

# PERFORMANCE OF SEALED LEAD ACID BATTERY ENHANCED BY GAS SEPARATION MEMBRANE TECHNOLOGY

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## ABSTRACT

This paper reports the development of an effective method of controlling the evaporation of electrolyte in the newly developed membrane-assisted sealed lead acid battery for the applications in higher temperature conditions such as in an automotive applications, renewable energy sectors and uninterrupted power supply systems. Real time performance evaluation was conducted to determine the effectiveness of the new battery in retaining the electrolyte. Asymmetric polysulfone membrane that functions as an electrolyte retainer was introduced and attached to the battery using a special designed battery top cover assembly. The in-car testing results exhibited that during charging process, electrolyte losses of a membrane-assisted sealed lead acid battery over a period of 1440 hours is approximately 0.134 grams per hour as compared to 1.790 grams per hour for conventional lead acid battery.

## INTRODUCTION

One of the oldest and best known devices used to store energy is the lead acid battery. The technology is based on the reduction of lead dioxide to lead sulphate at the positive electrode and simultaneous oxidation of lead sulphate at the negative electrode. When the electrolyte, which is sulphuric acid, is consumed, the energy will discharge during this process. Energy is stored by reversing these reactions, which is, charging the battery. Nowadays, the lead-acid batteries have been widely used as automotive, stationary and traction batteries and submarines batteries. The lead acid battery which is used especially in tropical countries and countries with hot summer will have critical electrolyte evaporation problem that has deteriorating its life cycle and performance. The combination factors of high rate equalising charging at 14.4V to 15.8V and hot weather, contribute to the electrolyte losses in the lead acid battery. When the electrolyte level goes down below the minimum level, both positive and negative electrodes plates will be exposed to air, thus sulphurisation will occur and the battery will be permanently damaged. Sealed tropicalized lead acid battery by applying the application of the gas separation membrane is proposed to solve the electrolyte evaporation and corrosive problems in the lead acid batteries industries as well as environmental issues. The membrane for gas separation technology, which acts as a selective barrier, will allow certain gas

component permeate faster than the other one in a gas mixture. Therefore, this research is applied the membrane technology into the lead-acid battery. Membrane will be used to retain electrolyte level by controlling or minimised the rate of vaporised electrolyte disposal into the atmosphere. Gases such as hydrogen and oxygen which are found during charging and discharging will be permeating through membrane, as to balance the pressure build up inside the battery, or else explosion might occurs.

## METHODOLOGY

The experiments have been divided into two parts that consists of membrane preparation and testing on a lead-acid battery. Polysulfone (Udel bisphenol A polysulfone (Udel P 1700)) purchased from Amoco Performance products) was selected as the membrane material because of the commercial availability, easy of processing and favourable selectivity-permeability characteristic, mechanical and thermal properties, durability to high acidity conditions and its cost effectiveness. All the chemicals used such as N, N-dimethylacetamide (DMAc), dimethylformamide (DMF) ethanol and tetrahydrofuran (THF) were laboratory grade and obtained from Aldrich (Solvay, 2003).

The membranes applied on lead-acid batteries were prepared by casting a polymer solution. The polymer solutions are tabulated in Table 1. The casting process was performed using a pneumatically-controlled machine. The casting

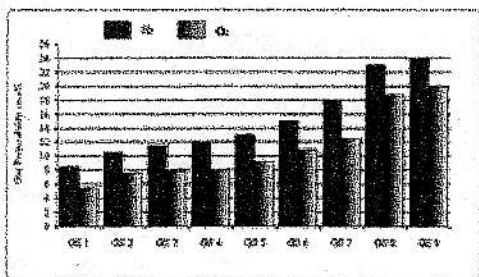
solution was cast on glass plate with a casting knife gap setting of 150  $\mu\text{m}$  with shear rate of  $244\text{ s}^{-1}$ . After various type of membranes were fabricated, these membrane were then tested on lead-acid batteries to search for an optimum composition in retaining the most electrolytes in the lead-acid battery throughout the charging process.

