-bars). Therefore, the picket fence weir length reduction can be quite significant.

If the designer is working with a reduction in weir length that only effectively blocks 25% or less of the total chord length then a picket fence design such as the one in Figure 1 could be employed:

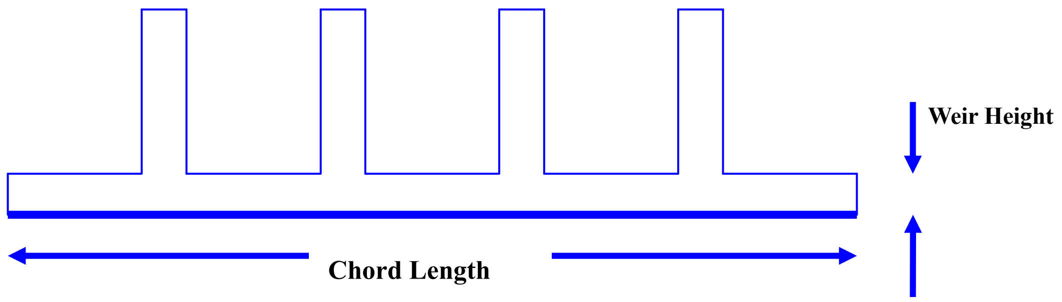

Figure 1 – low blockage picket fence outlet weir

This arrangement has a high open area for liquid to flow through and for the up-flowing vapor to "expand" over the downcomer. Current vapor capacity correlations take advantage of this area/volume over the downcomer as a place for the vapor to expand and help "drop" the liquid it carries upward. Having as much as a 25% blockage above the weir does not inhibit this expansion of vapor and limit vapor capacity on the tray. Please note that the opening/blockages are spread uniformly over the full length of the chord.

For the range of 25% to 50% blockage, the picket fence weir will look more like that shown in Figure 2:

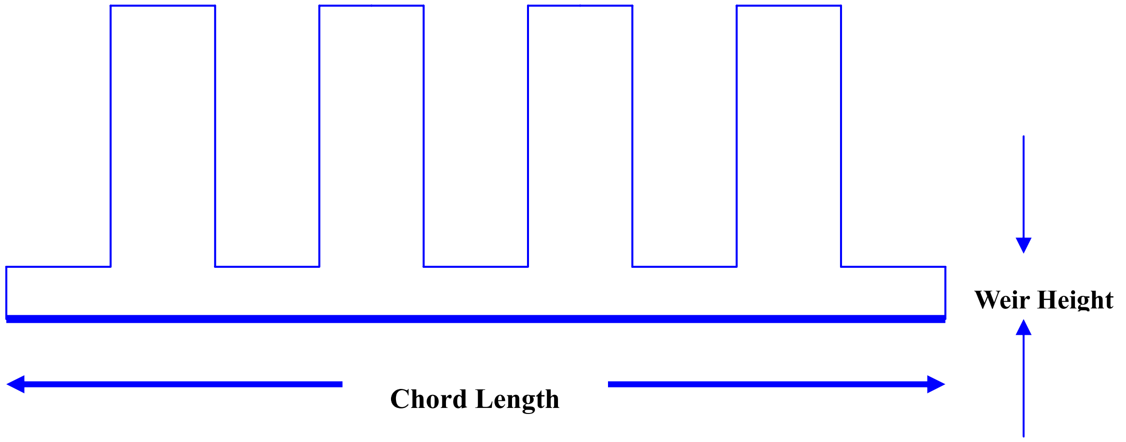

Figure 2 – medium blockage picket fence outlet weir

For this situation there is a certain amount of blockage that will inhibit a portion of the vapor expansion over the downcomer. The designer should examine the vapor capacity very carefully to see what the difference is between the free area and the bubbling area and potentially decrease vapor capacity.

The capacity of a tray can be adjusted to account for this by the loss of free area over the downcomer. At the present time this is not accounted for. Free area is simply defined as the bubbling area plus the area over the downcomers (and is sometimes limited to 1.15 times the bubbling area). This limiting of the free area can be accomplished by proportionalizing the additional area the calculated free area has in excess of the bubbling area to the effective chord length divided by the true chord length at the outlet weir. Basically in our tray design programs we would do the following:

1.) Calculated the excess area: $A_{ex} = A_F - A_A$
2.) Proportion the excess area: $A_{ex}' = A_{ex}$(weir length/chord length)
3.) New Free Area would then be: $A_F = A_{ex}' + A_A$

where,

A_{ex} = Excess Area

A_F = Free Area

A_A = Bubbling Area (or Active Area)

For the weir length divided by chord length range of 5% to 25%, the picket fence weir will look more like what is shown in Figure 3:

