Journal of Hazardous Materials, 7 (1983) 341—351
Elsevier Scientific Publishing Company, Amsterdam — Printed in The Netherlands

ACID SEPARATION PERFORMANCE OF BATTERY VENT PLUGS

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(Received May 24, 1982; accepted July 5, 1982)

Summary

To reduce maintenance and corrosion hazards, battery plugs are required to minimise the loss of battery acid whilst venting charge gases safely. The entrainment of acid mist by the charge gases has been studied experimentally. The mean droplet diameter is typically between 5 μm and 10 μm. Previously, it has been difficult to assess the effectiveness with which different plug designs separate droplets from the gases. A simple technique has been developed to quantify this using unsaturated absorbent packing and titration. The results show how different plug elements contribute to an overall efficiency of separation exceeding 99% in a modern plug design.

1. Introduction

Increasing awareness of the safety aspects of manufactured goods has led to improvements in the design of many components including battery vent plugs. In addition to allowing the hydrogen and oxygen emanating from the cells to escape, a well designed vent plug is now expected also to act (a) as a flame arrester to prevent a random spark from propagating to the flammable gases inside the battery which could cause it to explode, and (b) as an acid separator to prevent gas-borne droplets of acid from issuing with the gases and causing corrosion and electrolyte depletion.

A comprehensive study of the performance of battery vent plugs was undertaken by the authors, commissioned by Chloride Technical Ltd. The results pertaining to the explosion minimising performance of vent plugs were the subject of two previous publications [1, 2]. The present paper deals with the acid separation performance of vent plugs.

2. Typical vent plug and mode of operation

As the battery is charged, liberated gases, having a much lower density than the battery fluid, rise in the form of bubbles to the electrolyte surface. The action of gas bubbles breaking through the liquid surface causes the formation of small liquid droplets which are projected into the gas currents above the

0304-3894/83/$03.00

surface within the battery enclosure. The forces acting on the droplets are now gravitation, inertia, a drag force due to the relative velocity between the droplets and the surrounding gas, and forces due to interactions with other particles or surfaces. Depending on the size of droplet, the net result is that it will be entrained, deposited on a surface, or settled back into the main body of acid. Sufficient numbers of small droplets are formed for some to be entrained into the vent plug and if not separated these will escape with the evolved gases.

Figure 1 shows a typical vent plug. The gases enter the plug through two gaps in the base disc into the baffle chamber. They are deflected round the baffle, then pass through the two lower holes, percolate through the Vyon (a sintered polyethylene material) disc and go out of the plug through the top two holes. The porous Vyon disc constitutes the flame-arresting element. It also contributes to the acid-separation function. The gas-borne droplets of acid are separated first by gravitational settling inside the baffle chamber, then by inertia and centrifugal impaction on the baffle and inner walls of the baffle chamber, then by inertial impaction as the gases follow their tortuous path through the porous disc to the exit holes.

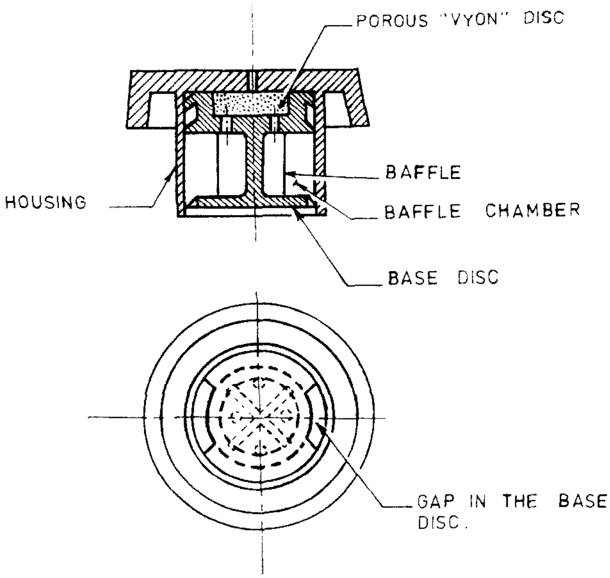


Fig. 1. Assembly of a typical vent plug.

The theory for droplet and mist separation is available in the literature. A certain amount of adaptation is necessary to cover the situations in the vent plug but on the whole the standard methods were found to apply and to give a good prediction [3]. Calculations show, for example, that droplets down to a diameter of 40 μm will settle out by gravitation in the baffle chamber.

