# The CONTACTOR™

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## Tray Operating Regimes and Contactor Performance

Trays operate hydraulically in one of two basic modes. The most common one is the froth regime where the gas is dispersed in a more or less continuous but violently agitated liquid phase. The other operating region is called the spray regime. Here, there is too little liquid flow to maintain a continuous pool on the tray so the liquid becomes dispersed as droplets within a continuous gas phase. In reality, neither mode usually exists to the exclusion of the other; instead, one or other dominates. And there is certainly no sharp transition between the two. Which one is dominant depends on the liquid and gas loads. The tray's vapor load is characterized by the so-called Souders-Brown C-factor:

$$C_a = u_V \sqrt{\frac{\rho_V}{\rho_L - \rho_V}}$$

For the practicing engineer, $C_a$ is the most useful measure of vapor load—it is based on the superficial vapor velocity through the tray's *active* area. The liquid load on the tray is characterized by the volumetric liquid flow rate per unit length of overflow weir:

$$L_{Load} = Q_L / \ell_{Weir}$$

There are as many measures of tray capacity as there are tray vendors but all are based on the notion that at a given liquid load the jet flood capacity is the value of $C_a$ above which tray operation in some sense becomes either unstable or the efficiency starts to fall off rapidly *because of excessive entrainment* of liquid. Figure 1 shows a typical tray capacity curve, defined as 85% of jet flood by some vendors and maximum useful capacity by others.

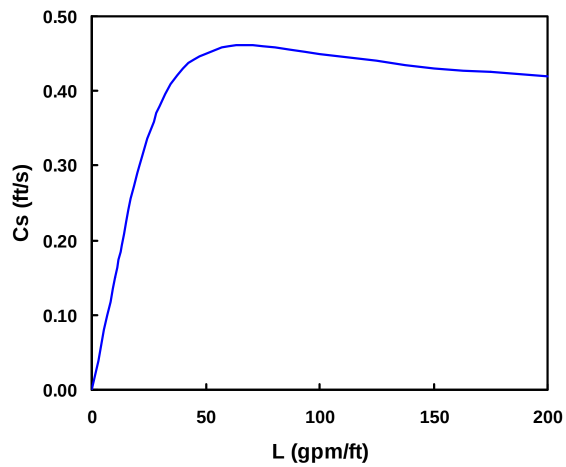


**Figure 1 Typical tray capacity curve**

Downcomer backup flood is another flood mechanism in which too small a clearance under the downcomer (too small a flow area onto the tray below) increases the pressure loss experienced by the liquid and forces it to back up in the downcomer to develop head. *All the liquid can't get out* and eventually the downcomer fills. This is a relatively easy-to-control form of flood which can be alleviated by increasing the downcomer clearance.

Yet a third form of flood is called downcomer choke flood. This is a more insidious type of flood. It can be quite hard to detect and to distinguish from jet flood. Basically, the downcomer mouth just isn't large enough and *all the liquid can't get into it*. A good analogy is chugalugging beer too fast into a gaping mouth—the consequence is, quite literally, choking.

The way to handle jet and choke flood issues is to provide enough active area and tray spacing to handle the vapor load, and enough downcomer mouth area to handle the liquid load. These two forms of flood influence each other, however, although tray designers are only just now learning how. How does this impact gas contactor performance?

The maximum in Figure 1 occurs because different flow regimes dominate on either side of it. At higher liquid loads, the biphase on the tray is a froth of discontinuous vapor dispersed in continuous liquid. But at low liquid loads there's just not a high enough liquid flow to the tray to maintain a continuous pool of liquid. The liquid pool (if it existed) is so shallow the vapor shatters it into a myriad of tiny droplets and the biphase becomes a spray of discrete droplets in a continuous vapor. For a tray operating near jet flood capacity, a weir load of 30 – 45 gpm/ft (2 – 3 gpm/in) is a good rule-of-thumb to use in deciding whether spray regime operation might be of concern. Certainly a tray operating at 10 – 15 gpm/ft is fully in the spray regime, and its performance will be quite different.

