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BRIEF COMMUNICATION

SPRAY-BUBBLING TRANSITION ON SIEVE TRAYS

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INTRODUCTION

In the first systematic study of the spray-bubbling transition on sieve trays, Porter & Wong (1969) supposed that the gas velocity above a tray slows down from the hole velocity u_h to the superficial velocity in the empty column u_s. Between these two extreme velocities a plane of large drop terminal velocity is located where large drops form a barrier which tends to concentrate the spray below this plane. Transition from spray to bubbling is assumed to take place when enough liquid has been added to increase the drop concentration so that a continuous liquid surface is formed.

On the grounds of dynamic similarity experimental results in the range $0 < [(u_h - u_t)/(u_h - u_s)] < 0.8$ were found to be correlated by

$$\frac{h_f}{d_h} = 9.0[(u_h - u_t)/(u_h - u_s)] + 4.0 \qquad [1]$$

where h_f is the height of the gas–liquid mixture above the tray at transition, d_h the hole diameter and u_t the large drop terminal velocity. Because of the difficulties in measuring h_f and in the determination of the exact point of transition, there is always a certain degree of uncertainty inherent in spray-bubbling transition data.

It was however found that [1] did not correlate well results obtained from trays with free area A_f other than about 5% and Wong & Kwan (1979) subsequently modified the correlation to [2] which was also valid for trays of free area other than about 5%.

$$\frac{h_f}{d_h} = 3.09(u_h/u_t) + 2.06. \qquad [2]$$

More recently, Lockett (1981) put forward a "modified jet penetration model". A somewhat arbitrary velocity distribution equation was given.

$$u = u_h[1 + (ax/d_h)]^{-(2/n)} \qquad [3]$$

where u is the axial jet velocity at a distance x above the tray, a and n are unknown constants.

Combining [3] with the momentum balance equation written for the situation when the expanding gas jet is bridged by the liquid which was suggested as being the point at which the spray-bubbling transition occurs, a rather cumbersome form of equation was derived which bears some resemblance to the correlations of Barber & Wijn, Hofhius & Zuiderweg, and Payne & Prince (all quoted by Lockett 1981) when the unknown parameters a and n are assigned certain arbitrary values and with the assigned values varying with the particular correlation that is being considered. Despite the detailed analysis, Lockett did not apply the derived equations to available experimental results, but proceeded instead to correlate data from various sources by an empirical equation given by

$$\frac{h_{CL}}{d_h} = 2.78(\rho_G/\rho_L)^{0.5}u_h. \qquad [4]$$

This equation is not dimensionless, the units of u_h being in ms^{-1} since the constant 2.78 has the dimensions of sm^{-1}. h_{CL} is the clear liquid height above the tray at transition, ρ the density and the subscripts G and L refer to gas and liquid respectively.

ANALYSIS AND DISCUSSIONS

Taitel, Barnea & Dukler (1980) proposed a criteria for the annular-slug transition in vertically upward two-phase gas–liquid flow. They reasoned that if the gas velocity was sufficient to lift the liquid drops present in the flow, annular flow will persist. Otherwise, the liquid drops will descend and accumulate to bridge the flow tube resulting in slug flow. The concept is in many ways similar to the model of Porter & Wong (1969) except that Porter & Wong proceeded with their analysis by proposing correlation parameters as given in [1] for data presentation. Thus, if the spray-bubbling transition on sieve trays may be considered as being analogous to the annular-slug transition in vertically upward gas–liquid flow, it is possible to apply the criteria of Taitel, Barnea & Dukler to the spray-bubbling transition above sieve trays provided that the variation of gas velocity above the sieve tray is allowed for. If [3] as proposed by Lockett was used to describe the axial velocity profile, then equating u to u_t, an equation for spray-bubbling transition will result with the vertical height x corresponding to h_f, giving

$$\frac{h_f}{d_h} = \frac{1}{a}(u_h/u_t)^{n/2} - \frac{1}{a}. \qquad [5]$$

It is found that [5] is similar to [2] if n is assigned a numerical value of 2.0. However, the value of a appears to be inconsistent in having to assume two different numerical values simultaneously.

The equation for describing the centre-line axial velocity distribuiton of a circular jet is given by Abramovich (1963) as

$$\frac{u}{u_h} = \frac{K}{(x-\delta)/d_h} \qquad [6]$$

where K is some parameter and δ the distance between the virtual origin of the jet and the orifice, and often δ is omitted due to experimental uncertainties (Rajaratnam 1967). There is also a variation of gas velocity in the radial direction but this will not affect the present analysis. If it is assumed that in the range of sieve tray operations, the form of [6] may also be used for describing the axial velocity of the drop-laden gas above a tray, which may be regarded as a multiple jet systems with entrained droplets, then, equating u_t to u of [6], and writing $x = h_f$, it is possible to show that

$$\frac{h_f}{d_h} = K(u_h/u_t) + (\delta/d_h) \qquad [7]$$

and the form of [2] is again obtained. In fact, [7] and [2] are identical if the following numerical values are assigned: $K = 3.09$, $(\delta/d_h) = 2.06$, indicating indirectly that these values when substituted into [6] provides an equation for the axial velocity above a wet sieve tray.