Centrifugal action due to the baffle is found to be weak and would not lead to a high separation efficiency. Impaction within the porous Vyon disc was calculated to lead to separation of droplets down to about 5 μm. It can also be shown using existing data that re-entrainment is not likely to be a problem and that draining arrangements for the separated acid are not critical. Before any theory can be applied, however, knowledge of the mean droplet size and of the concentration of droplets in the incoming gases is needed.

3. Measurement of incident drop size and escape drop size

A 2 V cell was specially fitted out for these tests. This is shown in Fig. 2. The method of measurement to be used was the Malvern Instruments 2200 laser diffraction particle sizer and therefore optical access to the cell was needed. Hence two perspex blocks were fitted either side of the cell with optical glass end-covers (Fig. 2) allowing measurements to be made at three heights

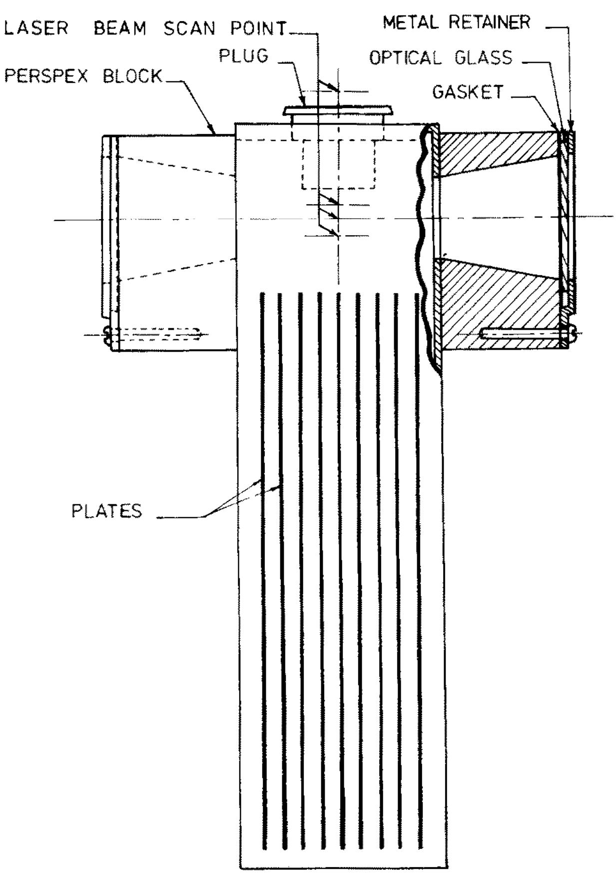


Fig. 2. Modified 2 V cell used for the measurement of the incident and escape acid drop-size.

above the acid level (or below the vent plug inlet opening). A further measuring point was at the plug exit. The positions and corresponding results are shown in Table 1. Measurements were taken at 15, 30 and 40 A charge rates. The glass windows were removed in the later tests due to misting.

TABLE 1

Summary of particle size analysis

Position (mm)		Current (A)	Particle size (μm)			Exponent n	Concentration % by volume	Remarks
Above acid	Below plug		Max.	Min.	Mean $\bar{x}$			
10	12	15	7.9	3.0	5.57	15.6	0.03	Glass windows fitted
		15	7.9	3.0	5.57	16.0	0.03	
		30	7.9	3.0	5.44	16.0	0.03	
		30	7.9	3.0	5.49	14.9	0.03	
		40	7.9	3.0	5.44	15.0	0.03	
		40	7.9	3.8	5.44	16.0	0.03	
14	8	15	21.5	1.9	10.16	3.6	0.04	Glass windows removed
		15	21.5	1.9	9.50	3.45	0.04	
		30	16.7	1.9	9.29	3.5	0.04	
		30	21.5	1.9	10.16	2.9	0.04	
		40	21.5	1.9	9.73	3.14	0.04	
		40	16.7	1.9	8.85	3.6	0.04	
18	4	15	16.7	1.9	8.63	4.39	0.04	
		15	16.7	1.9	8.63	4.46	0.04	
		30	16.7	1.9	9.07	3.79	0.04	
		30	16.7	1.9	8.20	3.69	0.03	
		40	16.7	1.9	8.0	3.10	0.03	
		40	16.7	1.9	8.0	2.90	0.03	
5 mm above vent plug		40			1—2			Estimated

Note: Rosin—Rammler distribution function used is $R = \exp[-(x/\bar{x})^n]$ where R is the volume fraction of drops having diameter $> x$.

