

# Tray hydraulic operating regimes and selectivity

Tray hydraulics is discussed in terms of froth and spray operating regimes, and possible impacts on selectivity are pointed out by reference to performance data

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**M**ost gas treating contactors are highly liquid loaded, with good designs operating at vapour loads approaching the jet-flood limit. An optimal design will also have downcomers sized to approach the choke flood limit at the design point, as this allows for the maximum tray active area, hence the smallest column diameter for a given throughput.

At high weir liquid loads, trays operate predominantly in the froth regime, where the gas dispersion rises through continuous liquid, interfacial areas are large and the liquid is highly agitated. This results in high absorption efficiency for both CO<sub>2</sub> and H<sub>2</sub>S. Low weir loads correspond to the spray regime, where the liquid is dispersed as large droplets that are projected through a continuous gas phase as a spray. The droplets behave like nearly stagnant, rigid spheres and have extremely small liquid-side mass transfer coefficients. Consequently, CO<sub>2</sub> absorption is severely retarded because its rate is controlled by the liquid-side resistance to mass transfer. This leads to a concomitant improvement in H<sub>2</sub>S removal.

A number of cases have come to light in which seemingly impossibly low H<sub>2</sub>S leak rates have been realised and much higher than normal CO<sub>2</sub> rejection rates observed from trayed columns. In every case, liquid rates were low and the weirs were long enough to have weir loads of 10 gpm/ft or less, putting the trays well into the spray regime. Simulations could be matched to plant performance data only by using greatly reduced liquid-film

coefficients for mass transfer (stagnant liquid), and by increasing the gas-side coefficient as expected for turbulent gas flow past drops.

The spray regime is quite effective in achieving ultra-low H<sub>2</sub>S leaks and greatly improved CO<sub>2</sub> rejection rates and, if conditions cause an existing plant to operate there, selectivity will probably greatly exceed what might be expected. Therefore, under certain circumstances, consideration might be given to trying to operate in this region.

Usually, contactors containing trays are initially designed to operate at 70–80% of jet and downcomer flooding rates using very conventional valve-type trays with few or no hydraulic performance enhancers, such as tapered downcomers and swept-back weirs. These are safe designs because they use older, broadly established technology and leave plenty of room for easy capacity improvement should they fall short in the field and to accommodate the inevitable future increases in plant throughput. Most contactors in gas treating applications have relatively high liquid-to-gas (L/G) ratios, usually quite a bit higher than in distillation, because the large amounts of acid gases to be removed require large solvent flows for absorption. A well-designed tray has a turndown ratio of at least 4:1; in other words, it can operate satisfactorily from a hydraulic standpoint down to about one-quarter or less of design rates. Below three- or four-to-one turndown, liquid starts to weep through the trays to an extent that mass transfer performance begins to suffer.

At the L/G ratios common in gas treating, trays normally operate in the froth regime. In this flow regime, the biphasic on the tray has the gas dispersed in a more or less continuous liquid, and the mixture flows across the tray as an intensely agitated froth.

Sometimes a raw gas contains either very small amounts of H<sub>2</sub>S and CO<sub>2</sub>, or perhaps a small concentration of H<sub>2</sub>S and a larger fraction CO<sub>2</sub>, but the H<sub>2</sub>S must still be removed to meet a parts-per-million specification. In such cases, only modest solvent flow is needed to treat the gas with MDEA so the L/G ratio in the contactor is low. As the liquid flow is reduced, the froth gives way to a spray because there is insufficient liquid flow to maintain a reasonable volume of liquid on the tray. The still large vapour flow shatters the liquid, converts it to droplets and ejects it into the downcomer, not as a stream of continuous liquid flowing over a weir, but as a swarm of drops (a spray) thrown over the weir and into the downcomer. Interfacial areas, and gas- and liquid-side mass transfer coefficients can be radically different in the froth and spray regimes, with the consequent likelihood that selectivity may be affected significantly.

