The Effect of Hole Size on Sieve Tray Performance

M. Sakata[*], D.W. King, T. J. Cai, G. X. Chen**

Fractionation Research, Inc., P.O. Box 2108, Stillwater, OK 74076 USA

T. Yanagi

WorleyParsons

181 West Huntington Drive, Monrovia, California 91016

Presented in the Distillation Symposium of the 2007 Spring AIChE Meeting
Houston, Texas
April 22-27, 2007

UNPUBLISHED

The Effect of Hole Size on Sieve Tray Performance

M. Sakata[*], T. Yanagi, D.W. King, T. J. Cai, G. X. Chen**

Fractionation Research, Inc., P.O. Box 2108, Stillwater, OK 74076 USA

T. Yanagi

WorleyParsons

181 West Huntington Drive, Monrovia, California 91016

ABSTRACT

The effect of hole size on the performance of sieve tray was systematically studied in a 1.22 m distillation column with various tray configurations. The diameters of the sieve hole covered the range of 3.2 to 66.7 mm. The tests were conducted with three different hydrocarbon systems, cyclo-hexane/n-heptane, iso-butane/n-butane, and o/p-xylene at pressures of 0.02 to 27.6 bar. The performance of the sieve trays with different hole sizes was determined and compared. It is found that hole size affects the mass transfer efficiency and capacity. The results also show significant effect of the hole size on tray pressure drop and weeping. A fundamental analysis is given to explain the effect of hole size on the sieve tray performance.

Key Words: Distillation, hole size, sieve tray, efficiency, capacity, pressure drop

---

* Deceased

**Corresponding author. E-mail: King@fri.org , Phone: 1-405-385-0354, Fax: 1-405-385-0357

INTRODUCTION

The effect of hole size on the performance of sieve trays was studied in a 1.22 m distillation column with various tray configurations. Sieve tray performance is obviously a multi-variable problem, however we will attempt to show the impact of hole size on sieve tray performance from a set of experimental data obtained at Fractionation Research, Inc.

The diameter of the sieve holes ranged from 3.2 to 66.7 mm. The tests were conducted with three different hydrocarbon systems, cyclo-hexane/n-heptane, iso-butane/n-butane, and p/o-xylene at pressures from 0.02 to 27.6 bar. The performances of similar sieve trays with different hole sizes were compared. The data will show how the hole size relates to the mass transfer efficiency, pressure drop and capacity.

AIChE's meetings and conferences are designed to help us stay current on the latest advances in core areas and emerging fields, from bioengineering and nanotechnology to process safety; Including many topical conferences covering a wide range of areas in chemical engineering.

On a much smaller scale, Fractionation Research, Inc. (FRI_{SM}) addresses research of fractionating devices including sieve, bubble cap, dualflow, baffle and valve trays; as well as random and structured packing. Fractionation Research, Inc. is a non-profit research consortium supported by company memberships that include the largest petroleum and petrochemical companies in the world. Founded in the 1950's, FRI research includes the only commercial scale experimental program operating with hydrocarbon systems at pressures ranging from deep vacuum to 34 bar. Thirty-seven member companies completed the original organizational framework that has now grown to include the leading companies in the field of distillation, of which more than 60% are international. FRI data are confidential to the membership of FRI, however FRI data are released to the Oklahoma State University library(1) after 30 years from their original publication.

This paper will show the results of a study by FRI that can now be released as well as reflections of the influence of hole size on sieve tray performance based on additional data. Sieve tray performance is obviously a multi-variable problem, however this paper will show how hole size influences the results of testing a particular sieve tray where the hole size is varied.

EXPERIMENTAL SETUP

A picture of the $FRI_{(SM)}$ experimental unit is shown in **Figure 1**. The unit consists of two main columns (1.22 m x 9.15 m) configured for low pressure and high pressure applications. The low pressure column also has a larger diameter column (2.44 x 6.1 m) attached to the top. A schematic drawing of the unit is shown in **Figure 2**. After fractionating devices are installed, the experimental unit operates over a wide range of liquid and vapor rates

REVIEW OF THE IMPACT OF HOLE SIZE ON SIEVE TRAY PERFORMANCE

Several authors have commented on the influence of hole size on sieve tray performance. **Figure 3** shows a flow regime map that will be helpful to our discussion. Kister notes in his book on the topic of sieve tray entrainment (Jet) flooding that the capacity factor at flood increases as hole diameter is reduced(2). He also notes that hole diameter and hole area have a minimum effect on froth entrainment flooding(3). Kister also notes that entrainment increases with hole diameter and that the effect is large in spray regime and smaller in the froth regime(4). Addressing the issue of sieve tray weeping, studies have concluded that an increase in hole diameter results in a reduction of weeping, and other studies have shown the reverse trend(5). Addressing dry tray pressure drop, the hole diameter is related to tray thickness in its influence on the orifice coefficient. Kister states that the prime variables impacting the orifice coefficient are the fractional hole area and the ratio of tray thickness to hole diameter(6). Kister also states that increasing the hole size increased the tendency of trays to operate in the spray regime. Increasing hole size tends to shift the spray-froth boundary to the right. However, an increase in hole size has no impact on the froth-emulsion boundary(7). Addressing liquid flow patterns, channeling decreases as the hole diameter increases(8). In the froth regime smaller holes increase the interfacial area, and possibly froth height, but the enhancement in efficiency is small(9).

Kalbassi et al. report that a fourfold decrease in hole diameter increases tray efficiency by about 15%(10, 11). In humidification and stripping tests Prado and Fair report that decreasing the hole diameter by half results in an increase in efficiency of less than 2%(12, 13). Mahiout and Vogelpohl report that for high viscosity absorption systems a decrease in hole diameter results in a significant increase in tray efficiency(14). Sawistowski and Mahiout, et. al. report that in a spray regime adsorption scenario a 3 fold decrease in hole diameter decreases tray efficiency by 15-25% (15, 16).

Lockett points out two schools of thought regarding design approaches in regard to hole diameter:

(1) always use 12.7 mm, ½ inch holes, or
(2) better to use 4.8-6.4 mm unless fouling or corrosion is excessive. Smaller hole diameters give higher vapor capacity and allow increased turndown.

FRI SIEVE TRAY DATA

The sieve tray portion of the $FRI_{(SM)}$ database contains 7125 experimental runs. 70% of these runs are more than 30 years from their publication date. The distribution of data by hole size is:

3.175 mm	1/8 inch	4 reports	195 runs
4.763	3/16	3	146
6.35	¼	1	100
12.7	½	58	4264
19.1	¾	1	95
25.4	1	9	235
38.1	1 ½	1	57
66.7	2 5/8	1	36

Experimental studies were conducted to specifically address hole size at FRI. Some recent work and also some older work have been reported by FRI. The results of the original work will be discussed below. Also the predictions from current FRI models will reflect more extensive data.

FRI RESULTS OF RELEASED DATA

FRI conducted several studies addressing the impact of hole size on sieve tray performance. These data are listed in **Tables 1-3** of this paper. An initial report(18) covers studies of a sieve tray having:

12.7 mm diameter holes,
51 mm weirs,
610 mm tray spacing, and
10% hole area based on column cross-sectional area.

This report compares the performance to other devices tested at FRI and comments on capacity, efficiency, pressure drop, weeping and entrainment.

A subsequent report(19) documents test of sieve trays having:

4.8 mm and 25 mm diameter holes,
51 mm weirs,
610 mm tray spacing, and
10% hole area based on column cross-sectional area.

Comments regarding these two studies are:

> "Contrary to popular opinion, large diameter holes (1 inch to 1/2 inch) have efficiency characteristics which are as good as, or better than, that of smaller holes (1/8 to 1/4 inch). The optimum hole diameter for use with sieve trays is likely to be between 1/2 to 1 inch."

Further conclusions from this report are:

1. The vapor handling capacity of sieve trays at low liquid loads is independent of hole diameter. At high liquid loads the vapor handling capacity of sieve trays decreases with increasing hole diameter.
2. Tray efficiency increases with increasing hole diameter. For the C6-C7 system at 1 bar, there is a difference in efficiency of about 10 percentage points between 4.8 and 12.7 mm diameter holes and between 12.7 and 25.4 mm diameter holes. With the C6/C7 vacuum system and the iC4/nC4 system, the difference in efficiencies for the three hole diameters is small.
3. Pressure drop is considerably higher with 25.4 mm holes than with the 12.7 mm and 4.8 mm diameter holes. This explains in part the higher efficiency obtained with the 25.4 mm holes on the C6-C7 system at 1 bar.

Another report(20) documents test of sieve trays having:

67 mm diameter holes,
51 mm weirs,
610 mm tray spacing
11.5% hole area based on column cross-sectional area.

Conclusions from this tests are:

1. The capacity of sieve trays decreases as hole diameter becomes larger. This loss in capacity is due to higher entrainment.
2. The lower operating limits of sieve trays having hole sizes from 4.8 mm to 67 mm are identical for a given system.
3. The efficiency of sieve trays at high vapor rates increases with increasing hole diameter up to hole diameters of about 25 mm. At a hole diameter of 67 mm, the efficiency is appreciably lower due to higher entrainment. The optimum hole diameter is in the region of about 12.7 to 25 mm.
4. The pressure drop of sieve trays with 67 mm diameter holes is appreciably higher than with 12.7 mm holes.

Figure 4-6 show the tray capacity for three different systems. **Figure 4** is the data for C6/C7 at 0.28 bar. **Figure 5** shows the tray capacity for C6/C7 at 1.65 bar and **Figure 6** is the data for iC4/nC4 at 11.4 bar. These data show a decrease in capacity as the hole size increases. However, **Figure 6** shows a different dependence on hole size.

Figure 7-9 show the tray efficiency for three different systems. **Figure 7** is the data for C6/C7 at 0.28 bar. **Figure 8** shows the tray efficiency for C6/C7 at 1.65 bar and **Figure 9** is the data for iC4/nC4 at 11.4 bar. The efficiency increases with hole size up to 25 mm then reverses for 67 mm hole size. **Figure 9** shows a reversal of trend from 12.7 to 25 mm hole size.

Figure 10-12 show the Pressure Drop Per Tray for three different systems. **Figure 10** is the data for C6/C7 at 0.28 bar. **Figure 11** shows the Pressure Drop Per Tray for C6/C7 at 1.65 bar and **Figure 12** is the data for iC4/nC4 at 11.4 bar. The pressure drop increases with hole size with the exception of the 4.8 mm hole which has a higher pressure drop that the 12.7 mm hole.

FRI MODELS CONSIDERING ALL EXPERIMENTAL DATA

FRI conducted several studies addressing the impact of hole size on sieve tray performance. Some of these data are not available to the public; however the more comprehensive set of data can be reflected in FRI models. FRI computer models have been incorporated into a design rating computer program (DRP). The opening page of the DRP is shown in **Figure 13**. The three panels address the process input, the hardware input, and the output or results. Examples of the three panels are shown in **Figures 14-16**. The DRP was used to generate responses where only the hole size was varied.

Figure 17 shows the model prediction of tray efficiency from low to high vapor velocities. This figure shows that tray efficiency is relatively independent of hole size up to about 25 mm and then shows a sharp decline from 25 mm to 50 mm.

Figure 18 shows the model prediction of tray pressure drop for various hole sizes. This figure shows that tray pressure drop increases as hole size increases.

Figure 19 shows the model prediction of % Jet or entrainment flood for various hole sizes. This figure shows that % Jet Flood increases as hole size increases.

Figure 20 shows the model prediction of % Downcomer flood for various hole sizes. This figure shows that % Downcomer Flood increases as hole size increases.

Figure 21 shows the model prediction of entrainment as a % of liquid rate for various hole sizes. For this hardware description and system, there is very little entrainment until a C_S value of about 0.08 m/s. This figure shows that the entrainment increases as hole size increases after a C_S value of 0.08 m/s.

Figure 22 shows the model prediction of weeping as a % of liquid rate for various hole sizes. For this hardware description and system, there is very little weeping after a C_S value of about 0.04 m/s. This figure shows that the weeping increases as hole size decreases before a C_S value of 0.04 m/s.

Figure 23 shows the model prediction of Downcomer Backup for various hole sizes. The tray spacing for this simulation is 610 mm. This figure shows that Downcomer Backup increases as hole size increases

CONCLUSIONS AND DISCUSSION

The effect of hole size on the performance of sieve trays was studied in a 1.22 m distillation column with similar tray configurations with the exception of hole size. The diameters of the sieve hole covered the range of 3.2 to 66.7 mm. The tests were conducted with three different hydrocarbon systems, cyclo-hexane/n-heptane, iso-butane/n-butane, and p/o-xylene at pressures of 0.02 to 27.6 bar. The performance of the sieve trays with different hole sizes was compared based on data released by FRI. The FRI computer models package (DRP) was used to reflect the influence of hole size based on more extensive data from FRI.

The hole size affects the mass transfer efficiency, capacity and pressure drop. The results also show a significant effect of system pressure on the relative conclusions. Hole size does have an impact on sieve tray performance, but is one of many variables that influence the performance of sieve trays. A quality model that accounts for several variables and that can be verified by experimental data is the best tool for predicting sieve tray performance.