The results show that the mean diameter of the air-borne acid droplets lies between 5 μm and 10 μm and that the size distribution is a narrow one. Thus the problem is one of 'mist' as against 'dust' [4]. Size dependence on charge rate above 15 A appears to be weak. Also, comparing the two sets of results taken without windows, there seems to be a small reduction in mean droplet size from the position 14 mm above the acid to the 18 mm position. The change is not significant and it would seem that the overall effect of height above the acid level is very small. However, a fountain of larger droplets rising and falling back again was plainly noticeable to the naked eye. The number of these large drops was too small to weight the time-averaged distribution. The small range of droplet size observed indicates that the mist is well stirred by this fountain action and that there is little gravitational settling of the mist.

The volume concentration of 0.03—0.04% indicated in Table 1 is in line with the direct experimental measurements described below which gave typically a concentration inside the baffle chamber of 0.02%.

4. Experimental method for measuring acid separation efficiencies

A direct experimental method for measuring the overall plug efficiency and the individual plug element efficiencies was developed and is described in the following.

To determine these efficiencies we need to measure the quantity of acid entering and leaving the various parts of the plug under test conditions.

Shortly after battery charging begins, the flow of charge gases starts to deposit entrained acid particles on the plug walls. When enough acid has collected it forms a film and drains back into the battery. The period from acid entrance into the plug to the first sign of drain-back will be designated as the transient period. As charging continues, the process approaches an equilibrium condition when there is no net accumulation of acid in the plug. This stage will be referred to as the steady-state period.

At any instant in the steady-state period the amount of acid entering any part of the plug is given by the amount of acid returned or drained back plus the amount of acid leaving with the gases. In practical situations it is very difficult to obtain a measure of the amount of acid returned. Accordingly the amount of incoming acid cannot be determined under steady-state conditions.

In the transient situation the amount of acid entering will be equal to the amount of acid remaining plus the amount of acid leaving. It is possible in the transient case to measure both the acid remaining and the acid leaving any of the compartments and hence to fully quantify the performance.

The amount of acid remaining in any part of the plug is measured by using an absorbent that can trap the incoming acid. So long as the absorbent is unsaturated, drain-back does not occur and the amount of acid absorbed gives a measure of the amount of acid remaining.

Fibreglass wool was chosen as the absorbent in the present investigation as it is not attacked by the acid and the fine wool fibres trap and retain a large quantity of acid. Thus by lightly filling the baffle area with fibreglass wool the amount of acid entering the chamber can be obtained. Similarly, by replacing the Vyon disc by fibreglass the amount of acid entering that area can be determined.

The acid leaving any part of the plug is determined by trapping the issuing gases and filtering them through Sintaglass bottles as shown in Fig. 3.

The amount of acid in each case is obtained by titration using standard solutions of sodium hydroxide with phenolphthalein as indicator.

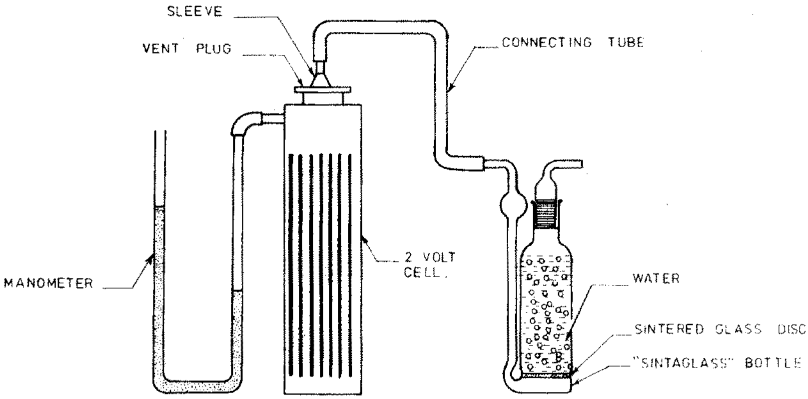


Fig. 3. Arrangement to trap the escape acid.

The standard test procedure is as follows:

(1) The battery cell is fully charged.

