THE DEVELOPMENT OF A NEW HIGH PERFORMANCE TRAY

ADAM T. LEE AND
KUANG WU
AMT INTERNATIONAL INC.
RICHARDSON, TX. 75080
U. S. A.

KARL T. CHUANG
DEPARTMENT OF CHEMICAL AND
MATERIAL ENGINEERING
UNIVERSITY OF ALBERTA
EDMONTON, ALBERTA, CANADA
T6G6

PREPARED FOR PRESENTATION AT
THE 2001 AICHE PETROCHEM EXPO DISTILLATION SYMPOSIUM
SESSION V, IN HOUSTON, TX, APRIL 25, 2001.

Unpublished

ABSTRACT

This paper is to present AMT's ADV® (Advanced Dispersion Valve) Tray, a well-behaved valve-type high performance tray, to the industry. The starting point for the development of AMT's high performance tray was the invention of the Advanced Dispersion Valve (ADV®).

This paper outlines the development history of the ADV® Tray from inception of the design concept through pilot tests and finishes with the validation of the technology by reviewing three commercial applications applying the ADV® Pinnacle Performance Trays.

INTRODUCTION

Valve trays have been widely accepted in the industry because of their ability to maintain efficient operation over a wide operating range. Because vapor has to make flow directional changes, while passing holes and valve assemblies on deck, trays are less prone to liquid entrainment (as compared to sieve trays). Numerous approaches, as described in the published literature, have suggested further performance enhancement can be realized using smaller sizes of valves in various shapes.[1,2]

One of the most widely used conventional valve trays yields a 37.4% "blocked dispersion area" by valve plates, based on using standard valve pitch, on the active area, which is demonstrated in the pitch dispersion area calculation as shown in the Figure 1 and Table I below:

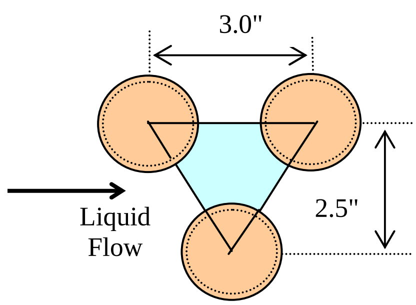


Figure 1. Standard Valve Pitch

Table I. Pitch Dispersion Area Calculation	
Hole diameter, in (mm)	1.535 (39)
Valve diameter, in (mm)	1.890 (48)
Triangular base, in (mm)	3.0 (76.2)
Triangular height, in (mm)	2.5 (63.5)
Triangular area, in^2 (mm^2)	3.750 (2419)
Triangular area blocked by valves, in^2 (mm^2)	1.402 (904.5)
% Triangular area blocked by valve plates	37.4%

The inherent problem as described above cannot be effectively resolved by using smaller valves. In fact, due to the need for having enough valve plate over-hangs (typically around 3/16") to allow valves to be securely locked-in above the tray deck, the percent blockage on the active area for smaller valves is even greater than that of large valves. For example, for small valves with a 1" hole diameter and 1-13/16" triangular pitch, the actual dispersion blockage is almost 50%.

To overcome the inability of producing fine dispersion from conventional valves, a new valve (figure 2) called the Advanced Dispersion Valve (ADV®) was developed.[3]

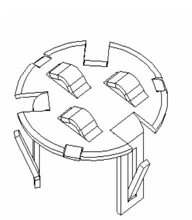


Figure 2. Advanced Dispersion Valve

The ADV® has approximately the same size as the conventional valve. The key difference is that there are three "canopies" at the top of the ADV® unit. With the existence of the canopies, dispersion at the area just above the valve plates becomes possible. These canopies allow a portion of the ascending vapor to pass through, disperse horizontally, and activate the area immediately above the valve plate, which is typically blocked and inactive with conventional valves.

