

# CONTROL OF LIQUID FLOW ON FRACTIONATING TRAYS

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# CONTROL OF LIQUID FLOW ON FRACTIONATING TRAYS

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## SUMMARY

The understanding of liquid movement on a tray is essential for the better prediction of tray mass transfer and hydraulic performance. Liquid flow non-idealities on single-pass cross-flow sieve trays were studied in a 2.44 m diameter section of Fractionation Research, Inc. (FRI) low pressure column and a 1.22 m diameter simulator. Liquid residence times were measured in the 2.44 m diameter section using fiber optic technique. Liquid cross-flow was investigated in the 1.22 m simulator using dye technique. A practical and simple solution was found to remove these non-idealities. A shaped outlet weir, together with a shaped and slotted downcomer baffle and liquid guide-vanes, produced a uniform flow across the tray. With these devices, no retrograde flow was observed. The design was tested over a wide range of flow rates from 9 to 70 m<sup>3</sup>/h-m of weir. Experimental results, flow profiles, and video footage are presented and discussed.

## INTRODUCTION

The local rate of interfacial mass transport at any point on a distillation tray is determined by the local thermodynamic conditions of the liquid and vapor and the local microscopic fluid motion on either side of the vapor-liquid interface. The net transfer occurring over an entire tray depends not only on these local rates, characterized by the point efficiencies, but also on the bulk fluid motion on the tray. The understanding of the liquid flow distribution or movement on a tray plays an important role for the better prediction of tray mass and momentum transfers. The idealized flow distributions may not be the case on many commercial trays. The deviation from idealized flow pattern can be caused by the recycling of fluid on the tray, or by the existence of stagnant regions or pockets of fluid.

One of the conventional ways of characterizing fluid movement is to measure the distribution of residence time of fluid elements within the column. This is usually done by changing the concentration of a tracer in a pulsewise or stepwise fashion and then monitoring the response distribution downstream from the tracer inlet. FRI developed a fiber optic technique for this purpose. This paper describes the experimental and the analytical techniques employed in these studies and the results obtained from these studies.

## EXPERIMENTAL TECHNIQUE

### Description of Equipment

**Figure 1** shows the FRI experimental unit that consists of two commercial size distillation columns and their support systems. For most operation modes only one column is used. The 1.22 m inside diameter high pressure column is 8.4 m tall from bottom headseam to the top flange and rated for pressures up to 37 bar. The low pressure column is rated from deep vacuum to 11.4 bar and consists of two sections. The lower section is essentially identical to the high pressure column but is topped with a 3.66 m tall transition zone. The upper section has a 2.44 m inside diameter and 6.7 m tall. Each column has a flanged head and clean inner wall design which allows installation of hardware at any location in the column. Sight windows are strategically located to provide visual observation points inside the column. Couplings are available every 152 mm along the shell, which permits temperatures and pressures to be measured and samples to be withdrawn. The low pressure column was used for this study.

The technique used in this test is based on the use of a fluorescent tracer with a very rapid decay time. Tracers used for this test are Rhodamine B and Yellow C-4. These tracers, when activated by light of a certain wavelength, fluoresce at a wavelength, sufficiently removed from the excitation wavelength that complementary filters may be used on the light source and detector.

**Figure 2** shows the schema for the technique. The probe consists of a fiber optic light pipe whose end is placed at the desired detection point. The other end of the light pipe is bifurcated with one end going to the excitation light source and the other end going to a photomultiplier tube. The combinations for the primary and secondary optical filters depend on particular fluorescent dye being used. The light passing through the primary filter is transmitted down one arm of the bifurcated bundle, through the combined bundle and out the end.

This technique requires no electrical connections to the column. The probe is a single element which does not enter or surround the volume being monitored and therefore causes a minimal disturbance to the flow. The technique is reliable and sensitive. “Point” measurements can be obtained on the tray.

### Water-Table Studies in a 2.44m Diameter Column

In the 2.44 m diameter section of FRI’s low pressure column, two wooden trays with 13 percent segmental downcomers were installed. Liquid flow rates in different sections along the tray inlet were controlled by an adjustable inlet baffle. To monitor the response of a pulse input, light pipe probes were placed at several locations on the second tray and in the downcomer as shown in **Figure 3**. Dye was injected with a spray nozzle along a cross-section parallel to the outlet weir at the outlet of the top tray. Several flow rates were investigated. Downcomer opening was varied to control the liquid flow in different sections at the tray inlet. The experiments are briefly described as follows:

Case No.	Description of Downcomer Lip Configuration
A	Downcomer lip was fully open with clearance of 50 mm
B	Downcomer lip was restricted with V-shaped metal piece shown in <b>Figure 4</b>
C	Total of 375 mm of central 750mm of downcomer lip were blocked by closing middle five Gates. Gates were 75mm wide and were 75mm apart. A detail drawing is shown in <b>Figure 5</b>
D	Central 375 mm of the downcomer lip were blocked with a widen block

### Flow Visualization Studies in a 1.22 m Diameter Simulator

A 2.1 m high and 1.22 m diameter simulator was assembled by jointing three round sections rolled from 10 gage carbon steel. The top two sections were 610 mm high while the bottom section was 915 m high. Two 12 gage carbon steel trays were installed between the sections. Four 254 mm diameter windows were provided in each section. Two were oriented 25 degrees apart from the centerline running normal to the flow path. Sections were put together by 12 tie rods of 6.4 mm diameter and spaced evenly around the middle section. Three angles were welded to the bottom of the base section 120 degrees apart for leveling the unit. A 10 gage carbon steel entry baffle with adjustable gates was provided on the top section. A 16 gage carbon steel downcomer also with adjustable gates was provided in the middle section while a 16 gage carbon steel envelope downcomer with seal pan was provided in the bottom section. The trays were painted white to permit better photography. A schematic diagram of the simulator is presented in **Figure 6**.