(2) 1 cm^3 of the cell fluid is mixed with 199 cm^3 of distilled water, 2 cm^3 of the resulting mixture is then titrated. A simple calculation then yields the concentration of acid within the cell fluid. The dilution procedure is used to increase the accuracy of the results obtained.

(3) One individual part of the dry plug is lightly filled with fibreglass wool and the plug is placed on the cell. The plug is also connected to a sintaglass bottle via the sleeve (Fig. 3).

(4) Charging is started and an internal timer in the charger is set to the required test period (normally 5 min for a transient test).

(5) When the exposure time is over the charger is switched off. The vent plug is removed and its base disc is wiped dry. The glass wool is put into a beaker of distilled water. The walls of the member under test are washed with distilled water using a syringe fitted with a hypodermic needle and the drain is added to the contents of the beaker.

(6) The contents of the beaker are titrated to obtain the mass of collected acid. The contents of the sintaglass bottle are also titrated after adding the drain resulting from washing the sleeve and connecting tube (see Fig. 3).

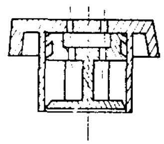
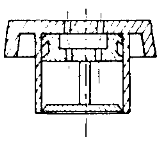
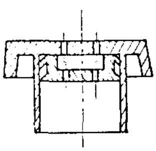
(7) The mass of collected acid obtained from the titration is converted to volume of entrained acid using the concentration of the acid obtained for that particular test as in (2) above.

5. Study of the efficiencies of a CABL plug and of the effect of the baffle and base disc

The apparatus and test procedure described above were used to assess the acid separation performance of the CABL plug shown in Fig. 1. The efficiencies of the plug as a whole, of the baffle chamber, and of the porous Vyon disc were measured. To assess the effect of the baffle and the base disc (see Fig. 1)

TABLE 2

Test results on CABL plug

Plug	Averaged measured flow (mm^3/5 min)	Current (A)		
		10	20	45
 1 Original CABL plug	A_1 B_1 C_1	69.0 1.60 0.300	143 3.53 1.04	327 8.34 2.90
 2 Baffle removed	A_2 B_2 C_2	69.0 2.35 0.710	143 4.61 1.42	327 10.4 3.28
 3 Baffle and base disc removed	A_3	94.6	190	430

on performance, the plug was modified first by removing the baffle and then by removing the baffle and disc, as shown on the illustrations in Table 2.

In order to stay within the transient regime, referred to earlier, the tests were limited to 5 min duration. As the amount of escape acid could not be measured accurately over the short 5 min test period imposed by the transient requirement, tests over longer intervals of up to 20 min were used to determine the rate of acid escape for the various charge rates. The results were plotted versus time, and the escape acid for a 5 min period was obtained from these graphs.

Performance tests for each plug configuration were conducted at 10, 20 and 45 A charge rate. Each test was repeated three or four times, the results were then plotted and an average value was derived from the plots. The averaged values are given in Table 2. In the table, subscript 1 refers to the original CABL plug, subscript 2 to the baffle-removed configuration and subscript 3 to the baffle-and-base-disc-removed configuration. Thus in Table 2, A_3 measures the volume of acid entering the plug with the base disc and baffle completely removed. A_2 measures the acid entering the plug with the base disc in position. B_2 measures the volume of acid leaving the baffle chamber when the baffles are removed. B_1 is the volume of acid leaving the baffle chamber with the baffles in position (and entering the porous Vyon disc) and, finally, C_1 is the volume of acid escaping from the plug.

Figure 4 shows these quantities, plotted against charge current, as percentages of the volume of acid incident upon the plug inlet. In order to cover the range of values an interrupted scale is used for the percentages. Figure 4 immediately shows the contribution of the various elements making up the plug to the acid-separation performance. Also it is obvious that the plug's overall performance is excellent as only about 0.3% of the acid that could enter the plug finally escapes, giving an overall efficiency of around 99.7%.