REFERENCES

1. Oklahoma State University Library, Stillwater, OK 74078-1071
   Phone 405-744-9729; URL: http://www.library.okstate.edu
2. H.Z. Kister, Distillation Design, McGraw-Hill, New York, 1992, p 277.
3. H.Z. Kister, Distillation Design, McGraw-Hill, New York, 1992, p 283.
4. H.Z. Kister, Distillation Design, McGraw-Hill, New York, 1992, p 296.
5. H.Z. Kister, Distillation Design, McGraw-Hill, New York, 1992, p 301.
6. H.Z. Kister, Distillation Design, McGraw-Hill, New York, 1992, p 309.
7. H.Z. Kister, Distillation Design, McGraw-Hill, New York, 1992, p 331.
8. H.Z. Kister, Distillation Design, McGraw-Hill, New York, 1992, p 386.
9. H.Z. Kister, Distillation Design, McGraw-Hill, New York, 1992, p 390.
10. Kalbassi et al.(184 Kalbassi, M.A., M.M. Dribika, M.W. Biddulph, S Kler, and J.T. Lavin, I. Chem. E. Symp. Ser. 104, p. A511, 1987.

11. Lopez Bonillo(187 Lopez-Bobillo, F., M. Nolla, and F. Casrwlla, I. Chem. E. Symp. Ser. 104. p. B461, 1987.

12. Prado and Fair (110 Prado, M. abd J.R. Fair, I. Chem. E. Symp. Ser 104, p. A529, 1987, p. 144.

13. Prado, M. and J.R. Fair, Ind. Eng. Chem. Res. 29, p. 1031, 1990.

14. Mahiout, S., and A. Vogelpohl, I. Chem. E. Symp. Ser. 104, p. A495, 1987.

15. Sawistowski, H., Chem. Ing. Tech. 50(10), p. 743, 1978 .

16. Mahiout, S., and A. Vogelpohl, I. Chem. E. Symp. Ser. 104, p. A495, 1987.

17. Lockett, M.J., Distillation Tray Fundamentals, Cambridge University Press, New York, 1986, p. 9.

18. FRI Progress Report, Jan. 1957.

19. FRI Progress Report, Aug. 1957.

20. FRI Progress Report, Dec. 1957.

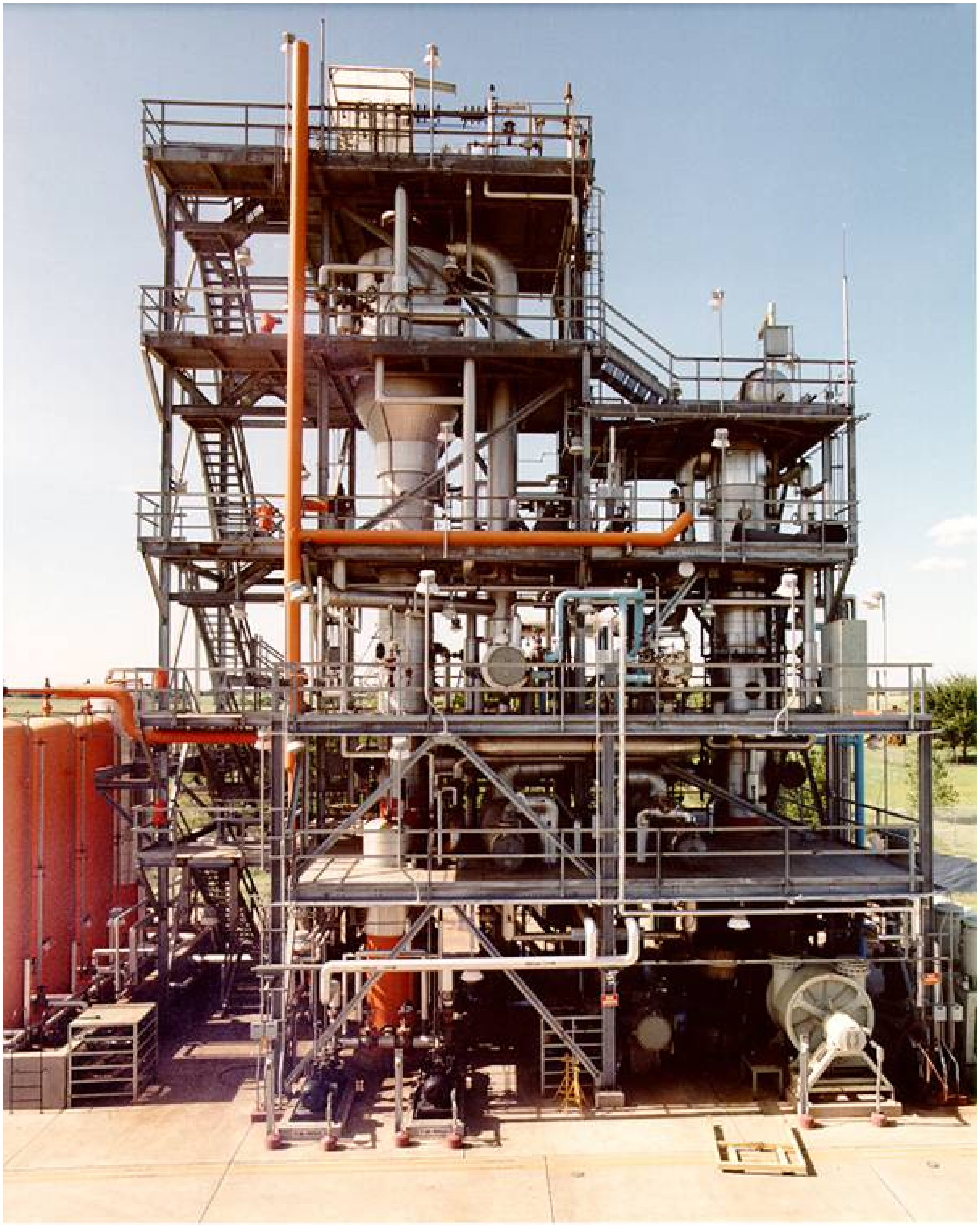


Figure 1. Picture of the FRI$_{(SM)}$ Experimental Unit

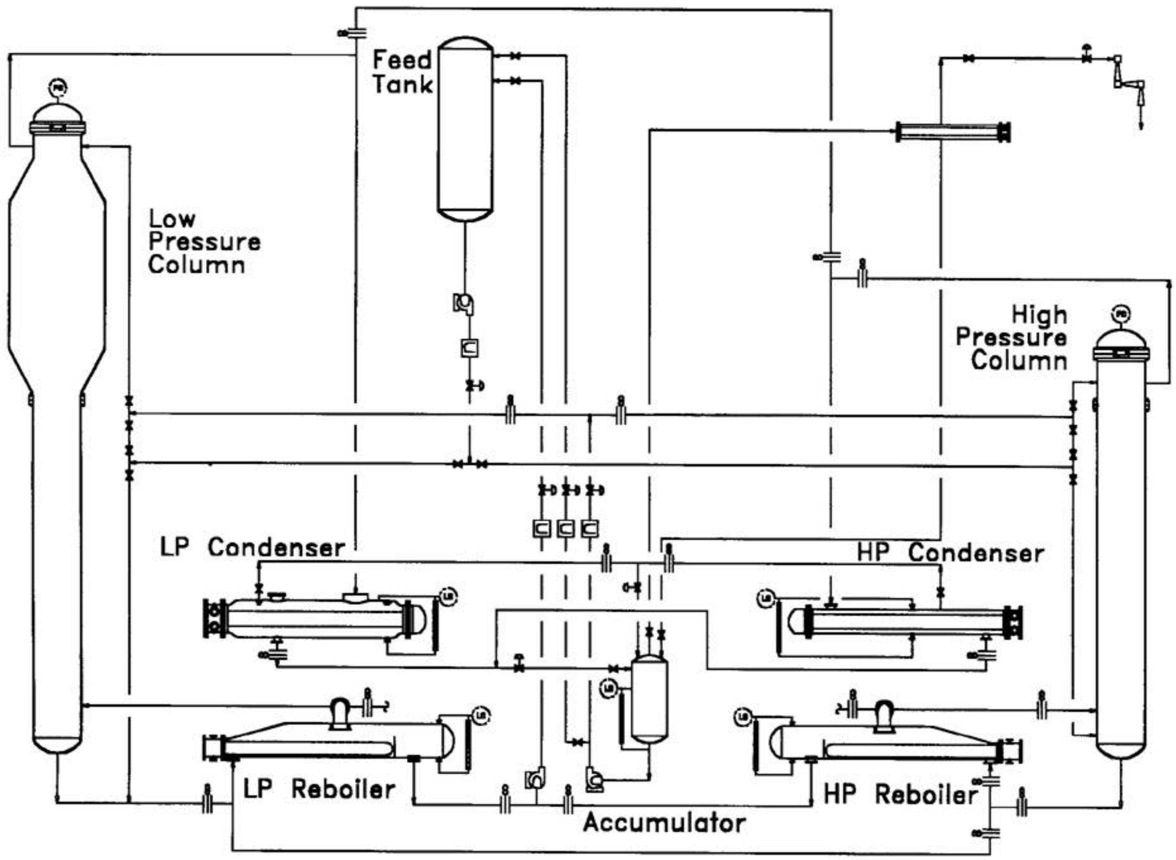


Figure 2. Schematic drawing of the FRI$_{(SM)}$ Experimental Unit

