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A DOWNHOLE GAS SEPARATOR FOR GEOTHERMAL FLUIDS

PART III: EXPERIMENTAL SEPARATION EFFICIENCY TESTS AND RESULTS

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ABSTRACT

A half linear scale surface model of a downhole separator was tested, using geothermal water, to investigate effects which might prevent attainment of equilibrium in the flashing fluid.

The device has moderate turndown but shows sharply reduced efficiency at very high vapour volume fractions. A reasonable estimate of the performance of a full sized separator is near *80%* phase separation efficiency. The flashing process is rather slow, and results in a steam separation that is lower than might be expected from pressure drop calculations. CO_2 is distributed between the two phases at near the published equilibrium values.

INTRODUCTION

As a geothermal fluid flashes, gases transfer from the liquid solvent into the newly formed vapour phase. Most of the non condensible gas is released into the vapour phase near the region of "first flash", for CO_2 in particular 502 of the CO_2 *is* removed from in the first *0.5%* of mass flashed, while removal of *75%* of the gas requires a flash fraction of 1.42.

For a process such as this, the final outcome depends on the two different types of equilibrium, the physical equilibrium between two phases, and the (subsequent) chemical equilibrium of a solute distributed between these two phases. Either (or both) of these processes might be so slow as to prevent complete equilibrium being achieved during the residence time of a flashing fluid in a device used to separate them.

EXPERIMENTAL

The downhole separator is as described previously, (Braithwaite and Brown, 1981). The vortex generators are as described in part II of this series (Kanyua and Grant-Taylor, 1984).

A dimensioned cross section of the internal structure of the model downhole separator is given in figure 1.

The pipework for the model separator was established at Br22. Steam and water from the primary wellhead separator are regulated and mixed before being passed to the test separator. This small vertical unit is instrumented to monitor flow rates and pressure drops, with sampling and pressure tappings on each line. A general arrangement is given in figure 2. Inlet streams are metered by orifice plate, while the liquid flow from the secondary separator is measured by "bucket and stopwatch" technique. All remaining flow rates are calculated from a chloride ion balance, using measured concentrations in samples drawn from each line. Using this method also permits estimation of the contribution of flash induced over the inlet tract of the DHS to the total steam separated.

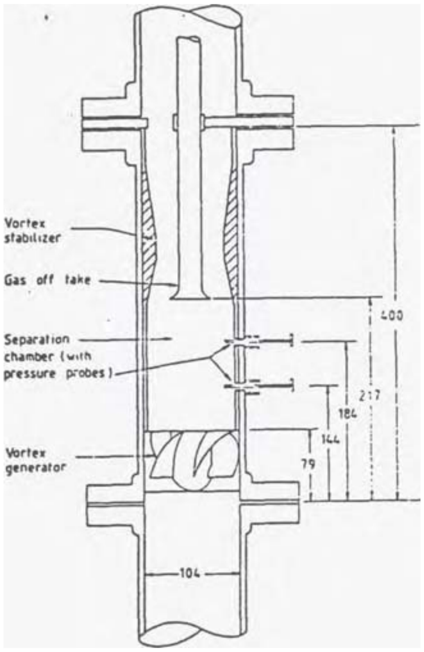

Figure 1 : Internal arrangement of down hole separator

FLOW RATES

Flow rate measurements were made for 72 runs, and mass balances applied. (In four cases balance could not be achieved). Flow rates ranged from 300 to 1000 kg min^{-1} total flow, with vapour mass fractions up to 2%. Extra flash due to pressure drops over the pipework ranged up to 1.5%.

The flash is due to the operation of the inlet valves rather than inherent in the separator. Table I gives 6 values which examine this flash in relation to the residence time over the distance from the single phase flows (at the control valves) to the inlet to the separator. Holdup time in the separator cannot at present be estimated.

Table I

Run	33	37	41	42	43	44
Total flow kg/min	643	800	914	391	391	399
Measured flash %	0.16	0.20	0.20	0.27	0.53	1.50
Calculated flash %	0.37	0.83	0.46	0.46	0.65	1.68
Residence time s	1.0	0.9	0.8	1.8	1.8	1.8

In no case is the flash measured at the discharge of the separator as great as would be expected from the

