

ON DISTILLATION TRAY WEIR LOADINGS

By

Michael R. Resetarits & A. Y. Ogundeji

Fractionation Research, Inc.

424 S. Squires St

Stillwater, OK 74074

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blowing

ABSTRACT

Distillation tray liquid rates are usually described via a term known as “weir loading.” A weir loading on a tray is simply the volumetric liquid flow rate per unit horizontal length of outlet weir. The last 50 years of distillation tray literature proposes to tray designers a very wide, and confusing, range of “weir loading criteria.” It is often unclear as to whether the high-end criteria are referring to the points at which flooding occurs, or, the points at which the number of flow passes need to be increased. There are also low-end criteria which refer to spray fluidization points or points at which picket fence weirs need to be used. This paper explains the utility of the weir loading variable and the associated literature criteria.

Impact of Weir Loadings on Tray Hydraulics

Engineers who design distillation trays always heed outlet weir loadings. The majority of such engineers measure weir loadings via the units of “gpm per horizontal inch of outlet weir” or “gpm/inch.”

At low and very low weir loadings, spray fluidization or “blowing” often occurs. In such cases, designers often specify picket fence outlet weirs or “weir blocks” to artificially increase weir loads, and avoid fluidization, and increase vapor-liquid contact times. Some designers regard 4.0 gpm/inch as a low weir loading. Some regard 2.0 gpm/inch as a very low weir loading. The primary focus of this article, however, is high rather than low weir loadings.

At high weir loadings, Figure 1 shows some of the possible deleterious hydraulic results as follows:

1. Large crests and high froth heights and “jet flooding”
2. Crests that are so large that those crests do not fit into downcomer mouths, and “choke flooding” occurs
3. High froth heights sometimes yield excessive pressure drops, and “downcomer backup flooding” occurs

Some distillation engineers contend that both choking and excessive downcomer back-up both lead to excessive froth heights, and so, all floods end up being jet floods.

Many distillation tray hydraulicists avoid high weir loadings. They employ weir loading criteria which they sometimes adhere to strictly. One cure for high weir loadings is increased column diameter. More often, multi-pass trays or counterflow trays (e.g. UOP MD or Shell HiFi) are selected. Engineers faced with high weir loadings on 1-pass trays, select instead 2-, 3- and 4-pass trays. There are very significant disadvantages to multi-pass trays as follows:

1. Reduced tray efficiencies
2. Increased tray costs (more complicated drawings and more tray parts)
3. Increased horizontal ring and vertical bolting bar costs
4. Longer tray installation times

Because of these disadvantages, tray hydraulicists minimize the number of flow passes whenever possible - and when their weir loading criteria will allow.

It should be noted, however, that flow pass minimization is not without peril. Large weir loadings and long flow path lengths can lead to large froth height gradients, with larger froth heights at tray inlets than outlets. These gradients can yield inlet weeping. They can also yield vapor crossflow channeling. Nevertheless, flow pass minimization has appreciable benefits.

Literature Weir Loading Criteria

Generally, the Glitsch, Koch, Nutter and Norton tray design manuals (3, 4, 5, 6) have withstood the tests of time.

Particularly, the flooding correlations of those manuals have successfully predicted tray flooding, with a reasonable degree of accuracy, for many columns for many years. Those manuals, and other references, have offered up weir loading criteria, i.e., weir loading maxima. For example, the Glitsch manual (3) first states the following:

“Usually, a smaller tower diameter can be obtained by using multipass trays to hold liquid rates below 8 gpm/wfp.”

Later, on the same page, the following is stated:

“If the number of passes is restricted, either by customer preference or by tower diameter limitations, liquid rates up to 20 gpm/wfp can be and have been used.”

Then, in Glitsch Bulletin 674 (7), the following is offered:

“From a capacity viewpoint, a liquid rate greater than 6 gpm/inch of weir is the rate at which a larger number of flow paths should be considered.”

The Glitsch manual is not the only literature source that seems to be indecisive regarding weir loading criteria. Table 1 presents the most easily found of such criteria (3, 4, 6, 7, 8, 9, 10). Table 1 shows that there is no national historical consensus regarding the maximum weir loading at which hydraulic malfunctions occur or when additional flow passes should be employed.