## Tray hydraulics

Maximum tray hydraulic capacity can be limited by any one of three types of flooding mechanism: jet or entrainment flood, downcomer backup flood and downcomer choke flood. The ability of a tray to operate at the lower end of the

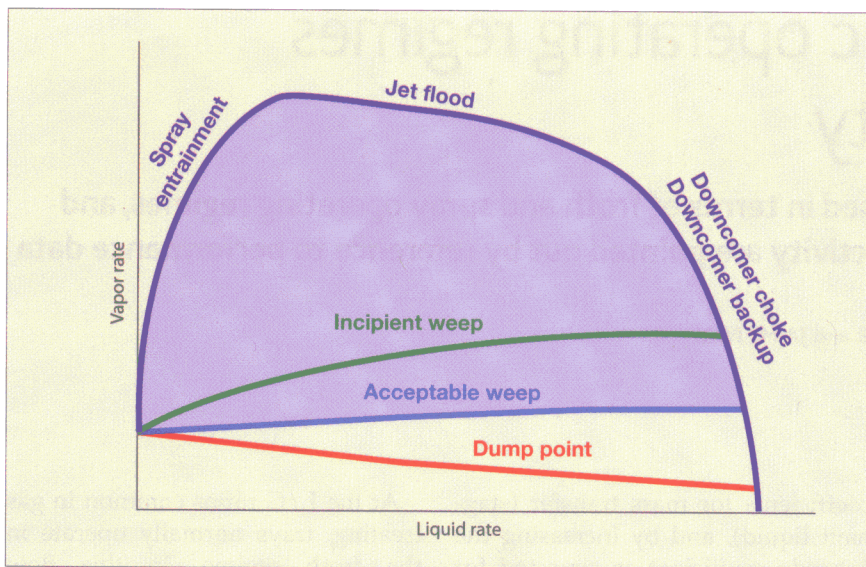


Figure 1 Tray operating diagram

loading range is limited by weeping and also by entrainment that occurs even in the spray regime of operation as the liquid flow on the tray is decreased while maintaining a high vapour flow rate.

The other low liquid rate limitation is vapour bypassing up downcomers as lowered liquid depths unseat the downcomers. In a perfectly balanced design, jet flood and choke flood occur simultaneously and the column's diameter is sized to be just adequate for the proposed loads; certainly pressure drop will not be high enough nor downcomer clearance tight enough to induce backup flood problems, nor will vapour bypass up downcomers.

### Entrainment flood

Figure 1 shows a typical tray operating diagram illustrating stable limits. The portion of the upper operating line labelled spray entrainment is in the froth regime and corresponds to the upper limit of vapour flow where the tray begins to flood, the so-called jet flood line. This should not be interpreted as a finely drawn, sharp line because the definition of jet flood varies from vendor to vendor. Some vendors call 85% jet flood the vapour velocity at which 10% of the liquid is entrained from the tray and flows with the vapour to the tray above. Others call it the maximum useful capacity. Whether the definition is 80 or 90%, jet flood

corresponding to 10 or 20% entrainment is arbitrary and the pinpointing of maximum useful capacity is certainly subjective. However, near the jet flood limit, the entrainment rate is exponentially sensitive to small changes in vapour rate and only a small increase in vapour flow will cause the column to flood. This is not a condition at which one would like to operate because the column approaches instability and becomes harder to control.

Vapour load is best described by the C-factor, usually based on the superficial vapour velocity,  $u_s$ , through the empty column but sometimes based on the gas velocity through the tray active area or even through the area of the actual openings (valves and so on). The superficial velocity definition is:

$$C_s = u_s \sqrt{\frac{\rho_v}{\rho_t - \rho_v}}$$

A conventional valve tray with 13% straight downcomers operating at normal weir loads (50–150 gpm/ft of weir) will flood when  $C_s$  is much above 0.38 ft/s. A more modern, high-capacity tray uses special downcomer treatments to recover much (and, in the case of truncated downcomers, all) of the area under the inlet downcomer, so it enjoys between a 10 and 20% higher capacity. This higher jet flood capacity is achieved simply by converting more of the

tower area into tray active area.

One jet flood mechanism is froth entrainment by gas, which carries liquid to the tray above in large enough quantities that downcomer capacity is exceeded on the top tray. Except for the bottom-most and top-most trays, each tray in the column receives as much entrainment from the tray below as it loses to the tray above, so it experiences very little change in liquid load caused by entrainment. The bottom tray actually has a lower liquid load than any other tray in the column because it receives no entrainment from below but loses liquid to the tray above. However, the top tray has most of its entrainment returned to it by the mist pads commonly installed in the top of the tower, so the liquid load on the top tray is incremented by the entrainment rate from the tray below. Thus, the top tray has the highest liquid load and would be expected to flood first.

