

Management of Waste Bentonite Based Slurry from Drilling Operations

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This study investigates low energy, cost effective techniques for enhancement of solid content of the waste bentonite slurry from drilling operations. The mechanisms studied for achieving this objective were coagulation, ion exchange and viscosity reduction. Conversion of the commercial sodium bentonite to calcium bentonite, which retains much less water, was found to be the most suitable solution. This cation exchange was attempted by the use of calcium salts like gypsum, calcium chloride and lime, of these, gypsum was found to be the most suitable. The simulated waste slurry samples were prepared to have 4% to 10% of bentonite by weight, as against the normal working range of 6% to 8%. A relationship was developed from the experimental data between the controllable variables, ie, the dose of gypsum, the initial percentage of bentonite in the slurry, the settling time and the percentage volume reduction. It is possible to achieve more than 50% volume reduction, thus considerably reducing the handling, disposal and management costs.

Keywords : Bentonite; Waste drilling slurry; Volume reduction; Ion exchange; Solid content; Coagulation

INTRODUCTION

The waste slurry generated from the construction industry during drilling operations is essentially a non-settleable suspension of bentonite clay particles and drill solids. Bentonite is a clay mud composed essentially of minerals of montmorillonite group. Generally, Sodium Bentonite is added to water to form viscous slurry that finds multifarious uses in the construction and drilling industries¹. It is known to adsorb exceptionally large amounts of water (up to 1000% of its weight)². Bentonite clay suspensions are colloidal in nature and do not aggregate rapidly³.

A suspension of 6% to 8% Sodium Bentonite in water along with the other stabilising chemicals is commonly used as a drilling fluid to carry the drill cuttings out from the borehole¹. The other functions performed by a drilling fluid are to control the well hydrostatic pressure, stabilize the well bore and lubricate the drill bit^{1, 4}.

The slurry is generally reused two to three times before being disposed by spreading and mixing in agricultural land or landfilling. These processes though economical for small-scale operations may not be feasible for large-scale operations for, namely, construction sites of Delhi

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Metro Rail Corporation, which generate an average of 50 m³ of waste slurry per day per kilometre at each construction site. Hence, there is the need to develop disposal methods that are both technically and economically feasible. High-energy solutions for volume reduction such as decanting centrifuges and hydrocyclone separators exist¹. But in developing countries, where energy is a major constraint, such solutions are not feasible and there is a need to investigate low energy solutions for managing spent bentonite slurry. This study aims to investigate the possibilities of management of this large volume of spent slurry by creating conducive conditions for aggregation and enhancing the rate of aggregation of the clay (Sodium Bentonite) particles.

MECHANISMS INVESTIGATED FOR TREATMENT OF SPENT BENTONITE SLURRY

The conditions for enhancement of solid content in the slurry could be directed towards aggregation of clay particles or reducing hydration of the clay or reducing viscosity or a combination thereof. In this study, three low energy mechanisms namely, coagulation, ion exchange and reduction of viscosity were investigated for feasibility of achieving the aforesaid objective.

Coagulation

Coagulation is concerned primarily with aggregation of thermodynamically unstable and irreversible colloids. Coagulation processes are used to increase the rate at which colloidal system aggregates, ie, these processes

transform a diturinal system into a caducous system⁵. This was accomplished by increasing the polyvalent cationic (for instance Al^{3+} , Fe^{3+} , Fe^{2+} etc) concentration in the solution. The coagulation effectiveness of these ions increased markedly with charge. But, such a sequence of destabilisation might not be observed in the system under consideration if there was exchange of cations adsorbed on the clay particle surface instead of aggregation of particles. Further, the slurries dealt with are viscous solutions as against dilute solutions, which were generally required for effective coagulation. Hence, this mechanism though effective, might not be the dominant one in this context.

Ion Exchange

The interlayer spacing of dry montmorillonite would be between 9.8 Å (sodium bentonite) and 12.1 Å (calcium bentonite), which was filled with tightly bound water⁴. On hydration, the calcium based bentonites expand to 17 Å only, while sodium bentonite expands to 40 Å, because the divalent cations (such as, Ca^{2+}) could give a greater attractive force among the clay platelets whereas the monovalent cations (such as, Na^+) give rise to a lesser attractive force and allow more water to penetrate between the platelets.

The compensating cations that are adsorbed on the unit layer surface ($800 \text{ m}^2/\text{g}$ to $900 \text{ m}^2/\text{g}$)¹ might be exchanged for other cations and called as the exchangeable cations of the clay. The cation exchange capacity (CEC) of montmorillonites is within the range of 80 meq/100 g to 150 meq/100 g of dry clay³. The following series⁴ was generally used to determine the relative exchange capacities of various cations:



Any cation to the left would replace any cation to its right in the series. Therefore, the conversion of sodium bentonite to other forms that adsorb relatively less inter-layer water as in the case of calcium bentonite could be a promising prospect for treatment⁴.