## Results of Residence Time Measurements

Residence time profiles at 70 m<sup>3</sup>/h for four different downcomer lip configurations are shown in **Figure 7**. Maximum difference in residence times across a cross-section taken parallel to the outlet weir at the inlet of the tray is plotted in **Figure 8** for different downcomer lip configurations at two liquid rates. The same parameter at the outlet of the tray is plotted in **Figure 9**. The flow will be most uniform when the difference in residence times is the smallest. Although the flow pattern was still far from ideal, the flow was more uniform at the higher flow rate and with the central 375 mm of the downcomer lip blocked.

Residence times at various points in the downcomer and at 150mm from the inlet of the tray for three liquid rates are plotted in **Figure 10**. Residence times were the same across the downcomer at all the flow rates, while there was a substantial difference at only 150mm from the inlet of the tray.

## Results of Simulator Studies

Experiments were designed to alter the liquid flow field by changing the following variables; the outlet weir configuration, flow distribution at the downcomer exit, flow direction using liquid guide vanes in the downcomer. Experiments were carried out at liquid flow rates ranging from 9 to 70 m<sup>3</sup>/h-m of weir (weir length 0.94 m).

### 1. Outlet weir

Effect of three features of outlet weir, height, length and shape, on flow pattern was investigated.

#### a. Height:

Outlet weir 0.94 m long and 50 mm high were installed on both of the trays. This reproduced the non-idealities in the liquid flow. A high velocity flow was present in the center of the bubbling area while liquid elements in side zones of the tray were moving very slowly. A severe retrograde flow along both of the column walls was observed. Calm zones were present on the tray. The outlet weir height was reduced to 25 mm. The same type of flow non-idealities as observed with 50 mm high weir is present.

#### b. Length (partial weir):

The length of the outlet weir was shorted by 90 mm on each end while remaining weir was 25 mm high. Although the flow was still not uniform, no backflow due to the outlet weir was observed.

#### c. Shape:

When an outlet weir 50 mm high and 0.76 m long was installed (90 mm along the edges of the tray outlet did not have a weir), retrograde flow, although considerably reduced, appeared. When several sections of 50 mm high weir were reduced to a height of 25 mm and more liquid escaped into the downcomer at intermediate locations, retrograde flow caused by outlet weir was no longer present. **Figure 11** illustrates the final configuration used.

### 2. Downcomer Exit

To eliminate the expansion of flow as it enters the tray, more resistance to flow in the central portion of the downcomer is needed. Two different types of downcomer lip designs were tested. First, downcomer lip configuration as shown in **Figure 12** was used. The downcomer clearance in the central section was 3 mm and it increased to 13 mm in the side sections in two steps. Uniformity in velocity across a cross section improved considerably, but still some pockets of liquid were moving slowly. Liquid guide vanes were used to further direct the liquid from the central portion towards the side zones. By changing the location, orientation and number of these guide vanes, it was possible to shift the

relatively slow moving zones on the tray. Finally, two guide vanes, each 50 mm long, oriented parallel to the column wall and located approximately 330 mm from the edge of the inlet section and placed half on the tray and half in the downcomer produced a uniform liquid flow distribution. The slots present in the downcomer baffle produced high velocity liquid jets that were very effective in directing the liquid in the forward direction.

### **CONCLUSIONS**

An optic fiber technique has been successfully developed and used to measure the distribution of residence times on trays. Flow visualization studies using a colored dye technique have been carried out for liquid flow on single-pass cross flow trays. A practical and simple solution has been developed to control the liquid flow on those trays. The solution includes a shaped outlet weir, a shaped and slotted downcomer baffle, and liquid guide-vanes, which produces a uniform flow across the tray. It is expected that the solution will increase the tray separation efficiency and capacity.

### **ACKNOWLEDGEMENT**

The authors wish to express their gratitude to all members of Fractionation Research, Inc. Experimental work was carried out by G. B. Shah and T. Yanagi\_ of former staff of Fractionation Research, Inc.