EXPERIMENTAL TEST AND RESULTS

Extensive pilot testing has been performed to verity the design concept of the ADV®. Pressure drop and liquid entrainment have been measured for the ADV® and conventional (V-1) valve trays in two air/water simulators (12" and 24" diameter). The efficiencies of ADV® and V-1 trays were also determined for O_2 desorption in the 24" simulator. One set of pilot test results are presented in this paper:

Pressure Drop

As shown in the test results below, the pressure drop of the ADV® tray is approx. 20-25% lower than that of the V-1 tray at F-factor greater than 2.0 , $(kg/m)^{1/2} s^{-1}$:

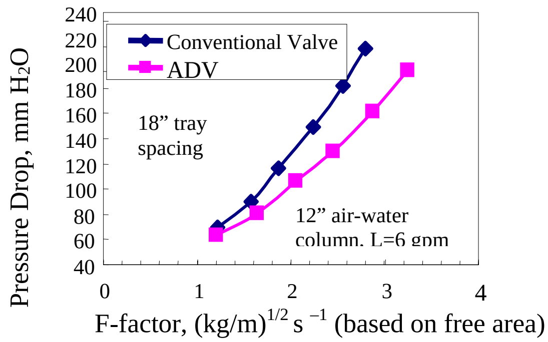


Figure 3. Pressure drop comparison For valve trays

Entrainment

The comparison of entrainment for ADV® and V-1 trays are shown in Figures 4. At F-factor greater than 2.0 $(kg/m)^{1/2} s^{-1}$, the entrainment of ADV® tray is substantially lower (over 30%) than that of V-1 tray.

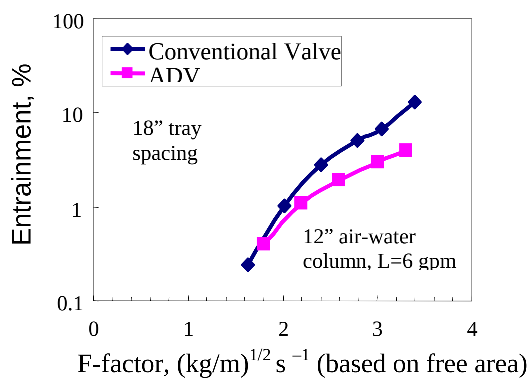


Figure 4. Entrainment comparison for valve trays

Efficiency

Figure 5 shows the efficiency vs. F-factor for ADV® and V-1 trays for O_2 desorption in the 24" column. The efficiency of the ADV® tray is approx. 15% higher than that of the V-1 tray.

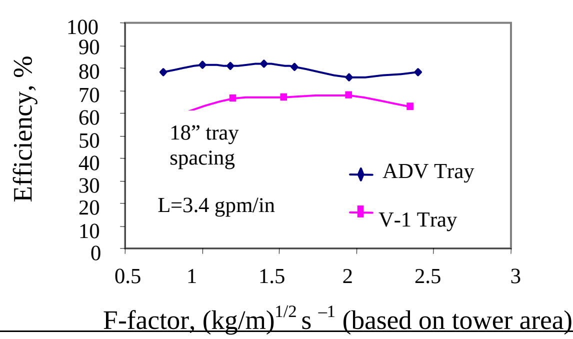


Figure 5. Comparison for valve tray efficiency

REVAMP CASE STUDY

Since its inception in late 1997, ADV® Pinnacle Performance Trays have been successfully applied in more than 120 commercial installations in the refining, petrochemical and chemical industries. ADV® Trays have been used in wide range of applications ranging from 1 to 8.1 meter tower diameters, 300 to 915 mm tray spacings, towers with a few to more than 200 trays, one to four passes (including three-pass), and in vacuum to high pressure systems. Three representative revamp cases detailing the scope of modifications as well as before and after performance comparison are discussed as below:

1. Xylene Splitter (1998)

A major petrochemical company has two Xylene Splitters, each with two towers in series and a total of 150 trays on 450 mm tray spacing. The No. 1 Xylene Splitter (4.9 meter I.D.) has 31 two-pass trays and 119 four-pass trays in the rectifying and stripping sections, respectively. The No. 2 Xylene Splitter (7.5 meter I.D.) is basically scaled up from the No. 1 Xylene Splitter, with the exception that four-pass trays are used throughout two columns. While the No. 1 Xylene Splitter has been operating satisfactorily with an observed tray efficiency of 80% throughout two columns; however, poor efficiency was observed in the No. 2 Xylene Splitter, i.e., 80% and 56% for the rectifying and stripping section trays, respectively. Moreover, low tray efficiency resulted in excessive energy consumption and limited further reflux and/or throughput increase.