Reduction of viscosity

One of the main purposes of addition of sodium bentonite in the drilling fluids was to increase viscosity of the slurry. As indicated by the viscosity curve shown in Figure 1⁴, up to 5% of bentonite in the slurry, there was an incremental increase in viscosity. Further after 6%, the gain in viscosity was exponential. It was for this reason that the drilling fluids generally contain above 6% of sodium bentonite. The waste slurry generated was also high in sodium bentonite content because of loss of water by filtration through the permeable formations. Highly viscous slurry, fulfilling the criteria of a drilling fluid might not be feasible from waste management point of view due to exceptionally poor aggregation and settling characteristics. The settling or thickening

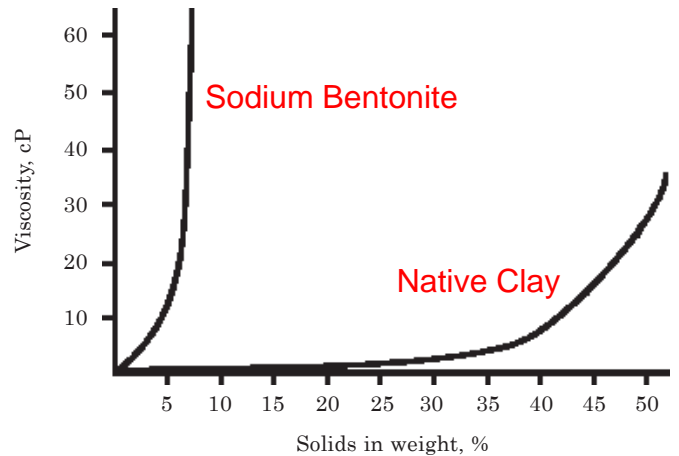


Figure 1 Viscosity curves resulting from different clay solids

characteristics of slurry depended upon the viscosity of the liquid in which the solid was suspended⁶. For treating the concentrated slurry, it might be desirable to first dilute it for efficient settling. Dilutions to very low solids content might not be desired as there would be large increase in volume of slurry and subsequent increase in handling costs. Thus, to determine the optimum level of dilution, a large range of 4% to 10% of sodium bentonite in the slurry was taken for experimentation.

MATERIALS AND METHODS

Experiments were made for several physico-chemical combinations in terms of coagulation, ion exchange and viscosity reduction, for achieving the objective of enhancing the aggregation of bentonite particles in the slurry. Preliminary investigations resulted in selection of certain physico-chemical combinations for further detailed investigations.

The percentage volume reduction, defined as the percentage change in the volume of thickened slurry from the original volume of the slurry, was used as the index of performance. The objective of the experiments was to identify the cost-effective physico-chemical combinations that would give higher percentage volume reduction.

The settling studies were conducted in 1 m glass columns at a temperature of $15 \pm 2^\circ\text{C}$. The simulated waste slurry was made from commercial grade sodium bentonite (obtained from a Delhi Metro Rail Corporation worksite) in water, with adequate agitation. The simulated slurry was prepared to have 4% to 10% of bentonite by weight.

In the first stage of experimentation, the chemicals selected for volume reduction, based on the principles of coagulation, ion exchange and commercial availability were, calcium salts (gypsum, lime, bleaching powder), aluminium salts (alum, poly aluminium chloride) and Iron salts (ferric hydroxide and ferric chloride). These chemicals were added and appropriately mixed with the

simulated waste slurry. A distinct interface between the settling solids and the clarified supernatant was formed, generally in 5 min to 10 min. This settling could either be due to coagulation or because of change of sodium bentonite to other forms or a combination of both these mechanisms with subsequent release of adsorbed water. Theoretically, the percentage volume reduction exclusively due to ion exchange, when sodium bentonite was converted to calcium bentonite would be 57.5%, as the exchange of sodium ions for calcium results in release of a large quantity of adsorbed water due to decrease in interlayer spacing from 40Å to 17Å. The settling was monitored by measuring the reduction in height of the liquid solid interface with time for 24 h. Gypsum was found to be the most effective alternative as it resulted in highest percentage volume reduction and is also a low cost commercially available chemical.

In the second stage of experimentation, doses of lab grade gypsum of 85.71 g/kg, 114.29 g/kg, 142.86 g/kg, 171.43 g/kg, 214.29 g/kg and 285.72 g/kg of bentonite (respectively equivalent to 6 g, 8 g, 10 g, 12 g, 15 g and 20 g of gypsum per litre of 7% bentonite slurry) were added to the simulated waste slurry. The doses were calculated on a mass of bentonite basis instead of volume of slurry basis to equalise the actual amount of gypsum available for ion exchange to different concentrations of bentonite. Again, the height of interface was noted regularly for 24 h. Also, the effect of varying the settling column depth (ranging from 0.5 m to 2 m) on the settling characteristics of the slurry was studied.