Individual element efficiencies provide important design data. In each case, efficiency is based on the fraction of acid entering the element which is separated by that element. Referring to Fig. 5, it can be seen that the efficiency of the baffles is low. The absolute quantity they separate is large, however, compared to the amount leaving the plug. The amount of acid escaping plug 2 as compared with plug 1 (see figures on Table 2) is shown in Fig. 6. At

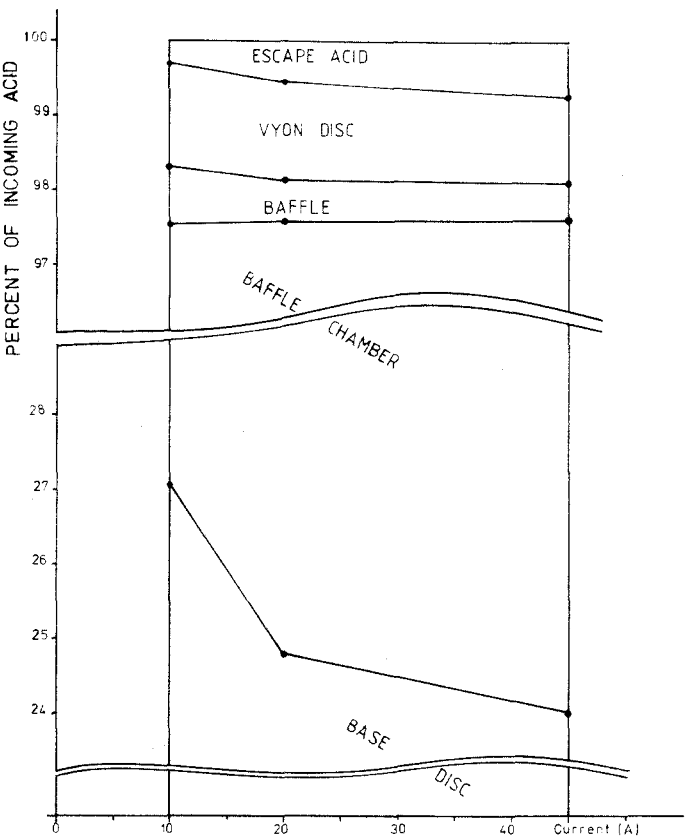


Fig. 4. Contribution to acid separation by different parts of the plug for various currents.

a low charging rate the effect of the baffle is substantial, reducing the escape by 54%. As the low charging rate is the normal service condition, the additional cost involved in including the baffles is justified.

The acid-separation capability of the Vyon disc is quite substantial (see Fig. 4). Its efficiency falls off a lot with charging rate but again its efficiency is highest under the normal service conditions of low charging rate. This efficiency could be improved further by using a finer sinter size in the porous disc. This would be at the expense of increasing the pressure drop across the plug, and the gain would be marginal considering the very high efficiencies already attained.

Looking at the general trend of these results, the incoming acid volume is found to increase linearly with current or gas flow rate indicating a constant