Equation [6] with $K = 3.09$ and $(\delta/d_h) = 2.06$ is plotted in figure 1 on which the velocity profiles obtained by Wong & Kwan (1979) above dry sieve trays are also included. Also plotted on the same diagram are the centre-line axial velocity profiles for a single circular jet, and the profiles for 5 jets and 9 jets as obtained by Raghunathan & Reid (1981). It is obvious that the velocity decay for multiple jets is much faster than for single jets, and that the axial velocity profiles above dry sieve trays obtained by Wong & Kwan also showed a faster decay rate. These velocity profiles may be shown to follow the general form of [6]. Furthermore, the

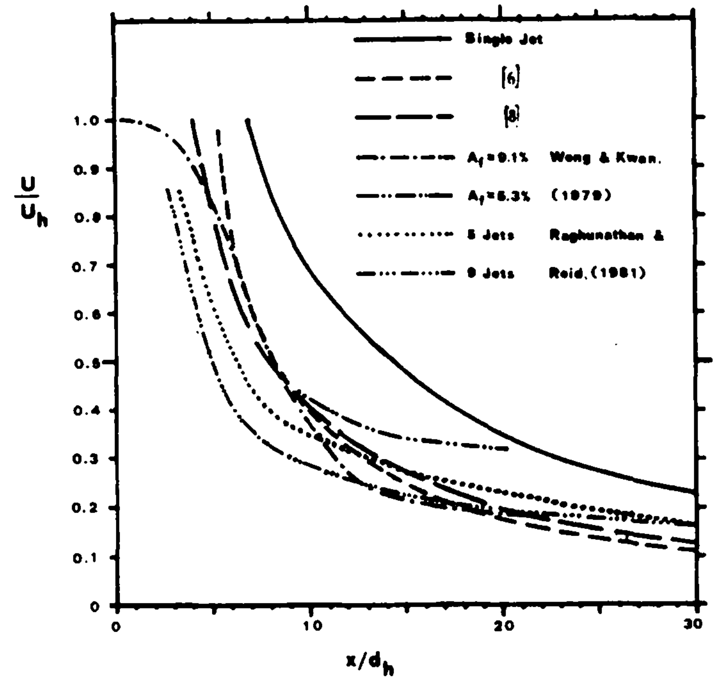

Figure 1. Comparison of the axial velocity decay of a single jet, multiple jets (Raghunathan & Reid) and above a dry sieve tray (Wong & Kwan) with [6] and [8].

velocity profile above an operating wet sieve tray obtained indirectly by comparing [2] and [7] appeared to be of no significant difference from the measured velocity profile above a dry sieve tray by Wong & Kwan (1979), at least in the range of $5 < (h_f/d) < 20$, the range within which sieve trays normally operate. This is, of course, not to say that the presence of liquid has no effect on the velocity profile, it merely points to the fact that the closeness in the velocity profiles between the wet and the dry trays is within the uncertainties inherent in the determination of h_f and the exact point of spray-bubbling transition. In view of the foregoing, Lockett's velocity distribution equation given in [3] appears to be inferior in that it was arbitrarily derived and contained factors which had to assume inconsistent values.

Further work on determining the velocity decay above a sieve tray is in progress (Kwan 1981). Results to hand indicate that changing A_f affects the rate of decay of the axial velocity profile. However, within the range of A_f commonly encountered with sieve trays, this variation in decay rate is well within the uncertainties associated with the determination of h_f.

The model of Lockett for spray-bubbling transition appears to be inappropriate. When liquid bridging occurs, a layer of liquid is formed above the gas and Taylor's instability sets in and eventually the bridge disintegrates to form drops. The consideration of liquid drops for the spray-bubbling transition as carried out in this work is therefore more realistic. Furthermore, Lockett's analysis does not yield a suitable spray-bubbling transition equation since he resorted to an empirical equation for data presentation while this work provided an equation, [7], which is in exact agreement with [2], an empirical correlation proposed originally by Wong & Kwan (1979).

It is of interest to point out that [6] with $K = 3.09$, $(\delta/d_h) = 2.06$ may be closely approximated in the range of interest by [8] which has a zero δ term and is also plotted in figure 1, for comparison.

$$u/u_h = 4.0/(x/d_h) \qquad [8]$$

Thus substituting $K = 4.0$ and $\delta = 0$ into [7], and writing $u_t = 0.317(\rho_L/\rho_G)^{0.5}\,\mathrm{ms}^{-1}$ (Porter & Wong 1969), with $h_{CL} = h_f(1-\epsilon)$ where ϵ is the voidage and the value of $(1-\epsilon)$ ranging between 0.1–0.3 (Payne & Prince 1977), the resultant equations, in fact, form the upper and lower bounds of the scatter in the data used by Lockett (1981) to obtain [4]. [See figure 6 of Lockett (1981)].

CONCLUSIONS

It is shown that the form of equation for describing the axial velocity decay of single circular jets may also be used for the velocities above dry and wet sieve trays. Combining this equation with the criteria of Barnea & Dukler for annular-slug transition, an equation was derived for the spray-bubbling transition on sieve trays, thus providing some rationale for the correlations of Wong & Kwan (1979) and Lockett (1981).

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