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THE EVALUATION OF OUT-OF-LEVEL TRAYS FOR THE IMPROVEMENT OF INDUSTRY GUIDELINES

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Industry guidelines have been developed from operational experience to predict the tray tilt angle that can be allowed without sacrificing tray operational performance. There can be a negative economic impact when operating a column with permanently tilted trays whether it is reduced throughput, purity or increased utility consumption. As a result, the validity of the industry tray guidelines has been questioned. Pilot plant experimental data was combined with an industrial example to elucidate the effect of tray tilt angle, specifically perpendicular to liquid flow, on the performance of a distillation column tray. A new guideline for the upper limit of the tray tilt angle has been developed thus providing industry confidence in deciding when to correct a tray tilt. A theoretical model has also been proposed that matches, within 5%, experimental and industrial data for a tilted tray, perpendicular to liquid flow, for diameters up to 1.7 m.

Keywords: distillation; mass transfer; internals; industry tray guidelines; maldistribution; hydrodynamics.

INTRODUCTION

There are known industrial scenarios where tray out-of-levelness will degrade distillation performance, and guidelines exist that attempt to set the limits for acceptable tray tilt.

The original published work on this subject by Lockwood and Glauser (1959) provides valuable insight into the tray tilt guidelines. They argued that tilted trays do not appreciably impact performance and thus do not need to be leveled. Their results were based on tests on a 1.7 m diameter column with a tilt of 13 mm in the direction of flow. This value was within the maximum guidelines in 1959 (and current ones), so they concluded that the tray level guideline was too stringent. However, and more importantly, the tilt direction was limited to one specific direction (tilt in the direction of liquid flow). The paper did not comment on the impact of tray tilt perpendicular to flow and thus did not account for this important direction of tray tilt. The goal of this paper is to provide an update to the current industrially accepted guidelines for tray levelness incorporating the important impact of tray tilt perpendicular to the liquid flow.

Over the many years of operating distillation columns, operating companies and tray vendors have developed simplistic, linear guidelines for determining when a tilted tray needs to be fixed (i.e., tilt lessened). Most operating companies believe, and they design to this standard, that as long as the tilt angle (regardless of tilt direction) is within their tray tilt guideline, the tray should operate adequately (Lockett and Augustyniak, 1991).

Equations (1) and (2) (Lockett and Augustyniak, 1991) provide the range within which companies believe tray levelness should be considered an issue. The two equations form the limits of the compiled tilt angles allowed in the guidelines of the surveyed companies. The maximum limit is greater than the most lenient of the guidelines found, while the minimum limit is less than the most stringent of guidelines found.

Tray levelness criteria (updated using latest industry best practice):

$$\text{Max. limit, mm} = 4.8 + 1.3\,D' \tag{1}$$

$$\text{Min. limit, mm} = 1.5 + 0.8\,D' \tag{2}$$

where D' is diameter of column in m.

Kister (1995) surveys column operating problems reported from tray out-of-levelness for tray tilts angles well above the maximum tray tilt industry guide line. To our knowledge no attempt has been made to verify if the range is correct or if a new limit should be defined. Figure 1 presents the maximum and minimum range for the existing tray levelness guidelines as defined by

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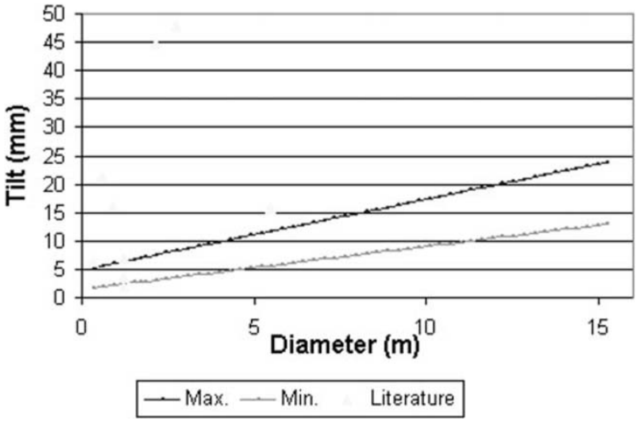

Figure 1. Literature data superimposed on tray levelness guidelines (mm).