Glitsch Manual Capacity Correlation

The almost-famous Glitsch Equation 13 (3) is probably the most familiar, and employed, of all of the publicly-available means for determining distillation tray flood points. That equation is shown below:

$$\frac{\% \text{ Flood}}{100} = \frac{V_{\text{load}} + \left(\text{GFM} * \frac{\text{FPL}}{13000} \right)}{\text{AA} * \text{CAF}}$$

Vapor rate dominates flood calculations, but liquid rate is included in Equation 13 via the GPM term.

In 2002, Weiland and Resetarits (11) pointed out that Equation 13 can be rearranged algebraically to yield the following:

$$\frac{\% \text{ Flood}}{100} = \frac{V_{\text{flood}}}{AA * CAF} + \frac{wl}{13000 * CAF}$$

The above equation reveals that Glitsch Equation 13 includes (inherently) a weir loading term, i.e., weir loading impacts calculated % Flood. This begs the following question: If the Glitsch flood correlation already includes a weir loading term, why is a separate and independent weir loading criterion required? Indeed, why does anybody require weir loading criteria?

Nutter Manual Weir Loading Criteria

Mike Lockett’s book entitled Distillation Tray Fundamentals (12) endorses the weir loading criteria of the Nutter manual (5). Those criteria are shown below:

<u>Tray Spacing (In.)</u>	<u>Increase Number of Passes if GPM/In. Weir Exceeds</u>
12	3
15	5
18	8
21	10
24	13

Those criteria are (possibly) unique in that they contend that a tray’s maximum weir loading should depend on tray spacing. This makes perfect sense. Weir loadings affect crest heights and then froth heights. Large tray spacings accommodate large weir loadings more easily, and vice versa. But - - - shouldn’t vapor rates also impact maximum operational weir loadings? Is there a single vapor rate implied by the Nutter table, or, are the increasing liquid rates of the Nutter table associated with increasing liquid rates on a 1-to-1 molar basis?

Assuming that every weir-loading-tray-spacing pair in the Nutter table is associated with a flood point, vapor rates were back-calculated for every weir loading. Two different flood correlations were assumed: Glitsch and Nutter. Two different vapor-liquid systems were assumed: depropanization and air-water. These calculations revealed that, nearly, but not perfectly, one vapor rate was assumed when the Nutter weir loading table was initially generated. It could also easily be inferred that the Nutter table was back-calculated from the Nutter flood correlation. If the Nutter weir loading criteria were back calculated from the Nutter flood correlation, or from Nutter laboratory flood data, then are the Nutter weir loading criteria redundant?

High Industrial Weir Loadings

What high weir loadings have been handled successfully industrially? The best single source of such information is probably the paper by Resetarits, Schmude and Morehead (10). Table 2 was extracted from that paper. Table 2 shows that weir loadings as high as 20 gpm/inch have been handled. Generally, the tray spacings of Table 2 are large. By assuming that each line of Table 2 represents a flood point, a vapor rate was calculated for each line. Those vapor rates are shown in the last column. Table 2 now implies that high weir loadings can be handled on distillation trays as long as the tray spacings and vapor rates are “appropriate.”

The Redundancy of Weir Load Criteria

The primary contention of this paper has been implied several times but has not been specifically stated until now: The maximum weir loading at which a distillation tray can function depends upon the tray spacing and the vapor rate. Trays can handle very high weir loadings as long as the tray spacings are large enough and the vapor rates are low enough. As long as a flood correlation includes a weir loading term, either directly or indirectly, weir loading criteria are redundant and misleading.

Figure 2 was prepared using Glitsch Equation 13. Two different tray spacings were studied. Each point on the graph represents 100% of Calculated Flood. At higher vapor rates, lesser weir loadings are attainable. At smaller tray spacings, lesser weir loadings are attainable. Figure 3 was also derived using Glitsch Equation 13. Again, each point represents 100% of Calculated Flood. At higher tray spacings, higher weir loadings are attainable.

Public FRI_(SM) Data

Fractionation Research, Inc. (FRI) is a non-profit company that performs distillation research, especially on trays and packings, for its 70 member companies. FRI data that are more than 30 years old are usually released to the public via the Oklahoma State University (OSU) library. Those public data provide additional information regarding weir loading criteria.