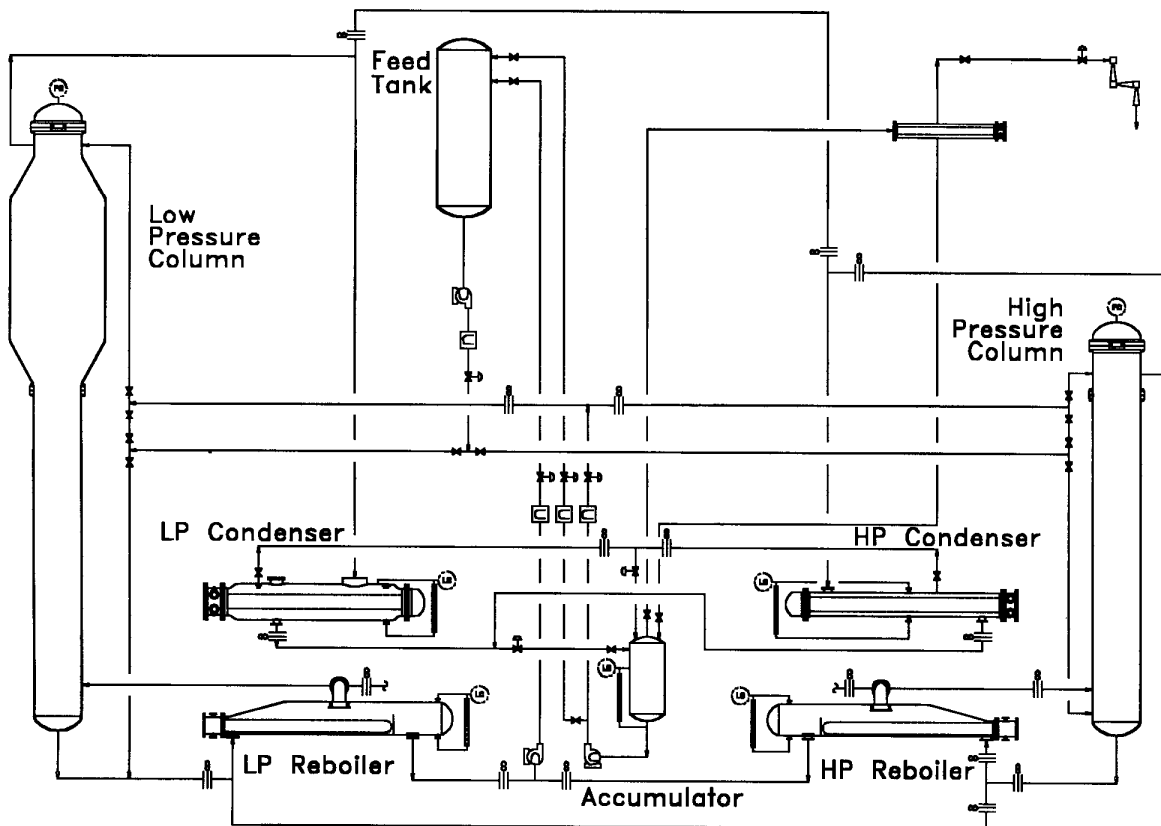
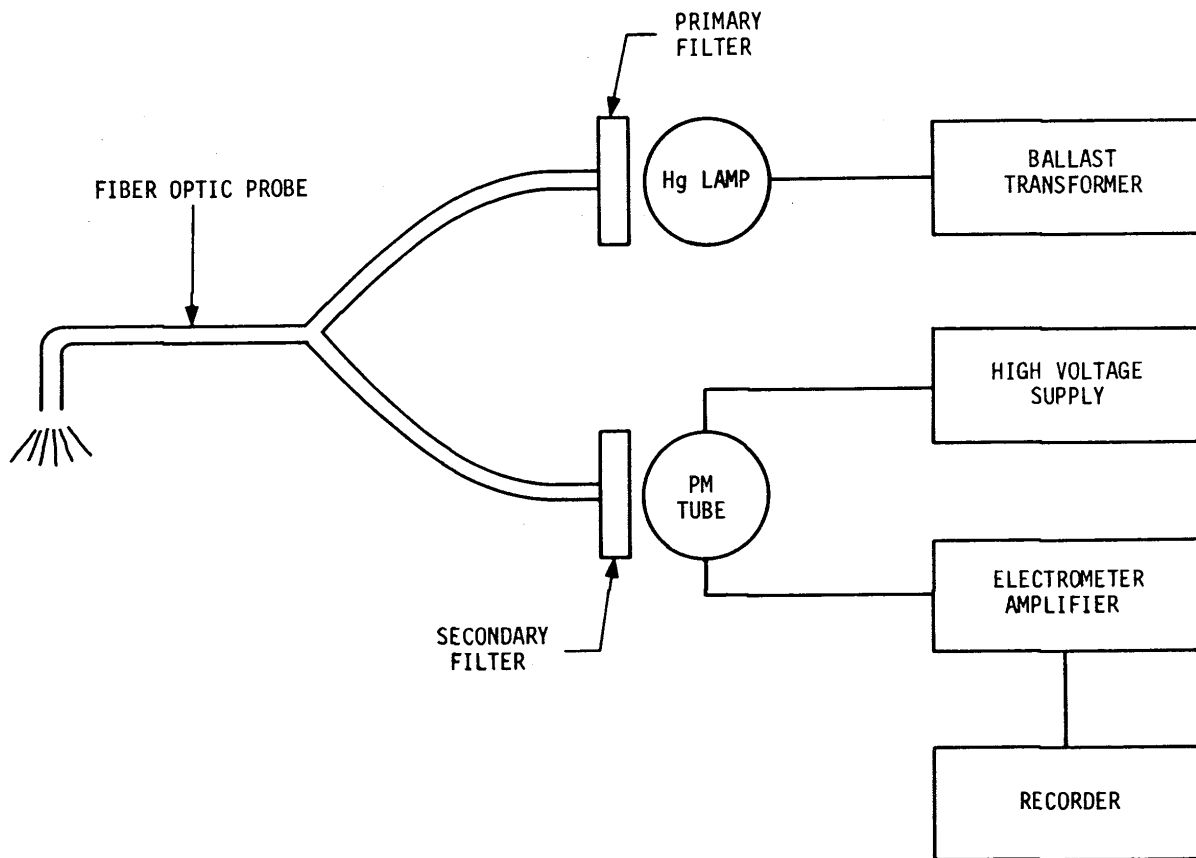