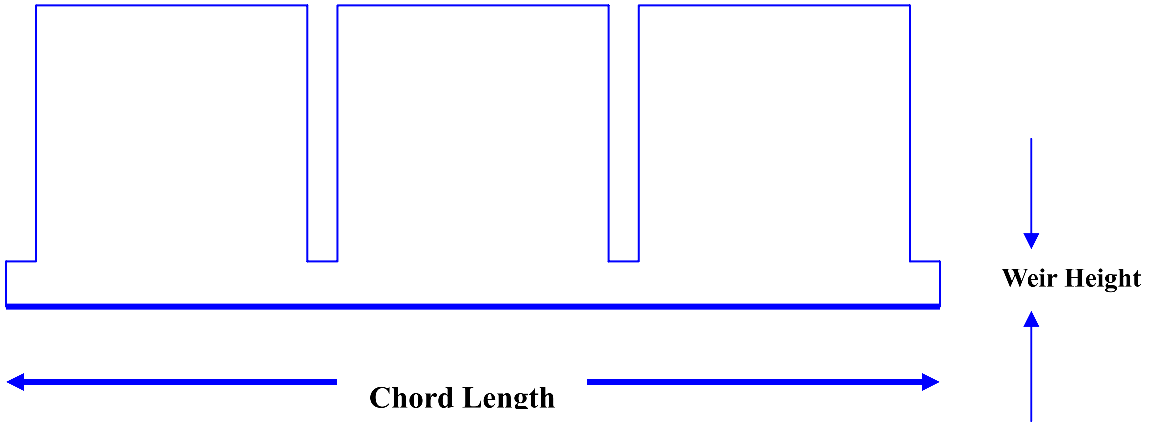

Figure 3 – High blockage picket fence outlet weir

Please note that there are openings at the ends of the picket fence weir to enable liquid to flow as uniformly as possible on the tray over the full length of the chord. Note that this sketch represents approximately a 10% effective weir length. This type outlet weir will most assuredly affect the free area calculation. For the openings in the picket fence weir the minimum recommended "slit width" would be 0.25" (6mm) for non fouling services and 0.75" (19mm) for moderately fouling services. For heavy fouling services, the idea to use picket fence weirs at all should be examined very carefully.

Flow to a highly "blocked" picket fence weir also must be examined carefully. Many small "slits" are obviously preferred over just a few large ones to ensure the best flow pattern on the tray deck and minimize stagnant zones near the outlet weir such as what is shown in Figure 4:

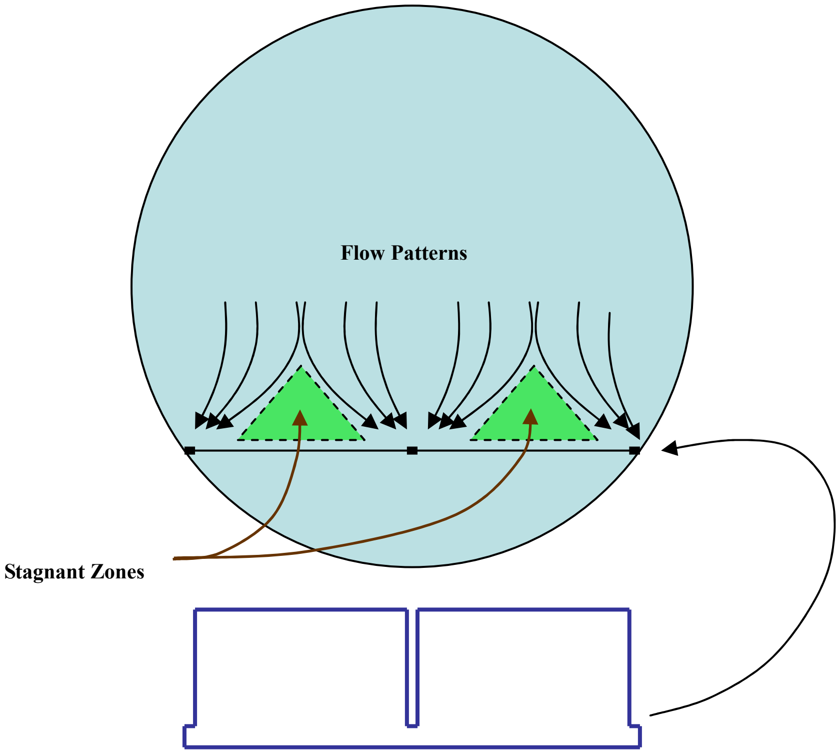

Figure 4 – Poor liquid flow pattern to a highly picketed outlet weir with too few openings

The above picket fence layout is very poor because of the large stagnant zones on the tray. Outlet weirs with a high amount of blockage should be designed with less distance between the openings and to look more like what is shown in Figures 5 and 6. Efforts should be made to keep the distance between opening to a maximum of about 8 inches or 210 mm.

Figure 5 – Example of a proper opening spread for a highly blocked weir

Figure 6 – Example of a proper opening spread for a highly blocked weir

Figure 7 –Caprolactam Tray Example

Conclusions

Based on the above discussion, low liquid load applications can be handled with proper Picket Fence design techniques. These techniques include:

1. Adjustments to capacity
2. Good Picket Weir Design Practices
3. Proper choice of minimum allowable weir loadings
4. Attention must be paid to the Spray Factor
5. Proper placement of outlet weir openings
6. Minimization of stagnant zones on highly picketed weirs

Blockages to the outlet weir length of 80 to 95% are not unusual and have been used frequently in the industry to ensure good tray performance at low liquid loads.