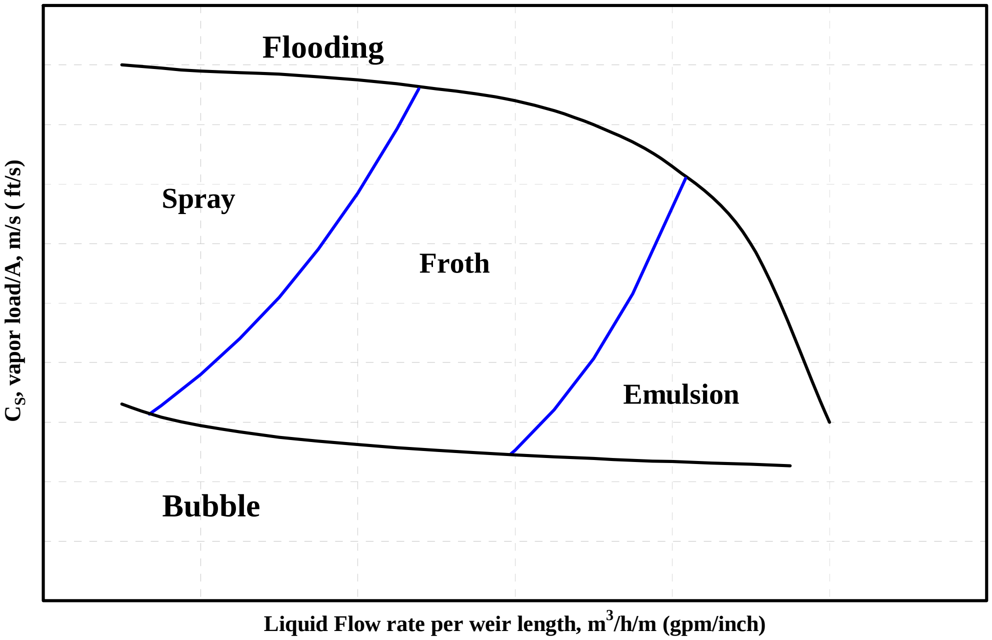


Figure 3. Flow Regime Map

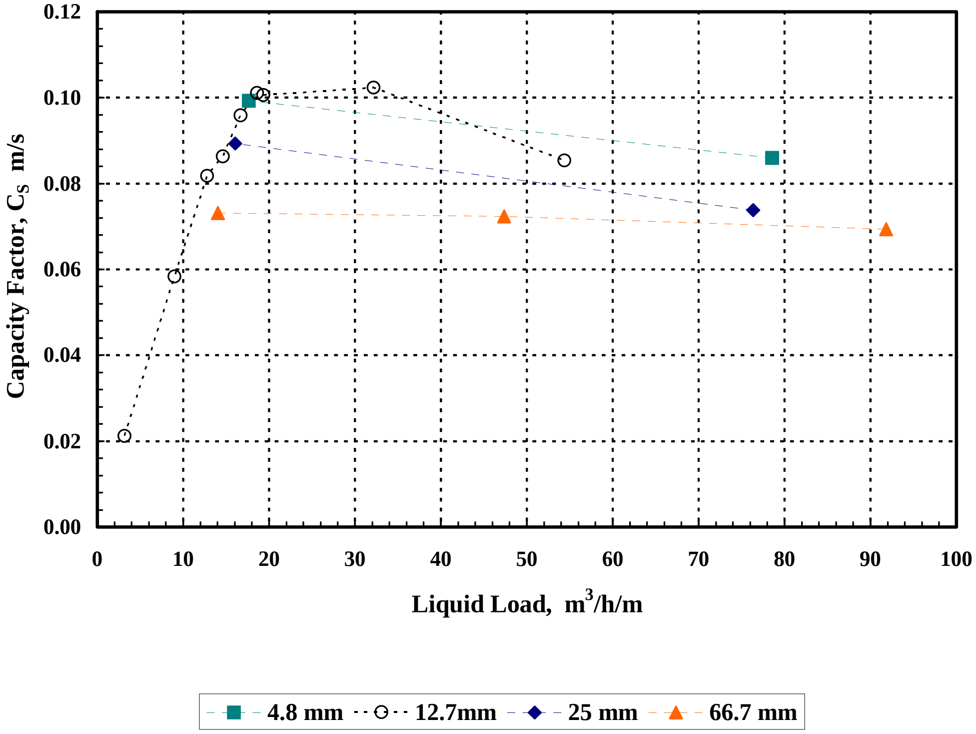


Figure 4. Tray Capacity for C6/C7 at 0.28 bar

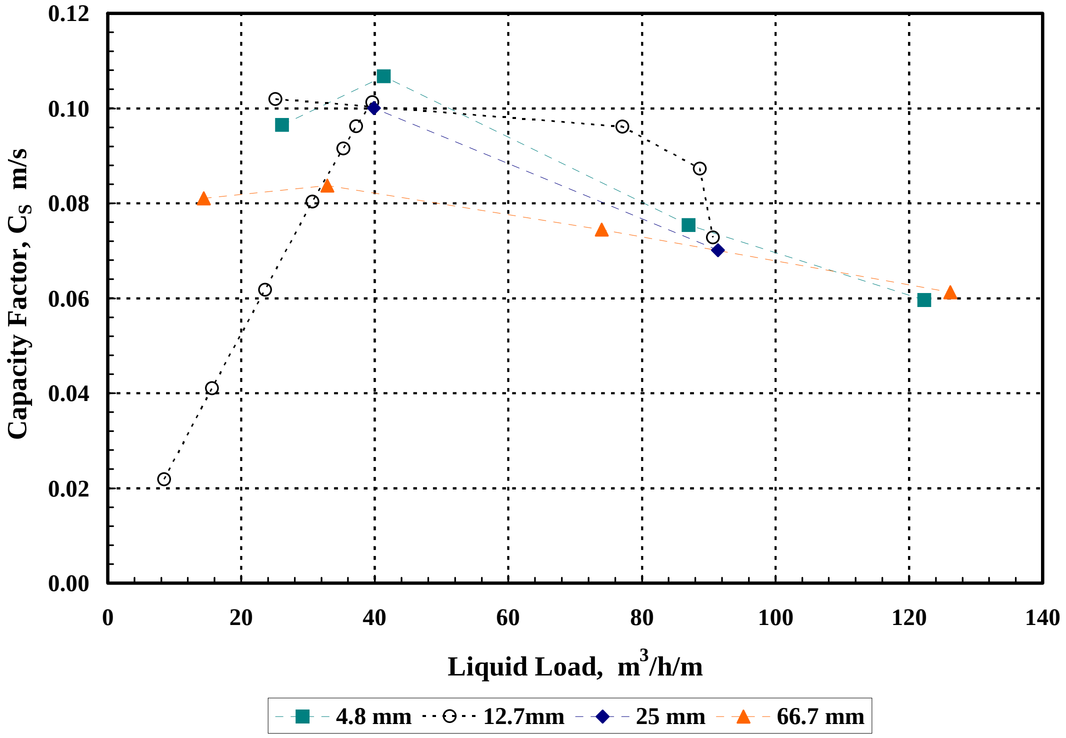


Figure 5. Tray Capacity for C6/C7 at 1.65 bar

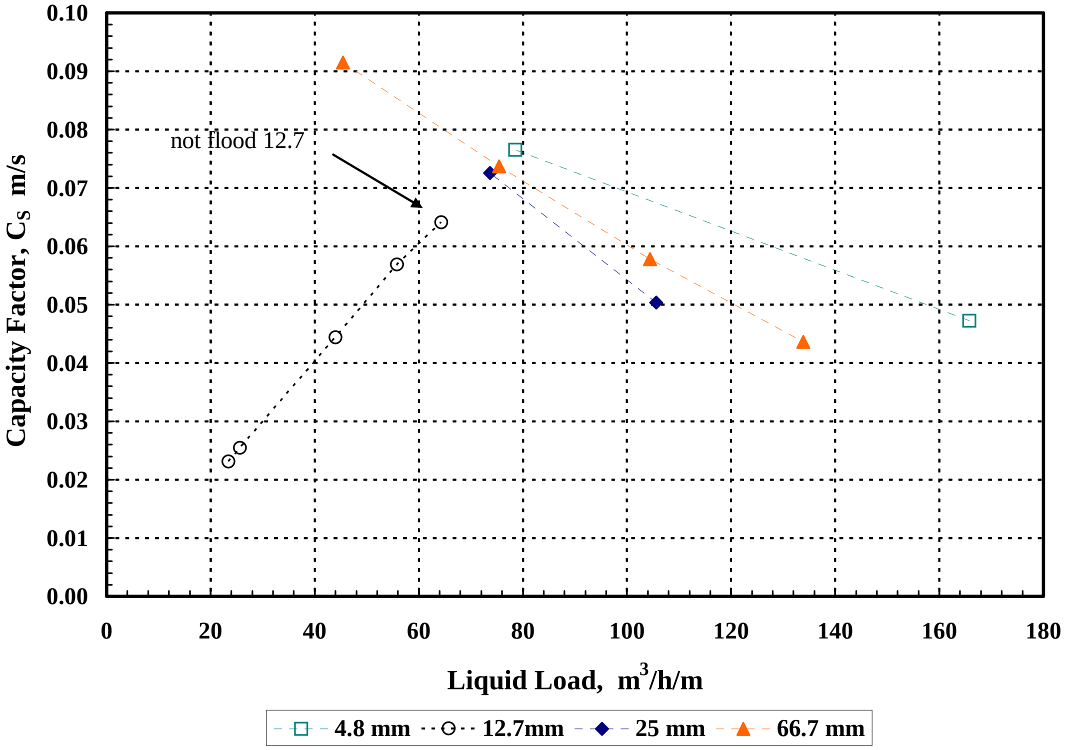


Figure 6. Tray Capacity for iC4/nC4 at 11.4 bar

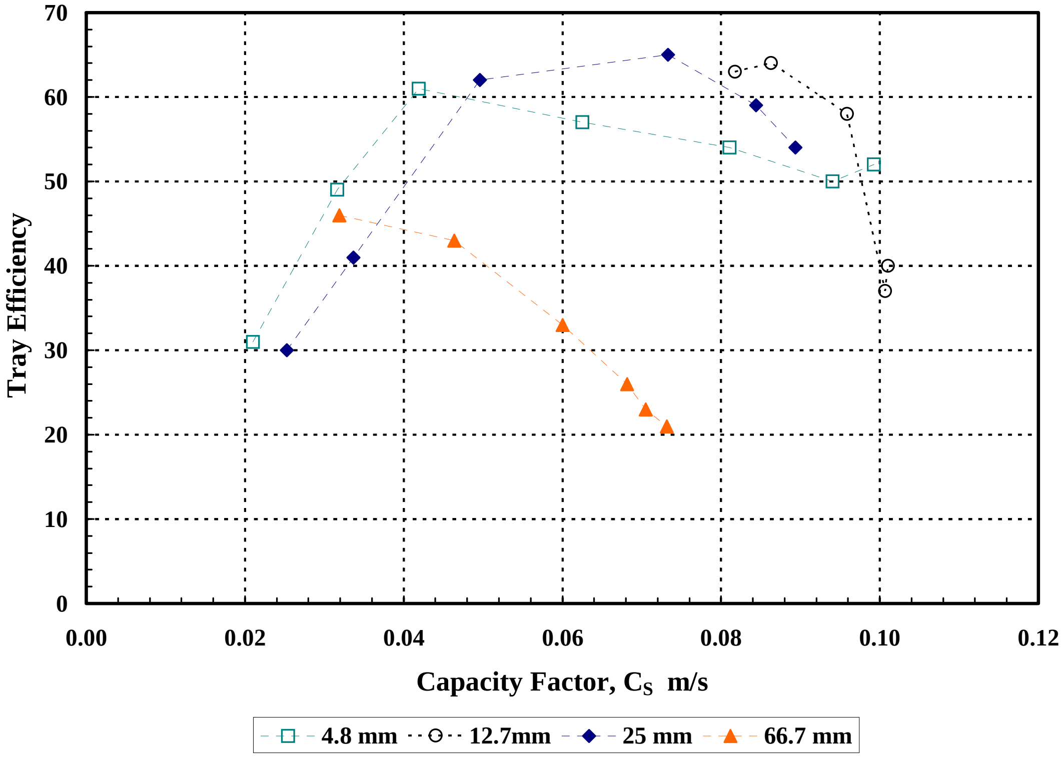


Figure 7. Tray Efficiency for C6/C7 at 0.28 bar

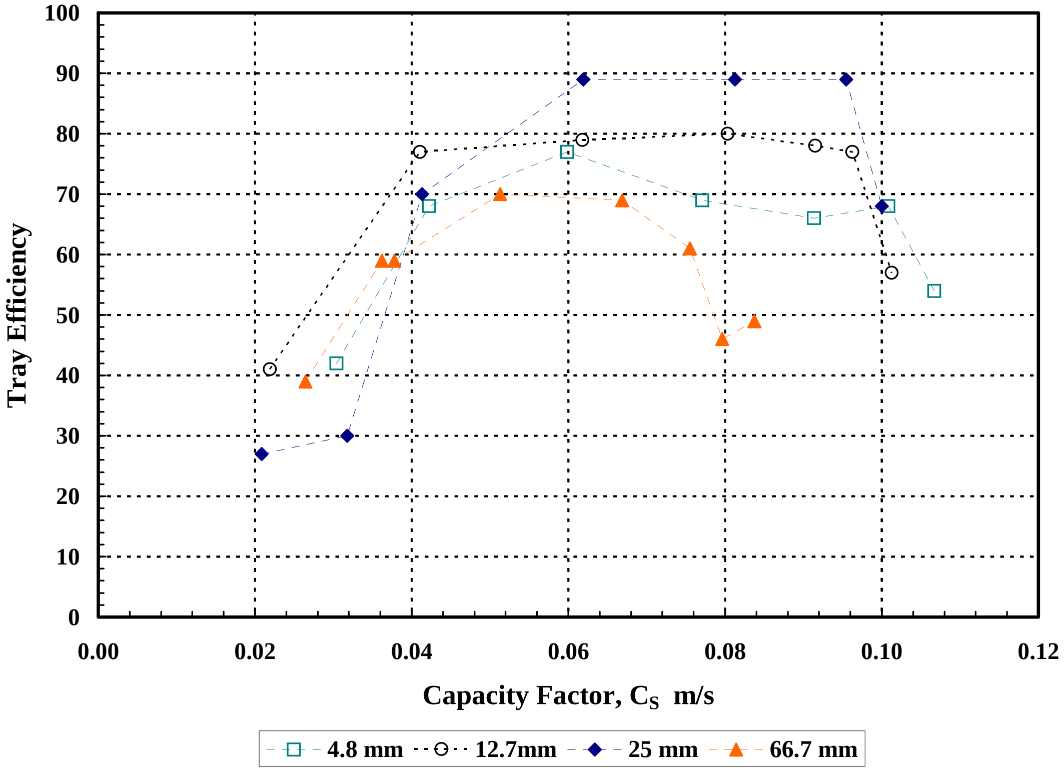


Figure 8. Tray Efficiency for C6/C7 at 1.65 bar

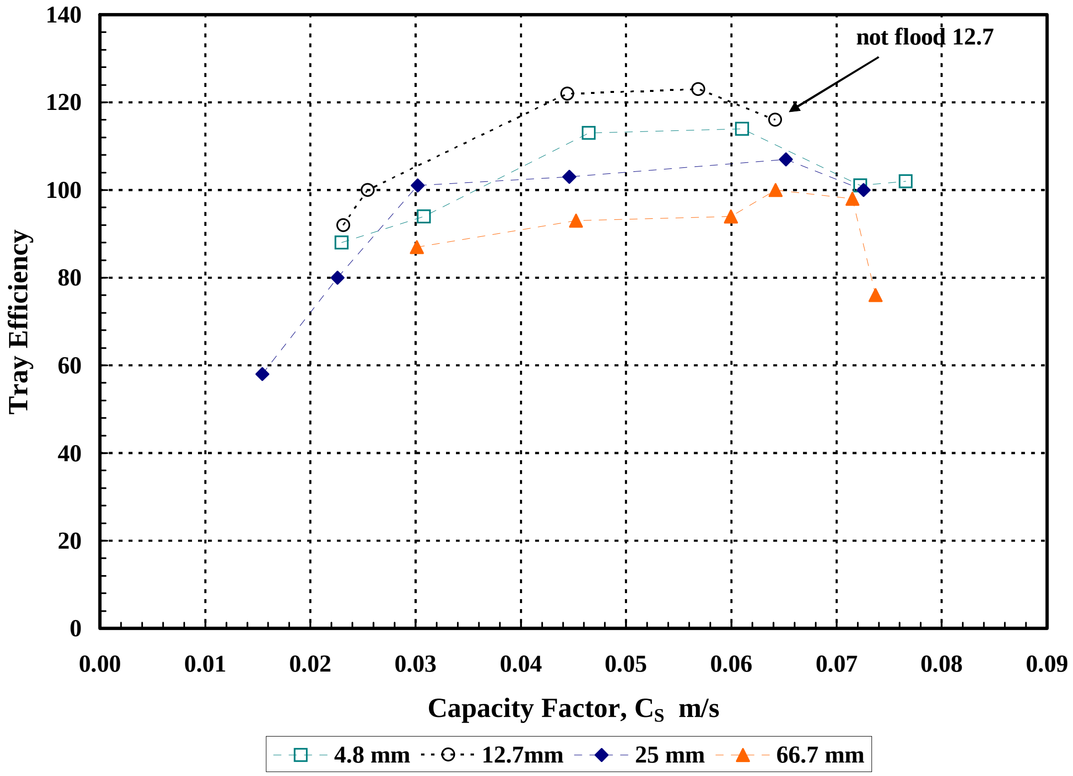


Figure 9. Tray Efficiency for iC4/nC4 at 11.4 bar

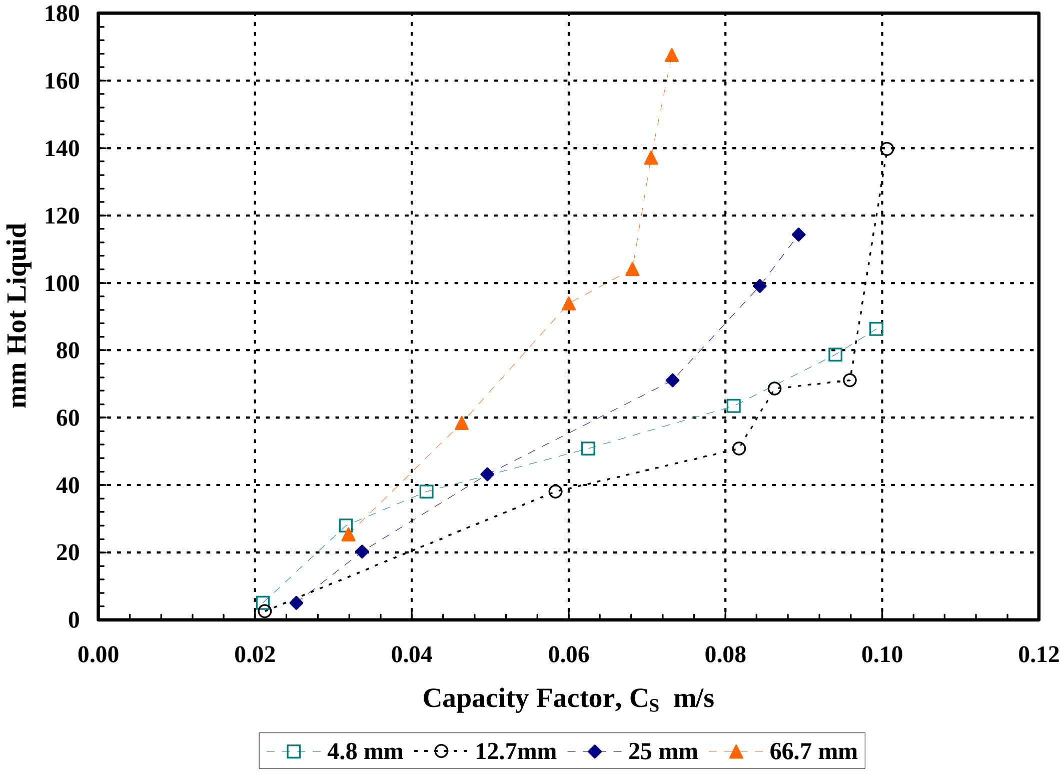


Figure 10. Tray Pressure Drop Per Tray for C6/C7 at 0.28 bar

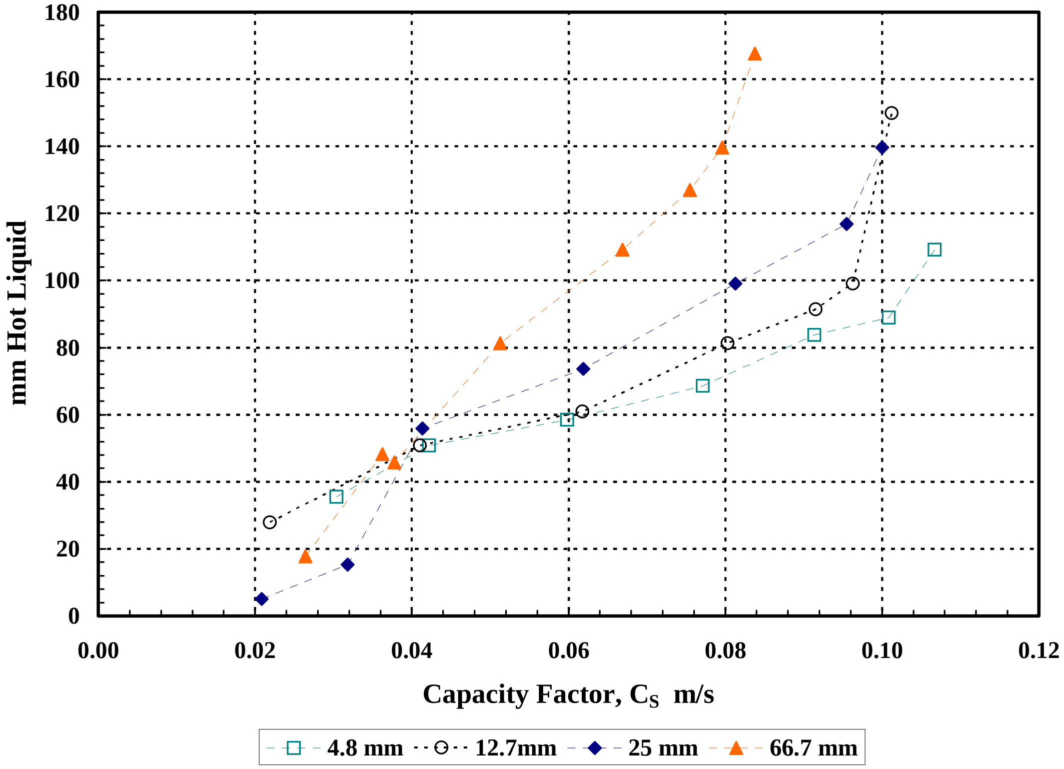


Figure 11. Tray Pressure Drop Per Tray for C6/C7 at 1.65 bar

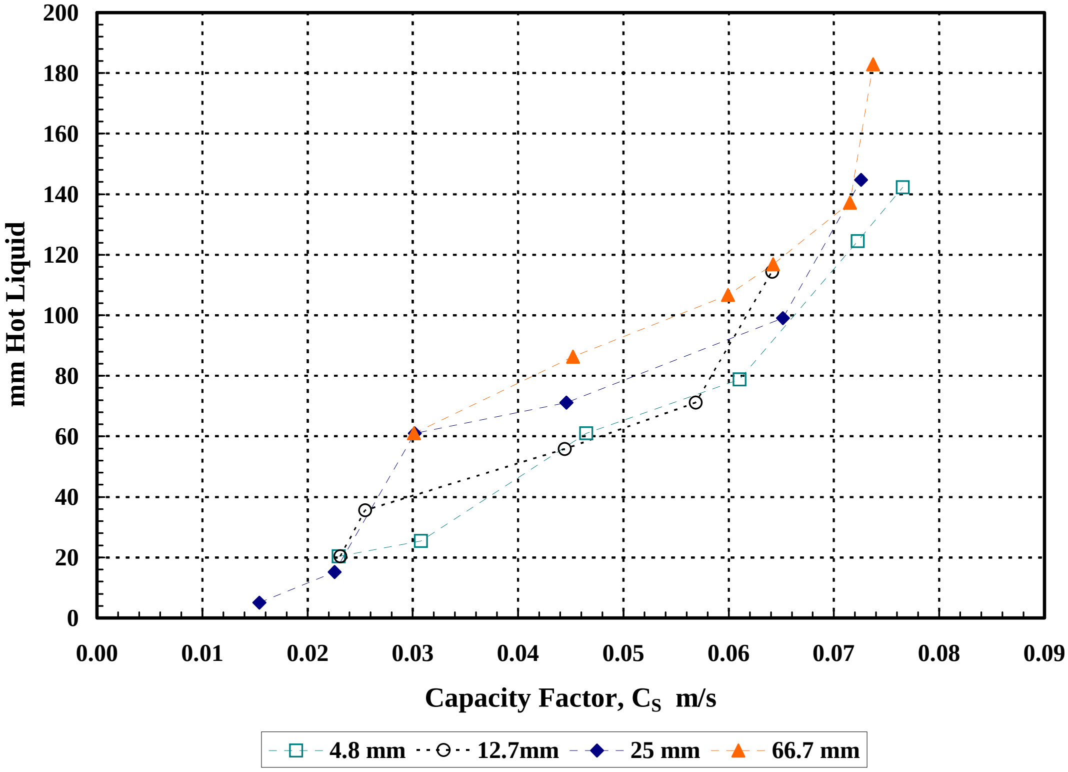
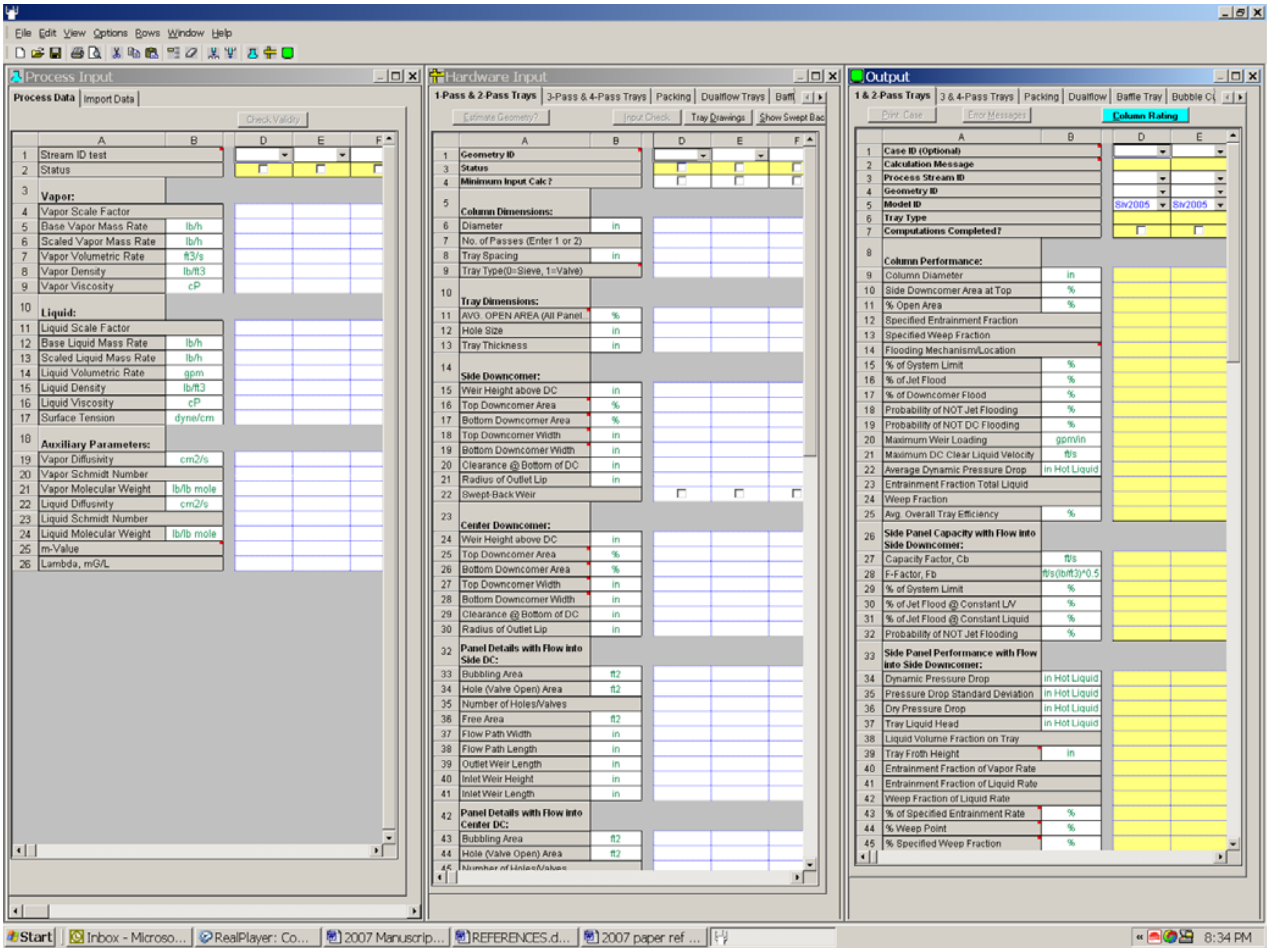