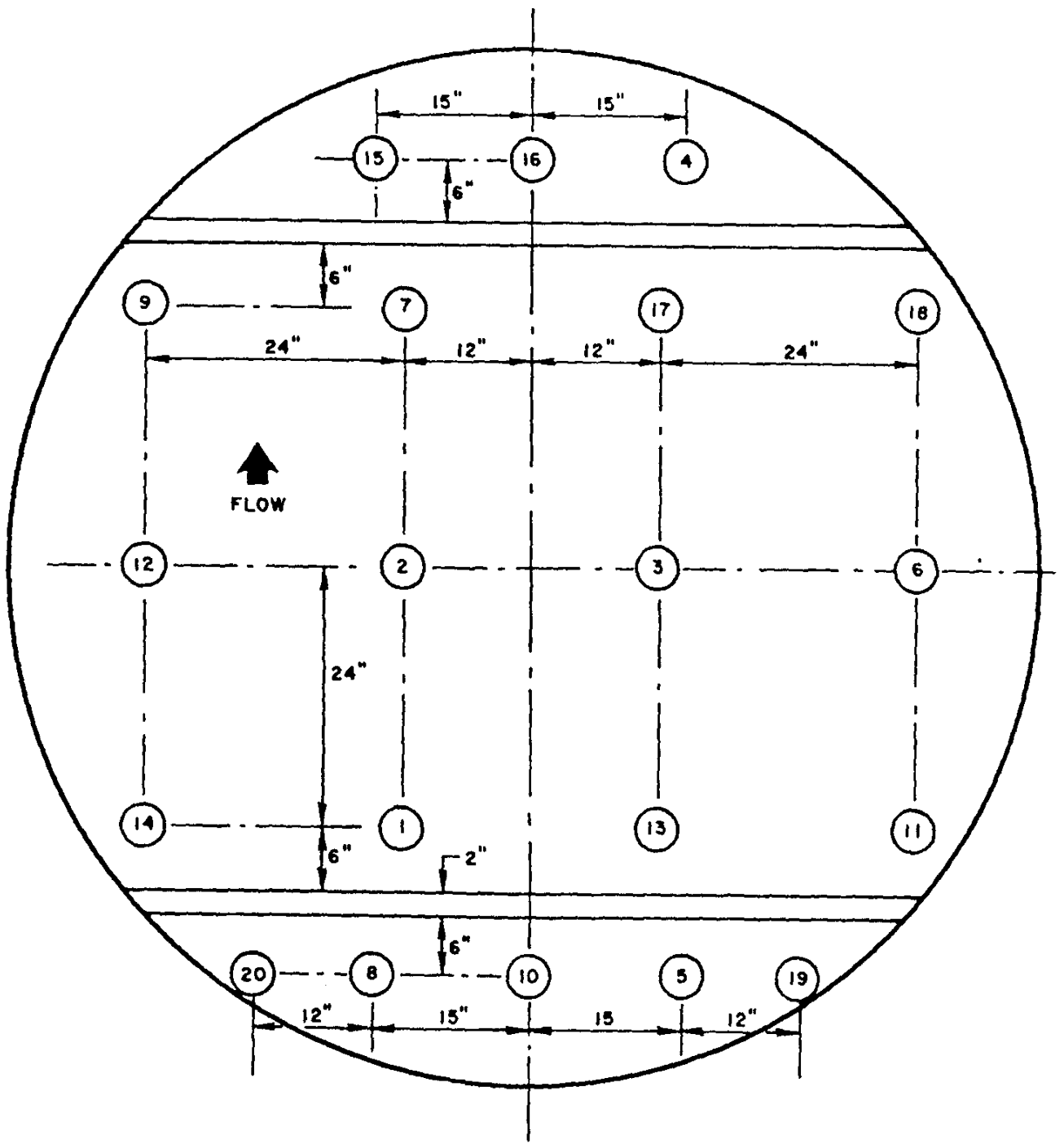