However, froths on operating trays are not well-behaved flows of uniform depth — massive eruptions and geysers occur with high frequency, with the liquid being thrown against the bottom of the overlying tray and forced through its perforations. At close tray spacing, the froth may occupy the whole space between the trays and flooding occurs when the froth tries to expand even further. This may not be limited to close tray spacing — it is hard to make more than a slight distinction between froth occupying the whole volume between trays and numerous geysers throwing liquid at the upper tray. Of course, when foaming occurs, the whole jet (and downcomer) flood situation is exacerbated in the extreme.

### Downcomer flood

Downcomers can flood by two possible mechanisms: excessive liquid backup inside the downcomer (backup flood) and choke at the downcomer mouth. The right-hand side of Figure 1 does not distinguish between the two mechanisms and, indeed, it is often hard to distinguish between them even visually in a large-scale, well-instrumented pilot plant.

## Backup flood

As shown in Figure 2a, the depth of liquid (or froth) in a downcomer is determined by the liquid depth on the tray, the pressure drop across the tray and the head loss for flow of aerated liquid under the downcomer skirt. The third factor can be controlled by using the right downcomer escape area, but the second depends on tray pressure drop, which is a function of the tray bubbling area, the type of tray opening being used and the fractional hole area. Backup flood is the easiest to avoid.

## Choke flood

The cross-sectional area (and to a lesser extent the shape) of the downcomer mouth is the primary factor that determines its capacity for accepting a given flow of liquid or froth. Referring to Figure 2b, at choke, liquid does not crest over the weir. Instead, the downcomer is simply presented with a higher volume flow of froth than can be driven into it when hydrostatic head is at its greatest, equal to the tray spacing (the maximum head possible). Once the downcomer mouth becomes covered with froth, liquid height over the weir is no longer proportional to volume flow to the power  $2/3$  as in the Francis weir formula. Instead, liquid height over the weir becomes proportional to the liquid rate raised to the 1.5 power; thus, any further increase in liquid flow requires greatly increased head to drive the flow into the mouth. Once the downcomer mouth becomes buried in froth, only small increases in liquid load are enough to throw the column into choke flood — the column becomes increasingly unstable and eventually impossible to operate.

During a foaming event, the downcomer choke flood might be considered the culprit because the froth volume is much increased, with the downcomer being asked to admit a greatly increased volume flow of even lower density material. Under choke conditions, even a large increase in froth depth drives only a modestly increased flow. But this is speculation because, once

flooding begins, it is extremely hard to ascribe one mechanism or another as the cause — they are all connected.

## Weeping through tray openings

Referring again to Figure 1, as the gas rate is decreased at a fixed liquid rate, a point is reached at which the tray starts to weep. This is the incipient weep point, where the first droplets of liquid find their way downwards through a few perforations. Further decreases to vapour rate result in increased weep rates until the weep rate becomes, in some sense, excessive. There have been instances where, during a turnaround, all the trays have been found in a heap in the tower sump, yet the column was making on-specification gas at design rates just before the turnaround. Obviously, what defines a weep rate as excessive depends very much on the operation. However, when slipping  $\text{CO}_2$  is important or meeting both an  $\text{H}_2\text{S}$  and a  $\text{CO}_2$  specification is the objective, the column must be more tightly designed, and too much weeping will compromise the separation because to some extent it spoils the split.

## Spray regime

Kister and Haas (1987) have shown that the entrainment rate goes through a minimum with weir liquid load (see Figure 3). The minimum might be considered to be somewhere in the transition

between the froth and spray regimes, the spray regime lying to the left. However, the transition itself is very gradual, so there is not a single point associated with it. The spray regime is entered at higher liquid rates in hydrocarbon systems (cyclohexane-n-heptane in the figure) than in air-water (much closer to amine treating fluids). The higher the gas rate, the higher the weir load at transition. However, unless the tray is operating at an extremely low vapour rate, full transition to the spray regime occurs at a weir liquid load (volume flow per length of weir) of between 11 and 22  $\text{m}^3/\text{m}\cdot\text{hr}$ , and the entrainment rate climbs super-exponentially as the liquid load is further reduced.