Figure 4 was taken from FRI Topical Report 10 (13). This graph provides raw capacity data from valve trays from FRI's 4-foot diameter test column. Figure 4 shows the following:

1. Different physical systems have different capacities
2. At higher vapor rates, weir loading capacities are lower

Experienced tray designers are very familiar with such trends.

Table 3 summarizes capacity/flood data that were collected from five sets of sieve and valve trays (13, 14, 15, 16, 17). All of those data were collected at 24 inch tray spacings. The table shows the maximum weir loadings that were studied using those trays. To achieve each of those weir loadings, the vapor rates needed to be sufficiently low – as shown in the table. Higher weir loadings would have been attainable – at lower vapor rates or at larger tray spacings. FRI has appreciable film and video footage showing trays functioning at high weir loadings, including weir loadings in excess of literature design criteria.

A careful side study of Table 3 shows that swept-back weirs seemingly have a maximum capacity benefit of “only” about 10%. Straight, chordal weirs certainly create bottlenecks near their ends where there is little horizontal area for froths to deaerate and enter downcomers. Although swept-back weirs make sense, the resultant lost bubbling area is significant. Table 3 does not provide a strong endorsement for swept-back weirs, but such weirs are a valuable tool that should not be removed from tray designers' toolboxes.

Most importantly, Table 3 shows that at least five sets of conventional trays have been run at FRI at very high weir loadings.

Summary

Several literature criteria are available that provide and promote maximum tray weir loadings. Trays have been operated industrially, and in commercial-sized pilot plants, at weir loadings in excess of the literature criteria.

Conclusion

Distillation trays can be designed for very large weir loadings, as long as the tray spacings are large enough and the vapor rates are low enough. A reliable flood correlation (or applicable field data) minimizes the utility of maximum weir loading criteria. Such criteria will never go away, however, especially because high weir loadings can sometimes lead to vapor crossflow channeling and inlet weeping.

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The authors also thank the past and future staffs of FRI for the many hours of difficult work that went into every single distillation data points.

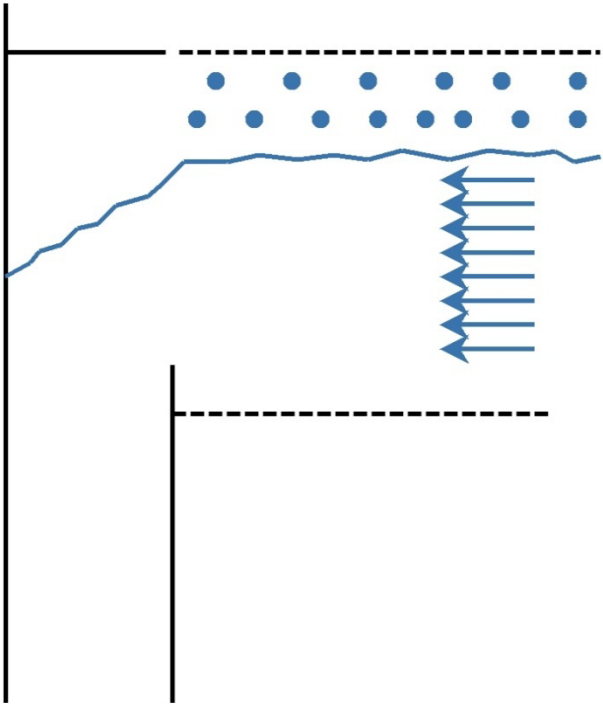
Nomenclature

AA	Bubbling area, ft ²
CAF	Capacity factor of Ballast trays after correcting for foaming (Graph of Reference 3)
C _b	Capacity factor $\frac{V_{load}}{AA}$, based on tray bubbling area, ft/s
CFS	Vapor rate, actual ft ³ /s
V _{load}	Vapor load, CFS $[\rho_v / (\rho_L - \rho_v)]^{0.65}$, ft ³ /s
ρ _L	Liquid density, lb/ft ³
ρ _v	Vapor density, lb/ft ³
FPL	Flow path length, inch
GPM	Liquid rate, U.S. gallons per minute
wl	Weir loading, U.S. gpm/inch
wfp	Width of tray flow path, inch