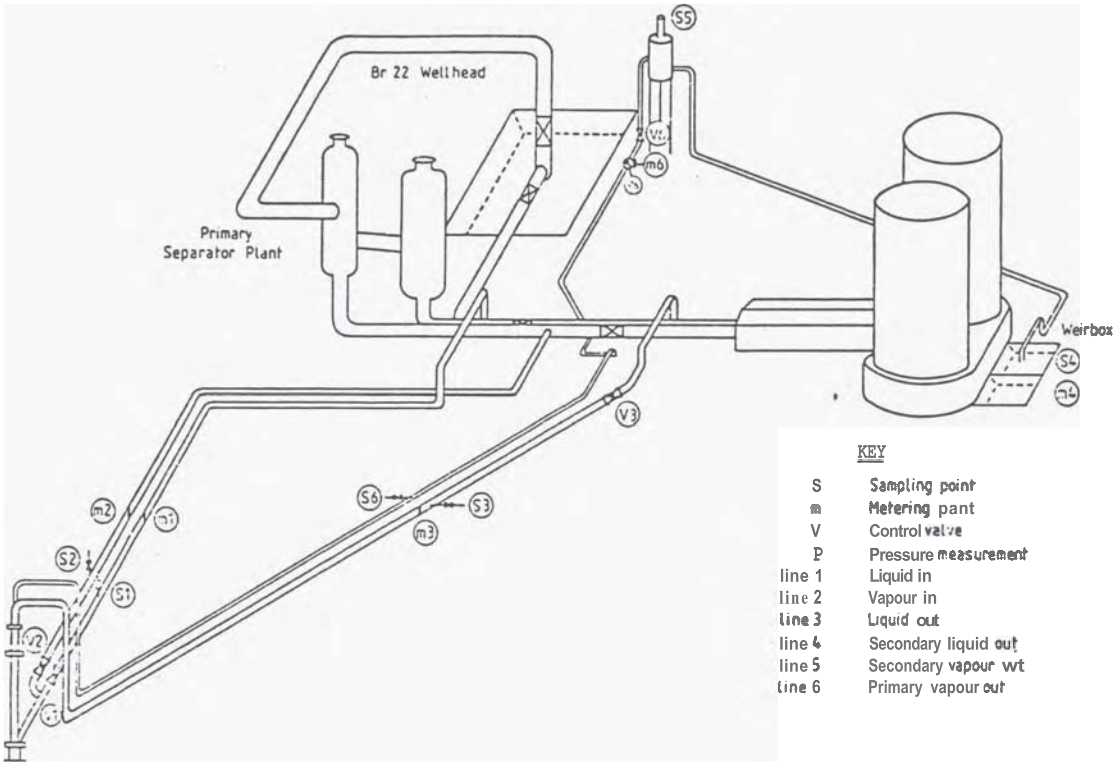

Fig.2. Downhole separator site layout (support structures omitted).

required to fully establish two phase flow conditions is greater than the residence time of around 1 second.

PHASE SEPARATION

Characterization of the physical efficiency of the separator requires definition of two efficiencies. The liquid separation efficiency is given as the efficiency of removal of liquid water to the liquid line; because the philosophy of operation requires a small liquid discharge from the secondary separator, this value is always high, about 0.995 or better. The steam separation efficiency (efficiency of removal of steam to the steam offtake) is variable, ranging from 0 to close to 1001, but in a predictable fashion (see part II). As expected, the separation at low vapour volume fractions is high decreasing with increasing vapour fraction. Figure 3 shows three pairs of curves at different total flow rates, the pairs of curves are for the two different vortex generators.

It is evident that at constant total flow there is a critical value of vapour fraction beyond which efficiency falls off very rapidly. This vapour fraction is around *0.5%* corresponding to a vapour phase volume fraction of 85%. It is probable that this limiting vapour fraction could be increased considerably, since a minor change in the vortex generator and its hub produces such greatly different efficiency curves at the same flow rate.

GAS DISTRIBUTION EQUILIBRIUM

The distribution of a gas between the liquid and vapour phase of a solvent is commonly described by the distribution coefficient A, where