Figure 12. Tray Pressure Drop Per Tray for iC4/nC4 at 11.4 bar

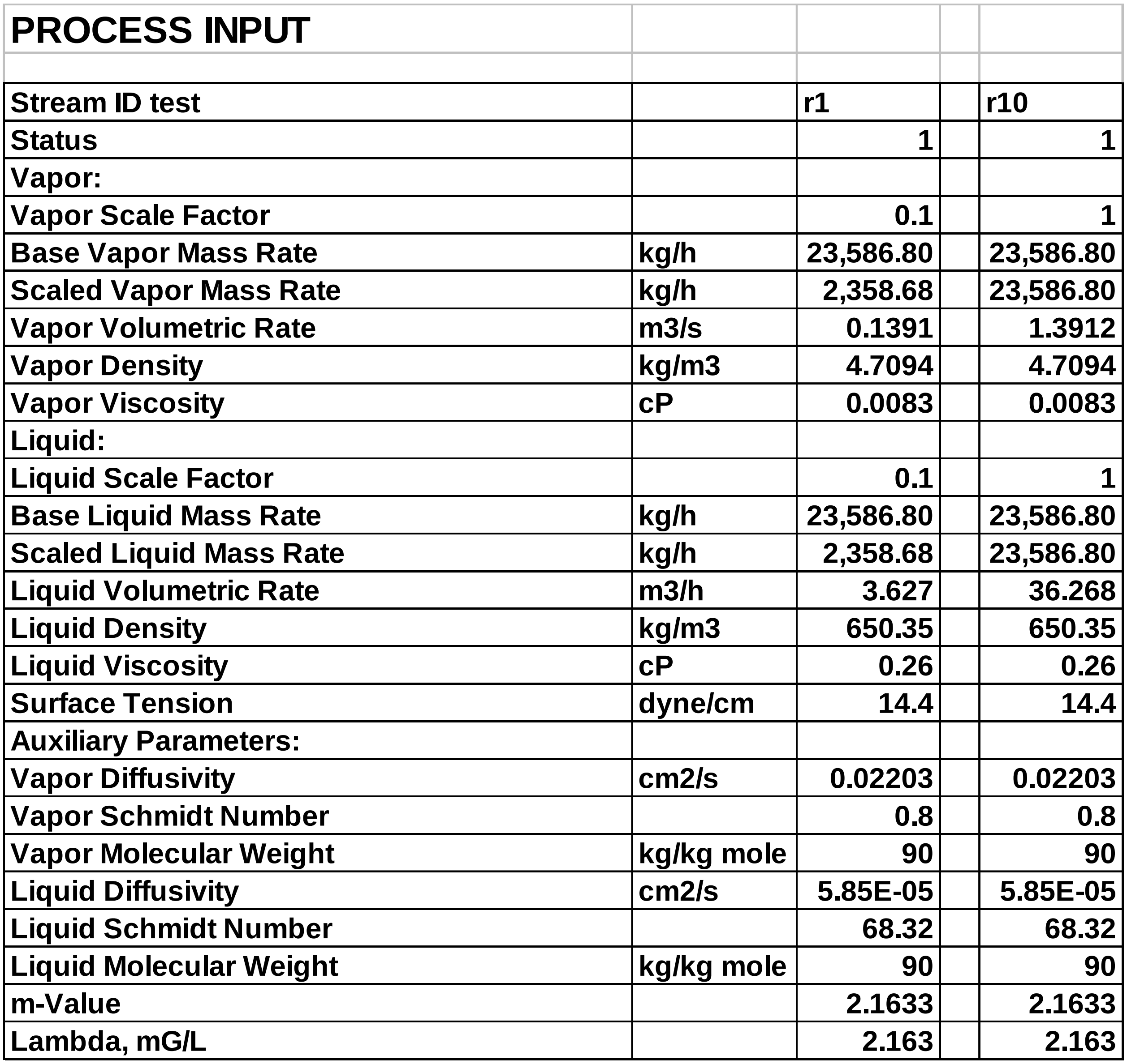


	A	B	D	E	F
1	Stream ID test				
2	Status		☐	☐	☐
3	**Vapor:**				
4	Vapor Scale Factor				
5	Base Vapor Mass Rate	lb/h			
6	Scaled Vapor Mass Rate	lb/h			
7	Vapor Volumetric Rate	ft3/s			
8	Vapor Density	lb/ft3			
9	Vapor Viscosity	cP			
10	**Liquid:**				
11	Liquid Scale Factor				
12	Base Liquid Mass Rate	lb/h			
13	Scaled Liquid Mass Rate	lb/h			
14	Liquid Volumetric Rate	gpm			
15	Liquid Density	lb/ft3			
16	Liquid Viscosity	cP			
17	Surface Tension	dyne/cm			
18	**Auxiliary Parameters:**				
19	Vapor Diffusivity	cm2/s			
20	Vapor Schmidt Number				
21	Vapor Molecular Weight	lb/lb mole			
22	Liquid Diffusivity	cm2/s			
23	Liquid Schmidt Number				
24	Liquid Molecular Weight	lb/lb mole			
25	m-Value				
26	Lambda, mG/L				

	A	B	D	E	F
1	**Geometry ID**				
3	**Status**		☐	☐	☐
4	**Minimum Input Calc?**		☐	☐	☐
5	**Column Dimensions:**				
6	Diameter	in			
7	No. of Passes (Enter 1 or 2)				
8	Tray Spacing	in			
9	Tray Type(0=Sieve, 1=Valve)				
10	**Tray Dimensions:**				
11	AVG. OPEN AREA (All Panel...	%			
12	Hole Size	in			
13	Tray Thickness	in			
14	**Side Downcomer:**				
15	Weir Height above DC	in			
16	Top Downcomer Area	%			
17	Bottom Downcomer Area	%			
18	Top Downcomer Width	in			
19	Bottom Downcomer Width	in			
20	Clearance @ Bottom of DC	in			
21	Radius of Outlet Lip	in			
22	Swept-Back Weir		☐	☐	☐
23	**Center Downcomer:**				
24	Weir Height above DC	in			
25	Top Downcomer Area	%			
26	Bottom Downcomer Area	%			
27	Top Downcomer Width	in			
28	Bottom Downcomer Width	in			
29	Clearance @ Bottom of DC	in			
30	Radius of Outlet Lip	in			
32	**Panel Details with Flow into Side DC:**				
33	Bubbling Area	ft2			
34	Hole (Valve Open) Area	ft2			
35	Number of Holes/Valves				
36	Free Area	ft2			
37	Flow Path Width	in			
38	Flow Path Length	in			
39	Outlet Weir Length	in			
40	Inlet Weir Height	in			
41	Inlet Weir Length	in			
42	**Panel Details with Flow into Center DC:**				
43	Bubbling Area	ft2			
44	Hole (Valve Open) Area	ft2			
45	Number of Holes/Valves				

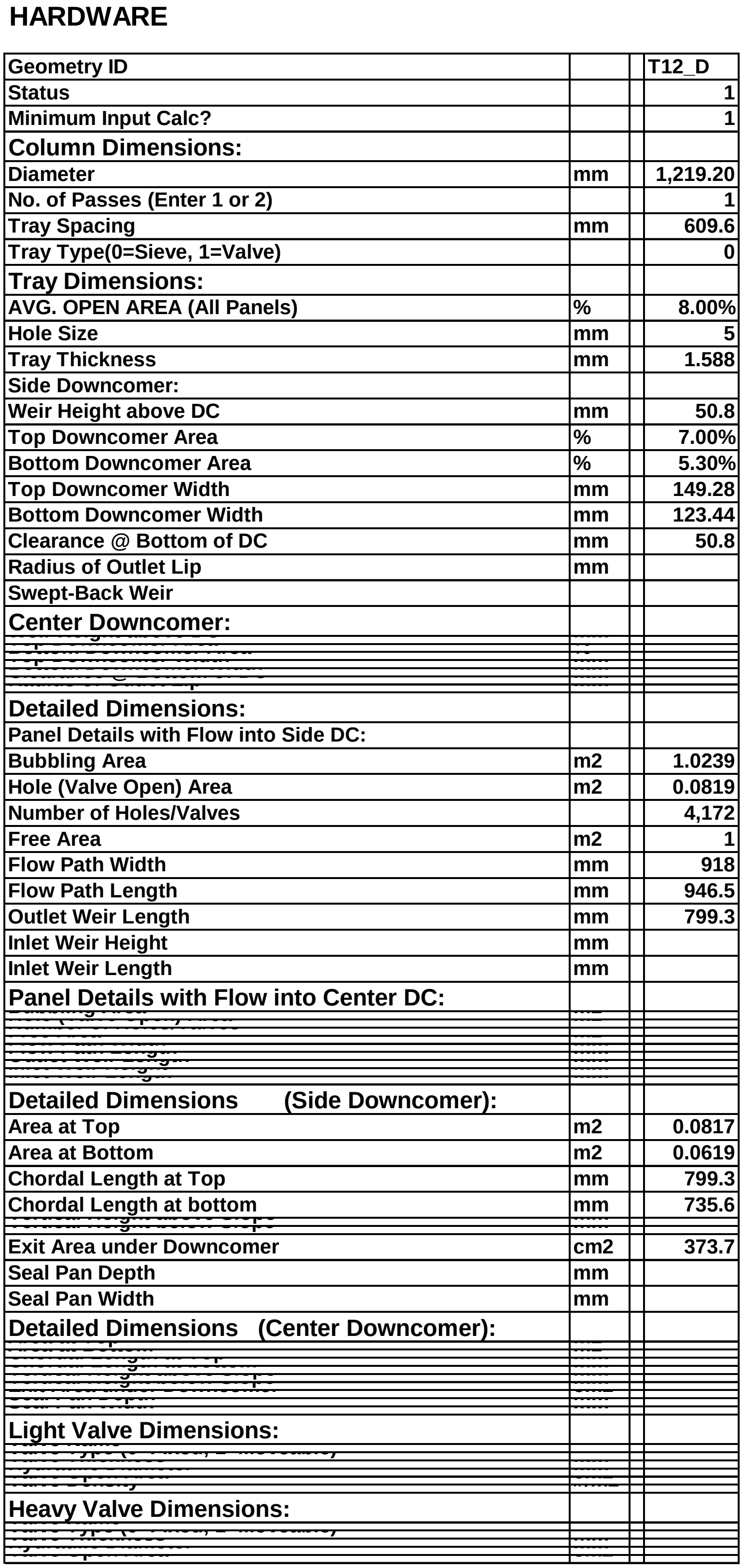
	A	B	D	E
1	**Case ID (Optional)**			
2	**Calculation Message**			
3	**Process Stream ID**			
4	**Geometry ID**			
5	**Model ID**		SIv2005	SIv2005
6	**Tray Type**			
7	**Computations Completed?**		☐	☐
8	**Column Performance:**			
9	Column Diameter	in		
10	Side Downcomer Area at Top	%		
11	% Open Area	%		
12	Specified Entrainment Fraction			
13	Specified Weep Fraction			
14	Flooding Mechanism/Location			
15	% of System Limit	%		
16	% of Jet Flood	%		
17	% of Downcomer Flood	%		
18	Probability of NOT Jet Flooding	%		
19	Probability of NOT DC Flooding	%		
20	Maximum Weir Loading	gpm/in		
21	Maximum DC Clear Liquid Velocity	ft/s		
22	Average Dynamic Pressure Drop	in Hot Liquid		
23	Entrainment Fraction Total Liquid			
24	Weep Fraction			
25	Avg. Overall Tray Efficiency	%		
26	**Side Panel Capacity with Flow into Side Downcomer:**			
27	Capacity Factor, Cb	ft/s		
28	F-Factor, Fb	ft/s(lb/ft3)^0.5		
29	% of System Limit	%		
30	% of Jet Flood @ Constant L/V	%		
31	% of Jet Flood @ Constant Liquid	%		
32	Probability of NOT Jet Flooding	%		
33	**Side Panel Performance with Flow into Side Downcomer:**			
34	Dynamic Pressure Drop	in Hot Liquid		
35	Pressure Drop Standard Deviation	in Hot Liquid		
36	Dry Pressure Drop	in Hot Liquid		
37	Tray Liquid Head	in Hot Liquid		
38	Liquid Volume Fraction on Tray			
39	Tray Froth Height	in		
40	Entrainment Fraction of Vapor Rate			
41	Entrainment Fraction of Liquid Rate			
42	Weep Fraction of Liquid Rate			
43	% of Specified Entrainment Rate	%		
44	% Weep Point	%		
45	% Specified Weep Fraction	%		

Figure 13. Opening Page of FRI DRP



PROCESS INPUT				
Stream ID test		**r1**		**r10**
Status		**1**		**1**
Vapor:				
Vapor Scale Factor		**0.1**		**1**
Base Vapor Mass Rate	**kg/h**	**23,586.80**		**23,586.80**
Scaled Vapor Mass Rate	**kg/h**	**2,358.68**		**23,586.80**
Vapor Volumetric Rate	**m3/s**	**0.1391**		**1.3912**
Vapor Density	**kg/m3**	**4.7094**		**4.7094**
Vapor Viscosity	**cP**	**0.0083**		**0.0083**
Liquid:				
Liquid Scale Factor		**0.1**		**1**
Base Liquid Mass Rate	**kg/h**	**23,586.80**		**23,586.80**
Scaled Liquid Mass Rate	**kg/h**	**2,358.68**		**23,586.80**
Liquid Volumetric Rate	**m3/h**	**3.627**		**36.268**
Liquid Density	**kg/m3**	**650.35**		**650.35**
Liquid Viscosity	**cP**	**0.26**		**0.26**
Surface Tension	**dyne/cm**	**14.4**		**14.4**
Auxiliary Parameters:				
Vapor Diffusivity	**cm2/s**	**0.02203**		**0.02203**
Vapor Schmidt Number		**0.8**		**0.8**
Vapor Molecular Weight	**kg/kg mole**	**90**		**90**
Liquid Diffusivity	**cm2/s**	**5.85E-05**		**5.85E-05**
Liquid Schmidt Number		**68.32**		**68.32**
Liquid Molecular Weight	**kg/kg mole**	**90**		**90**
m-Value		**2.1633**		**2.1633**
Lambda, mG/L		**2.163**		**2.163**