Figure 1. FRI Experimental Unit

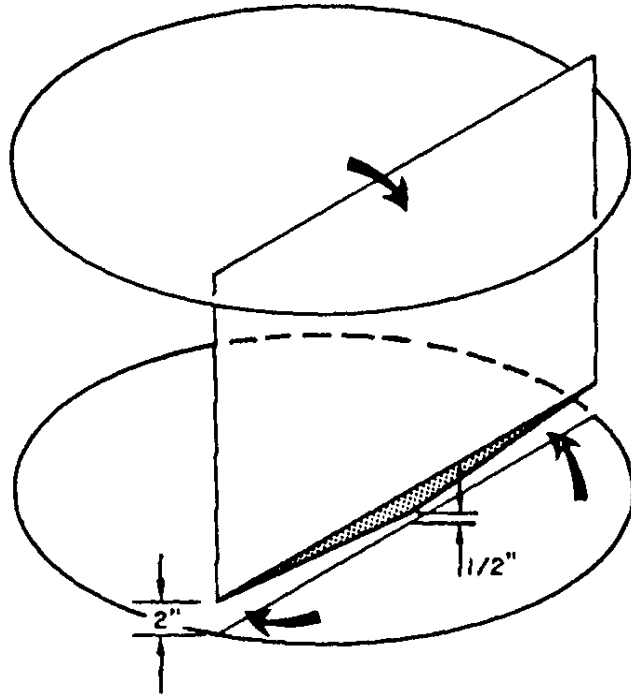


**Figure 2.** Schema For Fiber Optic Technique



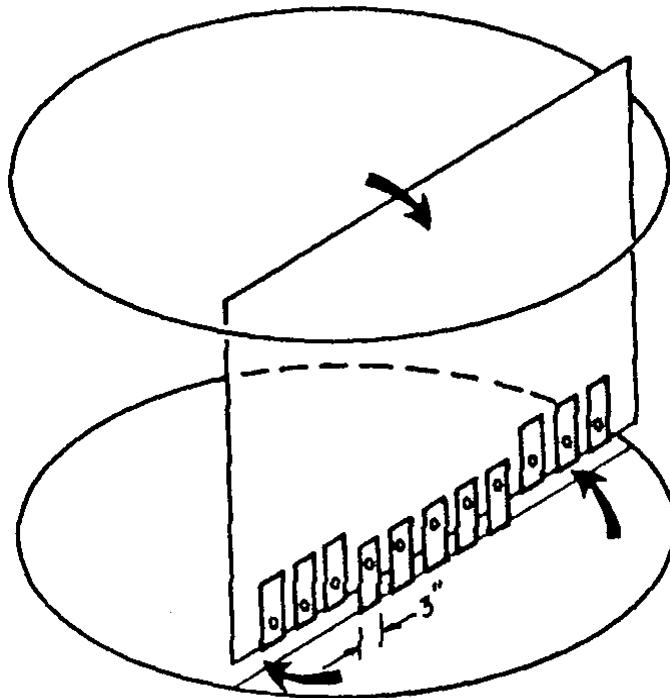
1" = 25.4 mm

**Figure 3.** Schematic Layout of Fiber Optic Probe



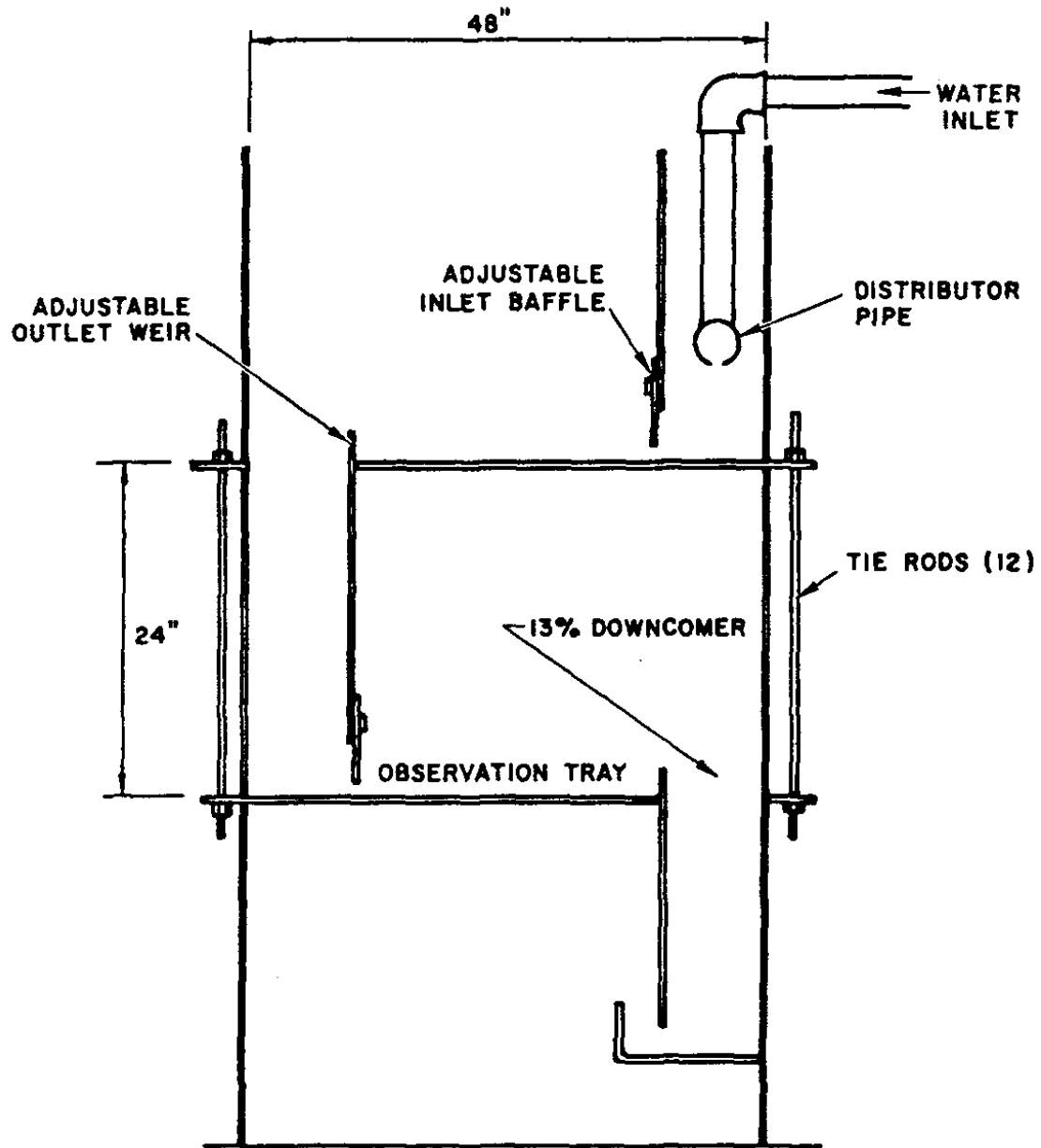
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**Figure 4.** V-Shaped Restrictor in Downcomer Opening



