Spouted Beds

1. Physical Evidence

British Coal were interested in identifying the principal mechanism controlling the operation of a spouted fluidised bed. Quantities of special interest are the "bubble" size, shedding frequency and mixing characteristics (as indicated in the upper half of Fig.1). Preliminary evidence suggested that bubble initiation took place through "necking" near the top of a spout as in Fig.2a and a model for such behaviour is given in the appendix. However, repeated examination of CRE videos gave the firm impression that the initiation resulted from the spout being periodically "nipped off" at the orifice as in Fig.2b. Note that Figs. 2a and 2b could easily be confused with each other but that if Fig.2a was correct a mechanism would have to be invoked which permitted the particulate phase to collapse inwards at a point well above the orifice, even in the presence of gravity. In any event the scenario in Fig.2b is supported by refs [1,2] and probably by most of the CRE videos except for fine particles. One situation in which it could clearly be wrong would be that for a very shallow bed where a steady spout could clearly exist as in Fig.2c. In summary, it was decided that the bubbling mechanism was controlled by periodic inward collapse of the particulate phase in the vicinity of the orifice and the modelling of

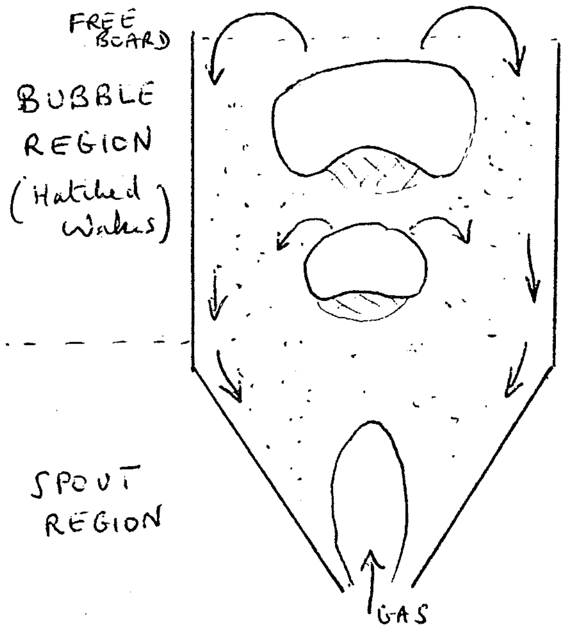


Fig 1

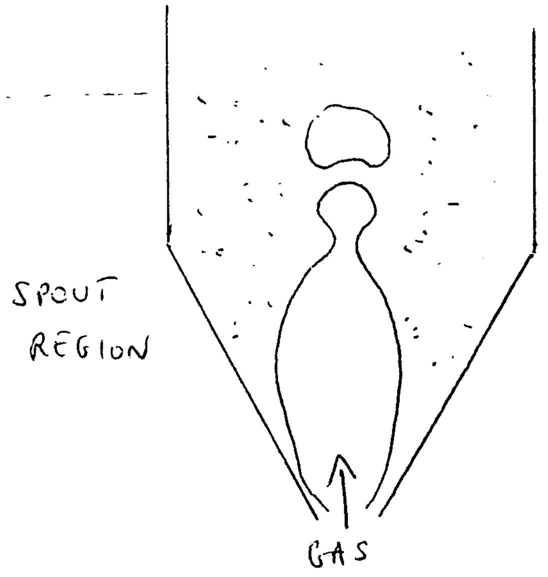


Fig.2a

the particulate phase thus became the primary objective. If this is a correct interpretation, it suggests that the hopper design and the particulate characteristics should be very important in determining the overall bubbling behaviour.

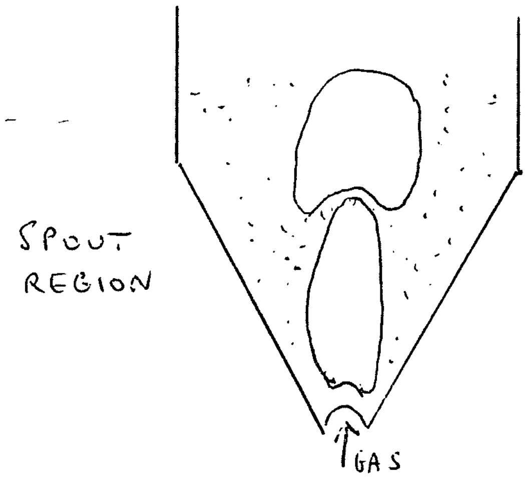


Fig.2b

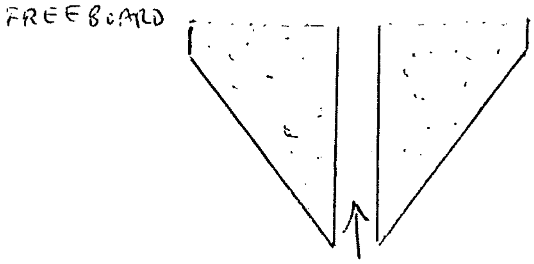


Fig.2c

2. Preliminary Modelling

Given the above scenario it was next noted that if the particulate phase was modelled as a granular material (i.e. a perfectly plastic material whose yield criterion was that limiting friction was attained on two slip planes through any point), it would be of interest to enquire as to the circumstances under which the region OAD in Fig.3 would yield under the action of gravity and pressures p_0 on OD and p on OA. The idea is that OAD represents the static particulate phase in Fig.2b. The region above OA is fluidised particulate, flowing down slowly in response to

