# Effectiveness of polymers on improving the fluid loss of bentonite used in geosynthetic clay liners

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## Introduction

Geosynthetic clay liners (GCLs) are generally used in engineering projects due to their low hydraulic conductivity with water. The bentonite component contributes hydration-induced swelling and imparts low permeability to GCLs. There are several engineering properties related to bentonite which control the qualification of bentonite used in GCLs, but fluid loss has been shown to be a valuable parameter (Rosin-Paumier et al. 2010). Industry standards for geosynthetic clay liners generally require the fluid loss values to be lower than 18ml for 6.0 wt/vol% suspensions in high quality water. Addition of polymers to bentonite may improve the bentonite properties to give a lower hydraulic conductivity. In this paper, two bentonites, a sodium bentonite from a commercial GCL and a magnesium/sodium bentonite currently not used in GCL were selected to study the effects of polymer type and loading on the fluid loss of two bentonites.

## Materials and Methods

A modification of the fluid loss test (ASTM D5891-02) was conducted using 0.5 wt%, 1 wt%, 2 wt% concentrations of three polymers (a positively charged Zetag, a negatively charged Alclar and a neutral Magnafloc, supplied by Ciba, Sydney) by combining attributes of the American Petroleum Institute's method (API Specification 13A; API Specification 13B), as well as some of our own methodology with the American Society of Testing and Methods (ASTM D5890-02) method.

According to the ASTM fluid loss method, bentonites with different concentrations of polymer were mixed with 350 ml DI water in the mixing cup for 20 minutes with the sides of the mixing cup scraped to dislodge any clay clinging to the walls. After aging for at least16 hours at ambient temperature, the bentonite-polymer suspensions were shaken to break the gel and then mixed for a further 5 minutes to re-disperse the suspension completely. Then the suspension was poured into the fluid cell and the cell was assembled. Two labelled leachate collection containers were pre-weighed and one was placed under the fluid cell drain tube. A pressure of 690 kPa (100 psi) was applied as two timers were started. At 7.5 minutes on the first timer, the collection container was removed and replaced immediately by the other container, which was used until the end of the second timer (30 minutes, or equivalent a flux time of 22.5 minutes). The fluid loss values were calculated using the following equations:

$$\text{Last 22.5 minute (mL)} = \frac{g_{\text{Container with 22.5 minute Filtrate}} - g_{\text{Empty container}}}{{}^{g}/_{\text{cm}^3}(\text{Filtrate Density}_{@\text{temp}\ \&\ Conc.})} \quad \text{(Eq.1)}$$

$$\text{Fluid loss value} = 2(\text{ml filtrate volume for last 22.5 min. interval})\text{mL} \quad \text{(Eq.2)}$$

The filter cakes at the bottom of the fluid cell were collected according to the API method for determining gel strength of bentonite suspensions, and the thickness of the filter cakes formed were measured. We also determined the wet mass and dry mass (after drying in the oven at 105 °C) of the filter cakes to enable determination of the gravimetric water content (Eq.3), gel strength (Eq.4), flux (Eq.5), permeability (Eq.6), effective void ratio ($e_{eff}$) (Eq.7) and effective porosity ($\eta_{eff}$) (Eq.8).

$$\text{Gravimetric water content}\left(\frac{g_{water}}{g_{clay}}\right)=\frac{g_{\text{Wet Filter Cake}}-g_{\text{Dry Filter Cake}}}{(g_{\text{Dry Filter cake}}-g_{\text{Filter Paper}})} \quad \text{(Eq.3)}$$

$$\text{Gel strength}=\frac{g_{\text{Gravimetric water content}}}{mm_{\text{thickness of the filter cake}}} \quad \text{(Eq.4)}$$

$$\text{Flux }(\text{Q m}^3m^{-2}S^{-1})=m^3_{Filtrate\ volume}/m^2_{Filter\ cake\ area}/time\ (s) \quad \text{(Eq.5)}$$

$$\text{Permeability }(\text{K, m/s})=\frac{Q_{Flux}\times m_{Filter\ cake\ thickness}}{m_{head\ of\ the\ water}} \quad \text{(Eq.6)}$$

$$e_{eff}=\frac{\rho_{s,particle\ density\ of\ clay}}{\rho_{d\ dry\ density}}-1 \quad \text{(Eq.7)}$$

$$\rho_d=\frac{g,dry\ mass\ of\ filter\ cake}{cm^3,total\ volume\ of\ filter\ cake}\ ; \quad \rho_s=2.7\ g/cm^3$$

$$\eta_{eff}=\frac{1+e_{eff}}{e_{eff}} \quad \text{(Eq.8)}$$

**Results and Discussion**

Data from the fluid loss tests are plotted in Figure 1. Na-bentonite always had lower fluid loss values than Na/Mg bentonite and its values were below the industry standard value (18ml). The three polymers had most effect on the Na/Mg bentonite. They had a similar effect on its fluid loss values. Magnafloc (neutral) and Zetag (positively charged) generally offered better performance for Na/Mg bentonite at concentrations of 0.5%, and 1%, but had a negative effect at 2% concentration. Only Alclar (negative charge) had no negative effects on the fluid loss values (i.e. decreased fluid loss values with increasing polymer content).