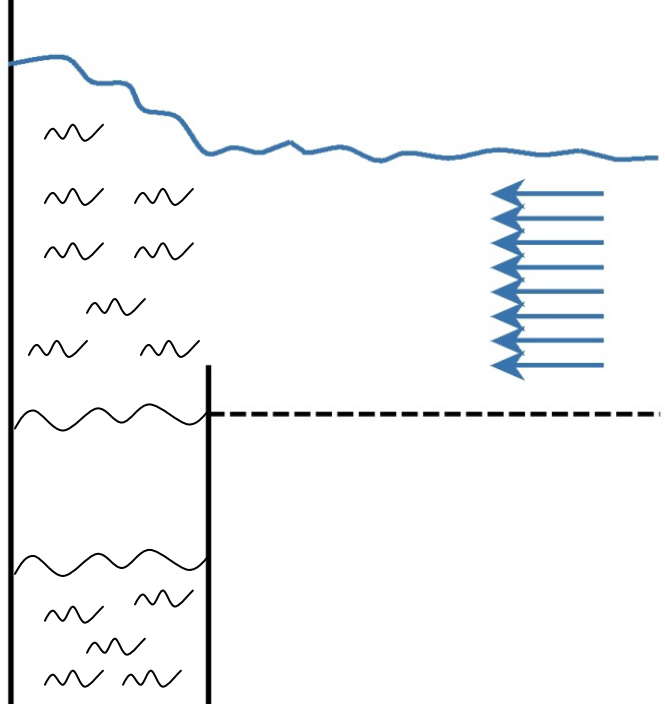
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Figure 1: Tray Flooding Mechanisms
Jet Flood