**Table 1** Casting solutions formulations

	PSF %	DMAc%	DMF %	THF%	Ethanol %
GS1	25	30.5	-	30.5	14
GS2	22	31.8	-	31.8	14.4
GS3	18.7	33.2	-	33.2	14.9
GS4	15.2	34.6	-	34.6	15.6
GS5	20	-	80	-	-
GS6	15	-	85	-	-
GS7	13	-	87	-	-
GS8	12.5	-	87.5	-	-
GS9	11	-	89	-	-
GS10	9.5	-	90.5	-	-

## RESULTS AND DISCUSSION

Figure 1 illustrated the membranes that had been fabricated from the ternary system such as in the GS1, GS2, GS3 and GS4. It was found that the permeability for GS4 is higher compared to the permeability of GS1. This phenomenon is formed because of the polymer concentration. The higher the polymer concentration in the casting solution will result in producing thicker skin layer membrane. Therefore, permeability will be lowered when the polymer concentration is increased. This is also similarly applied to the binary system such as GS5, GS6, GS7, GS8, GS9 and GS10. The polymer concentration for the GS 5 is lower than the GS4; therefore permeability for the GS5 is slightly higher than the GS4. The only difference between the binary and the ternary system is the structure of the resultant membrane, where the binary system membranes have more uniformed structure than that of the ternary system.



**Fig. 1** Permeability for different membranes (GS 10 has no reading)

The effect of membrane formulation on the membrane performance in retaining electrolyte level

showed in Table 2. The hydrogen, oxygen and water vapour are formed during the process of charging and discharging of the lead acid battery. Through the visual inspection made from the test after the short hours (estimated an hour) of charging, the membrane that was applied on the vent plug of the battery caps had inflated. At the same time, it was detected that the battery casing became bulge and the liquid level of the electrolyte was fluctuated. This phenomenon is because of the pressure built up inside the battery casing and simultaneously due to the membrane pore size that is too small for gases permeation. Once the battery casing is detected to bulge and to avoid any explosion, the charging process is immediately discontinued.

**Table 2** Test result of the preliminary screening membrane applied battery

Membrane	Rate of electrolyte losses after charging	Cell pressure (bar)	Remarks
GS1	unnoticeable	> 3	Battery casing severely bulge/ electrolyte fluctuated in less than 1 hour of charging
GS2	unnoticeable	> 3	Battery casing severely bulge/ electrolyte fluctuated in less than 1 hour of charging
GS3	unnoticeable	> 3	Battery casing severely bulge/ electrolyte fluctuated in less than 1 hour of charging
GS4	unnoticeable	> 3	Battery casing severely bulge/ electrolyte fluctuated in less than 1 hour of charging
GS5	unnoticeable	> 3	Battery casing bulge after 1 hour of charging
GS6	unnoticeable	2.5	Battery casing bulge after 1.5 hour of charging
GS7	unnoticeable	2.0	Battery casing fairly bulge after 1½ hours of charging.
GS8	±0.1 bar	1.8	Battery casing slightly bulge after 2 hours of charging.
GS9	± 1.0 bar	1.2	Battery casing slightly bulge after 2 hours of charging but droplets emerged on the membrane surface
GS10	NA	0.3	Membrane ruptured after 1 hour of charging.

As shown in Table 2, the ternary system solution consist of the polymer, solvent and non-solvent indicated as membranes GS1 to GS5 were too tight when the pressure aggressively built up inside the battery casing, hence causes the casing to bulge rapidly. Meanwhile, the application of the binary system with only one part of the polymer and another part of the solvent cast membranes from the GS5 to GS10 have better permeation rate as