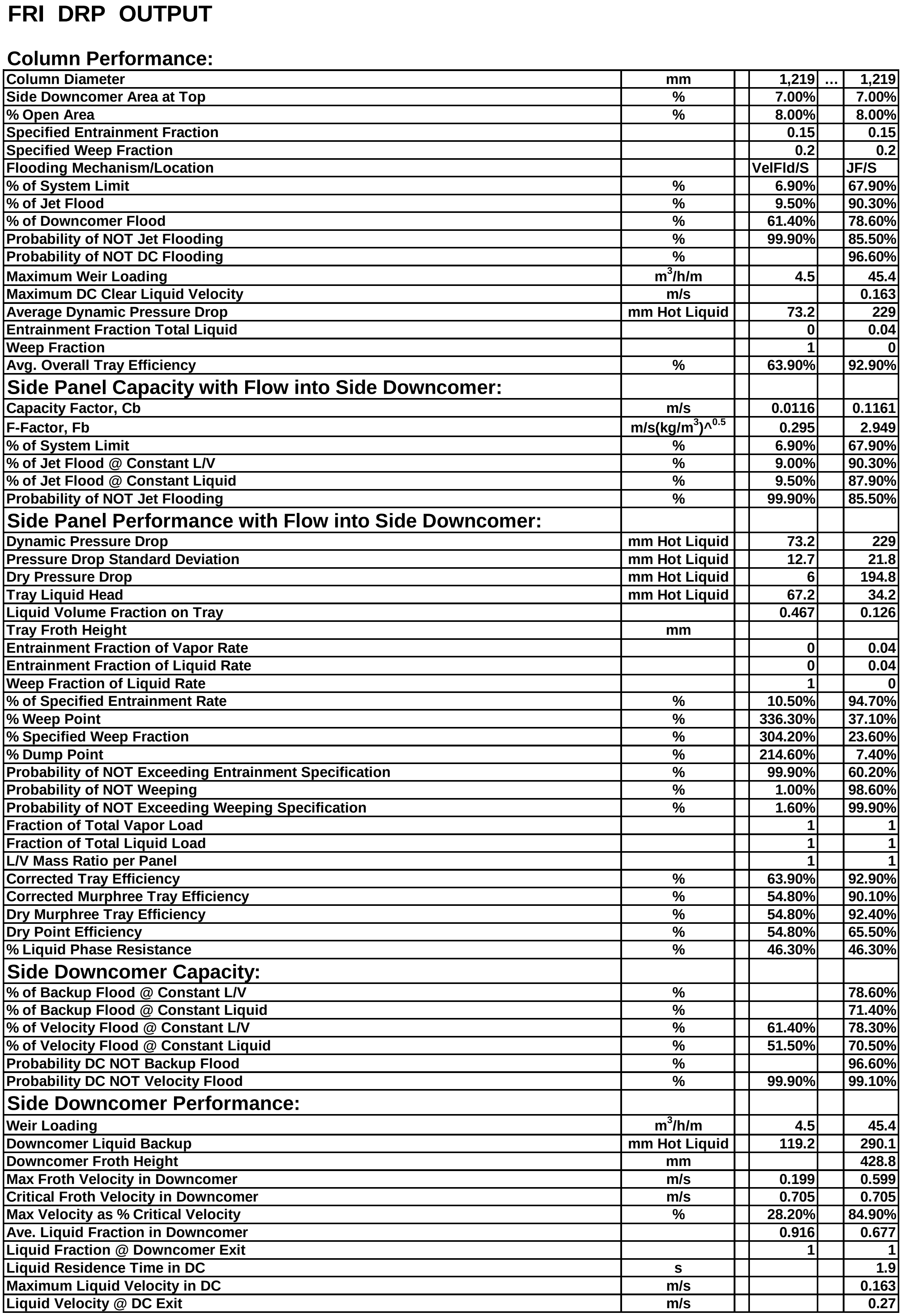
Figure 14. Opening Page of FRI DRP (Process Input)



HARDWARE

Geometry ID			**T12_D**
Status			**1**
Minimum Input Calc?			**1**
Column Dimensions:			
Diameter	**mm**		**1,219.20**
No. of Passes (Enter 1 or 2)			**1**
Tray Spacing	**mm**		**609.6**
Tray Type(0=Sieve, 1=Valve)			**0**
Tray Dimensions:			
AVG. OPEN AREA (All Panels)	**%**		**8.00%**
Hole Size	**mm**		**5**
Tray Thickness	**mm**		**1.588**
Side Downcomer:			
Weir Height above DC	**mm**		**50.8**
Top Downcomer Area	**%**		**7.00%**
Bottom Downcomer Area	**%**		**5.30%**
Top Downcomer Width	**mm**		**149.28**
Bottom Downcomer Width	**mm**		**123.44**
Clearance @ Bottom of DC	**mm**		**50.8**
Radius of Outlet Lip	**mm**		
Swept-Back Weir			
Center Downcomer:			
Detailed Dimensions:			
Panel Details with Flow into Side DC:			
Bubbling Area	**m2**		**1.0239**
Hole (Valve Open) Area	**m2**		**0.0819**
Number of Holes/Valves			**4,172**
Free Area	**m2**		**1**
Flow Path Width	**mm**		**918**
Flow Path Length	**mm**		**946.5**
Outlet Weir Length	**mm**		**799.3**
Inlet Weir Height	**mm**		
Inlet Weir Length	**mm**		
Panel Details with Flow into Center DC:			
Detailed Dimensions (Side Downcomer):			
Area at Top	**m2**		**0.0817**
Area at Bottom	**m2**		**0.0619**
Chordal Length at Top	**mm**		**799.3**
Chordal Length at bottom	**mm**		**735.6**
Exit Area under Downcomer	**cm2**		**373.7**
Seal Pan Depth	**mm**		
Seal Pan Width	**mm**		
Detailed Dimensions (Center Downcomer):			
Light Valve Dimensions:			
Heavy Valve Dimensions:			

Figure 15. Opening Page of FRI DRP (Hardware)



FRI DRP OUTPUT

Column Performance:

Column Diameter	mm		1,219	…	1,219
Side Downcomer Area at Top	%		7.00%		7.00%
% Open Area	%		8.00%		8.00%
Specified Entrainment Fraction			0.15		0.15
Specified Weep Fraction			0.2		0.2
Flooding Mechanism/Location			VelFld/S		JF/S
% of System Limit	%		6.90%		67.90%
% of Jet Flood	%		9.50%		90.30%
% of Downcomer Flood	%		61.40%		78.60%
Probability of NOT Jet Flooding	%		99.90%		85.50%
Probability of NOT DC Flooding	%				96.60%
Maximum Weir Loading	$m^3/h/m$		4.5		45.4
Maximum DC Clear Liquid Velocity	m/s				0.163
Average Dynamic Pressure Drop	mm Hot Liquid		73.2		229
Entrainment Fraction Total Liquid			0		0.04
Weep Fraction			1		0
Avg. Overall Tray Efficiency	%		63.90%		92.90%
Side Panel Capacity with Flow into Side Downcomer:					
Capacity Factor, Cb	m/s		0.0116		0.1161
F-Factor, Fb	$m/s(kg/m^3)^{\wedge 0.5}$		0.295		2.949
% of System Limit	%		6.90%		67.90%
% of Jet Flood @ Constant L/V	%		9.00%		90.30%
% of Jet Flood @ Constant Liquid	%		9.50%		87.90%
Probability of NOT Jet Flooding	%		99.90%		85.50%
Side Panel Performance with Flow into Side Downcomer:					
Dynamic Pressure Drop	mm Hot Liquid		73.2		229
Pressure Drop Standard Deviation	mm Hot Liquid		12.7		21.8
Dry Pressure Drop	mm Hot Liquid		6		194.8
Tray Liquid Head	mm Hot Liquid		67.2		34.2
Liquid Volume Fraction on Tray			0.467		0.126
Tray Froth Height	mm				
Entrainment Fraction of Vapor Rate			0		0.04
Entrainment Fraction of Liquid Rate			0		0.04
Weep Fraction of Liquid Rate			1		0
% of Specified Entrainment Rate	%		10.50%		94.70%
% Weep Point	%		336.30%		37.10%
% Specified Weep Fraction	%		304.20%		23.60%
% Dump Point	%		214.60%		7.40%
Probability of NOT Exceeding Entrainment Specification	%		99.90%		60.20%
Probability of NOT Weeping	%		1.00%		98.60%
Probability of NOT Exceeding Weeping Specification	%		1.60%		99.90%
Fraction of Total Vapor Load			1		1
Fraction of Total Liquid Load			1		1
L/V Mass Ratio per Panel			1		1
Corrected Tray Efficiency	%		63.90%		92.90%
Corrected Murphree Tray Efficiency	%		54.80%		90.10%
Dry Murphree Tray Efficiency	%		54.80%		92.40%
Dry Point Efficiency	%		54.80%		65.50%
% Liquid Phase Resistance	%		46.30%		46.30%
Side Downcomer Capacity:					
% of Backup Flood @ Constant L/V	%				78.60%
% of Backup Flood @ Constant Liquid	%				71.40%
% of Velocity Flood @ Constant L/V	%		61.40%		78.30%
% of Velocity Flood @ Constant Liquid	%		51.50%		70.50%
Probability DC NOT Backup Flood	%				96.60%
Probability DC NOT Velocity Flood	%		99.90%		99.10%
Side Downcomer Performance:					
Weir Loading	$m^3/h/m$		4.5		45.4
Downcomer Liquid Backup	mm Hot Liquid		119.2		290.1
Downcomer Froth Height	mm				428.8
Max Froth Velocity in Downcomer	m/s		0.199		0.599
Critical Froth Velocity in Downcomer	m/s		0.705		0.705
Max Velocity as % Critical Velocity	%		28.20%		84.90%
Ave. Liquid Fraction in Downcomer			0.916		0.677
Liquid Fraction @ Downcomer Exit			1		1
Liquid Residence Time in DC	s				1.9
Maximum Liquid Velocity in DC	m/s				0.163
Liquid Velocity @ DC Exit	m/s				0.27

Figure 16. Opening Page of FRI DRP (Output)