equations (1) and (2). Most literature data points are outside the range set by industry, and hence do not provide any insight into the validity of the guidelines. Data from six public domain literature sources was used (Hoerner *et al.*, 1982; Kovshov *et al.*, 1996; Lockett amd Augustyniak, 1991; Resetarits *et al.*, 1992; Sasaki *et al.*, 1979; Vybornov *et al.*, 1969) as a basis for evaluating previous test data on trays set at an angle and are superimposed onto Figure 1. Many more papers stated poor column performance with trays tilted, but provided no performance details; hence these references could not be used for any quantitative analysis. Of the six papers found containing quantitative data, two papers (Lockett and Augustyniak, 1989; Vybornov *et al.*, 1969) performed testing at or close to the maximum industry allowable tilt angles (305 mm ID, 5.5 m ID), and served as the benchmark for performing experiments at and below the maximum allowable tilt angle.

If the tray tilt guideline is too stringent, additional expenditure (field and lost production costs) will be spent during construction or during column turn around to ensure that the tray tilts are within level tolerances. On the other hand, if the guideline is overly optimistic, poor operation will occur from the tilted tray since adjustment of the tray will not be recommended. A reduction in throughput or excess operating costs needed to meet separation through over circulation in the tower (added cost for heating and cooling media) will result from not leveling the tilted trays.

MASS TRANSFER AND TRAY TILT

The distillation column tray has three distinct functions: exchange heat, provide contact to transfer components from one phase to another, and remove liquid from the vapor stream. Mass transfer between the liquid and vapor phases on a tray, and therefore the tray efficiency, is determined by the driving force, mass transfer coefficients, interfacial area, and the contact time between two phases (Kister, 1995). A single pass tray that is tilted perpendicular to liquid flow will impact the liquid and vapor flow pattern by creating a liquid gradient on the tray more so than either a level single pass tray or a tray tilted parallel (to the same angle) to the liquid flow (Hoerner *et al.*, 1982). It could be expected that a tray tilted perpendicular to liquid flow (at or below the maximum guidelines) will impact the tray efficiency when compared to a level tray. Studies have also shown that the performance of a tray having a permanent tilt will be poorer then the performance of a tray undergoing an oscillating tilt (i.e., from wave motion) (Resetartis *et al.*, 1992; Vybornov *et al.*, 1969).

PILOT PLANT COLUMN

The testing for this project was performed at the University of Alberta using a 305 mm ID column with three trays. Two systems, one consisting of air/water and the other consisting of isopropanol-methanol were used in the experimental part of the study. In order to perform the required experiments, three 305 mm ID cans with a novel tilting tray mechanism were designed as shown in Figure 2. The trays, fabricated by Koch-Glitsch Canada, were suspended from four bolting assemblies that allowed the tray to tilt, perpendicular to the liquid flow, up to an angle of 8°. The circumference of the tray was wrapped with a Teflon gasket to prevent liquid bypass when the tray was placed at an angle. The active area of the sieve tray, and a tapered envelope downcomer were fabricated as one unit. The dimensions of the test trays used in the experiment are given in Table 1. Additional details of the experimental equipment can be found in Remesat (2003).

INDUSTRY DATA COLLECTION

A distillation column at a refinery underwent a revamp, in order to increase its capacity by 15%. The column was a 1.7 m ID C_3/C_4 splitter and Koch-Glitsch high capacity Superfrac® III (2000) trays were used to debottleneck the tower. Some pertinent details of the trays (pre- and post-) are shown in Table 2 revealing the differences between the old and revamp trays. The feed nozzle and feed distributor were also modified to accommodate the larger flow rates. PWHT (post-weld heat treating) performed on the feed nozzle location was set at too high a temperature, which resulted in the column bending at that location. The result was a 5 mm (0.171°) perpendicular to liquid flow tilt for the top nine trays, which was less than the 6.9 mm (0.237°) maximum allowable by industry guidelines. The company decided that the cost to operate the column with the 5 mm tilt and the number of trays impacted was not as big a concern as the maintenance cost to repair the trays. Fortunately, data has been collected, thus providing one of the only comparisons between the operation of level and tilted trays in an industrial column.

AIR/WATER COLUMN PILOT PLANT TESTING

C-factor, equation (3), is used as a primary parameter in the evaluation of the tray tilt data.

$$\text{C-factor} = U_s\sqrt{\frac{\rho_v}{\rho_L - \rho_v}} \tag{3}$$

Figure 3 shows the entrainment measurements taken for different tray tilts while Figure 4 shows the percentage difference in entrainment between trays operating at tilt angles as compared to level trays. Entrainment