Choke Flood



Back-Up Flood

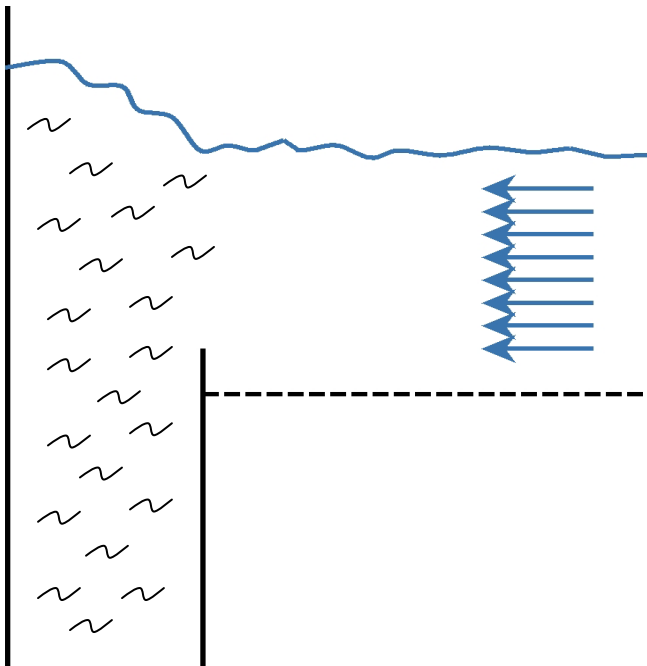


Figure 2: Glitsch Equation 13 Flood Calculations

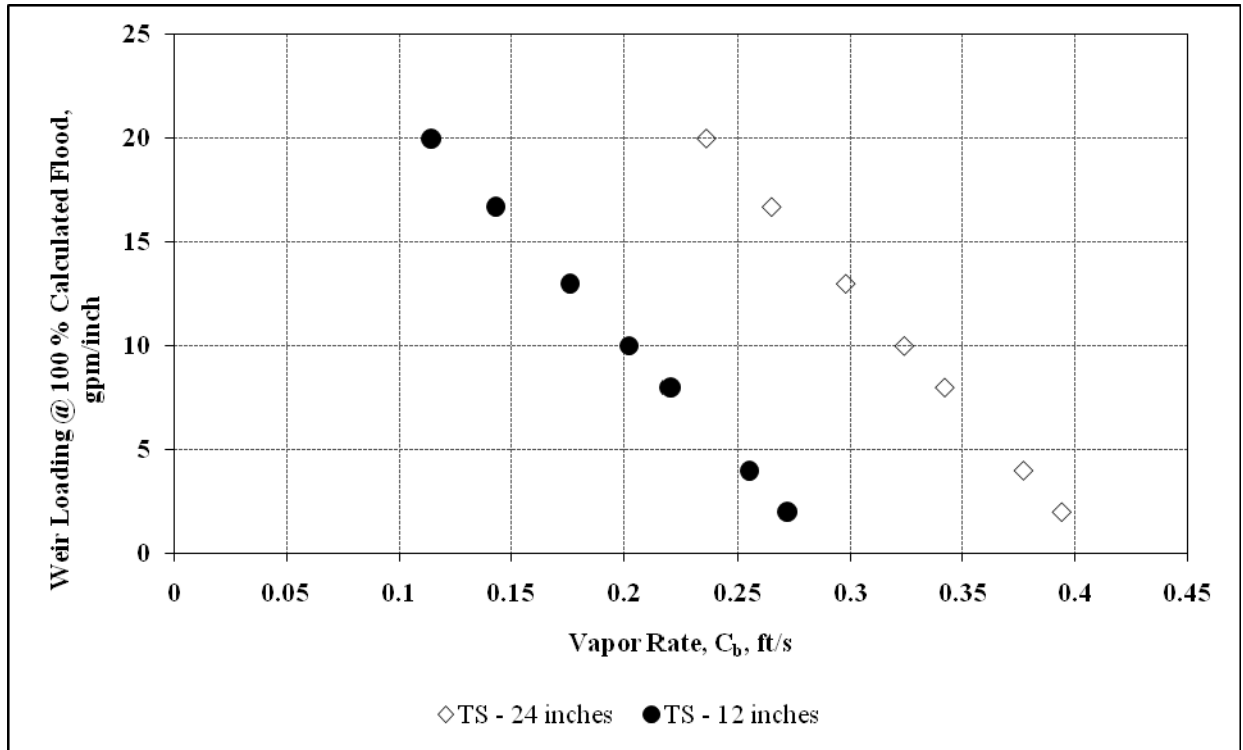


Figure 3 : Glitsch Equation 13 Flood Calculations ($C_b = 0.200$ ft/s)