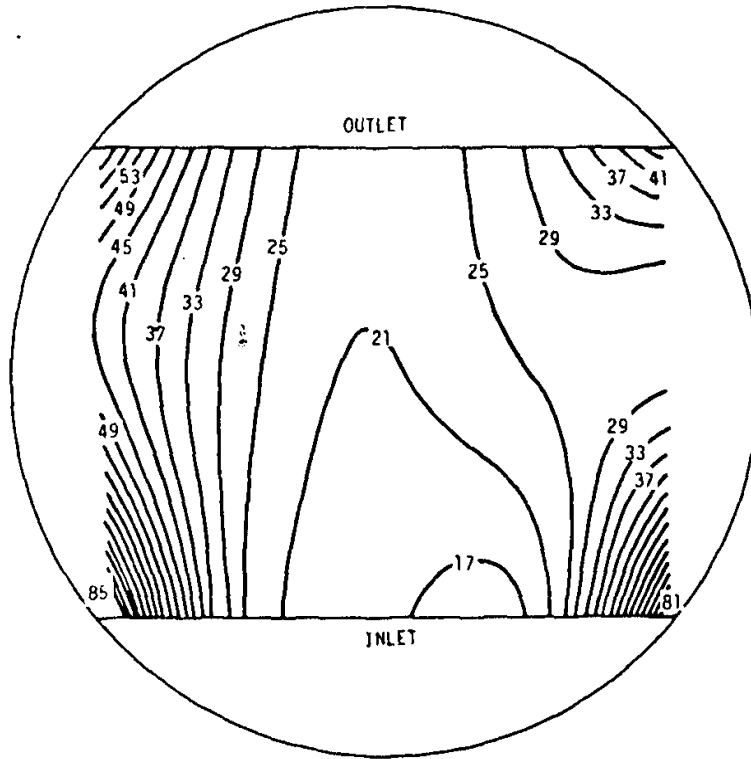
1" = 25.4 mm

**Figure 5.** Middle 5 Gates of Downcomer Baffle Closed

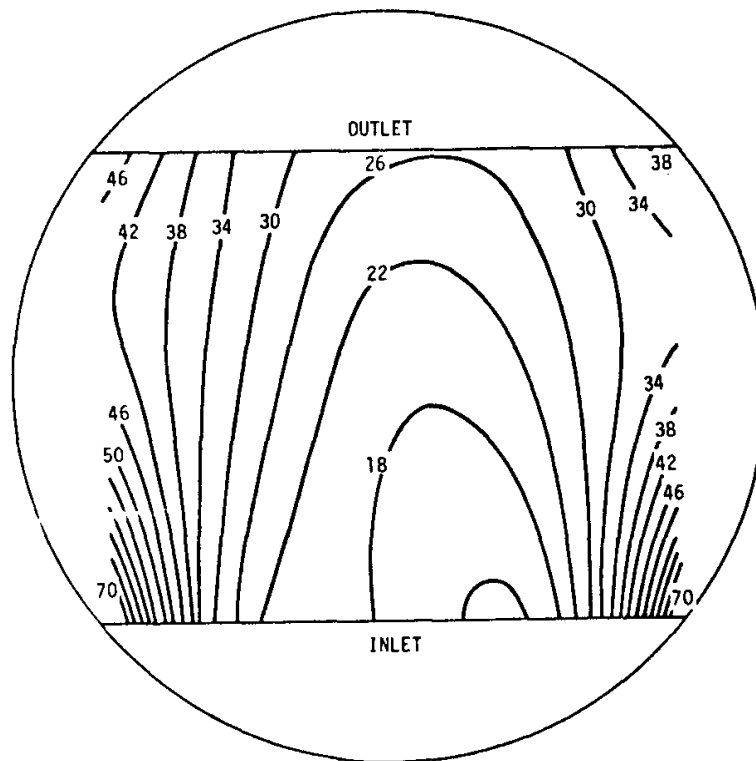


1" = 25.4 mm

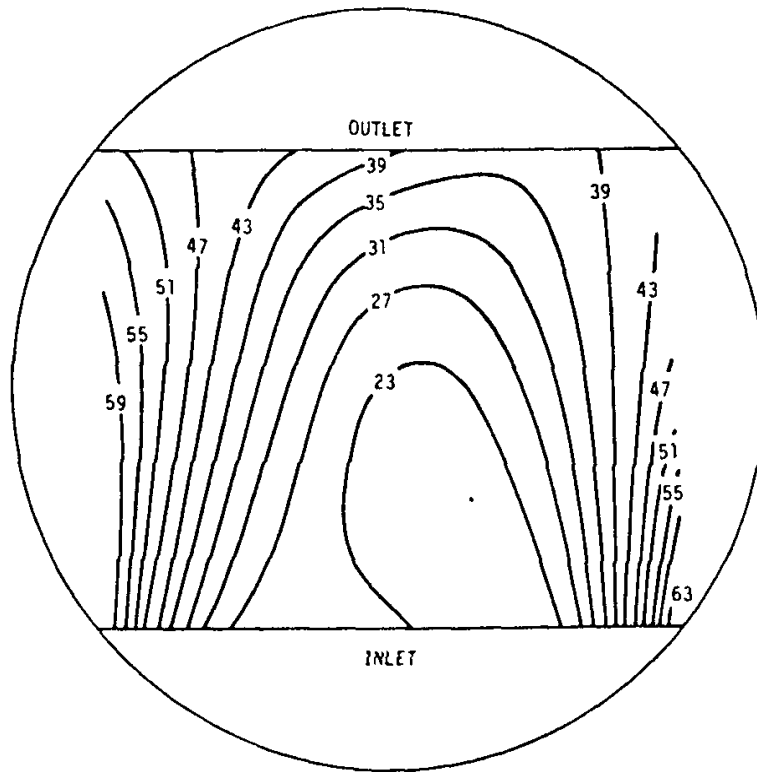
Figure 6. A Schematic Drawing of 1.22 m Diameter Simulator



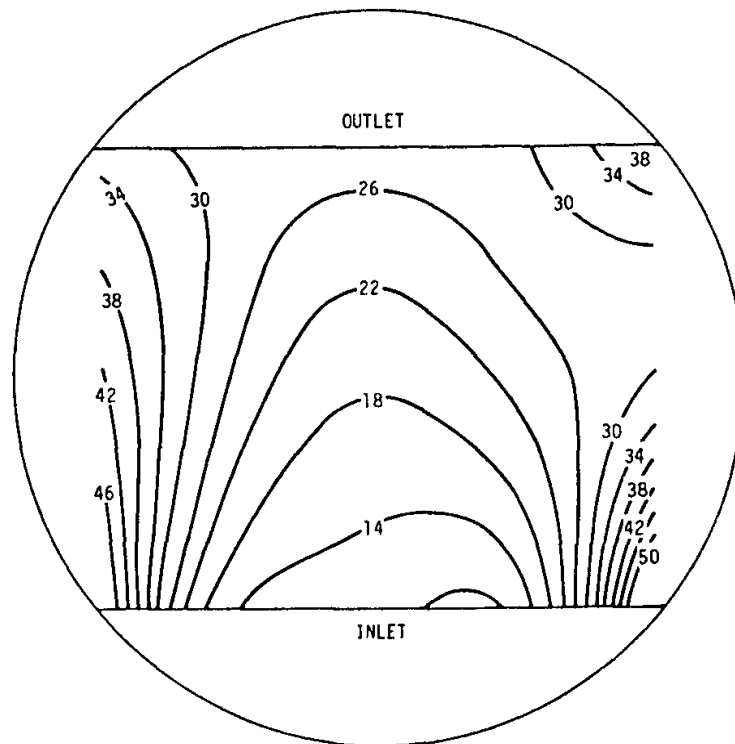
**Figure 7a.** Residence Time Profiles –No Restrictor in Downcomer Opening