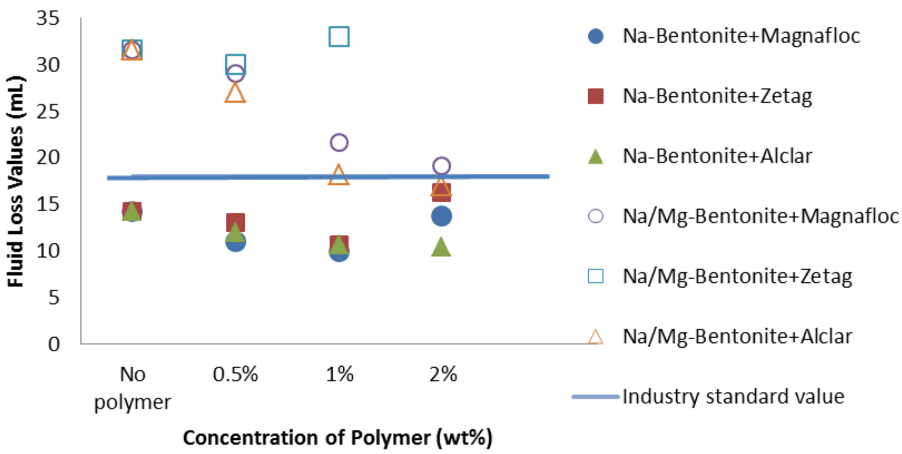



**Fig. 1.** Fluid loss values of two bentonites as a function of polymer concentration and type.

For the Na/Mg-bentonite, Zetag resulted in different behaviour than the other two polymers: the fluid loss values generally decreased at higher concentrations of Alclar and Magnafloc, but the bentonite suspension was unable to retain 350 mL of DI water even within 7.5 minutes at 2% loading of Zetag. Most of the fluid loss values were still above the industry standard value, except at 2% of Alclar.

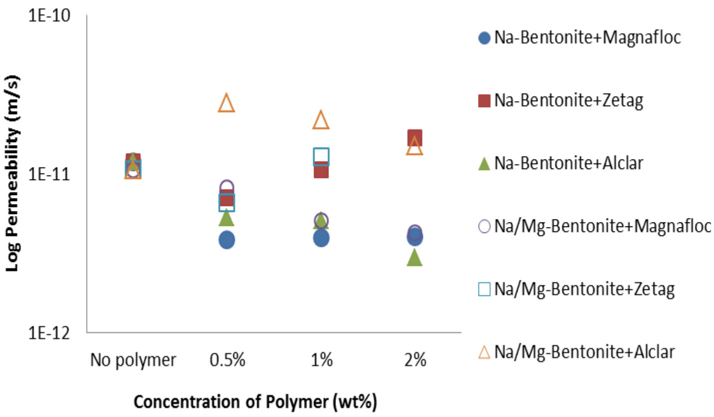
Results of gravimetric water content (GWC) of the filter cake are shown in Figure 2 and for permeability in Figure 3 and for other parameters in Table 1. The Na-bentonite had a greater GWC than the Na/Mg-bentonite, but both bentonites had similar permeability without polymers because the Na/Mg-bentonite filter cake was thinner (Table 1). For GWC values (Eq. 3; Figure 2), Alclar (negative charged) increased GWC of both Na and Na/Mg-bentonite at lower concentrations but had an inverse effect at 2% concentration. Zetag caused an increase in the GWC of Na-bentonite but had little effect on Na/Mg-bentonite GWC. Magnafloc behaved differently with the two bentonites as well: it caused a consistent increase in GWC for Na-bentonite, but a decreased GWC for Na/Mg-bentonite.