As the column transitions from the froth into the spray regime, the gas goes from being the dispersed phase to becoming continuous, and the liquid switches from continuous to dispersed. Spray is generally in the form of fairly large droplets, typically exceeding 1000  $\mu\text{m}$  (1 mm) diameter, which move at high velocity. When well into the spray regime, most of the liquid is in the form of droplets and little or none actually lies on the tray. The liquid no longer flows over the weir, but instead is projected through the vapour space and into the downcomer. The weir might as well not be there at all, and it has been observed in distillation that in this region neither pressure drop nor efficiency depend to any great

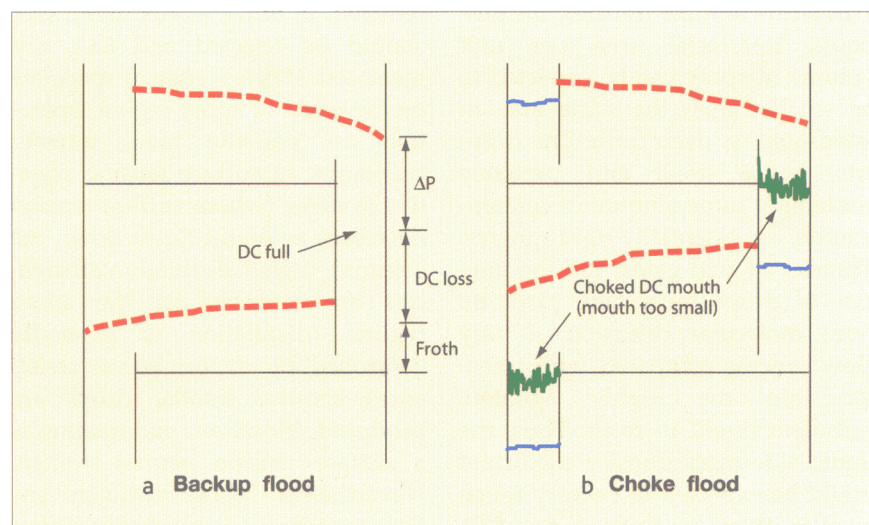


Figure 2 Two types of downcomer flooding

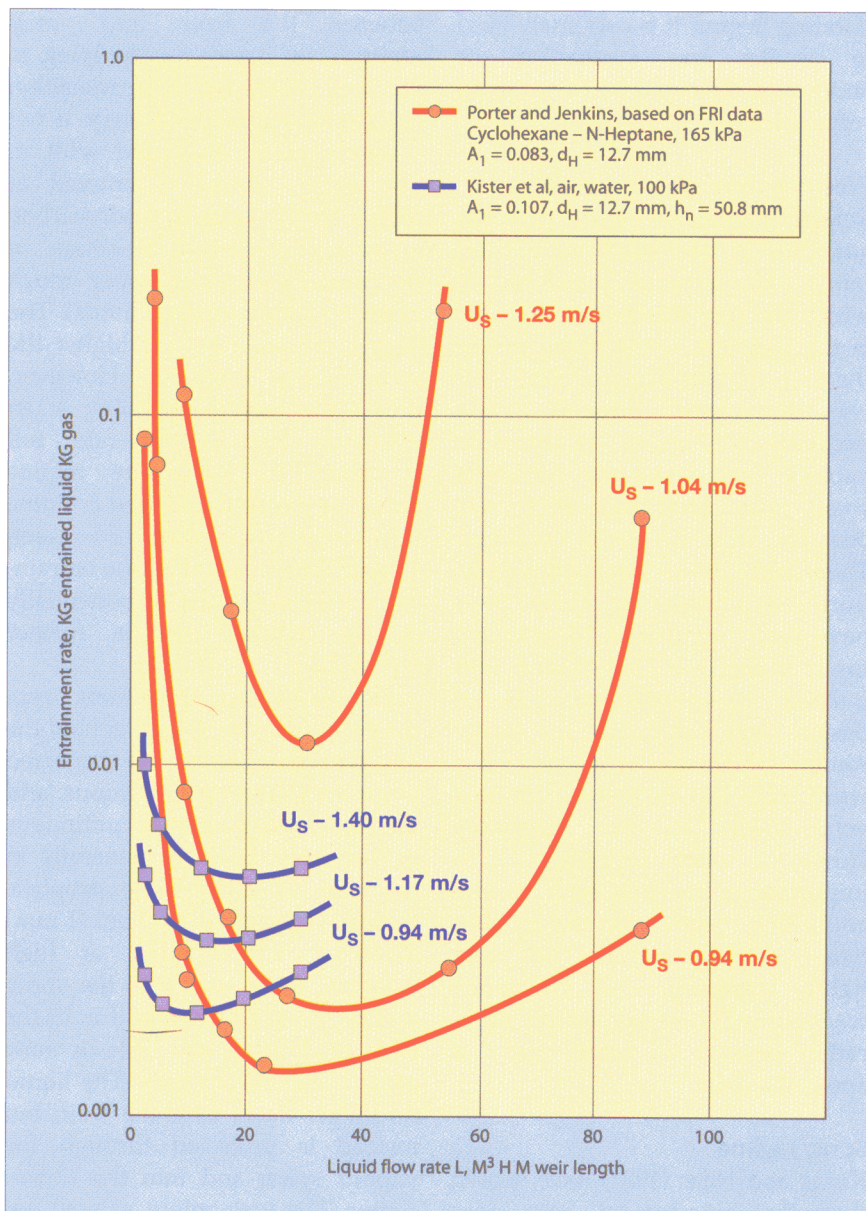


Figure 3 Dependence of entrainment rate on weir load at various gas rates for cyclohexane - n-heptane and air-water (Kister & Haas, 1987)

extent on the presence or absence of a weir.

In terms of mass transfer, the gas-liquid interfacial area per unit volume of spray can be expected to be smaller than the same area in good-quality, deep froth. The droplets, being small and probably containing some amount of contamination, are essentially rigid spheres. Transfer of acid gases into the interior of drops must take place by pure molecular diffusion, a very slow process compared with transfer into the highly agitated, turbulent liquid in froth. Thus, the liquid-side mass transfer coefficient might be expected to be very much smaller than in froth. Since CO<sub>2</sub> absorption is controlled largely by

resistance in the liquid phase, the CO<sub>2</sub> absorption rate should be reduced; in other words, more CO<sub>2</sub> should be rejected and CO<sub>2</sub> slip increased. It is less easy to speculate on the effect of spray regime operation on gas-side mass transfer resistance. In surface tension negative systems (where surface tension decreases as liquid flows down the column), higher distillation efficiencies are observed in the spray regime (distillation is generally controlled by vapour-phase resistance) because smaller drops are produced. However, gas treating is a surface tension neutral system. Nevertheless, highly turbulent gas flow past drops is markedly different from gas bubbles and jets

sparging into and rising through liquid. Unconfined gas flow past large drops probably is much more turbulent than gas in froth, especially near the interface, so higher gas-side mass transfer coefficients might be anticipated. (At atmospheric pressure, a 1 mm drop has a terminal velocity of about 7 m/s and falls at a Reynolds number of about 500; in other words, in the fully turbulent region.)

The point is that the spray and froth regimes present completely different types of fluid flow and, because hydraulics is one of the major determining factors for mass transfer, the mass transfer performance in these two regimes ought to be different, with the difference even being magnified in selective gas treating. Does this really lead to differences in CO<sub>2</sub> slip and, therefore, H<sub>2</sub>S absorption? The two sets of plant performance data presented next suggest that indeed it does.