**Figure 7b.** Residence Time Profiles – V-Shaped Restrictor in Downcomer Opening

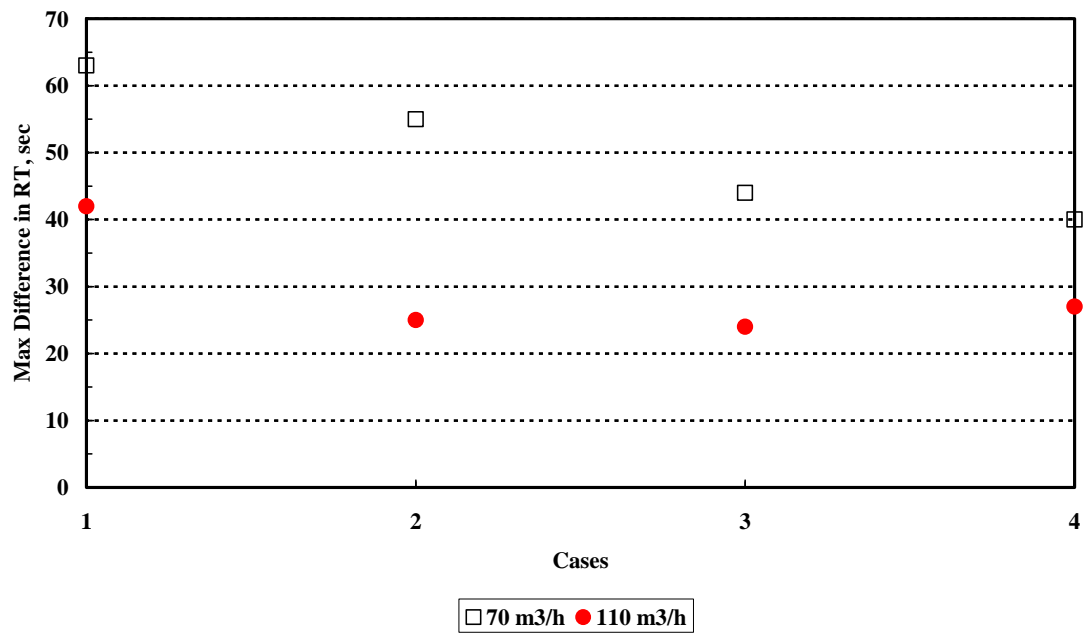


**Figure 7c.** Residence Time Profiles – Middle 5 Gates of Baffle Closed in Downcomer Opening



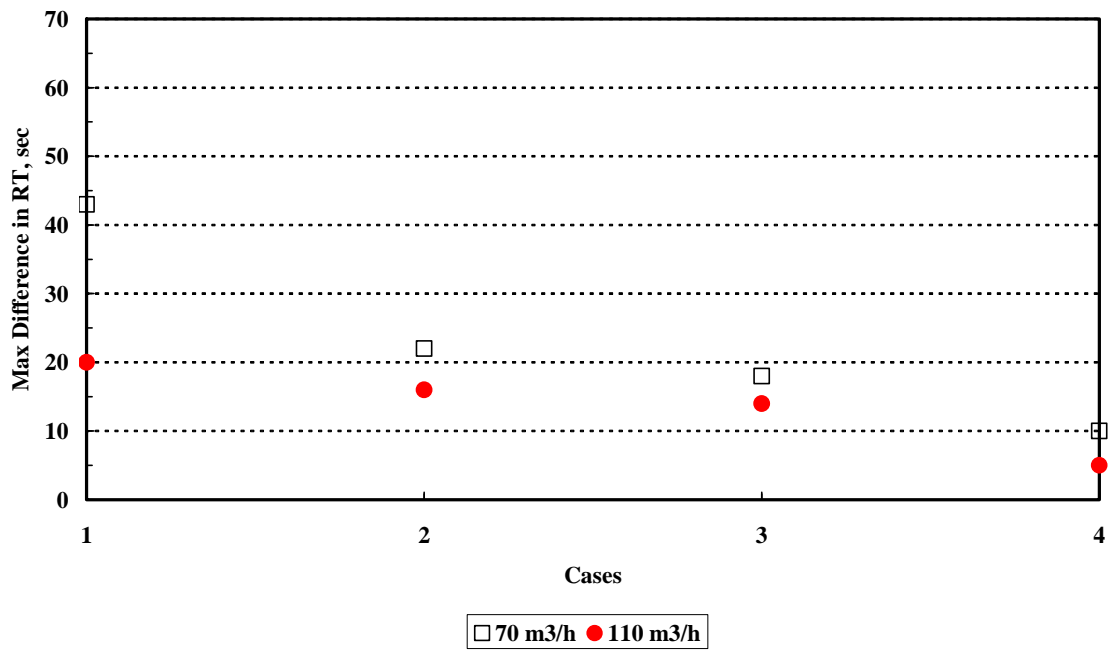
**Figure 7d.** Residence Time Profiles – Central 375 mm of Downcomer Opening Blocked

### Maximum Difference in Residence Time at Inlet of the Tray



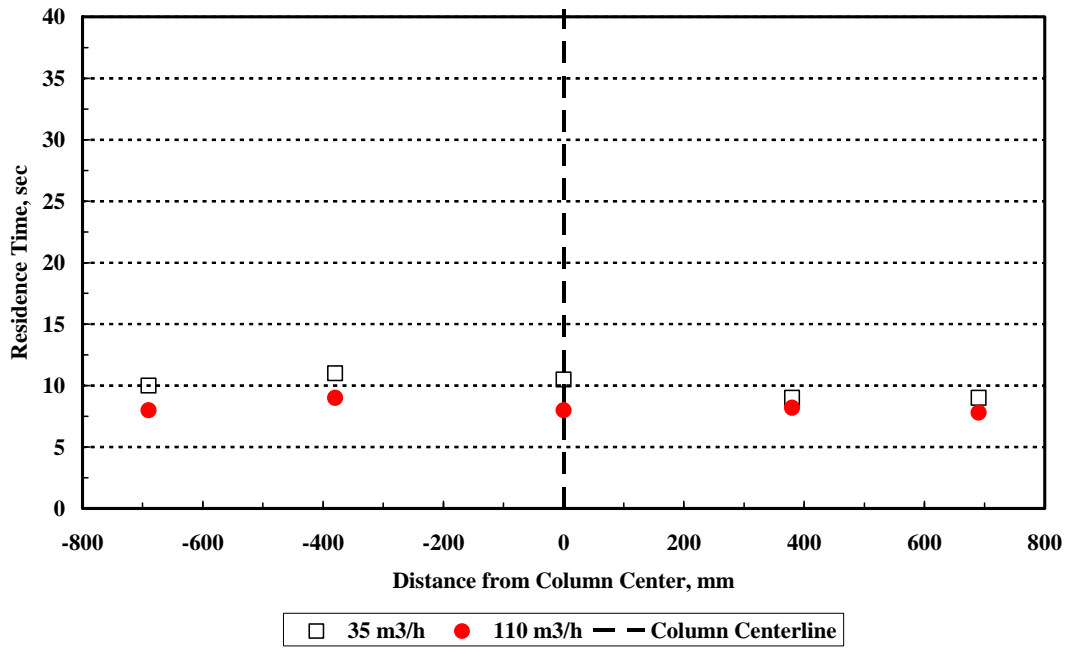
**Figure 8.** Maximum Difference in Residence Time at Inlet of the Tray