RESULTS AND DISCUSSION

Bentonite clay dewatering by low energy, cost effective techniques has not been researched extensively. It was desired in this study to investigate such techniques for enhancement of solid content of the colloidal waste slurry.

In the first stage of experimentation, out of the various commercial chemicals used, such as gypsum, lime, alum, poly aluminium chloride, gypsum gave the best results in terms of volume reduction and thus was used for subsequent experimentation. In the second stage, the maximum volume reduction achieved in the normal operating range of 6% to 8% of bentonite was 53.6%. An overall maximum volume reduction of 65% was achieved for the most dilute slurry of bentonite tested, *ie*, 4%. The stability of the natural sodium bentonite suspension could be seen from the fact that a blank run of the 7% slurry under similar conditions gave a volume reduction of only 2% in 24 h.

The change in the final volume reduction with variation in depth of the column from 2 m to 0.5 m was found to be statistically insignificant. Thus, it could be concluded that the contribution, if any, of compression settling to the final volume reduction was insignificant. The

dominant mechanism in the system under consideration was essentially expulsion of interlayer water due to exchange of associated cations, thus leaving no scope for compression settling.

Model Development

As the processes involved in this system of volume reduction were purely physical, a relationship was developed between the controllable variables⁷. The control variables are the dose of gypsum, percentage of bentonite in the slurry, the time of settling and the percentage volume reduction. The following relationship was obtained by means of non-linear multiple regression by method of least squares.

$$V_r = 0.0107d + 23.041 \log_{10}(t) + 199.055(W_b)^{-1.2545} \quad (1)$$

where V_r is the percentage volume reduction of the slurry; d , dose of gypsum applied in g of gypsum/kg of bentonite in the slurry; t , quiescent settling time allowed, h; and W_b is the percentage by weight of bentonite in the slurry.

The overall goodness of fit, *ie*, coefficient of multiple determination (R^2 value) of the entire data set of 390 values was 0.80.

Further, the data was also split into seven segments corresponding to 4%, 5%, 6%, ..., 10% of bentonite present in the slurry. An equation of the type,

$$V_r = C_1 d + C_2 \log(t) \quad (2)$$

which was fitted to each individual segment. The individual goodness of fit (R^2) values was reported in Table 1 and for each data segment R^2 values shown in equation (1). These values were comparable to the individual goodness of fit. Therefore, the general equation (1) was sufficient to describe the entire data set and separate equations of the type (2) were not needed.

The patterns of percentage volume reduction for various combinations of dose of gypsum and settling time for an initial bentonite content of 6% are shown in Figure 2. Similar patterns of percentage volume reduction could

Table 1 Values of coefficient of multiple determination with bentonite content

Percentage of bentonite	R^2 (individual)	R^2 (combined)
4	0.78	0.63
5	0.88	0.85
6	0.90	0.90
7	0.88	0.88
8	0.89	0.76
9	0.83	0.80
10	0.98	0.96

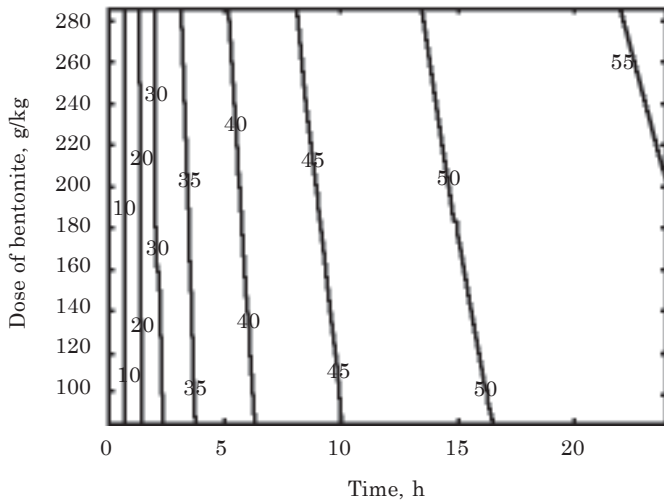


Figure 2 Patterns of percentage volume reduction for various combinations of dose of gypsum and settling time for an initial bentonite content of 6%

be derived for other percentages of bentonite in the slurry from equation (1). Figure 3 described the experimental and regression relationship between percentage volume reduction and dose of gypsum for an initial bentonite content of 6%, which demonstrates linear increase of percentage volume reduction with dose of gypsum.