It should be noted that operating in the spray regime can result in reduced tray vapour handling capacity unless the tray is carefully designed. There are ways to regain froth regime operation if this is desired. One is to reduce the number of tray passes. One of the main reasons for using multiple tray passes in the first place is to reduce excessive weir loads but, if the weir loads are already too small, using multiple passes is counter-productive and fewer passes should be used. The other approach is to use so-called weir blocks, or picketed weirs, which effectively shortens the weir length by placing a series of vertical barriers on the weirs to force part of the liquid spray back onto the tray and make the effective weir length shorter.

#### Simulation and field data

Before using the ProTreat simulator's mass transfer rate-based column model to explain why certain treating plants with absorbers operating in the spray regime have been observed to perform much better than they should, it is important to be convinced that simulation is capable of truly predicting plant performance at all.

## Predicting plant performance

A mass transfer rate-based column model uses the fundamental mass transfer characteristics of the specific tower internals (trays, random packing and structured packing) together with phase equilibrium and reaction kinetics to calculate the actual mass transfer rates occurring between the liquid and vapour phases flowing on real trays and through packed beds. The approach is completely analogous to the way heat transfer calculations have been done and heat exchangers have been designed for nearly a century. The real difference is the transferring entities: heat in one case and chemical species in the other, so temperature differences are used in one case and concentration differences in the other. Where heat exchangers' heat transfer properties are correlated, for example, in terms of shell- and tube-side heat transfer coefficients as functions of exchanger hydraulics and the transport properties of the heated and cooled streams, the mass transfer properties of trays and packing are correlated as liquid-side and vapour-side mass transfer coefficients, again as functions of hydraulics and the transport properties of the two phases. The analogy is a very strong one. Phase equilibrium and the number of species make mass transfer calculations a lot more challenging than heat transfer, but this is only a

computational technicality. If the underlying correlations themselves are reliable, the heat transfer rate and mass transfer rate models predict equipment performance with equal trustworthiness and fidelity. Engineers do not use efficiency-corrected equilibrium heat exchanger models, and there is no longer need to use their mass transfer equivalent in tower design.