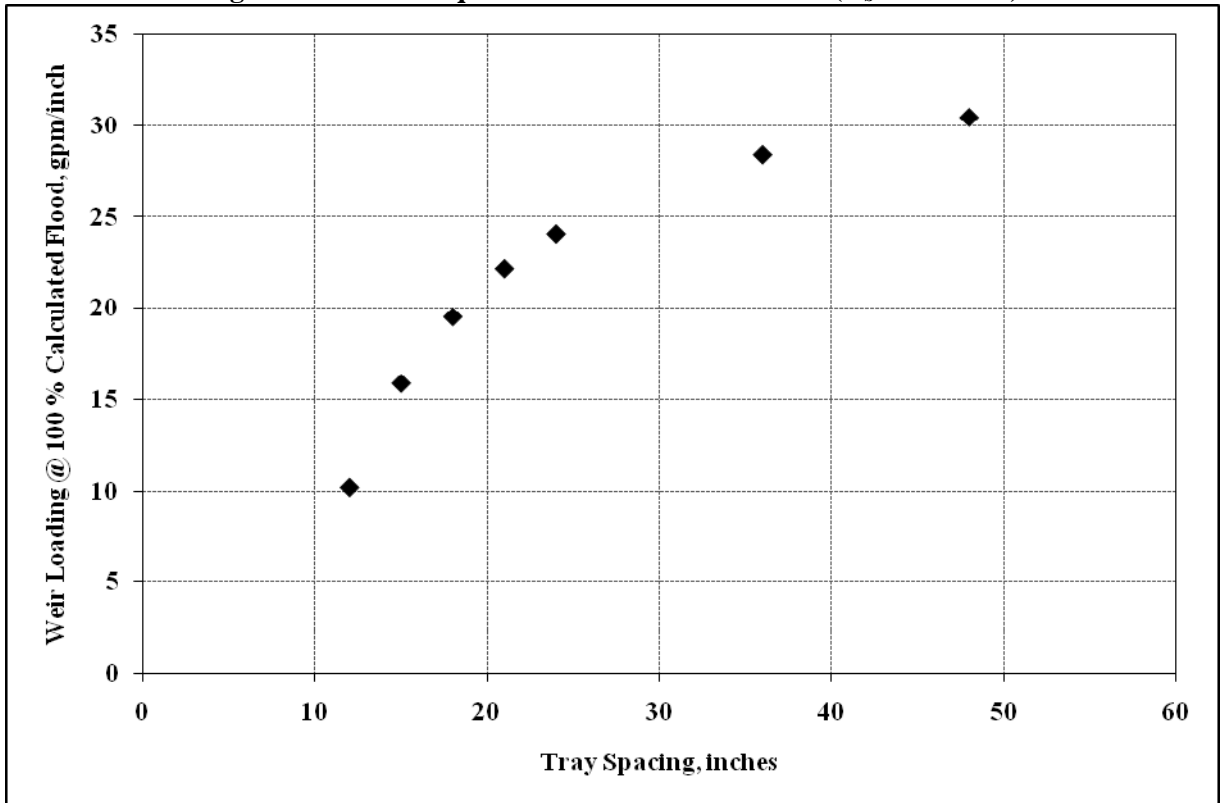


Figure 4 : FRI Valve Tray Capacity Data (Topical Report 10)