The minimum requirements for this revamp are:

a. Increase Xylene Splitter throughput by 20%.
b. Improve Xylene Splitter tray efficiency to 80% minimum.
c. Allow unit to operate at two modes, i.e.,
   - Mode 1: Max. P/M-Xylene production
   - Mode 2: Max. O-Xylene production

The scope of mass transfer internal modifications in the revamp include:

- Replace all (150) valve trays with (146) ADV® Trays.
- Convert the top tray in each column to a liquid distributor tray.
- Convert the bottom tray in each column to a vapor distributor tray.
- Install a new feed distributor.
- Reuse the existing major beams and tower attachments.

A simplified process flow diagram reflecting post-revamp scenario is shown in the Figure 6 below.

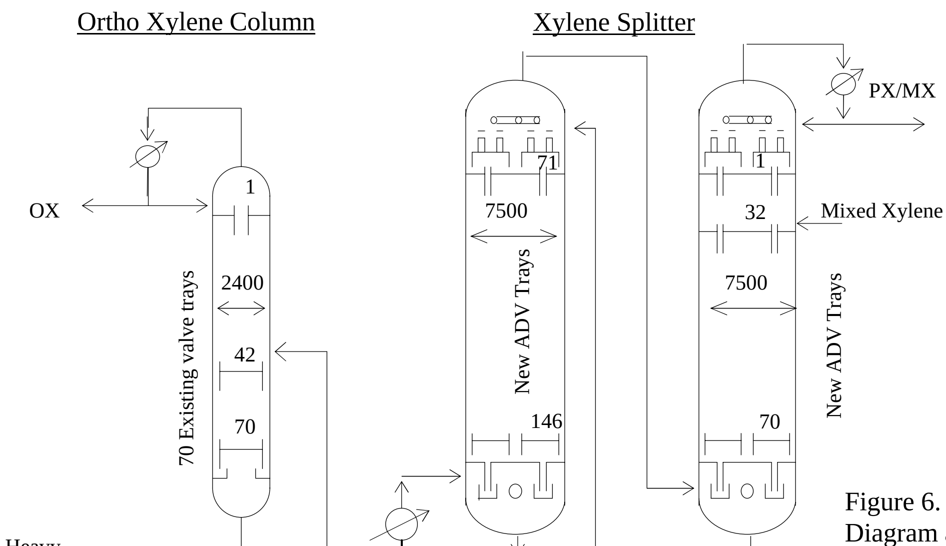


Figure 6. Process Flow Diagram after revamp

Table II below details the performance comparison, i.e., before vs. after revamp. It can be seen that the No.2 Xylene Splitter (7500 mm I.D.) with ADV® trays exceeded expectations with an observed tray efficiency of over 95% throughout two columns, superior to the performance of No. 1 Xylene Splitter (4900 mm I.D.). The plant has operated up to 123% of the pre-revamp rate without any evidence of reaching capacity limit of the new ADV® Trays. The corresponding product purity improvement in terms of reduction of impurities, i.e., Ortho Xylene in the overhead distillate and Meta Xylene in the bottom product, are from 17.3 wt.% to 15.7 wt.% and 0.79 wt.% to 0.10 wt.%, respectively, at 10% less reboiler duty than the pre-revamp operation.

Moreover, due to the drastic reduction of Meta Xylene content in the Splitter bottom product, the energy consumption of the downstream Ortho Xylene Column was subsequently reduced. As a result, the existing valve trays in the Ortho Xylene Column no longer hydraulically loaded, which leads into other benefits, i.e., increased Ortho Xylene purity in the column overhead and increased Ortho Xylene recovery. Presently, the entire plant is operating more stable and efficiently than ever.

Table II. Before Vs. After Revamp Performance Comparison (#2 Xylene Splitter)

	No. 1 Xylene Splitter	Before Revamp, Actual	After Revamp, Actual
Tower I. D., ft (mm)	16.1 (4,900)	24.6 (7,500)	24.6 (7,500)
No. of Trays	150	150	146
No. of Pass (above/below feed)	2/4	4/4	4/4
Tray Spacing, in (mm)	17.72 (450)	17.72 (450)	17.72 (450)
Tray Type	Sieve (7% hole area)	Valve	ADV
Feed Rate, %	40	100	123
Product Purities, wt%			
Ortho Xylene, Splitter Overhead	--	17.3	15.7
Meta Xylene, Splitter Bottom	--	0.79	0.10
Tray Efficiency, %			
Rectifying Section	80	80	>95
Stripping Section	80	56	>95
Reboiler Duty, % @ 100% feed rate	--	100	90

2. Acetic Acid Dehydration Column (1997 & 1999)

A PTA producer has four identical Acetic Acid Dehydration columns with the purpose of removing water from a vapor feed of acetic acid and water mixture. Unlike most distillation columns, these four dehydration columns have no reboilers. Instead, the heat source is provided by hot vapor feed (from oxidizers) entering the columns below the bottom tray.