compare to the ternary system cast membrane. As a result, the excessive pressure build up inside the battery casing has reduced or a longer period of time needed to build up the pressure. As for the GS10, the membrane failed to withstand the pressure, which generated by the battery cells due to very thin skin layer. This result is also in accord with the conclusion that made by the previous researchers (Chung *et al.*, 1997; Hachisuka *et al.*, 1996). With the application of the binary system solution cast membranes and with additional of the lower polymer concentration membranes such as in the GS7, GS8 and GS9, it will indicate that the trends of better permeability rate were observed. This has proven through the inspection of the battery electrolyte level and the compactness of the battery casing. However, the GS9 displayed less favourable in the electrolyte retaining characteristics when liquid droplets emerged on its surface of the membrane. Meanwhile, the GS10 membrane had burst after the battery was charged for about one hour. This has indicated that the GS9 and GS10 membranes were not strong enough to hold the pressure as well as the pore size is bigger that causes the gases to permeate faster. As for the GS8 that has the polymer concentration of approximate 12.5 wt % polysulfone and 87.5 wt % of DMF solvent, revealed the most excellent permeation rate with the minimum of vaporized electrolyte and similarly show the decreasing in the excessive pressure built up inside the battery casing. It has indicated that the GS8 membrane has passed the introductory test and practically it can be used as an electrolyte retaining mechanism. In future, all the experiments and evaluations will be based on this parameter of GS8. The above results are in agreement with the conclusion made by the previous study (Ismail and Hafiz, 2005).

The rheological factors are considered as one of the latest approach in the membrane formation process that can be manipulated. Figure 2, illustrates the profile of the electrolyte evaporation of the five selected membrane shear rates. The electrolyte loss from the five different shear rate exhibited similar trend is constantly decreasing until the end of the three hours evaluation. The electrolyte losses of about 12 grams of electrolyte from the initial wet weight of 12.80kg, which has an average of the electrolyte losses rate of 4.0 grams per hour or 0.66 grams per hour per cell is noted.

Table 3 tabulated the overall electrolyte losses for the battery that enhanced with the membranes at different shear rates. The electrolyte losses were coherent in the shear rates of  $300 \text{ s}^{-1}$  to  $200 \text{ s}^{-1}$ , with the rate of losses at 12 grams per hour. Therefore, this concluded that the shear rates of  $300 \text{ s}^{-1}$  to  $200$

$\text{s}^{-1}$ , did not have significant impact on this application. This may due to the membranes effective area was too small as well as the internal working pressure, with only 8 mm in diameter and less than 1 bar respectively. As such, no further evaluation on the shear rate will be conducted. Further evaluation from this point onwards will be based on the characteristics of the GS8 formulation with the standard default shear rate of  $244 \text{ s}^{-1}$ .

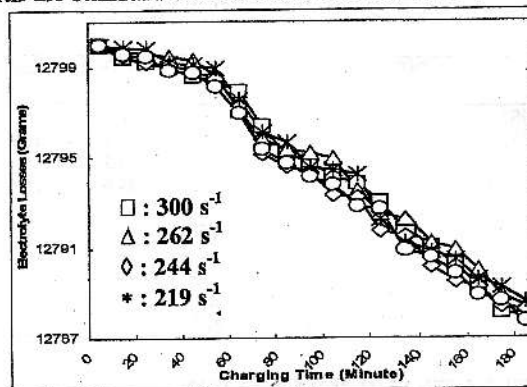


Fig2. Performance of the different shear rate in controlling the electrolyte evaporation

Table 3 Overall electrolyte losses with different shear rates of the membrane enhanced lead-acid battery

Membrane use	Total electrolyte losses	Rate of electrolyte losses (per cell/hour)
$300 \text{ s}^{-1}$	12.10 g	0.67 g
$262 \text{ s}^{-1}$	11.62 g	0.65 g
$244 \text{ s}^{-1}$	11.78 g	0.66 g
$219 \text{ s}^{-1}$	11.43 g	0.64 g
$200 \text{ s}^{-1}$	12.30 g	0.68 g

Figure 3 showed the electrolyte losses during sixty days of full functionalities trials. The full functionalities of trial assessments were based on the average drivers that using the automobile for about two hours per day excluding the public vehicles. The sixty days trial is more than enough to represent the lead acid battery which is equivalent to an approximately two years of operations on the fields, as during this test there were no rest period for the battery. The average serviceable life span for the lead acid battery in the tropical climate is about two years. Hence, the sixty days of trial period is sufficient to represent the average serviceable life span of the lead acid battery within two years of operations. As illustrated in Figure 3, the evaporation of the electrolyte and gaseous permeates aggressively from the battery without membrane. This demonstrated that the electrolyte is continuously evaporated without any application of