The mass transfer rate-based approach to column simulation as implemented for example in Aspen Plus and Pro/II under the name Ratefrac (a general-purpose module) by some solvent vendors and refiners, and within ProTreat (specifically for gas treating), has been used to simulate hundreds of columns around the world. The approach has been in continuous commercial use for some 20 years, so it is evidently a sound one. The advantage of mass transfer rate-based simulation is that it is truly and reliably predictive, without leaning on any knowledge of plant performance to tweak the model to get the right results.

## Case studies

Both case studies involve plants that are treating raw gas having parts per million  $H_2S$ , in the first case 60 ppmv and in the second 240 ppmv. Both plants produce treated gas having about 1 ppmv  $H_2S$  and, because neither is treating gas containing a lot of  $CO_2$ , only

low solvent rates are necessary to process the gas. In other words, the contactors in these plants are operating with unusually low L/G ratios.

## Case study 1

Ineos Gas/Spec SS-3 solvent at 45 wt% strength is used to treat gas containing 60 ppmv  $H_2S$  and 0.94 mol%  $CO_2$  at about 460 psig. Figure 4 shows the flowsheet.

Straightforward simulation of this process predicts that the treated gas should contain 27 ppmv  $H_2S$  and the  $CO_2$  level should have been reduced to 0.636 mol%, with the rich amine loaded to 0.634 moles of  $CO_2$  per mole of SS-3 solvent. However, a series of carefully planned and executed plant trials showed unequivocally that the raw gas, varying between 50 and 70 ppmv  $H_2S$ , was actually treated to between 1.0 and 1.2 ppmv  $H_2S$  and the treated gas was consistently at 0.865 mol%  $CO_2$  (93%  $CO_2$  slip!) with a rich solution  $CO_2$  loading of only around 0.13 mol/mol. The simulation results were not even close to reality.

These are one-pass valve-type trays and, because of the low L/G ratio, they have only 5% downcomers; that is, 90% active area. The trays run at about 50% of jet flood, with the downcomers at only 11% of choke flood. Jet flood and choke flood are not issues. The striking hydraulic parameter, however, is