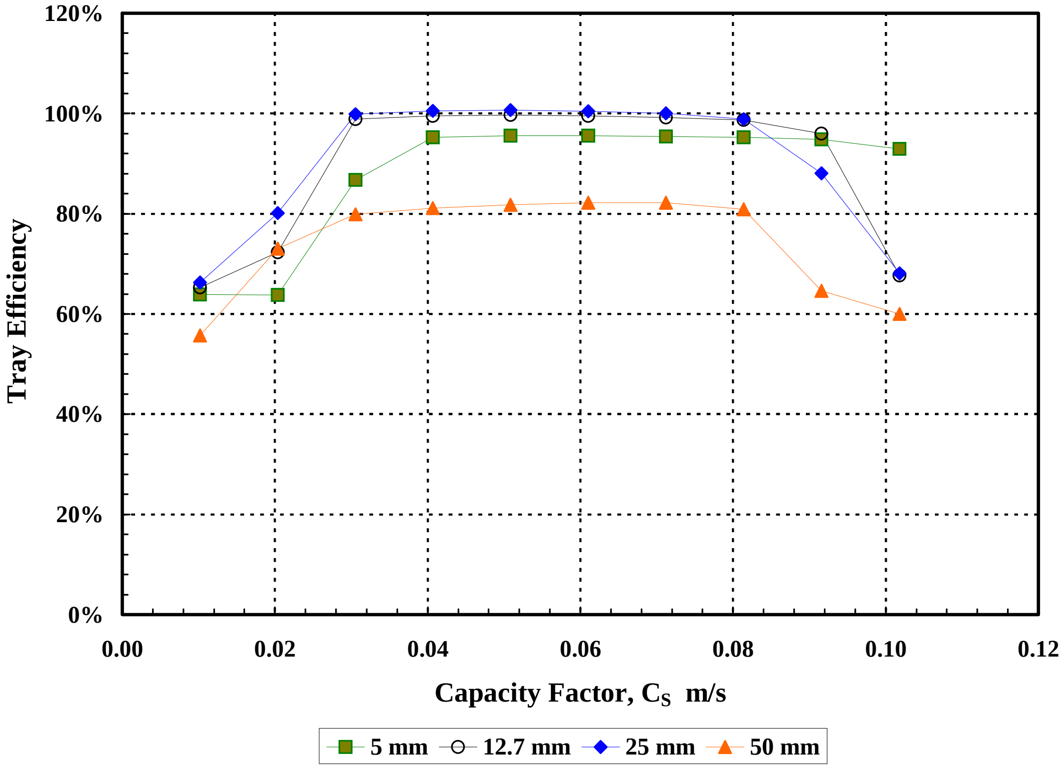


Figure 17. DRP Prediction of Tray Efficiency for Various Hole Sizes

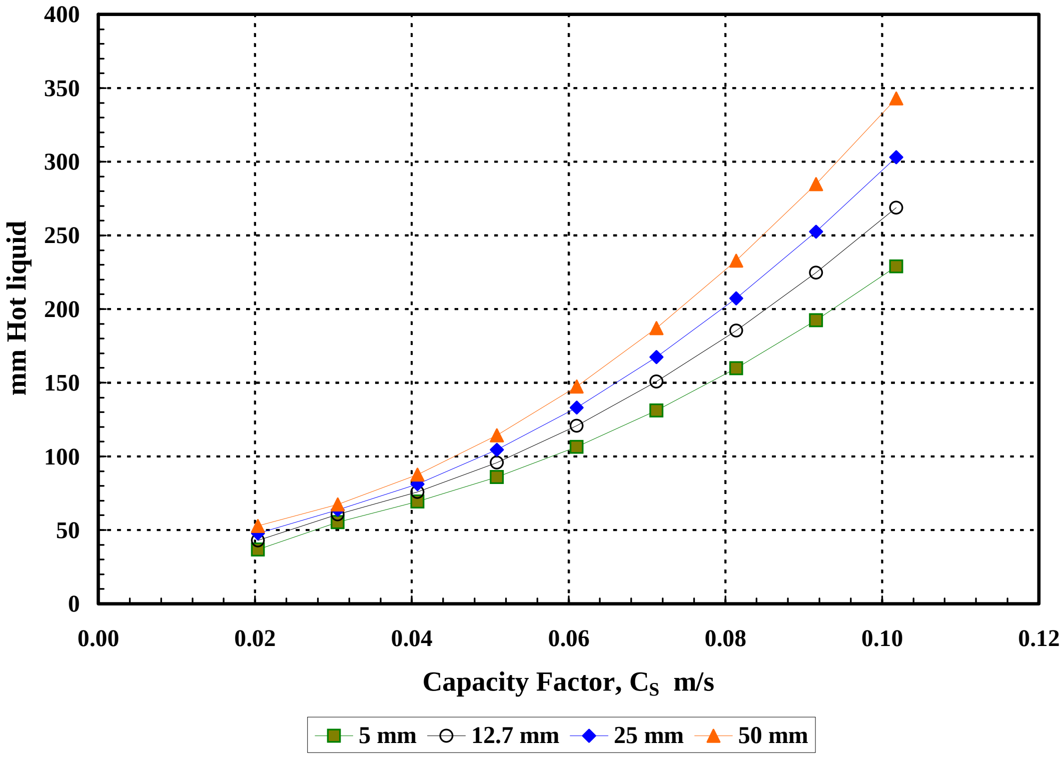


Figure 18. DRP Prediction of Tray Pressure Drop for Various Hole Sizes

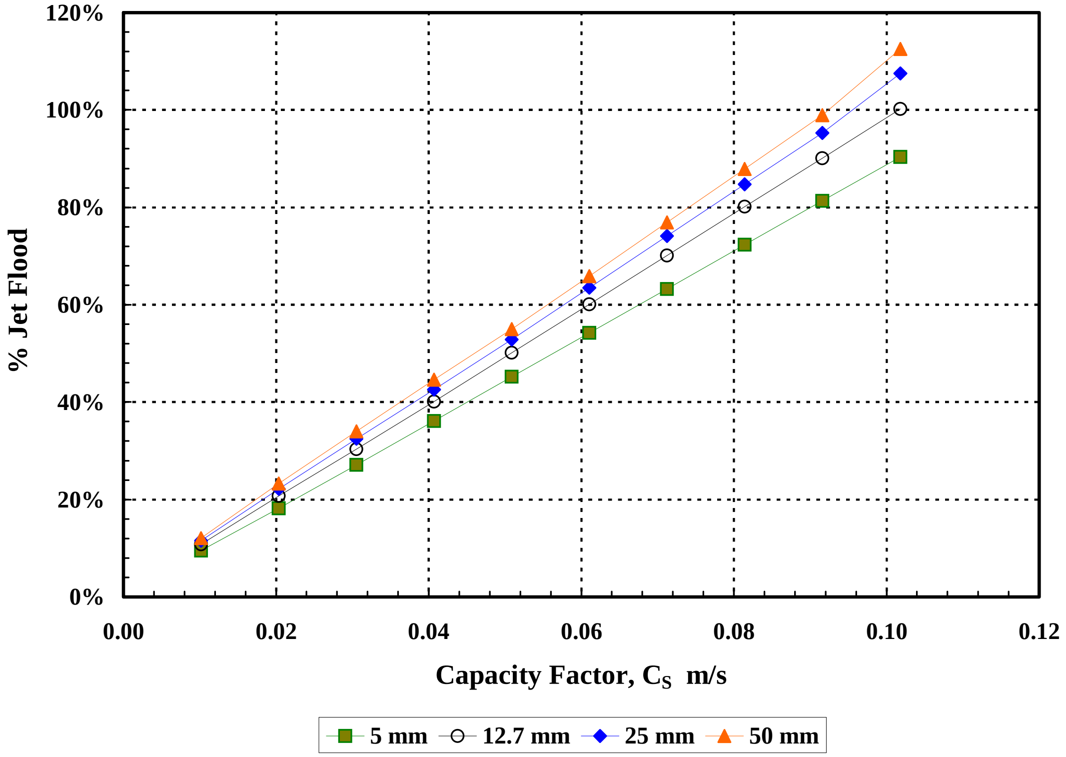


Figure 19. DRP Prediction of <u>%Jet Flood</u> for Various Hole Sizes

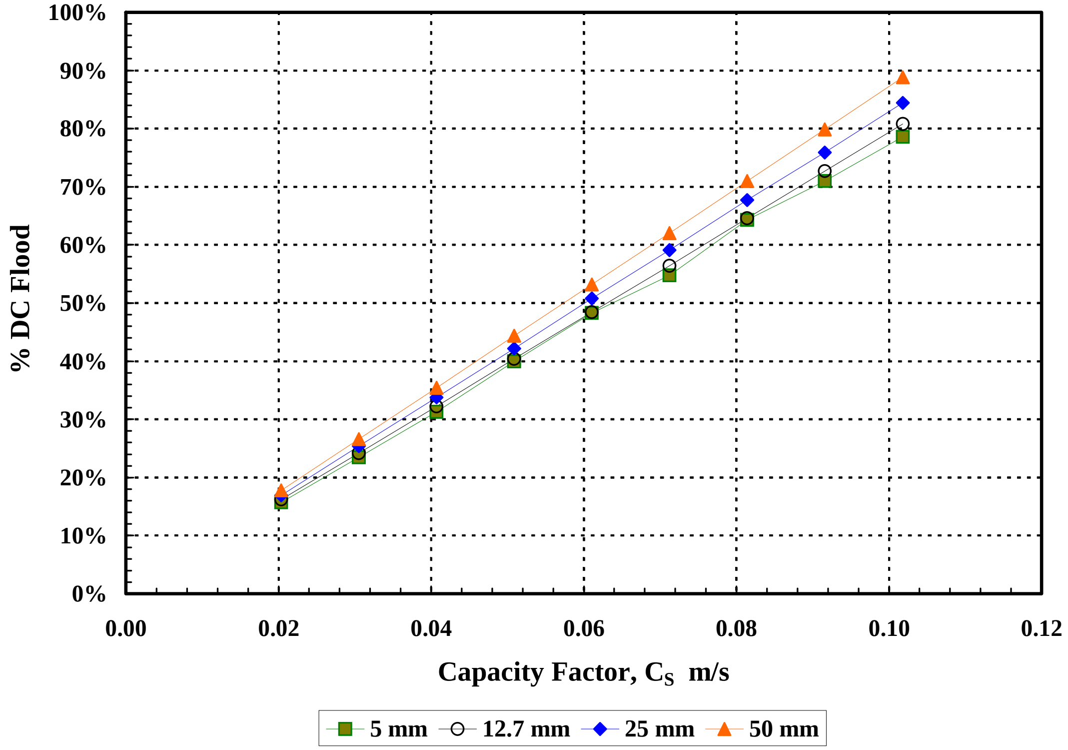


Figure 20. DRP Prediction of <u>% Downcomer</u> Flood for Various Hole Sizes

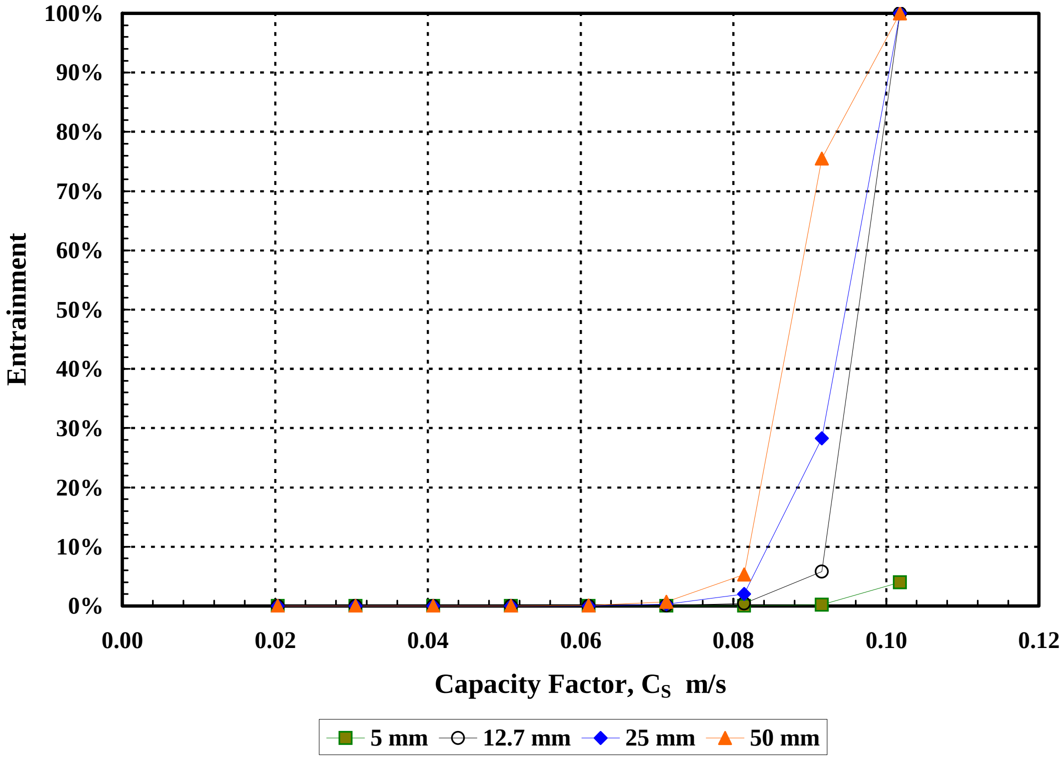


Figure 21. DRP Prediction of Entrainment for Various Hole Sizes

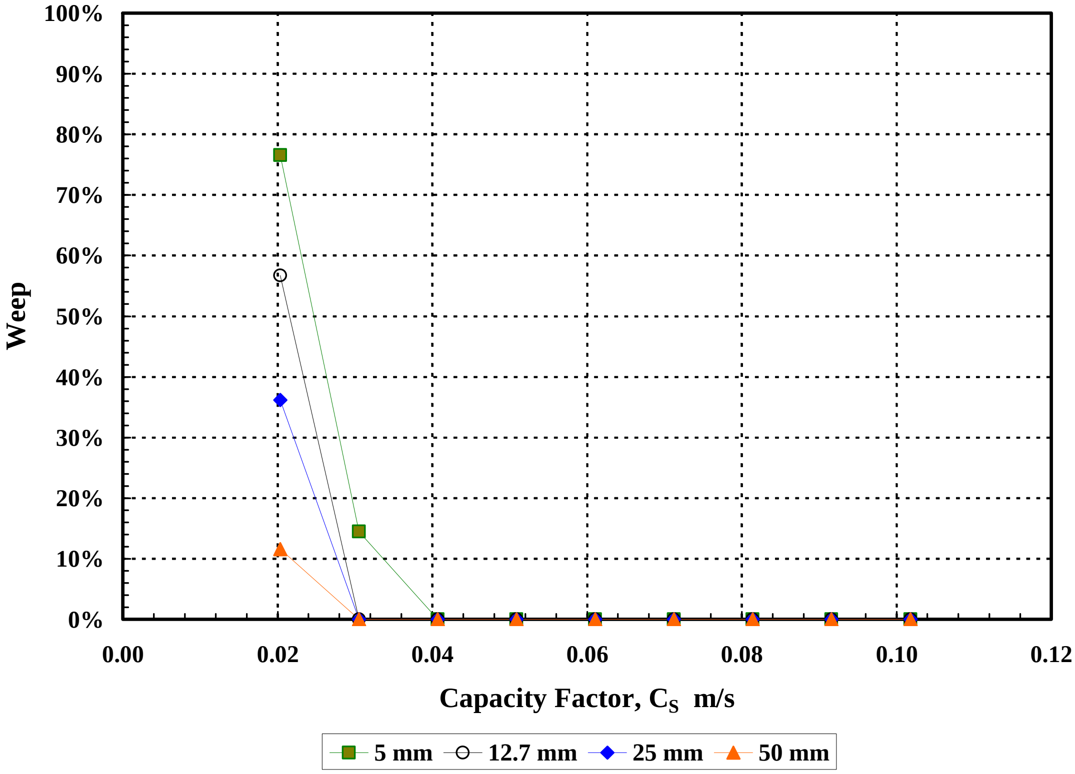


Figure 22. DRP Prediction of Tray Weeping for Various Hole Sizes

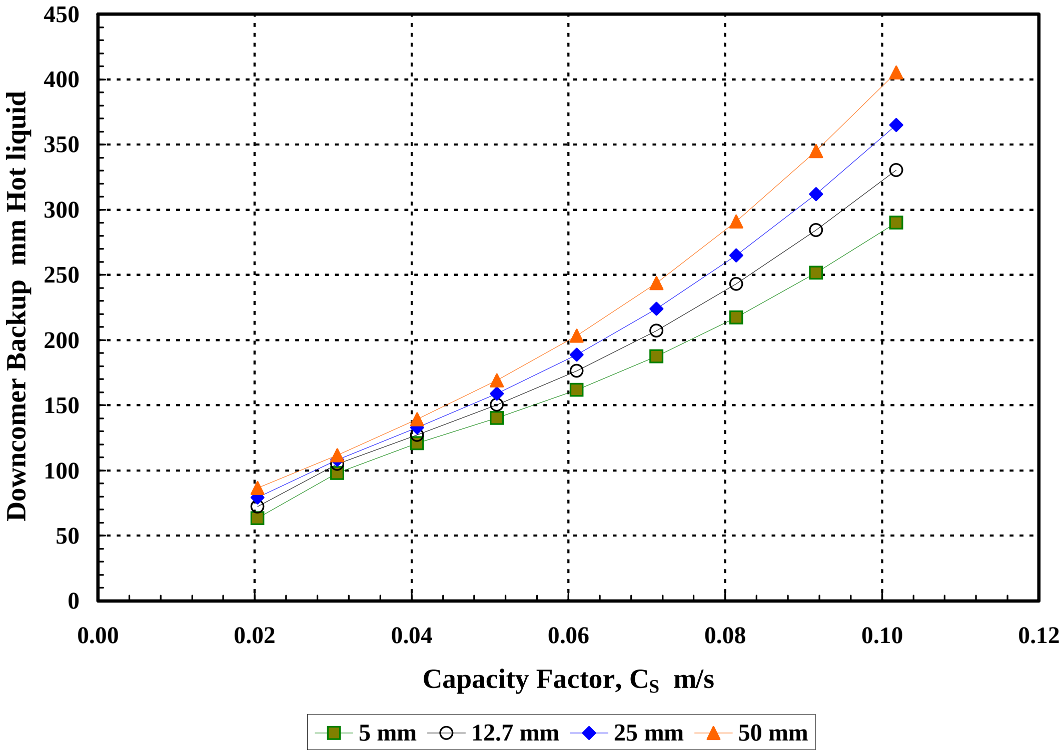


Figure 23. DRP Prediction of Downcomer Backup for Various Hole Sizes

Table 1
Data from FRI$_{(SM)}$ Progress Report Jan. 1957

Run No	System	Pressure	Dia Hole	Run Type	Liq load	Press Drop per tray	Cs	Efficiency
		bar	mm		$m^3/h/m$	mm Hot liquid	m/s	%
1346	C6/C7	0.28	12.7	TR	3.19	2.54	0.021	
1338	C6/C7	0.28	12.7	FL TF	54.38	144.78	0.085	
1339	C6/C7	0.28	12.7	FL TF	32.14	134.62	0.102	
1340	C6/C7	0.28	12.7	FT	19.33	139.70	0.101	37
1341	C6/C7	0.28	12.7	TR	18.61	111.76	0.101	40
1342	C6/C7	0.28	12.7	TR	16.68	71.12	0.096	58
1343	C6/C7	0.28	12.7	TR	14.62	68.58	0.086	64
1345	C6/C7	0.28	12.7	TR	9.01	38.10	0.058	
1344	C6/C7	0.28	12.7	TR	12.81	50.80	0.082	63
1328	C6/C7	1.65	12.7	TR	15.59	50.80	0.041	77
1320	C6/C7	1.65	12.7	FL TF	88.69	167.64	0.087	
1334	C6/C7	1.65	12.7	FL TF	90.63	106.68	0.073	
1329	C6/C7	1.65	12.7	TR	8.46	27.94	0.022	41
1327	C6/C7	1.65	12.7	TR	23.56	60.96	0.062	79
1326	C6/C7	1.65	12.7	TR	30.69	81.28	0.080	80
1325	C6/C7	1.65	12.7	TR	35.28	91.44	0.092	78
1324	C6/C7	1.65	12.7	TR	37.22	99.06	0.096	77
1323	C6/C7	1.65	12.7	FT	39.63	149.86	0.101	57
1322	C6/C7	1.65	12.7	FL OHP	25.13	160.02	0.102	
1321	C6/C7	1.65	12.7	FL TF	77.09	152.40	0.096	
1351	IC4/NC4	11.38	12.7	TR	64.29	114.30	0.064	116
1352	IC4/NC4	11.38	12.7	TR	55.83	71.12	0.057	123
1353	IC4/NC4	11.38	12.7	TR	43.98	55.88	0.044	122
1355	IC4/NC4	11.38	12.7	TR	23.44	20.32	0.023	92
1354	IC4/NC4	11.38	12.7	TR	25.62	35.56	0.025	100

FT	Total Reflux Flood
TR	Total Reflux
FL TF	Flood L/V>1
FL OHP	Flood L/V<1

Table 2
Data from FRI$_{(SM)}$ Progress Report Aug. 1957

Run No	System	Pressure	Dia Hole	Run Type	Liq load	Press Drop per tray	Cs	Efficiency
		bar	mm		m^3/h/m	mm Hot liquid	m/s	%
1472	IC4/NC4	11.38	4.7625	TR	23.56	20.32	0.023	88
1466	IC4/NC4	11.38	4.7625	FL TF	165.79	142.24	0.047	
1467	IC4/NC4	11.38	4.7625	FT	78.54	142.24	0.077	102
1468	IC4/NC4	11.38	4.7625	TR	73.95	124.46	0.072	101
1469	IC4/NC4	11.38	4.7625	TR	62.59	78.74	0.061	114
1470	IC4/NC4	11.38	4.7625	TR	47.85	60.96	0.046	113
1471	IC4/NC4	11.38	4.7625	TR	31.66	25.40	0.031	94
1496	C6/C7	0.28	25.4	FL TF	76.37	96.52	0.074	
1502	C6/C7	0.28	25.4	TR	4.30	5.08	0.025	30
1497	C6/C7	0.28	25.4	FT	16.07	114.30	0.089	54
1498	C6/C7	0.28	25.4	TR	15.13	99.06	0.084	59
1501	C6/C7	0.28	25.4	TR	5.75	20.32	0.034	41
1500	C6/C7	0.28	25.4	TR	8.56	43.18	0.050	62
1499	C6/C7	0.28	25.4	TR	12.81	71.12	0.073	65
1492	C6/C7	1.65	25.4	TR	24.17	73.66	0.062	89
1489	C6/C7	1.65	25.4	FT	39.88	139.70	0.100	68
1491	C6/C7	1.65	25.4	TR	31.90	99.06	0.081	89
1495	C6/C7	1.65	25.4	TR	8.22	5.08	0.021	27
1493	C6/C7	1.65	25.4	TR	16.19	55.88	0.041	70
1494	C6/C7	1.65	25.4	TR	12.33	15.24	0.032	30
1490	C6/C7	1.65	25.4	TR	37.94	116.84	0.095	89
1486	C6/C7	1.65	25.4	FL TF	91.35	129.54	0.070	
1507	C6/C7	3.45	25.4	TR	16.82	35.56	0.030	55
1503	C6/C7	3.45	25.4	FT	57.03	144.78	0.100	88
1504	C6/C7	3.45	25.4	TR	50.51	116.84	0.089	101
1505	C6/C7	3.45	25.4	TR	33.35	78.74	0.059	92
1506	C6/C7	3.45	25.4	TR	22.35	63.50	0.040	84
1477	IC4/NC4	11.38	25.4	TR	45.68	71.12	0.045	103
1473	IC4/NC4	11.38	25.4	FL TF	105.61	149.86	0.050	
1476	IC4/NC4	11.38	25.4	TR	66.46	99.06	0.065	107
1478	IC4/NC4	11.38	25.4	TR	30.69	60.96	0.030	101
1479	IC4/NC4	11.38	25.4	TR	23.08	15.24	0.023	80
1480	IC4/NC4	11.38	25.4	TR	15.95	5.08	0.015	58
1482	IC4/NC4	7.93	25.4	TR	59.69	88.90	0.071	
1483	IC4/NC4	7.93	25.4	TR	40.84	63.50	0.048	
1484	IC4/NC4	7.93	25.4	TR	27.07	50.80	0.032	
1485	IC4/NC4	7.93	25.4	TR	20.40	7.62	0.024	
1475	IC4/NC4	11.38	25.4	FT	73.71	144.78	0.073	100
1465	C6/C7	0.28	4.7625	TR	3.38	5.08	0.021	31
1459	C6/C7	0.28	4.7625	FT	17.64	86.36	0.099	52
1460	C6/C7	0.28	4.7625	TR	16.68	78.74	0.094	50