(i) the particulate circulation set up by the bubbles bursting at the freeboard

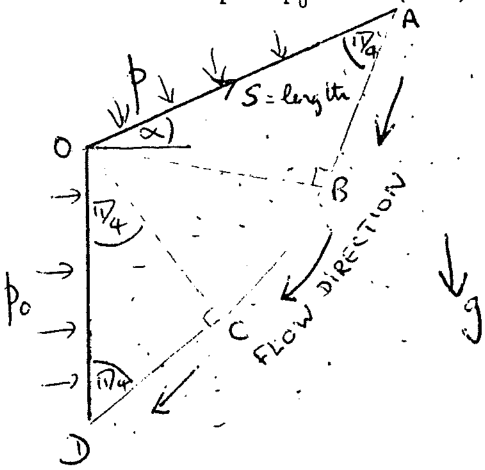
(ii) the fluidisation set up by gas penetrating from (probably) the top of the bubble. Hence p would be a combination of gas and solid pressure exerted on OA.

The pressure p_0 will model the effect of the spout on the static particulate region: we take it to be spatially constant to a first approximation because, in most gas fluidised beds, the imposition of a typical pressure gradient, as experienced by the gas in the particulate phase, on gas in the spout would result in unrealistically large gas velocities in the spout.

The outcome of the idealisation in Fig.3 is that as long as

$$p > p_0 - 2k(1+\alpha) - \rho gs(1+\sin\alpha) \qquad (1)$$

then yielding will not occur but that when equality is attained in this equation then slip will occur everywhere in OAD along the (characteristic) directions shown. Also, the velocity of OD can be predicted in terms of the velocity of OA. However the precise details are unimportant, merely the result that when p_0 is sufficiently small in comparison to p, plastic flow will occur.



k=yield stress

ρ=sand density

Fig.3

We thus have the beginnings of a theory of bubble initiation but it remains to relate p_0 to the dimensions of the spout if we are to predict the length of the spout at the time it is nipped off at the orifice. To do this some simple modelling was carried out on the idealised configuration in Fig.4 where the effect of the bed walls and the ascending bubble train were neglected and the particulate phase assumed to extend to infinity. Also the gas supply was modelled by a point mass source of strength M at the centre of the ellipse (recall that the CRE spouted bed is driven by a displacement pump). A simple conformal map thus shows that, for a slender ellipse

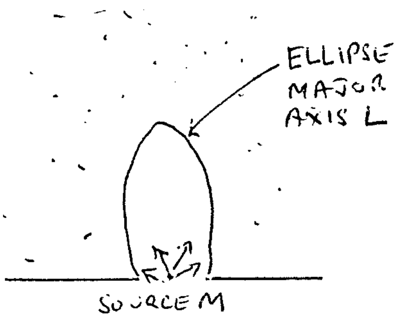


Fig.4

$$p_0 \propto \frac{M}{L} \qquad (2a)$$

and for a circular spout

$$p_0 \sim - M \log L \qquad (2b)$$

Thus, in principle, (1,2) could yield the critical spout length.

3. Discussion

The above ideas are tentative but if they gain acceptance there is a great deal of refinement which could be done to make the model more realistic Areas where more thought would be needed would be

(i) the calculation leading to (2) which would be seriously affected b the presence of the ascending bubble train causing a gas flow short-circuit vertically above the orifice.

(ii) the assumption that the static particulate phase extends the whol length of the spout or first cavity. It would be very helpful to have furthe experimental evidence concerning this.

The most serious shortcoming is the absence of any prediction of the bubble shedding rates. If our scenario is correct these would also be governed by the bulk particulate motion in response to the pushing action of the gas in the spout but this may be a very different process to model. The possibility which was suggested was that the top of the spout acted as a permeable piston being pushed by the spout gas (Fig.4) and if this was realistic it would permit calculations both of the (p_0,L) relationship and the time scale for p_0 via the equation of motion of the "piston".

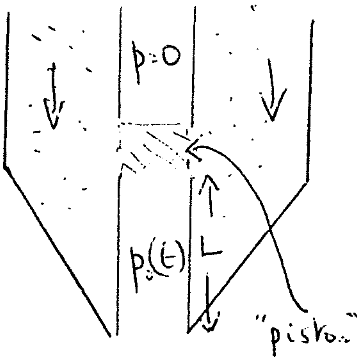


Fig.4

References

1. Davidson, J.F., *Fluid Combust.; Conf. [Proc.]*, 3 (1981).

2. Kececioglu, I., Wang, W.C. & Keairns, D.L., *74th AIChE Annual Meet. AIChE J.*, 30 (1981) pp99-110.

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