$$n_c^{\ell}/n_{H_2O}^{\ell}$$

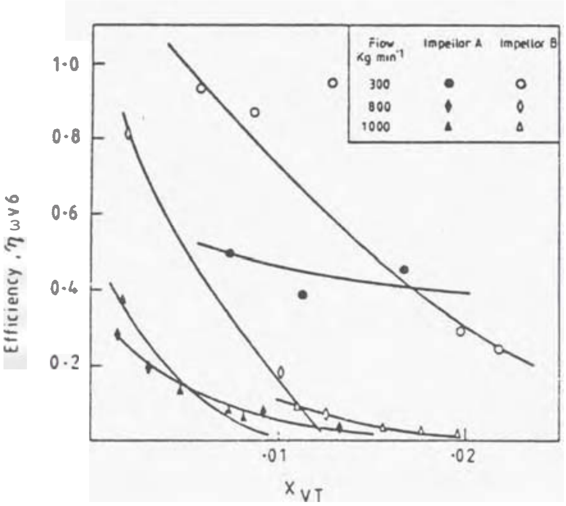

Figure 3 : Efficiency as a function of vapour phase mass fraction

with n being the number of moles, subscript c stands for carbon dioxide, and superscripts ℓ and v stand for liquid and vapour respectively. The coefficient A (measured empirically by Ellis and Golding (1960)) increases with increasing temperature (making a high temperature separation less attractive). The distribution coefficient applies only to the Henry's Law component of the gas CO_2 (aqueous). On dissolving this component hydrates and undergoes further hydrolysis reactions. At the near neutral pH of geothermal waters the overwhelming contribution to dissolved carbonate species is from HCO_3^- so that conversion of this species to carbonic acid, followed by dehydration might be expected to exert some control over the establishment of equilibrium between the carbonate species, and gas in the vapour.

Fortunately the proton transfer step

$$HCO_3^- + H^+ \rightleftarrows H_2CO_3$$

occurs in the millisecond time range (Butler, 19641, it is characteristic of very high rates of proton transfer.

For the dehydration step,

$$H_2CO_3 \rightleftarrows H_2O + CO_2$$

Patel Boe and Atkinson 1973 report a rate constant of 12 s^{-1} at 18°C, (a relaxation time of 80 ms); at 200°C, the relaxation time may be estimated as around 0.1 ms if there is no change in the dehydration mechanism.

Neither of these steps could be expected to significantly control the establishment of chemical equilibrium between the liquid and vapour phases in a separator.

CHEMICAL PERFORMANCE

As the water flashes and CO_2 transfers to the vapour phase the pH changes, rising slightly in response to the reduced dissociation contribution. The pH of the liquid discharged from the separator is calculated back from the discharges from the atmospheric separator using the charge balance method of Glover, 1982.

The liquid flowing in line 6 is calculated to be mildly alkaline, with pH near 7. (At this temperature the neutral point of water is 5.7). The water contained in the discharge buffers the gas discharge against wide pH variations, and the very acid condensate that would form in the event of a completely dry vapour line discharge.

APPROACH TO CHEMICAL EQUILIBRIUM

By manipulation of the dissociation equations, and gas distribution coefficient definitions, we can show that for complete mass balance

$$[C_T] = (1-Y)[CO_2]_v \cdot A \cdot Q + Y[CO_2]_v$$

where symbols have the usual meanings, with

$[C_T]$ = average concentration of total carbon containing species, and

$$Q = 1 + \frac{K_1}{a_{H^+}}\left[\frac{1}{Y_{HCO_3^-}} + \frac{K_2}{a_{H^+}Y_{CO_3^=}}\right]$$

is the proportion of total dissolved carbon containing species present in a liquid as dissolved CO_2.

Since this is true for the total flow in lines 3 and 6, then and for equilibrium separation,

$$\frac{[CO_2]_{v6}}{[CO_2]_{v3}} = 1$$

Table II lists values of pH_6 and of the ratio $\frac{[CO_2]_{v6}}{[CO_2]_{v3}}$ for 9 runs made with the second vortex generator.

Table II

Run	62	64	65	66	67	68	69	70	72
pH_6	6.9	8.8	7.0	7.4	8.5	7.1	7.1	7.0	7.1
$\frac{[CO_2]_{v6}}{[CO_2]_{v3}}$	1.27	0.4	.74	.43	3.2	.88	1.05	.83	1.82

It is clear that the discharge from the separator is not at equilibrium, but shows preferential transfer of CO_2 to one or other of the lines in somewhat random fashion. There is no correlation with flow rate, or with non equilibrium flash formation.

For the 72 runs the mean value of the quotient $\frac{[CO_2]_{v6}}{[CO_2]_{v3}}$ is 1.8; in view of the lack of correlation with any parameter, it is probable that the non equilibrium gas stripping is due to the flow pattern in the separator.

Non equilibrium gas stripping has also been observed in a "pressure-jump" separator developed by BHRA (Silvester, 1982).

CONCLUSIONS

While the experiments have demonstrated that the downhole separator works in very much the fashion predicted, it still requires careful optimisation before it could be emplaced. Lack of understanding of the processes involved in flashing are underlined by the fact that the separator will not strip flash produced near the inlet, where presumably the two phase flow has not fully established. As well as this, there appear to be preferential flow patterns inside the separator, giving variable, but near equilibrium, gas distribution.

As a working model however, the downhole separator could be described as having a phase separation efficiency of better than 80%, with equilibrium gas distribution.

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