A simplified PFD for the acetic dehydration process (Figure 7) shows a column with two diameters (7'-0" I.D. for trays #60-#8, and 8'-6" I.D. for trays #7-#1) with a main feed in vapor phase at the bottom of the column and a small recycle weak acid feed in liquid phase to tray #7. The top and bottom products are water and concentrated acetic acid, respectively. Conventional valve trays were used throughout the four columns.

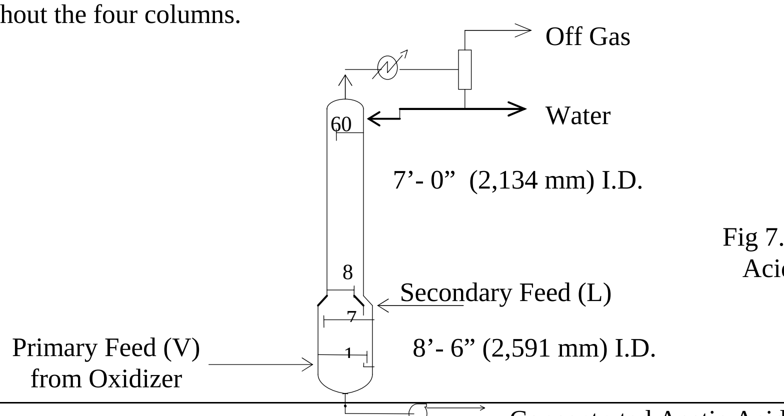


Fig 7. PFD for Acetic Acid Dehydration

The objective of this revamp was to increase Acetic Dehydration Column throughput by an initial target of 17% and an ultimate goal of 30% for all four towers respectively, while maintaining at least the same product purities. As Titanium material, which costs more than 10 to 13 U. S. dollars per pound, is specified for all internals in the dehydration columns, the stake of trays not performing after revamp is very high. Moreover, unlike most distillation processes, product purities can be increased with greater reflux ratio and reboiler duty. For this system, however, no reboilers are used; thus, any reduction of tray efficiency after revamp will have a detrimental effect, e.g., producing “off-spec” bottom acetic acid product or decreased yield.

In the first phase of the project in November 1997, ADV® Trays were applied on a one-for-one replacement basis throughout the entire column, in two of the four columns. In the tray design evaluation process, it was found that the existing downcomers for the original valve trays were somewhat oversized even for the new revamp loadings. To balance tray design for the new trays in terms of jet flood and downcomer capacity, the original segmental downcomers were converted to swept-back downcomers throughout columns, which resulted in marginal increase in active areas and outlet weir lengths. The tray geometry comparison before and after revamp is summarized in table III.

Table III. Before vs. After Revamp Comparison (Tray Geometry)

Status	Before Revamp		After Revamp	
Section	Top	Bottom	Top	Bottom
Column Diameter, ft (mm)	7.0 (2,134)	8.5 (2591)	7.0 (2,134)	8.5 (2,591)
No. of Trays	53	7	53	7
Type of Downcomer	Segmental	Segmental	Swept-Back	Swept-Back
Outlet Weir Length, ft (mm)	4.53 (1,381)	5.53 (1,686)	4.74 (1,445)	5.73 (1,747)
% Outlet Weir Increase	N/A	N/A	4.6	3.6
Active Area, ft^2 (m^2)	33.32 (3.10)	49.03 (4.56)	34.65 (3.22)	50.50 (4.69)
% Active Area Increase	N/A	N/A	4.0	3.0

Initial revamp target of 17% feed rate increase was easily achieved immediately after column startup. During the test run, it was confirmed that ADV® trays reached the ultimate goal, i.e., 130% of the maximum capacity of the original valve trays. The capacity advantage of ADV® Trays can be reasonably demonstrated in Figure 8, which shows the overall column pressure drop data before and after revamp at various feed rates. It was interesting to find, at the maximum operable capacity for the original valve trays and the ADV® Trays at 130% rates, the overall column pressure drops are essentially the same, i.e., 0.47 kg/cm^2.