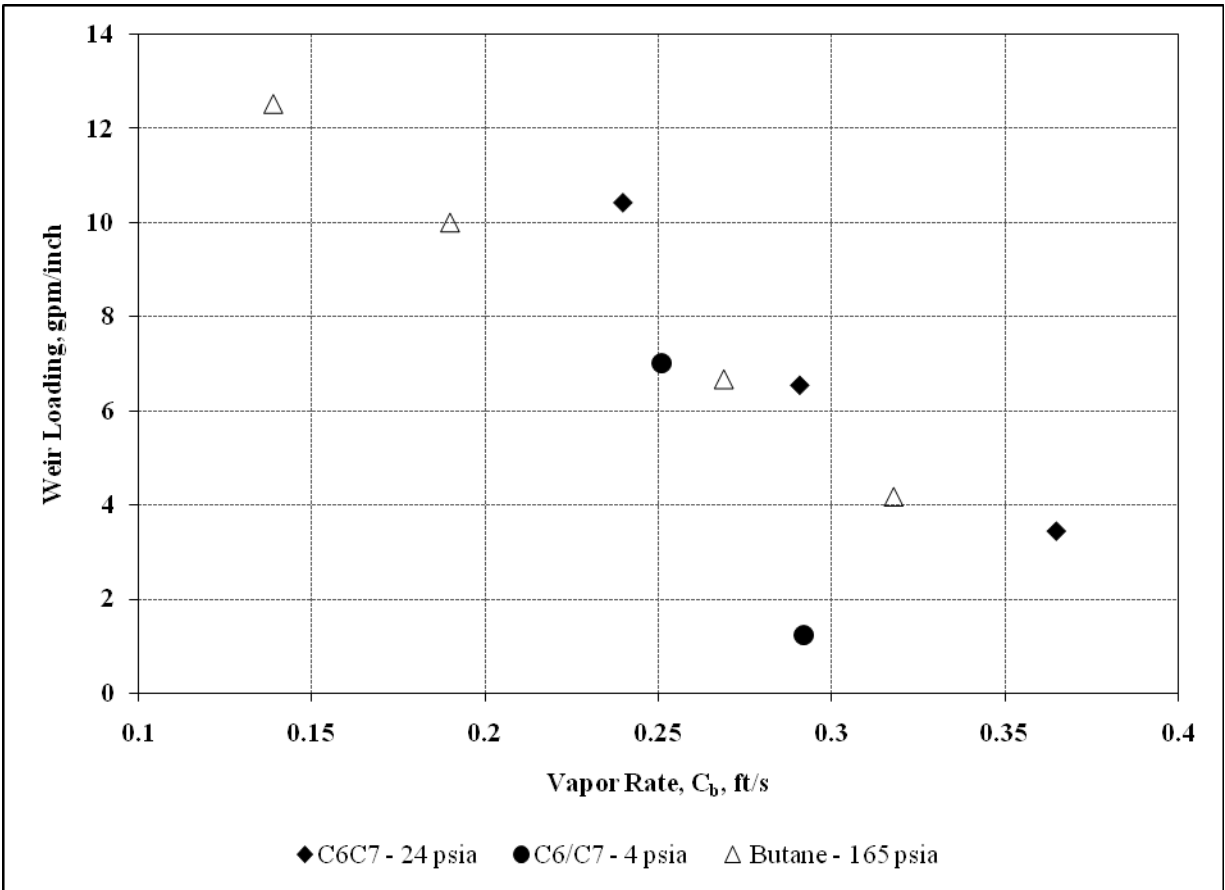


Table 1

Literature Weir Loading Criteria			
gpm/inch			
Reference	First Quote	Second Quote	Third Quote
3	8	20	
7	6		
6	10	13.5	10 - 15
4	10.4 – 11.7		
8	7 – 13		
9	7 – 13	10 – 13	20
10	25	18.8	20

Table 2

Industrial Design Points						
Application	Tray Type	Tower Diam., ft	No. of Passes	Tray Spacing, inches	Weir Load, gpm/inch	C_b @ flood, ft/s
Product Stripper	Conv. Valve	9	2	27	19.17	0.228
Deethanizer	SUPERFRAC	5	1	24	14.25	0.275
Crude Twr – PA	Bi-FRAC	25.5	2	30	15.92	0.271
Crude Twr – PA	SUPERFRAC	14.3	2	36	18.17	0.264
VGO Stripper	Sieve	9.8	2	29.5	19.58	0.232
Stabilizer	SUPERFRAC	10	2	24	17.58	0.234
Deethanizer	Sieve	7.5	2	24	14.5	0.265
Debutanizer	SUPERFRAC	5.6	2	24	13.08	0.280
FCC Main Frac – PA	Bi-FRAC	24	2	36	20	0.246
C3 Splitter	NYE	11.5	2	18	12.08	0.250
Stripper	Conv. Valve	10	2	24	18.75	0.222
FCC Debutanizer	SUPERFRAC	9.5	2	24	18.17	0.228
Crude Twr – Stripper	Sieve	16	2	24	13.83	0.272

Table 3

FRI Valve Tray Capacity Data – Maximum Weir Loadings						
FRI Topical Report	System	Pressure (psia)	Tray Spacings (inches)	Weir Type	Maximum Weir Load (gpm/Inch)	C_b (ft/s)
10	iC4-nC4	165	24	Swept Back	12.52	0.172
10	C6/C7	24	24	Swept Back	10.42	0.297
10	C6/C7	4.5	24	Swept Back	7.02	0.311
15	C6/C7	24	24	Swept Back	10.5	0.326
15	C6/C7	4.5	24	Swept Back	9.1	0.356
15	C6/C7	50	24	Swept Back	10.6	0.270
15	iC4-nC4	165	24	Swept Back	12.5	0.179
19	C6/C7	24	24	Straight	14.6	0.284
19	C6/C7	4.5	24	Straight	12.6	0.357
19	iC4-nC4	165	24	Straight	17.7	0.178
31	iC4-nC4	165	24	Swept Back	13.04	0.233
31	C6/C7	24	24	Swept Back	10.20	0.350
41	C6/C7	24	24	Straight	14.46	0.319
41	iC4-nC4	165	24	Straight	17.54	0.174

WEIR LOADINGS IN DIFFERENT UNITS

GPM/FT	GPM/INCH	CFS/FT	M ³ /HR/M
22.4	1.87	0.0500	16.7
24.0	2.00	0.0535	17.9
36.0	3.00	0.0802	26.8
48.0	4.00	0.107	35.8
50.0	4.17	0.111	37.3
72.0	6.00	0.160	53.7
84.0	7.00	0.187	62.6
96.0	8.00	0.214	71.5
100	8.33	0.223	74.5
112	9.35	0.250	83.6
120	10.0	0.267	89.4
150	12.5	0.334	112
156	13.0	0.348	116
200	16.7	0.446	149
240	20.0	0.535	179
250	20.8	0.557	186
300	25.0	0.668	224

Notes:

1. CFS/FT * 448.8 = GPM/FT
2. CFS/FT * 334.46 = M³/HR/M
3. Linde range: 0.05 to 0.25 CFS/FT
4. Good guideline for fluidization is 2.0 gpm/inch
5. TR138 If statement kicks in at 4.0 gpm/inch at TS=24in