**Table 1.** Measured and calculated parameters of the fluid loss test.

| Sample | Leachate | Filter Cake Thickness (mm) | Gel Strength | Flux ($m^3/m^2/s$) | Void Ratio ($e_{eff}$) | Porosity ($\eta_{eff}$) |
|---|---|---|---|---|---|---|
| **Na-Bentonite** | DI Water | 3.23 | 3.08 | 2.4E-06 | 18 | 0.95 |
| **Na-Bentonite+0.5%Magnafloc** | DI Water | 1.90 | 5.61 | 1.4E-06 | 13 | 0.93 |
| **Na-Bentonite+1%Magnafloc** | DI Water | 2.01 | 5.64 | 1.3E-06 | 14 | 0.94 |
| **Na-Bentonite+2%Magnafloc** | DI Water | 1.64 | 7.56 | 1.7E-06 | 16 | 0.94 |
| **Na-Bentonite+0.5%Zatag** | DI Water | 2.96 | 3.71 | 1.7E-06 | 16 | 0.94 |
| **Na-Bentonite+1%Zatag** | DI Water | 3.87 | 3.14 | 1.8E-06 | 21 | 0.96 |
| **Na-Bentonite+2%Zatag** | DI Water | 5.31 | 2.61 | 2.2E-06 | 23 | 0.96 |
| **Na-Bentonite+0.5%Alclar** | DI Water | 2.44 | 4.08 | 1.5E-06 | 20 | 0.95 |
| **Na-Bentonite+1%Alclar** | DI Water | 2.91 | 3.50 | 1.2E-06 | 21 | 0.96 |
| **Na-Bentonite+2%Alclar** | DI Water | 1.76 | 4.72 | 1.2E-06 | 16 | 0.94 |
| **Na/Mg-Bentonite** | DI Water | 1.39 | 3.52 | 5.0E-06 | 7 | 0.87 |
| **Na/Mg-Bentonite+0.5%Magnafloc** | DI Water | 1.46 | 5.68 | 3.8E-06 | 5 | 0.83 |
| **Na/Mg-Bentonite+1%Magnafloc** | DI Water | 1.33 | 4.75 | 2.7E-06 | 7 | 0.88 |
| **Na/Mg-Bentonite+2%Magnafloc** | DI Water | 1.28 | 4.22 | 2.3E-06 | 8 | 0.89 |
| **Na/Mg-Bentonite+0.5%Zatag** | DI Water | 1.1 | 4.22 | 4.1E-06 | 5 | 0.83 |
| **Na/Mg-Bentonite+1%Zatag** | DI Water | 1.99 | 2.56 | 4.4E-06 | 8 | 0.89 |
| **Na/Mg-Bentonite+2%Zatag** | DI Water | * | * | * | * | * |
| **Na/Mg-Bentonite+0.5%Alclar** | DI Water | 5.03 | 2.04 | 3.8E-06 | 17 | 0.94 |
| **Na/Mg-Bentonite+1%Alclar** | DI Water | 4.88 | 2.15 | 2.9E-06 | 18 | 0.95 |
| **Na/Mg-Bentonite+2%Alclar** | DI Water | 3.5 | 2.38 | 2.8E-06 | 20 | 0.95 |

*The leachate was expressed from the cell within 7.5 mins, thus the fluid loss value and associated parameters could not be obtained.

For permeability values (Figure 3), Magnafloc and Alclar generally decreased the permeability of Na-bentonite, while the concentration showed nearly no effect on the permeability for Magnafloc. On the other hand, Na- bentonite mixed with Zetag showed increased permeability with polymer loading, but only at 2% concentration was the value higher than the initial one without polymer.



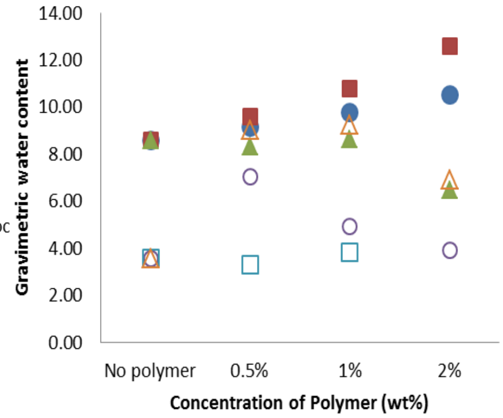




**Fig. 2.** Gravimetric water content for two bentonites. **Fig. 3.** Permeability values for two bentonites.

For the Na/Mg bentonite, only Magnafloc showed consistently decreased permeability with increasing polymer loading. However, Alclar additions had a negative effect on the permeability: although increasing the concentration attenuated the increasing trend, in permeability, it was still higher than the value without polymer. Zetag caused a decreased permeability only at 0.5% concentration; high polymer loading had a strongly negative impact. These results are in general agreement with the fluid loss described above: the two bentonites reacted differently when combined with the polymers.

Unexpectedly, there was no discernable relationship between GWC values and permeability, Zetag for the Na-bentonite caused low GWC but low permeability and Magnafloc for the Na/Mg-bentonite caused high GWC but still led to high permeability. Perhaps better measures are the effective porosity ($\eta_{eff}$) and the effective void ratio ($e_{eff}$) which can be determined from the dry density and total volume of the filter cake.

While Magnafloc provided best enhancement of the hydraulic performance of the Na/Mg-bentonite, Alclar was the best at decreasing the permeability of the Na-bentonite. Permeability and flux (Table 1) values fluctuated with Zetag loading and an optimum content probably exists, around 0.5% in the permeability tests for both bentonites. The permeability values with or without polymers for both bentonites reached the industry standard of $1x10^{-10}$m/s, although the fluid loss values for the Na/Mg-bentonite were considerably higher than the standard value (18mL).

## References

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