References

1. H. Z. Kister, "Distillation Operation", 1990, pp 162-163
2. M. J. Lockett, "Distillation tray fundamentals", 1986, p 103
3. A. W. Sloley, "Improve Tray Operations", Hydrocarbon Processing, June 2001, pp 85-86
4. C. J. Colwell, "Clear Liquid Height and Froth Density on Sieve Trays", Ind. Eng. Process Design and Development, 1981, Volume 20, pp 298-307
5. A. Sloley, "Improve Tray Operations", 2001, pp 85-86
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7. G.X. Chen, Z Fan, "Models for Liquid Head, Pressure Drop and Weeping of Sieve Trays", October 15, 1995, FRI Topical Report 119
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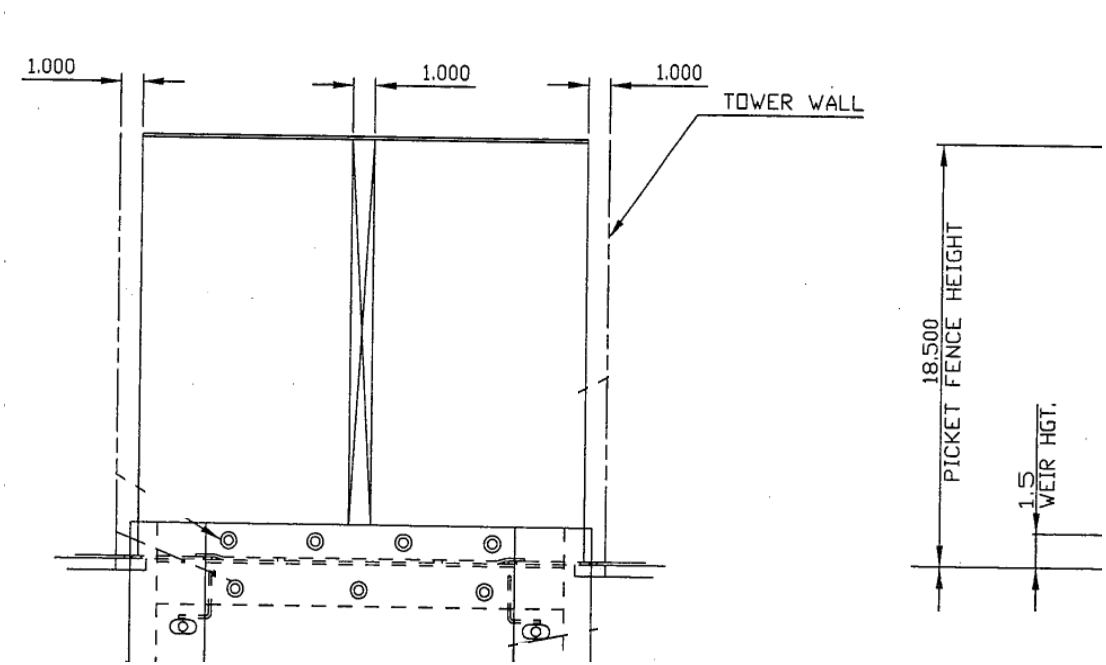
9. M. Sakata and T. Yanagi, "Performance of a Commercial Scale Sieve Tray", I. Chem. E. Symposium Series No. 56, 1979, pp 3.2/21-33
10. H. Z. Kister and J. R. Haas, "Entrainment from Sieve Trays in Froth Regime", Ind. Eng. Chem. Res., 1988, pp 2331-2341

Appendix A – Weir Details



Project:
Service: Toluene Recovery
Item: V-1005-INT
Top pressure:
Date Run: 27-Feb-2006

Sulzer Chemtech

Downcomer Type: STANDARD

Geometry: TRAYS

Tray Dimensions:

Deck Type:	SVG	Tray Spacing, [in]:	24
Tower Diameter,[in]:	35.25	Valve Lift, [in]:	0.5
Number of Passes:	1	No. of Valve Units:	56
Tray Thickness, [in]:	0.1345		

Downcomer Dimensional Input Data:

	Side	Center	Off-Center
Downcomer Top Width, [in]:	4	N/A	N/A
Downcomer Bottom Width, [in]:	4	N/A	N/A
Downcomer Clearance, [in]:	0.75	N/A	N/A
Outlet Weir Height, [in]:	1.5	N/A	N/A
Outlet Weir Length per D.C.,[in]:	0	N/A	N/A
Inlet Weir Height, [in]:	0	N/A	N/A
Rec. Pan Depth, [in]:	0	N/A	N/A
Pan Width, [in]:	0	N/A	N/A
Radius Tip Downcomer:	NO	NO	NO

Tray Area Calculated Output:

Open Area, [ft2]:	0.66
Open Area, [%]:	11.07
Tower Area, [ft2]:	6.78
Downcomer Area, [ft2]:	0.42
Downcomer Area, %:	6.3
Active Area, [ft2]:	5.93
Active Area, %:	87.5

Downcomer Calculated Output:

	Side	Center	Off-Center
Downcomer Top Area, [ft2]:	0.42	0	0
Downcomer Bottom Area, [ft2]:	0.42	0	0
Eff. Weir Length/Downcmr,[in]:	22.36	0	0

Valve Density, [#/ft2]: 9.4

Fluid Data Input:

Original Trays from 1998

Case Number:	1	2
Fluid Name:	TRAY 6	TRAY 12
Description:		TOP
	1998 Trays	1998 Trays
Vapor:		
Flow Multiplier:	1	1
Mult. Vapor Rate, [lb/hr]:	16103	17263
Density, [lb/ft3]:	0.234	0.237
QV, [CFS]:	19.12	20.23
Liquid:		
Flow Multiplier:	1	1
Mult. Liquid Rate, [lb/hr]:	2233	3383
Density, [lb/ft3]:	48.59	48.36
Surface Tension, [d/cm]:	17.65	17.44
Viscosity, [cP]:	0.249	0.233
QL, [gpm]:	5.73	8.72
System Factor :	1	1

Calculated Output:

Jet Flood, [%]:	54	58
Downcomer Velocity, [%]:	5	8
Downcomer Froth Backup, [%]:	16	18
Downcomer Clear Liquid, [in Liq]:	2.61	2.98
Weir Loading, [gpm/in]:	0.26	0.39
DryDrop, [in H20]:	1.27	1.44
Delta P, [mmHg]:	2.9	3.3

Design Notes:

Engineer Name: DRSummers

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Project:
Service: Toluene Recovery
Item: V-1005-INT
Top pressure:
Date Run: 27-Feb-2006

Sulzer Chemtech

Geometry: TRAYS

Summarized Calculated Output:

Case Number:	***1***	***2***
Fluid Name:	*TRAY 6*	*TRAY 12*
Vapor Flow Multiplier:	***1***	***1***
Mult. Vapor Rate, [lb/hr]:	*16103*	*17263*
Liquid Flow Multiplier:	***1***	***1***
Mult. Liquid Rate, [lb/hr]:	*2233*	*3383*
QV, [CFS]:	***19.12***	***20.23***
QL, [CFS]:	*0.01*	*0.02*
Vload, [CFS]:	***1.33***	***1.42***
GPM:	*5.7*	*8.7*
Cb, [ft/sec]:	***0.224***	***0.24***
Cf, [ft/sec]:	*0.209*	*0.224*
Weir Loading, [gpm/in]:	***0.26***	***0.39***
Crest over Weir, [in]:	*0.16*	*0.21*
Spray Regime Factor:	*1.45*	*1.55*
Sieve Vibration Factor:	***7.85***	***7.36***
Tray Froth Height, [in]:	*4.39*	*5.01*
HF/TS Ratio, [%]:	***18.3***	***20.9***
Tray Aeration Factor:	*0.084*	*0.084*
Hydrostatic Head, [in]:	***0.37***	***0.42***
Dry Tray Delta-P, [in H20]:	*1.268*	*1.438*
Vapor Head, [mmHg]:	***0.165***	***0.167***
Tray Pressure Drop, [in H20]:	*1.56*	*1.77*
Tray Pressure Drop, [mmHg]:	***2.9***	***3.3***
Tray Pressure Drop, [psi]:	*0.06*	*0.06*
Downcomer Velocity, [ft/sec]:	*0.03*	*0.046*
Downcomer Froth Backup, [in]:	*4*	*4.6*
Downcomer Froth Backup, [%]:	***16***	***18***
D.C. Clear Liquid, [in Liq]:	2.61	2.98
Downcomer Aeration Factor:	*0.646*	*0.649*
Downcomer Exit Froth Density:	***1***	***1***
Downcomer Head Loss, [in]:	*0.01*	*0.01*
D.C. Exit Velocity, [ft/sec]:	***0.11***	***0.17***
Max. Dncmr Res. Time, [sec]:	*70.7*	*46.4*
Deck Holdup, [lbs]:	***8.9***	***10.1***
Downcomer Holdup, [lbs]:	*4.5*	*5.1*
Tray Holdup, [lbs]:	***13.4***	***15.2***
Residence Time,[sec]:	*21.6*	*16.2*
Useful Capacity, [%]:	*63.58*	*67.94*
Jet Flood, [%]:	***54***	***58***
Limit Flood, [%]:	*37.02*	*39.63*

Design Notes:

Engineer Name: DRSummers File: C:\DRS\PAPERS\April 2006\C024774.STF

Project:
Service: Toluene Recovery
Item: V-1005-INT
Top pressure:
Date Run: 27-Feb-2006

Sulzer Chemtech

Downcomer Type: STANDARD

Geometry: NEW A_FEED

Tray Dimensions:

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Number of Passes:	1	No. of Valve Units:	56
Tray Thickness, [in]:	0.1345		

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	Side	Center	Off-Center
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Outlet Weir Height, [in]:	1.5	N/A	N/A
Outlet Weir Length per D.C.,[in]:	3	N/A	N/A
Inlet Weir Height, [in]:	0	N/A	N/A
Rec. Pan Depth, [in]:	0	N/A	N/A
Pan Width, [in]:	0	N/A	N/A
Radius Tip Downcomer:	NO	NO	NO

Tray Area Calculated Output:

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Open Area, [%]:	11.07
Tower Area, [ft2]:	6.78
Downcomer Area, [ft2]:	0.42
Downcomer Area, %:	6.3
Active Area, [ft2]:	5.93
Active Area, %:	87.5

Downcomer Calculated Output:

Downcomer Top Area, [ft2]:	0.42	0	0
Downcomer Bottom Area, [ft2]:	0.42	0	0
Eff. Weir Length/Downcmr,[in]:	3	0	0

Valve Density, [#/ft2]: 9.4

Fluid Data Input:

Case Number:	3	4
Fluid Name:	TRAY 6	TRAY 12
Description:	New Design 2001 Trays	New Design 2001 Trays
Vapor:		
Flow Multiplier:	1	1
Mult. Vapor Rate, [lb/hr]:	16103	17263
Density, [lb/ft3]:	0.234	0.237
QV, [CFS]:	19.12	20.23
Liquid:		
Flow Multiplier:	1	1
Mult. Liquid Rate, [lb/hr]:	2233	3383
Density, [lb/ft3]:	48.59	48.36
Surface Tension, [d/cm]:	17.65	17.44
Viscosity, [cP]:	0.249	0.233
QL, [gpm]:	5.73	8.72
System Factor :	1	1

New Trays with Picketing

Calculated Output:

Jet Flood, [%]:	54	58
Downcomer Velocity, [%]:	5	8
Downcomer Froth Backup, [%]:	21	24
Downcomer Clear Liquid, [in Liq]:	3.93	4.53
Weir Loading, [gpm/in]:	1.91	2.91
DryDrop, [in H20]:	1.27	1.44
Delta P, [mmHg]:	3.64	4.16

Design Notes:

Engineer Name: DRSummers

File: C:\DRS\PAPERS\April 2006\C024774.STF

Project:
Service: Toluene Recovery
Item: V-1005-INT
Top pressure:
Date Run: 27-Feb-2006