Figure 8. Tray Capacity Comparison

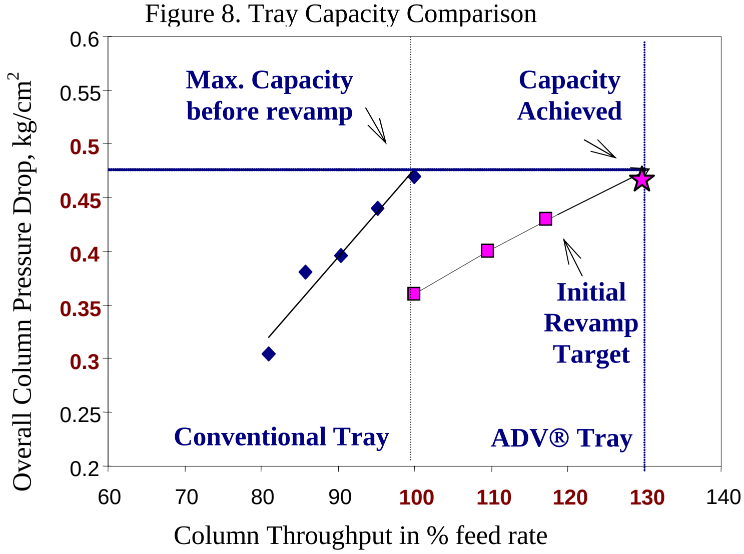


Table IV details the performance comparison before versus after revamp. It can be seen that Acetic Acid Dehydration Column with ADV® trays performed well with observed tray efficiency also higher than that of the original valve trays in the pre-revamp operation.

Table IV. Before Vs. After Revamp Performance Comparison

	Before Revamp	After Revamp	
Type of Trays	Valve	ADV®	
Operating Case	Max. Operable	Design Target	Actual Achieved
Feed Rate, %	100	117	130
Reflux Ratio	100	100	100
Product Purities			
- Distillate	0.46 wt% HAc	0.43 wt% HAc	
- Bottom	92.8 wt% HAc	93.5 wt% HAc	
Overall Column Pressure Drop, kg/cm^2	0.47	0.43	0.47

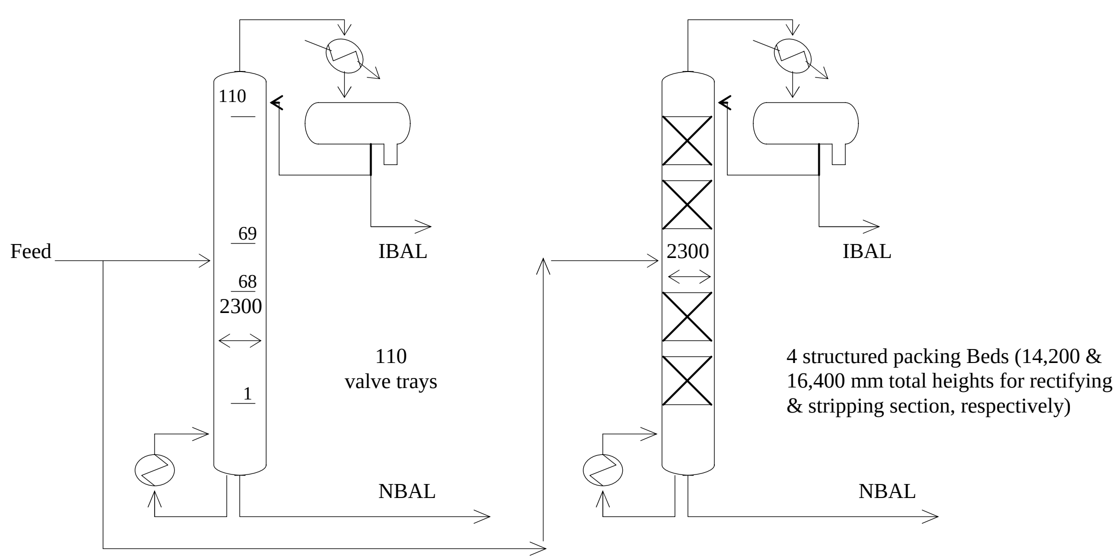
The remaining two Acetic Acid Dehydration Columns were also revamped with the identical ADV® Trays in 1999, and the same improvements were observed.