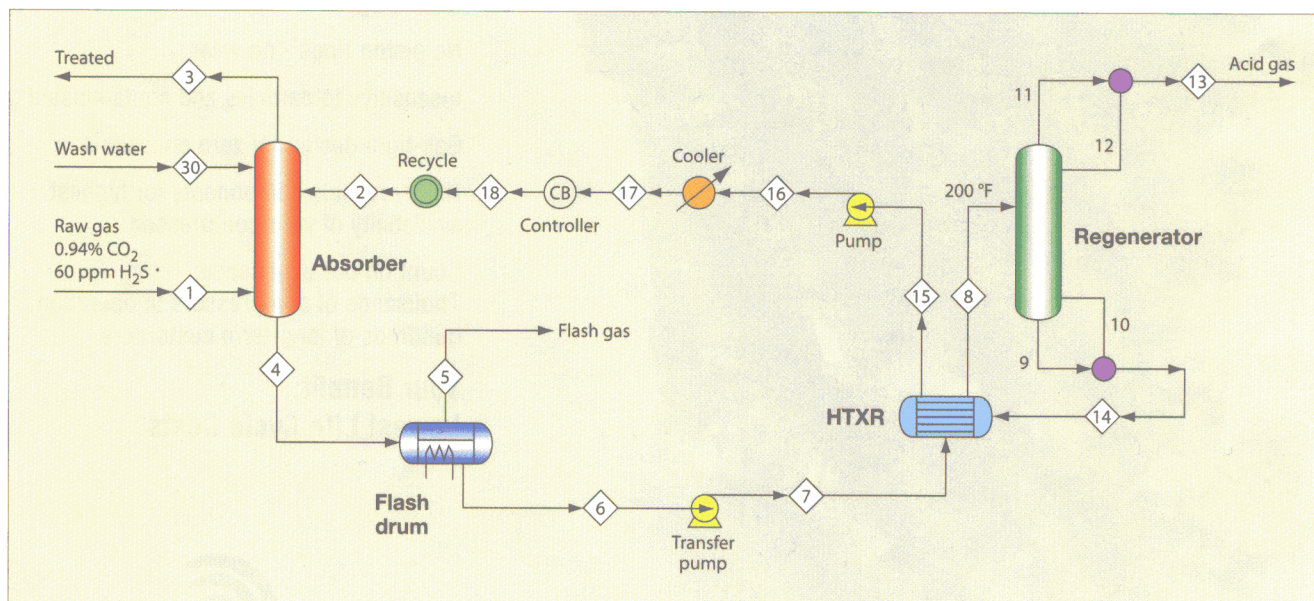


Figure 4 PFD for case study 1

the weir load at only 8 m<sup>3</sup>/m·hr (11 gpm/ft). At a superficial gas velocity of 0.39 m/s (1.27 ft/s), this puts the trays well into the spray regime of operation; on the other hand, the simulation is based on mass transfer characteristics that pertain to the froth regime. Much work has been reported on the froth-to-spray transition. However, no work appears ever to have been done, and none has been reported, which measures such fundamental mass transfer parameters as film coefficients and interfacial areas for mass transfer in the spray regime, possibly because the general recommendation is not to operate there. Therefore, all mass transfer rate-based simulators do their calculations using mass transfer characteristics that pertain to froths, and this takes care of the majority of operating distillation and absorption columns.

The measured plant data are accurately reproduced by the simulation if the liquid- and gas-side coefficients are decreased and increased, respectively, by a factor of roughly 10. The simulated results in this particular case were not very sensitive to reasonable changes in interfacial area. It is interesting to note that decreasing the liquid-side coefficient alone produced the observed CO<sub>2</sub> slip and also resulted in a significant (albeit insufficient) improvement in H<sub>2</sub>S pickup because less solvent was used up by over-absorption of CO<sub>2</sub>. A further significant increase in the gas-side mass transfer coefficient was needed to reach the observed H<sub>2</sub>S treat.

### Case study 2

For this case, only data for the contactor were available. A lower pressure gas (11.7 bar, or 155 psig) was being treated than in Case 1, using a solvent mixture comprising 19.15 wt% MDEA and 10.85 wt% DEA (30 wt% total amine) flowing at only 1 m<sup>3</sup>/hr (5 gpm) to the contactor. The raw gas contained 2.1 mol% CO<sub>2</sub> and 240 ppmv H<sub>2</sub>S. Lean amine CO<sub>2</sub> and H<sub>2</sub>S mole loadings were 0.0136 and 0.0005, respectively. The H<sub>2</sub>S leak from the absorber was measured to be 1 ppmv and the treated gas

contained about 1 mol% CO<sub>2</sub>. However, simulation based on froth regime, mass transfer coefficients predicted 23 ppmv H<sub>2</sub>S and 0.72 mol% CO<sub>2</sub>. Again, too much CO<sub>2</sub> pickup is predicted and, partly as a consequence, simulated H<sub>2</sub>S removal is too low by a substantial margin. The hydraulic calculations gave a weir liquid load equal to the amazingly low value of 2 m<sup>3</sup>/m·hr (2.8 gpm/ft), making the spray regime an absolute certainty. But, just as in Case 1, if the liquid- and gas-side coefficients are decreased and increased, respectively, by roughly the same factor (10), the plant data are perfectly matched by the simulation. It should be mentioned that the trays in this example were turned down to only 11% of jet flood so serious weeping was possibly another issue. Nevertheless, regardless of whether there was weeping or not, the liquid was definitely in the form of a spray and spray regime mass transfer corrections should apply. The results indicate that indeed they do.

These are not small changes in individual phase mass transfer coefficients. However, it should be realised that the flows of the phases change from turbulent to stagnant in the case of the liquid, and from relatively quiet for gas bubbles to very turbulent near drop surfaces in the case of the gas. The size of the corrections emphasises the radical difference in the flows.

### Discussion

For the most part, gas treating engineers seem unaware of the important distinction between spray and froth regimes of tray operation, and the effect of weir load in determining where a given set of trays actually operates. More importantly, the impact of froth versus spray flow regime on selective performance appears never before to have been addressed quantitatively. However, the idea that a laminar or stagnant liquid might promote CO<sub>2</sub> rejection is certainly not new. Sigmund and Butwell (1981), for example, developed a special tray intended to produce a laminar liquid flow with the specific objective of increasing

CO<sub>2</sub> slip and, therefore, improving H<sub>2</sub>S removal rates. Their idea was to produce laminar liquid jets on trays, with the liquid flowing into truncated downcomers with perforated bottoms. Although a version of their tray design was installed in a New Mexico gas plant owned by El Paso Natural Gas, this patented tray has never been truly commercialised.