the membrane. After the peak point at about 14 days, the evaporation of the electrolyte shows a drastic reduction trend. This was not a good indication of the ability to control the electrolyte losses. In fact the electrolyte level was descended below the minimum acceptant level. In view of this rationale, the internal electrical resistances of the battery cells have increased. Hence, the electrical current (ampere) decreases and resulting in the charging rate reduced and concurrently the electrolyte volume decreased. Ultimately it relates to the evaporation velocity that has slow down when the quantities of the electrolyte shrank. Meanwhile, the flow rate of the gaseous permeating from the battery throughout the charging process with the new unique designed battery top cover assembly and combination of the application of the GS8 membrane were restrained and saturated as time elapses. Hence, this has indicated that wherever the charging goes along the way, the permeation of the gaseous will be continuously increase and the evaporation of the electrolyte will take place if the lead acid battery is not enhanced with the membrane technology. From Figure 3 and 4, it has testified that the unique GS8 membrane were extremely effective for the application on the lead acid battery in retaining electrolytes from being evaporated. Based on the data, the average rate of the electrolyte losses over a period of 1440 hours is approximately 0.134 grams per hour, while the rate of the electrolyte losses in the battery that does not incorporate membrane is approximately 1.79 grams per hour or 42.96 grams per day. As such, the electrolyte will plunge below the minimum level of the battery after 14.9 days of usage, which is based on the initial weight of the electrolyte of 643 gram at the minimum to the maximum of the nominal electrolytes level. As such, it has proven that the battery enhanced with membrane and combined with the new unique designed battery top cover assembly, is competent to control the electrolyte losses.

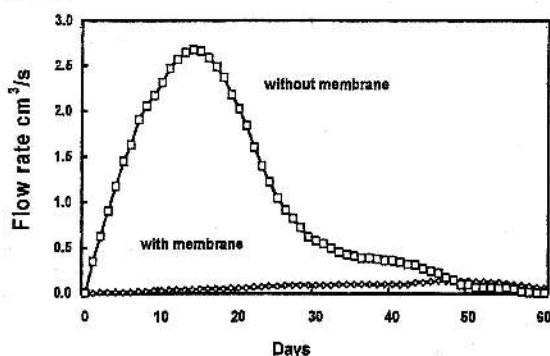


Fig. 3 Flow rate of the gas permeating from the battery during the stimulated charging

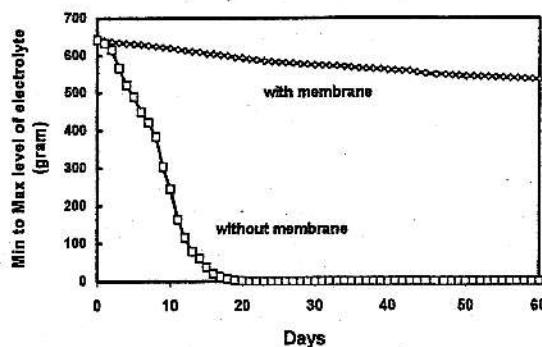


Fig. 4 The electrolyte losses during the battery charging

## CONCLUSION

The manipulation of polymer concentration and casting shear rate during the preparation of gas separation membranes has successfully produced the most suitable membrane featuring minimized electrolyte loss during the battery charging process. Based on the results obtained, the most suitable gas-separation membrane to be applied in the lead-acid batteries for the purpose of minimizing electrolyte loss is that prepared from the casting solution of 12.5 % (w/w) PSF and 87.5 % (w/w) DMF, and cast at the shear rate of  $244 \text{ s}^{-1}$ .

Electrolytes evaporation during the full functionalities test of sixty days test was recorded at the peak of approximately  $0.18 \text{ cm}^3/\text{s}$  as compare to  $2.71 \text{ cm}^3/\text{s}$  that without membrane. This has proved that the newly developed battery top cover assembly with GS 8 is able to significantly control the evaporation of the electrolyte. The application of asymmetric gas separation membrane GS8 by incorporating to the newly designed unique battery top cover assembly has demonstrated the distinctive edge of the mechanism as the retention of gaseous and impedes the electrolytes being released into the environments. The GS8 membrane can further be commercialized in membrane-assisted lead-acid battery.

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