3. Isomer Columns (Plant –1, 1999 and Plant-2, 2000)

In 1999, an Oxo-Alcohol plant requested a technical proposal to revamp its Isomer Column to improve the purity of its key products, isobutyraldehyde (IBAL) and normal butyraldehyde (NBAL), i.e., reducing NBAL content at overhead distillate (IBAL) and IBAL content in the bottom product (NBAL), from 0.73 to 0.01 wt% and from 0.06 to 0.01 wt%, respectively. This revamp would not only make the products more competitive in the market place, but also allow them to demand a premium price for the enhanced purity.

Isomer separation prior to revamp was based on operating two columns (2300 mm I.D. for both columns) in parallel. One of the columns has (110) two-pass valve trays on 305 mm tray spacing, while the other column is a packed column packed with (4) high surface-area structured packing beds. The existing valve trays in the tray column are operating at approximately 58% tray efficiency while the structured packing column was producing even worse product separation than the trayed column. A simplified PFD reflecting pre-revamp configuration is shown below in the Figure 9.

Fig. 9. Isomer Column (Plant-1) PFD (before revamp)



After extensive simulation study and a series of test runs, it was determined that neither the existing trayed nor packed column offered enough capacity as well as theoretical stages for the required high purity separation. A pilot plant test[4] was then carried out to investigate whether a process change, i.e., from parallel to series operation is feasible in meeting required throughput and product separation. The results of pilot plant tests confirmed the targeted separation could be achieved with more theoretical stages while operating at a low reflux ratio. A different process flow scheme using a two-column system with the columns operating in series was finally adopted. Accordingly, a new column with an internal diameter of 2950 mm (the largest possible due to site limitation) together with 114 trays on 305 mm tray spacing was incorporated in the new scheme. For the new system, the existing smaller column (2300 mm I.D.) and new column (2950 mm I.D.) perform the functions of rectifying and stripping section, respectively. For this project, new ADV® trays throughout the two columns (224 total) were the centerpiece of the new process. The simplified post-revamp PFD is shown in Figure 10.

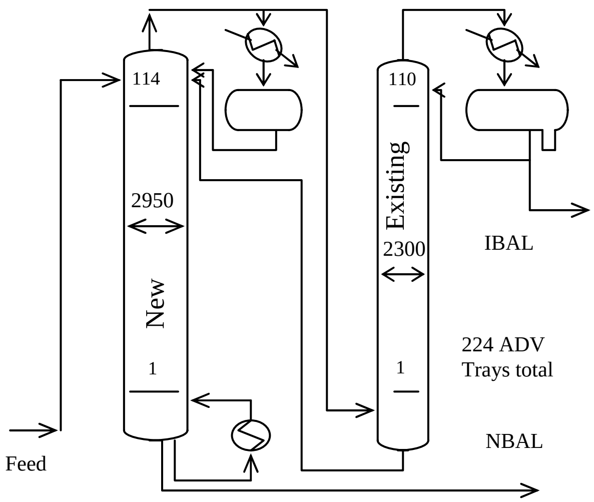


Fig. 10. Isomer Column (plant-1) PFD (after revamp)

The results of the revamp were quite successful, as demonstrated in Table V below.

Table V. Before Vs. After Revamp Performance Comparison, Isomer Column (1)

Case	Before Revamp (actual)	Design Basis (max)	After Revamp
Tower I. D., mm	2,300/2,300 (in parallel)	2,300/2,950 (in series)	
No. of Trays	110	110/114	110/114
No. of Pass	2	2/2	2/2
Tray Spacing	305	305	305
Tray Type	Valve	ADV/ADV	ADV/ADV
Total Charge Rate, %	100	107.5	107.5
Product Purities, wt%			
NBAL, Column Overhead	0.73	0.01	< 10 ppm
IBAL, Column Bottom	0.06	0.01	45~60 ppm
Tray Efficiency, %	58	74.5	80

From the table above, it can be seen that the performance of ADV® Trays in terms of tray efficiencies is greater than that of the pre-revamp as well as the design cases. In fact, NBAL product is being considered the best in the industry. This revamp demonstrated the superior performance of ADV® Trays on short tray spacing, as small as 305 mm, to the conventional valve trays.

In 2000, with another Oxo Alcohol plant (plant-2), the same customer decided to revamp its Isomer Column (3,000 mm I.D.) for 25% greater throughput with ADV® Trays (145 total on 305 mm tray spacing). The PFD of the Isomer Column for this plant is shown in the Figure 11.