### Maximum Difference in Residence Time at Outlet of the Tray



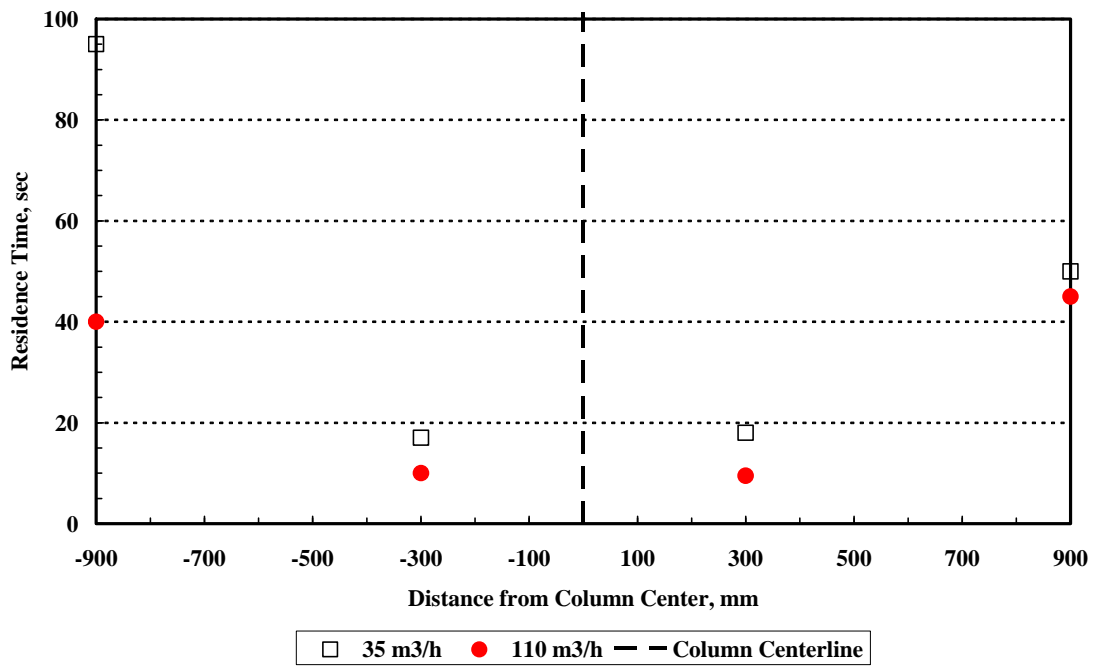
**Figure 9.** Maximum Difference in Residence Time at Outlet of the Tray

**Residence Time in the Downcomer**

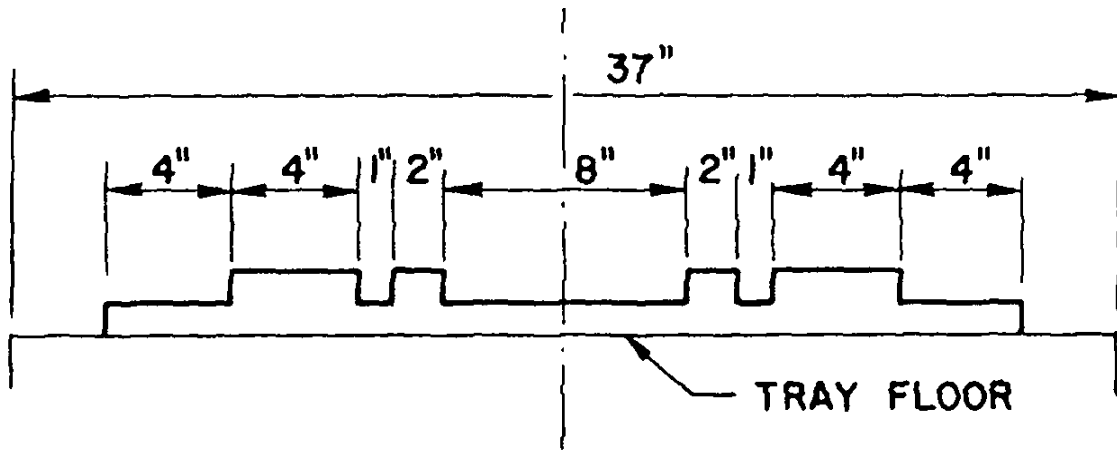


**Figure 10.** Residence Time in the Downcomer

**Residence Time at 150 mm from the Inlet of the Tray**

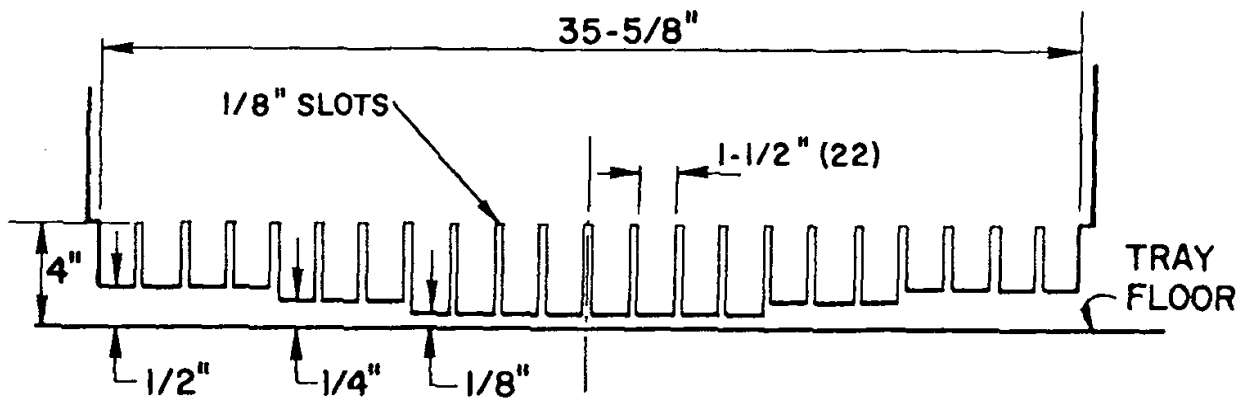


**Figure 11.** Residence Time at 150 mm from the Inlet of the Tray



1" = 25.4 mm

Figure 12. Detail of Outlet Weir



1" = 25.4 mm

Figure 13. Details of Inlet Baffle