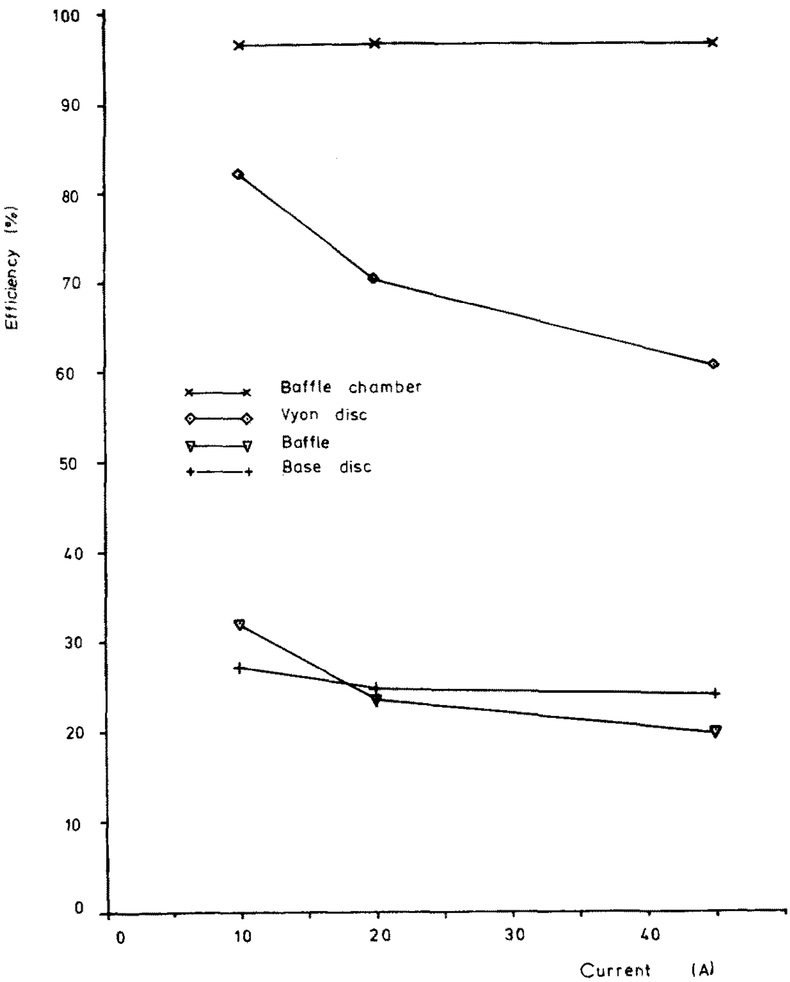


Fig. 5. Efficiency of different parts of the plug for various currents.

concentration of acid in the incoming gas. This works out to 0.02% by volume which is consistent with measurements made below the plug with the laser diffraction particle analyser, as mentioned earlier. The results for the escaped acid are also linear with charge current (see Fig. 6) and correspond to a volume concentration of only 0.00013%. Thus for the CABL plug the overall efficiency (see top graph in Fig. 4) is very high, though it decreases a little with charge current.

6. Conclusions

(1) A method has been developed for assessing the performance of vent plugs in separating the entrained acid spray. The method is capable of assessing each element forming the plug as well as the plug as a whole.

(2) A spray particle size analysis was carried out and it showed that the acid particles entering the plug are predominantly in the range of 5–15 μm. Hence separator design should be focussed on this order of particle size.

(3) The experimental findings were in line with the theoretical analysis for droplet and mist separation and hence the theoretical material can be used with confidence for design, or for assessing the acid spray separation performance of a proposed plug configuration.

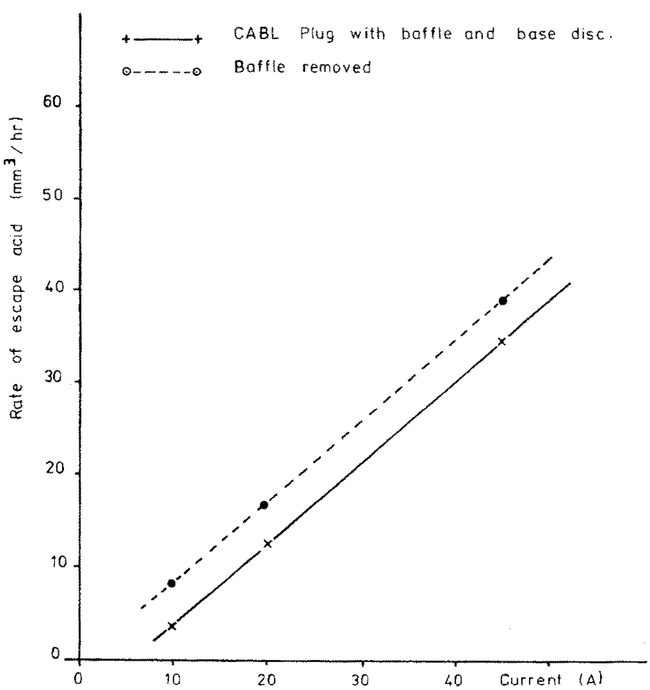


Fig. 6. Acid escape rate for various currents.

(4) The performance of the CABL baffled insert plug has been measured and the plug was shown to have an overall acid separation efficiency of between 99.1% and 99.6%. Efficiencies of different parts of the plug have also been evaluated. The baffle chamber area has an efficiency of 97.5% while the Vyon disc efficiency varied between 82% and 64%. It is interesting to note that the highest separation efficiency occurs when the charging current is low, the condition which normally prevails in service.

(5) The role that the baffle and base disc play in reducing escape acid was evaluated. These two elements were found to reduce the escape acid by 54% at low charge rate and hence their inclusion is worthwhile.

(6) The performance of present baffled insert vent plugs is good, as is shown by the high values of overall plug efficiencies obtained. Further improvements might be achieved by using a finer sinter size porous disc.

Acknowledgements

The work described in this paper was sponsored by Chloride Technical Ltd., and was carried out in the Department of Mechanical Engineering, University of Nottingham. The authors wish to thank Chloride Technical Ltd. for permission to publish this paper.

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