Sulzer Chemtech

Geometry: NEW A_FEED

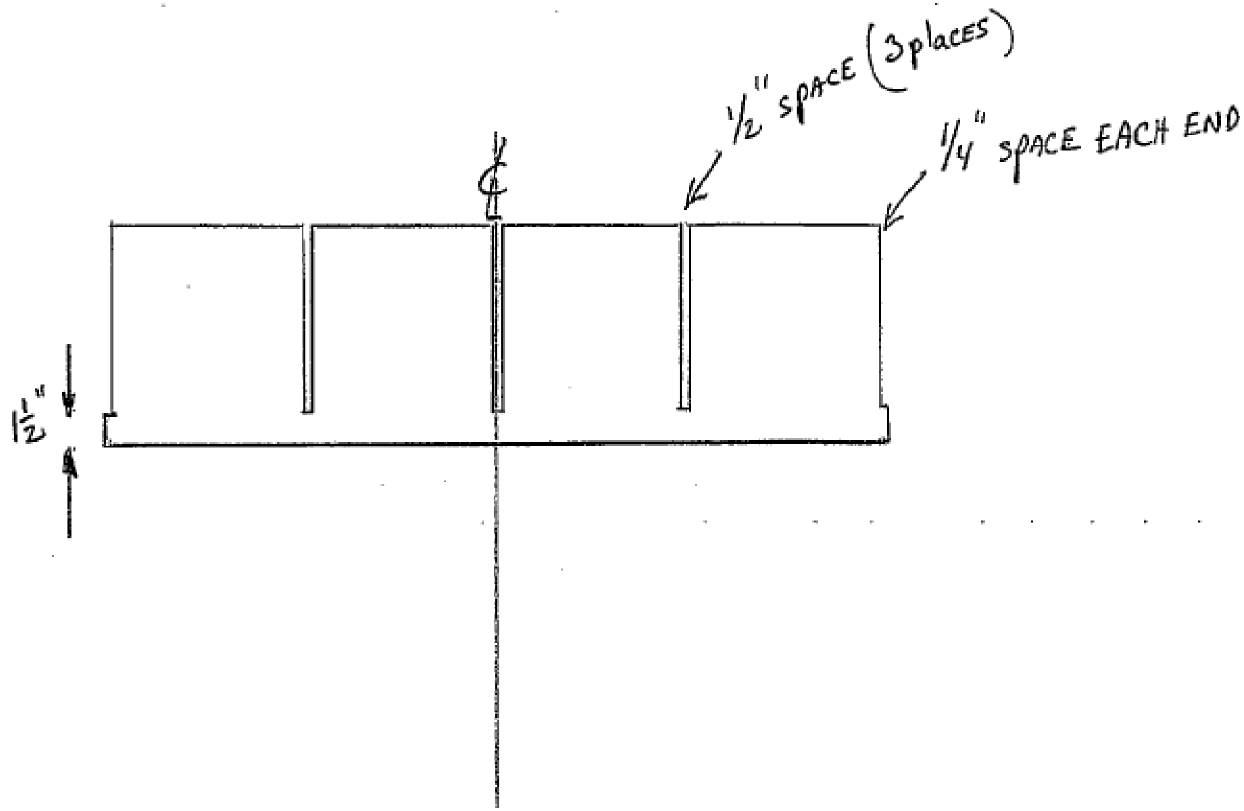
Summarized Calculated Output:

Case Number:	***3***	***4***
Fluid Name:	*TRAY 6*	*TRAY 12*
Vapor Flow Multiplier:	***1***	***1***
Mult. Vapor Rate, [lb/hr]:	*16103*	*17263*
Liquid Flow Multiplier:	***1***	***1***
Mult. Liquid Rate, [lb/hr]:	*2233*	*3383*
QV, [CFS]:	***19.12***	***20.23***
QL, [CFS]:	*0.01*	*0.02*
Vload, [CFS]:	***1.33***	***1.42***
GPM:	*5.7*	*8.7*
Cb, [ft/sec]:	***0.224***	***0.24***
Cf, [ft/sec]:	*0.209*	*0.224*
Weir Loading, [gpm/in]:	***1.91***	***2.91***
Crest over Weir, [in]:	*0.62*	*0.81*
Spray Regime Factor:	*3.43*	*3.74*
Sieve Vibration Factor:	***3.32***	***3.05***
Tray Froth Height, [in]:	*7.73*	*8.93*
HF/TS Ratio, [%]:	***32.2***	***37.2***
Tray Aeration Factor:	*0.113*	*0.114*
Hydrostatic Head, [in]:	***0.88***	***1.02***
Dry Tray Delta-P, [in H20]:	*1.268*	*1.438*
Vapor Head, [mmHg]:	***0.162***	***0.163***
Tray Pressure Drop, [in H20]:	*1.95*	*2.23*
Tray Pressure Drop, [mmHg]:	***3.64***	***4.16***
Tray Pressure Drop, [psi]:	*0.07*	*0.08*
Downcomer Velocity, [ft/sec]:	*0.03*	*0.046*
Downcomer Froth Backup, [in]:	*5.3*	*6.1*
Downcomer Froth Backup, [%]:	***21***	***24***
D.C. Clear Liquid, [in Liq]:	3.93	4.53
Downcomer Aeration Factor:	*0.739*	*0.744*
Downcomer Exit Froth Density:	***1***	***1***
Downcomer Head Loss, [in]:	*0.01*	*0.01*
D.C. Exit Velocity, [ft/sec]:	***0.11***	***0.17***
Max. Dncmr Res. Time, [sec]:	*70.7*	*46.4*
Deck Holdup, [lbs]:	***21***	***24.3***
Downcomer Holdup, [lbs]:	*6.7*	*7.8*
Tray Holdup, [lbs]:	***27.8***	***32.1***
Residence Time,[sec]:	*44.8*	*34.2*
Useful Capacity, [%]:	*63.58*	*68.79*
Jet Flood, [%]:	***54***	***58***
Limit Flood, [%]:	*37.02*	*39.63*

Design Notes:

Engineer Name: DRSummers File: C:\DRS\PAPERS\April 2006\C024774.STF

Appendix B – Weir Details



Project:
Service: Pressure column
Item: CL-5
Top pressure:
Date Run: 27-Feb-2006

Sulzer Chemtech

Downcomer Type: STANDARD

Geometry: TRAY

Tray Dimensions:

Deck Type:	BDH	Tray Spacing, [in]:	24	Valve Thickness, [in]:	0.0747
Tower Diameter,[in]:	72	Valve Lift, [in]:	0.5		
Number of Passes:	1	No. of Valve Units:	230		
Tray Thickness, [in]:	0.13	No. of Push Valves:	6	Push Valve Lift [in]:	0.375

Downcomer Dimensional Input Data:

	Side	Center	Off-Center
Downcomer Top Width, [in]:	7	N/A	N/A
Downcomer Bottom Width, [in]:	5	N/A	N/A
Downcomer Clearance, [in]:	1	N/A	N/A
Outlet Weir Height, [in]:	1.5	N/A	N/A
Outlet Weir Length per D.C.,[in]:	2	N/A	N/A
Inlet Weir Height, [in]:	0	N/A	N/A
Rec. Pan Depth, [in]:	0	N/A	N/A
Pan Width, [in]:	0	N/A	N/A
Radius Tip Downcomer:	YES	NO	NO

Tray Area Calculated Output:

Open Area, [ft2]:	2.85
Open Area, [%]:	10.95
Tower Area, [ft2]:	28.27
Downcomer Area, [ft2]:	1.41
Downcomer Area, %:	5
Active Area, [ft2]:	26
Active Area, %:	92

Downcomer Calculated Output:

Downcomer Top Area, [ft2]:	1.41	0	0
Downcomer Bottom Area, [ft2]:	0.86	0	0
Eff. Weir Length/Downcmr,[in]:	2	0	0

Valve Density, [#/ft2]: 8.8

Fluid Data Input:

Case Number:	1	2
Fluid Name:	FLUID1	FLUID2
Description:	BDH Normal	50% increase 50% Cap increas
Vapor:		
Flow Multiplier:	1	1
Mult. Vapor Rate, [lb/hr]:	15703	23283
Density, [lb/ft3]:	0.053	0.065
QV, [CFS]:	82.3	99.5
Liquid:		
Flow Multiplier:	1	1
Mult. Liquid Rate, [lb/hr]:	1018	1545
Density, [lb/ft3]:	59.3	59
Surface Tension, [d/cm]:	55.93	54.67
Viscosity, [cP]:	0.22	0.234
QL, [gpm]:	2.14	3.26
System Factor :	1	1

Calculated Output:

Jet Flood, [%]:	23	30
Downcomer Velocity, [%]:	0	1
Downcomer Froth Backup, [%]:	15	17
Downcomer Clear Liquid, [in Liq]:	3.33	3.61
Weir Loading, [gpm/in]:	1.07	1.63
DryDrop, [in H20]:	0.83	1.02
Delta P, [mmHg]:	3.5	3.88

Design Notes:

Engineer Name: Petar Pribic

File: C:\DRS\PAPERS\APRIL 2006\CL-5-BDH.STF

Project:
Service: Pressure column
Item: CL-5
Top pressure:
Date Run: 27-Feb-2006

Sulzer Chemtech

Geometry: TRAY

Summarized Calculated Output:

Case Number:	***1***	***2***
Fluid Name:	*FLUID1*	*FLUID2*
Vapor Flow Multiplier:	***1***	***1***
Mult. Vapor Rate, [lb/hr]:	*15703*	*23283*
Liquid Flow Multiplier:	***1***	***1***
Mult. Liquid Rate, [lb/hr]:	*1018*	*1545*
QV, [CFS]:	***82.3***	***99.5***
QL, [CFS]:	*0*	*0.01*
Vload, [CFS]:	***2.46***	***3.3***
GPM:	*2.1*	*3.3*
Cb, [ft/sec]:	***0.095***	***0.127***
Cf, [ft/sec]:	*0.091*	*0.122*
Weir Loading, [gpm/in]:	***1.07***	***1.63***
Crest over Weir, [in]:	*0.42*	*0.55*
Spray Regime Factor:	*9.79*	*7.47*
Sieve Vibration Factor:	***3.06***	***2.74***
Tray Froth Height, [in]:	*5.22*	*6.36*
HF/TS Ratio, [%]:	***21.7***	***26.5***
Tray Aeration Factor:	*0.211*	*0.177*
Hydrostatic Head, [in]:	***1.1***	***1.13***
Dry Tray Delta-P, [in H20]:	*0.832*	*1.017*
Vapor Head, [mmHg]:	***0.036***	***0.044***
Tray Pressure Drop, [in H20]:	*1.88*	*2.08*
Tray Pressure Drop, [mmHg]:	***3.5***	***3.88***
Tray Pressure Drop, [psi]:	*0.07*	*0.08*
Downcomer Velocity, [ft/sec]:	*0.003*	*0.005*
Downcomer Froth Backup, [in]:	*3.8*	*4.4*
Downcomer Froth Backup, [%]:	***15***	***17***
D.C. Clear Liquid, [in Liq]:	3.33	3.61
Downcomer Aeration Factor:	*0.864*	*0.826*
Downcomer Exit Froth Density:	***1***	***1***
Downcomer Head Loss, [in]:	*0*	*0*
D.C. Exit Velocity, [ft/sec]:	***0.02***	***0.03***
Max. Dncmr Res. Time, [sec]:	*506.2*	*331.9*
Deck Holdup, [lbs]:	***141.2***	***143.9***
Downcomer Holdup, [lbs]:	*14.8*	*16*
Tray Holdup, [lbs]:	***156***	***159.9***
Residence Time,[sec]:	*551.6*	*372.7*
Useful Capacity, [%]:	*26.59*	*35.29*
Jet Flood, [%]:	***23***	***30***
Limit Flood, [%]:	*12.27*	*16.59*

Design Notes:

Engineer Name: Petar Pribic File: C:\DRS\PAPERS\APRIL 2006\CL-5-BDH.STF

Appendix C

Project:
Service: Gasoline Fractionator
Item: KT-10
Top pressure:
Date Run: 19-Feb-2007

Sulzer Chemtech

Downcomer Type: STANDARD

Geometry: TRAYS 6-10

Tray Dimensions:

Deck Type:	SVG	Tray Spacing, [mm]:	830
Tower Diameter,[mm]:	9500	Valve Lift, [mm]:	12.7
Number of Passes:	2	No. of Valve Units:	7188
Tray Thickness, [mm]:	4.55		

Downcomer Dimensional Input Data:

	Side	Center	Off-Center
Downcomer Top Width, [mm]:	310	200	N/A
Downcomer Bottom Width, [mm]:	310	200	N/A
Downcomer Clearance, [mm]:	32	32	N/A
Outlet Weir Height, [mm]:	32	32	N/A
Outlet Weir Length per D.C.,[mm]:	0	0	N/A
Inlet Weir Height, [mm]:	0	0	N/A
Rec. Pan Depth, [mm]:	0	0	N/A
Pan Width, [mm]:	0	0	N/A
Radius Tip Downcomer:	NO	NO	NO

Tray Area Calculated Output:

Open Area, [m2]:	7.83
Open Area, [%]:	11.99
Tower Area, [m2]:	70.88
Downcomer Area, [m2]:	1.9
Downcomer Area, %:	2.7
Active Area, [m2]:	65.27
Active Area, %:	92.1

Downcomer Calculated Output:

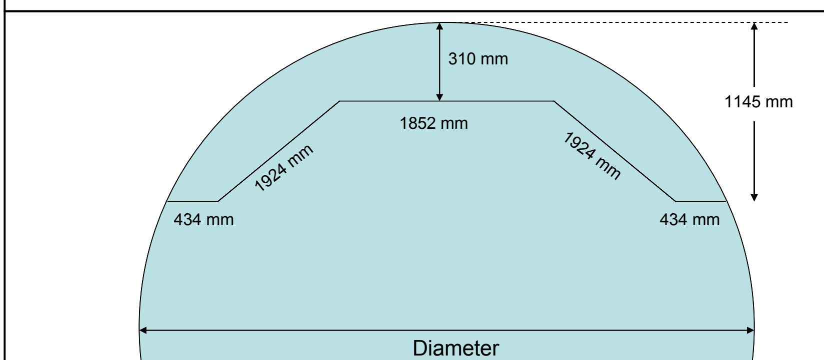
	Side	Center	Off-Center
Downcomer Top Area, [m2]:	1.86	1.9	0
Downcomer Bottom Area, [m2]:	1.86	1.9	0
Eff. Weir Length/Downcmr,[mm]:	6510	18996	0

Valve Density, [#/m2]: 110.1

Fluid Data Input:

Case Number:	1
Fluid Name:	MAX 6-10
Description:	Existing Trays Desired Max
Vapor:	
Flow Multiplier:	1
Mult. Vapor Rate, [Kg/hr]:	838784
Density, [Kg/m3]:	1.277
QV, [m3/sec]:	182.46
Liquid:	
Flow Multiplier:	1
Mult. Liquid Rate, [Kg/hr]:	180458
Density, [Kg/m3]:	911.84
Surface Tension, [mN/m]:	25.29
Viscosity, [mPa-s]:	0.683
QL, [m3/hr]:	197.88
System Factor :	1

Side Downcomers are ModArc Type with these Dimensions



Calculated Output:

Jet Flood, [%]:	71
Downcomer Velocity, [%]:	19
Downcomer Froth Backup, [%]:	27
Downcomer Clear Liquid, [mm Liq]:	123.8
Weir Loading, [m3/mh]:	15.2
DryDrop, [mm H20]:	78.59

Delta P, [mbar]: 8.99

Design Notes:

Engineer Name: DRSummers

File: C:\DRS\PAPERS\April 2006\03-0973 KT-10.STF

Project:
Service: Gasoline Fractionator
Item: KT-10
Top pressure:
Date Run: 19-Feb-2007

Sulzer Chemtech

Geometry: TRAYS 6-10

Summarized Calculated Output:

Case Number:	***1***
Fluid Name:	*MAX 6-10*
Vapor Flow Multiplier:	***1***
Mult. Vapor Rate, [Kg/hr]:	*838784*
Liquid Flow Multiplier:	***1***
Mult. Liquid Rate, [Kg/hr]:	*180458*
QV, [m3/sec]:	***182.46***
QL, [m3/sec]:	*0.055*
Vload, [CFS]:	***241.3***
GPM:	*871.3*
Cb, [m/sec]:	***0.105***
Cf, [m/sec]:	*0.099*
Weir Loading, [m3/mh]:	***15.2***
Crest over Weir, [mm]:	*14.47*
Spray Regime Factor:	*1.44*
Sieve Vibration Factor:	***7.02***
Tray Froth Height, [mm]:	*203.85*
HF/TS Ratio, [%]:	***24.6***
Tray Aeration Factor:	*0.073*
Hydrostatic Head, [mm]:	***13.25***
Dry Tray Delta-P, [mmH20]:	*78.588*
Vapor Head, [mmHg]:	***0.077***
Tray Pressure Drop, [mmH20]:	*91.8*
Tray Pressure Drop, [mbar]:	***8.99***
Tray Pressure Drop, [psi]:	*0.13*
Downcomer Velocity, [m/sec]:	*0.029*
Downcomer Froth Backup, [mm]:	*233.8*
Downcomer Froth Backup, [%]:	***27***
D.C. Clear Liquid, [mm Liq]:	123.8
Downcomer Aeration Factor:	*0.53*
Downcomer Exit Froth Density:	***1***
Downcomer Head Loss, [mm]:	*2.44*
D.C. Exit Velocity, [m/sec]:	***0.13***
Max. Dncmr Res. Time, [sec]:	*29.8*
Deck Holdup, [Kgs]:	***862.1***
Downcomer Holdup, [Kgs]:	*416.9*
Tray Holdup, [Kgs]:	***1279***
Residence Time,[sec]:	*25.5*
Useful Capacity, [%]:	*83.91*
Jet Flood, [%]:	***71***
Limit Flood, [%]:	*55.1*

Design Notes:

Engineer Name: DRSummers File: C:\DRS\PAPERS\April 2006\03-0973 KT-10.STF

Project:
Service: Gasoline Fractionator
Item: KT-10
Top pressure:
Date Run: 19-Feb-2007

Sulzer Chemtech

Downcomer Type: STANDARD

Geometry: NEW 6-10

Tray Dimensions:

Deck Type:	SVG	Tray Spacing, [mm]:	830
Tower Diameter,[mm]:	9500	Valve Lift, [mm]:	12.7
Number of Passes:	2	No. of Valve Units:	7188
Tray Thickness, [mm]:	4.55		

Downcomer Dimensional Input Data:

	Side	Center	Off-Center
Downcomer Top Width, [mm]:	310	200	N/A
Downcomer Bottom Width, [mm]:	310	200	N/A
Downcomer Clearance, [mm]:	32	38	N/A
Outlet Weir Height, [mm]:	90	90	N/A
Outlet Weir Length per D.C.,[mm]:	5500	11000	N/A
Inlet Weir Height, [mm]:	0	0	N/A
Rec. Pan Depth, [mm]:	0	0	N/A
Pan Width, [mm]:	0	0	N/A
Radius Tip Downcomer:	NO	NO	NO

Tray Area Calculated Output:

Open Area, [m2]:	7.83
Open Area, [%]:	11.99
Tower Area, [m2]:	70.88
Downcomer Area, [m2]:	1.9
Downcomer Area, %:	2.7
Active Area, [m2]:	65.27
Active Area, %:	92.1

Downcomer Calculated Output:

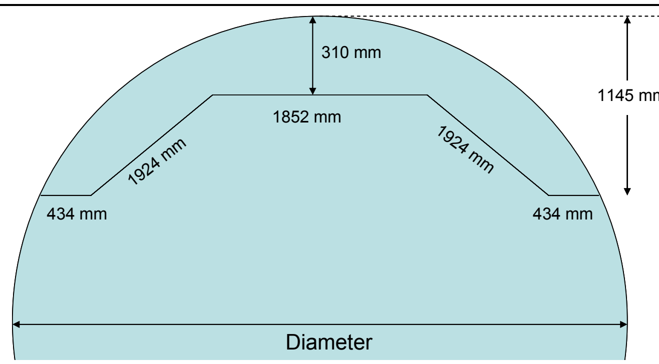
	Side	Center	Off-Center
Downcomer Top Area, [m2]:	1.86	1.9	0
Downcomer Bottom Area, [m2]:	1.86	1.9	0
Eff. Weir Length/Downcmr,[mm]:	5500	11000	0

Valve Density, [#/m2]: 110.1

Fluid Data Input:

Case Number:	2
Fluid Name:	MAX 6-10
Description:	New Pickets Desired Max
Vapor:	
Flow Multiplier:	1
Mult. Vapor Rate, [Kg/hr]:	838784
Density, [Kg/m3]:	1.277
QV, [m3/sec]:	182.46
Liquid:	
Flow Multiplier:	1
Mult. Liquid Rate, [Kg/hr]:	180458
Density, [Kg/m3]:	911.84
Surface Tension, [mN/m]:	25.29
Viscosity, [mPa-s]:	0.683
QL, [m3/hr]:	197.88
System Factor :	1

Side Downcomers are ModArc Type with these Dimensions



Calculated Output:

Jet Flood, [%]:	71
Downcomer Velocity, [%]:	19
Downcomer Froth Backup, [%]:	29
Downcomer Clear Liquid, [mm Liq]:	160.2
Weir Loading, [m3/mh]:	17.99
DryDrop, [mm H20]:	78.59

Delta P, [mbar]: 10.15

Design Notes:

Engineer Name: DRSummers File: C:\DRS\PAPERS\April 2006\03-0973 KT-10.STF

Project:
Service: Gasoline Fractionator
Item: KT-10
Top pressure:
Date Run: 19-Feb-2007

Sulzer Chemtech

Geometry: NEW 6-10

Summarized Calculated Output:

Case Number:	***2***
Fluid Name:	*MAX 6-10*
Vapor Flow Multiplier:	***1***
Mult. Vapor Rate, [Kg/hr]:	*838784*
Liquid Flow Multiplier:	***1***
Mult. Liquid Rate, [Kg/hr]:	*180458*
QV, [m3/sec]:	***182.46***
QL, [m3/sec]:	*0.055*
Vload, [CFS]:	***241.3***
GPM:	*871.3*
Cb, [m/sec]:	***0.105***
Cf, [m/sec]:	*0.099*
Weir Loading, [m3/mh]:	***17.99***
Crest over Weir, [mm]:	*16.19*
Spray Regime Factor:	*2.99*
Sieve Vibration Factor:	***3.38***
Tray Froth Height, [mm]:	*293.41*
HF/TS Ratio, [%]:	***35.4***
Tray Aeration Factor:	*0.094*
Hydrostatic Head, [mm]:	***27.48***
Dry Tray Delta-P, [mmH20]:	*78.588*
Vapor Head, [mmHg]:	***0.076***
Tray Pressure Drop, [mmH20]:	*103.64*
Tray Pressure Drop, [mbar]:	***10.15***
Tray Pressure Drop, [psi]:	*0.15*
Downcomer Velocity, [m/sec]:	*0.029*
Downcomer Froth Backup, [mm]:	*267.2*
Downcomer Froth Backup, [%]:	***29***
D.C. Clear Liquid, [mm Liq]:	160.2
Downcomer Aeration Factor:	*0.6*
Downcomer Exit Froth Density:	***1***
Downcomer Head Loss, [mm]:	*2.44*
D.C. Exit Velocity, [m/sec]:	***0.13***
Max. Dncmr Res. Time, [sec]:	*31.8*
Deck Holdup, [Kgs]:	***1635.3***
Downcomer Holdup, [Kgs]:	*542.2*
Tray Holdup, [Kgs]:	***2177.4***
Residence Time,[sec]:	*43.4*
Useful Capacity, [%]:	*83.91*
Jet Flood, [%]:	***71***
Limit Flood, [%]:	*55.1*

Design Notes:

Engineer Name: DRSummers File: C:\DRS\PAPERS\April 2006\03-0973 KT-10.STF