The normal weir loading range for conventional trays is from roughly 30–40 m<sup>3</sup>/m·hr (40 or 50 gpm/ft) to about 120 m<sup>3</sup>/m·hr (150 gpm/ft). Modern high-performance trays such as Sulzer's VGPlus tray and Koch-Glitsch's Superfrac tray have superior capacity across the board, but the absolute upper limit on weir load is independent of the type of tray. In gas treating applications, L/G ratios are generally high because most gases contain high concentrations of acidic components and the solvents have limited capacity, so high solvent rates are required relative to the gas flows being treated. Furthermore, except in tail gas treating and more recently CO<sub>2</sub> capture from power plant flue gases, treating pressures are usually in the 100s of psi range. These factors make spray regime operation somewhat exceptional (although not rare) in gas treating, perhaps explaining the general lack of appreciation for the very existence of this regime.

The two cases discussed here presented quite a puzzle when they first came to light. It just seemed physically impossible to produce 1 ppmv H<sub>2</sub>S gases under the stated conditions and slip as much CO<sub>2</sub> as was claimed. No amount of supposition about such things as possible effects of solvent contamination and tray damage made any sense. Perhaps a gamma scan might have led to an earlier resolution; however, in both cases, the contactors were treating the gases perfectly satisfactorily so there was certainly no commercial incentive to spend money diagnosing a non-problem. The inquiry was driven by the failure of the simulations to come even close to measured performance. It was intriguing that simulation of these two plants, operated by different companies

and using quite different solvents, showed similar deviations from measured performance.

When more detailed tray hydraulic calculations were done, it became blatantly evident that, in both cases, the contactors were operating well into the spray regime. (The trays used in these studies were not designed specifically for extremely low weir loads and spray regime operation. However, they used inlet sumps, so vapour bypassing up the downcomers was likely not an issue.) Therefore, the basic mass transfer coefficients used in the simulations were almost certainly at fault. Confirmation of this thinking was that the simulations required similar adjustments of basic mass transfer coefficients to bring the results into conformity with measurements. One of the outcomes is that much more detailed tray hydraulic calculations are now done as a routine part of ProTreat simulations.

Very low L/G ratios are not the norm in gas treating. However, in instances where they exist, much increased CO<sub>2</sub> rejection and far better H<sub>2</sub>S removal seem to result. So, should spray regime operation be encouraged (for example, by using multi-pass trays with long weir lengths when a one-pass tray is sufficient) as a means to promote better selectivity in gas treating? Conventional wisdom is to stay away from this region,\* supposedly because entrainment rates are higher, so superficial gas velocity would have to be reduced (tower capacity sacrificed), necessitating a more expensive, larger-diameter tower. However, this is far from the truth, as a properly designed tray (no vapour bypassing up downcomers) actually has higher vapour-handling capacity in the spray regime than in the froth regime. There certainly are circumstances, such as the ones in the case studies reported here, where a significant advantage can be had by purposefully operating in the spray regime. Indeed, two of the world's highest capacity (and most expensive) trays, Shell's ConSep and the Koch-Glitsch Ultrafrac, both operate primarily in the spray regime over

their entire operating range. Nevertheless, using conventional trays, some selective contactors have been enjoying the great selectivity benefits of the spray operating regime for years. What is new is knowing the reason for their success. Understanding certainly does not increase risk, it decreases it, so where possible there is a real incentive to operate in the spray regime because it may tremendously improve selectivity. What is needed to determine quantitatively the magnitude of this effect is a truly predictive mass transfer rate model, as featured within the ProTreat simulator.

Although trays are often not the best choice of tower internals for very low L/G operations, in the present case simulation and experience indicate that when it comes to selectivity neither random nor structured packing can come even close to well-designed trays operating in the spray regime.

\*The authors thank Henry Z Kister for pointing out just how ill-founded this conventional wisdom really is. In fact, trays can have even higher capacity in the spray than in the froth regime if they are properly designed. Obviously, downcomers must be designed to remain sealed without reliance on the outlet weir; an obvious way to do this is to use a sufficiently deep inlet sump.

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