1461	C6/C7	0.28	4.7625	TR	13.90	63.50	0.081	54
1462	C6/C7	0.28	4.7625	TR	10.51	50.80	0.063	57
1463	C6/C7	0.28	4.7625	TR	7.01	38.10	0.042	61
1464	C6/C7	0.28	4.7625	TR	5.32	27.94	0.032	49
1458	C6/C7	0.28	4.7625	FL TF	78.54	83.82	0.086	
1450	C6/C7	1.65	4.7625	FL OHP	26.10	71.12	0.097	
1452	C6/C7	1.65	4.7625	TR	35.04	83.82	0.091	66
1454	C6/C7	1.65	4.7625	TR	22.96	58.42	0.060	77
1455	C6/C7	1.65	4.7625	TR	16.19	50.80	0.042	68
1456	C6/C7	1.65	4.7625	TR	11.84	35.56	0.030	42
1448	C6/C7	1.65	4.7625	FL TF	87.00	111.76	0.075	
1457	C6/C7	1.65	4.7625	FT	41.33	109.22	0.107	54
1451	C6/C7	1.65	4.7625	TR	38.67	88.90	0.101	68
1447	C6/C7	1.65	4.7625	FL TF	122.29	111.76	0.060	
1453	C6/C7	1.65	4.7625	TR	29.73	68.58	0.077	69

Table 3
Data from FRI$_{(SM)}$ Progress Report Dec. 1957

Run No	System	Pressure	Dia Hole	Run Type	Liq load	Press Drop per tray	Cs	Efficiency
		bar	mm		$m^3/h/m$	mm Hot liquid	m/s	%
1907	C6/C7	0.28	66.675	TR	8.27	58.42	0.046	43
1901	C6/C7	0.28	66.675	FL TF	91.84	215.90	0.069	
1902	C6/C7	0.28	66.675	FL TF	47.37	180.34	0.072	
1903	C6/C7	0.28	66.675	FT	14.02	167.64	0.073	21
1904	C6/C7	0.28	66.675	TR	13.34	137.16	0.071	23
1906	C6/C7	0.28	66.675	TR	10.95	93.98	0.060	33
1908	C6/C7	0.28	66.675	TR	5.56	25.40	0.032	46
1905	C6/C7	0.28	66.675	TR	12.64	104.14	0.068	26
1889	C6/C7	1.65	66.675	TR	19.74	81.28	0.051	70
1890	C6/C7	1.65	66.675	TR	13.90	48.26	0.036	59
1888	C6/C7	1.65	66.675	TR	26.10	109.22	0.067	69
1900	C6/C7	1.65	66.675	TF	89.90	106.68	0.058	
1887	C6/C7	1.65	66.675	TR	29.48	127.00	0.076	61
1886	C6/C7	1.65	66.675	TR	31.18	139.70	0.080	46
1885	C6/C7	1.65	66.675	FT	32.87	167.64	0.084	49
1884	C6/C7	1.65	66.675	FL OHP	14.40	185.42	0.081	
1883	C6/C7	1.65	66.675	FL TF	73.95	190.50	0.074	
1891	C6/C7	1.65	66.675	TR	10.17	17.78	0.026	39
1892	C6/C7	1.65	66.675	TR	14.40	45.72	0.038	59
1882	C6/C7	1.65	66.675	FL TF	126.15	208.28	0.061	
1918	IC4/NC4	11.38	66.675	FL TF	133.89	254.00	0.044	
1909	IC4/NC4	11.38	66.675	TR	74.44	137.16	0.072	98
1910	IC4/NC4	11.38	66.675	TR	66.94	116.84	0.064	100
1911	IC4/NC4	11.38	66.675	TR	62.84	106.68	0.060	94
1912	IC4/NC4	11.38	66.675	TR	47.37	86.36	0.045	93
1913	IC4/NC4	11.38	66.675	TR	31.42	60.96	0.030	87
1915	IC4/NC4	11.38	66.675	FT	75.40	182.88	0.074	76
1916	IC4/NC4	11.38	66.675	FL OHP	45.43	200.66	0.091	
1917	IC4/NC4	11.38	66.675	FL TF	104.40	231.14	0.058	

FT	Total Reflux Flood
TR	Total Reflux
FL TF	Flood L/V>1
FL OHP	Flood L/V<1

Appendix

BENEFITS OF FRI$_{(SM)}$ MEMBERSHIP

The following benefits apply in varying degree to members of the following industries: chemical companies, refineries, equipment manufacturers, and engineering contractors.

1. **Reduced Uncertainty.** FRI members gets performance data on efficiency, capacity and pressure drop of distillation devices. Members have greater confidence in achieving a smooth startup and in operating at higher capacities at reduced costs.

2. **Capital Savings.** Performance comparisons among various devices provide opportunities for savings and optimization.

3. **Engineering Cost Savings.** The cost of FRI membership is much less than the cost of one engineer's salary. The member does not have to worry about the headcount and capital and operating costs involved with a dedicated 25-person research effort The member gets tremendous research value for its membership fee. Member's engineers are relieved from time-consuming and costly data gathering and calculations, freeing them to focus on other design and decision-making issues.

4. **Payout.** FRI members report that savings from just one retrofit project based on FRI$_{(SM)}$ technology justified the cost of membership.

5. **Objectivity.** FRI tests are unbiased and FRI neither endorses nor sells products. FRI members receive confirmation of performance claims from various hardware manufacturers.

6. **Confidence.** Research is done on large-scale equipment. Member finds out what performs well at a reasonable scale.

7. **Competition/Doing Business.** Four meetings a year provide open and private forums for all FRI members to discuss various problems and solutions.

8. **Control.** FRI members determine the research program.

9. **Tools.** FRI provides reports, manuals, recommended practices, computer programs, easily accessible data, and videotapes of action inside the columns. These tools provide valuable insight to the engineer.