Designers tend to avoid the spray regime because it has often led to performance failures, although these failures are generally a result of poor design rather than any inherent deficiency in the spray regime per se. One important factor is that the liquid phase is no longer agitated. In a clean system droplet contents are at best mixed via internal circulation, but in a dirty system (and most commercial towers are not pristine) the drops are rigid and there's no mixing at all. Liquid-phase mass transfer coefficients will be very low. The gas phase is also much more turbulent, especially in the immediate vicinity of the drop surfaces where the turbulence quite effectively reduces mass transfer resistance. The interfacial area for mass transfer between vapor and liquid may be higher or lower in a spray than a froth (finer dispersion) but interfacial area affects the absorption rate of all species to the same extent so selectivity is not likely to be much affected. But what's the likely impact of a more turbulent vapor and a less turbulent liquid on gas treating, in particular on selectivity when amines such as MDEA are used?

At low weir loads, the small liquid-side mass transfer coefficients in rigid drops in the spray retard $CO_2$ absorption. This is because the $CO_2$ absorption rate is controlled by the liquid-phase resistance to mass transfer. $H_2S$ absorption, on the other hand, is controlled by the vapor-phase resistance, which is reduced when the gas is more turbulent. Thus, $CO_2$ absorption is retarded, $H_2S$ absorption is accelerated, so selectivity can be expected to improve.

Over the last year or two, a number of cases have come to light in which trayed columns in the field have produced impossibly-low $H_2S$ leak rates (very high removal efficiencies) and much greater than normal $CO_2$ rejection or slip. In every case, the liquid rates were low[†] and the weirs were long enough to have weir loads of 10 gpm/ft or less. In one case a 5-ft diameter column had two-pass trays and a weir load of only 2 gpm/ft. $H_2S$ leaks of less than 1 ppmv were routinely achieved by plants when ProTreat™ simulation suggested 20 ppmv as a realistic expectation. However, the mass transfer coefficient information used by ProTreat is based on operation in the froth regime. This is because that's where all data have been collected that form the database of known fundamental tray mass transfer performance characteristics—there are no other basic data. However, ProTreat allows the engineer to "adjust" mass transfer parameters to account for unusual circumstances outside the database. In the present case, field performance data from several absorbers operating in the spray regime could be accurately matched by simulation if the liquid-phase mass transfer coefficients were decreased by a factor of 10, and the vapor-phase coefficients were increased by the same factor. The fact that identical numerical adjustments were required for all plants indicates that spray regime operation was affecting all the plants in exactly the same way.

The increased $CO_2$ slip and improved $H_2S$ absorption are direct consequences of a more stagnant liquid phase and a more turbulent gas. The thinking embodied in this is also reflected in a patent for a tray with improved selectivity characteristics (US 4,278,621 awarded to Paul Sigmund and Kenneth Butwell and assigned to Union Carbide Corp., July 14, 1981). The basic idea of the patent was to force the liquid into laminar flow while keeping the gas turbulent, although it was never implemented.

Evidently, although the spray regime offers design challenges that many tray designers seem to overlook (and which result in failures), it can be used quite effectively to achieve ultra low $H_2S$ leaks and greatly improved $CO_2$ rejection rates. Columns cannot always be forced to operate in the spray regime, however, because it's not always possible to provide sufficient total weir length for a given liquid flow, but if weirs can be made long enough, greatly improved separation performance can likely be achieved.

Tray (and packing) hydraulics and the close connection between hydraulics and mass transfer deserve more attention from practicing engineers. Spray regime operation is not usual—but maybe it deserves consideration as a means to improved selectivity. Don't discount the spray regime.

[†] Either because the columns were turned down or acid gas content of the raw gas was low and only a small solvent flow was needed for treating.

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