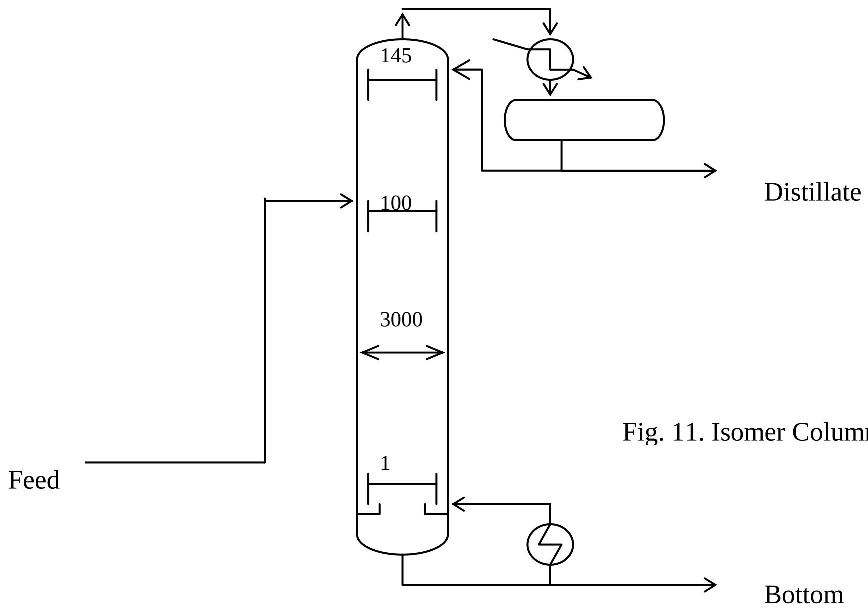


Fig. 11. Isomer Column (Plant-2) PFD

Although the PFD for the plant-2's Isomer Column, i.e., single column operation with 145 trays, is different from the plant-1's process flow scheme, i.e., two columns in series with a total of 226 trays, the tray design challenge was comparable, i.e., increased tray performance on very short tray spacing (305 mm). The proven tray design concept, as used in the plant-1, was applied for the new ADV® Trays for the plant-2's Isomer Column revamp. The results of the revamp were quite successful, as demonstrated in Table VI.

Table VI. Before Vs. After Revamp Performance Comparison, Isomer Column (2)

Case	Before Revamp	After Revamp
Tower I. D., mm	3,000	3,000
No. of Trays	145	145
No. of Pass	2	2
Tray Spacing	305	305
Tray Type	Conventional Valve	ADV/ADV
Total Charge Rate, %	100	125
Product Purities, wt%		
NBAL, Column Overhead	0.03	0.03
IBAL, Column Bottom	0.04	<50 ppmw
Tray Efficiency, %	70.4	78.8

The performance comparison as shown above further demonstrated the reproducibility of ADV® tray performance, in terms of capacity as well as efficiency advantages over conventional valve trays.

CONCLUSIONS

1. The installation of canopies on *Advanced Dispersion Valves* allows a more uniform froth distribution as well as higher mass transfer area and thus higher efficiency. The horizontal dispersion provided by the canopies results in lower froth height and lower entrainment. This significantly increases the tray capacity.

2. The advantages of ADV® Trays in capacity and efficiency have been further demonstrated in three successful commercial examples in this paper.

3. Since its inception in late 1997, ADV® Tray has been applied in over 120 commercial applications worldwide, including numerous complex distillation systems, where large quantities of trays, short tray spacings and/or large column diameters are employed. ADV® Tray has demonstrated its performance advantages and dependability in all cases in which it was applied.

NOMENCLATURE

F-factor, $(kg/m)^{0.5}s^{-1}$, (= Vs (ρ_V) ^{½})

V_s = vapor velocity, m/s

ρ_V = vapor density, kg / m^3

LITERATURE CITED

1. Nutter, D. E., and Perry, D., Sieve Upgrade 2.0 – The MVG TM Tray, Paper presented at AICHE Spring Meeting, Houston, TX, March 1995.
2. Nutter, D. E,, U.S. Patent 5,360,583 (1994)
3. Chuang, K. T., and Pan, G., U.S. Patent 6,145,816 (2000)
4. Fair, J. R., Null, H. R., and Bolles, W. L. *Ind. Eng. Chem. Process Des Dev.*, 1983, 22, 53-58.