The experimental and regression data of percentage volume reduction *vis-à-vis* percentage of bentonite for minimum and maximum gypsum dose are shown in Figure 4. Therefore, as expected from the viscosity curves shown in Figure 1, the percentage volume reduction decayed exponentially with increase in bentonite content for a wide range of gypsum dose. The effect of reaction and settling time on percentage volume reduction for the extreme values of initial bentonite percentage in the slurry for a specific gypsum dose (142.86 g/kg of

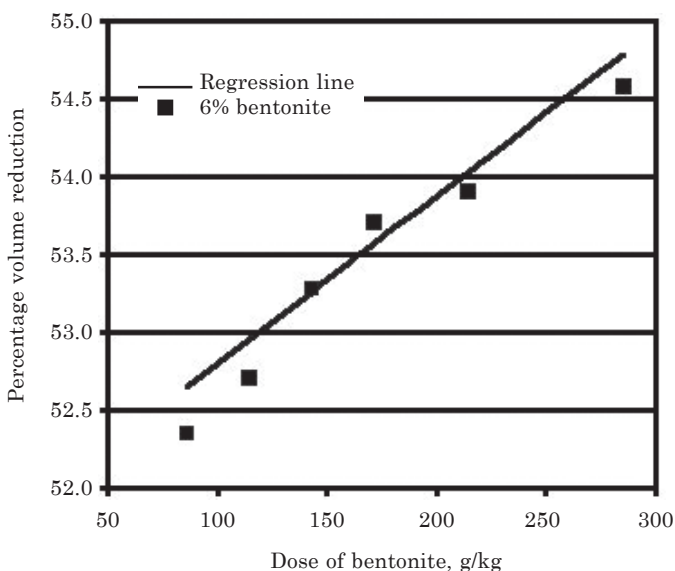


Figure 3 Variation of percentage volume reduction with dose of gypsum for an initial bentonite content of 6%

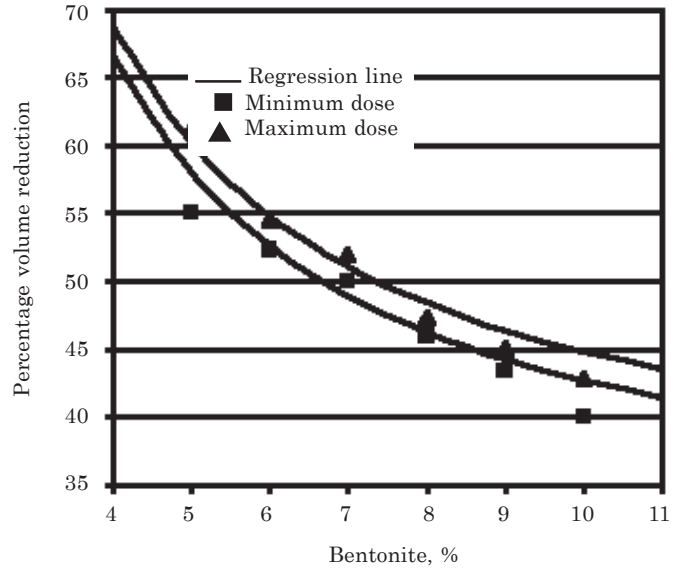


Figure 4 Variation of percentage volume reduction with initial bentonite content for the minimum and maximum dose of gypsum

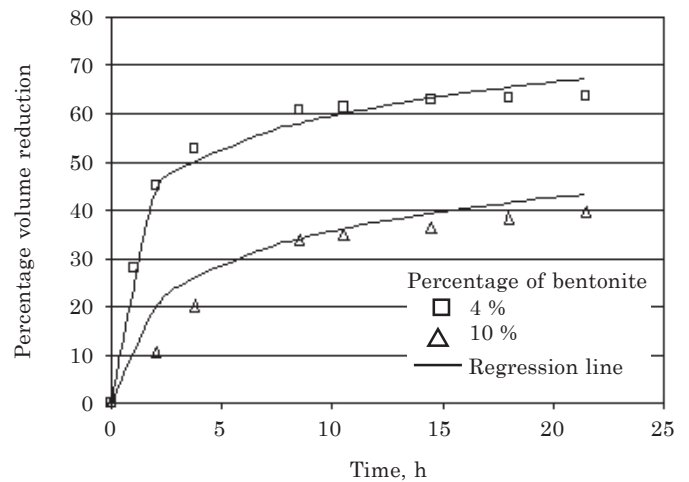


Figure 5 Variation of percentage volume reduction with time for initial bentonite content of 4% and 10% at a dose of gypsum of 142.86 g/kg of bentonite

bentonite) has been shown in Figure 5. It was noted that in all cases, close to 90% of the final percentage volume reduction was obtained in the first 8 h.

Effect of Dilution

It was observed from Figure 5 that slurries containing a lower initial percentage of bentonite gave higher settling rates. This fact suggested that dilution of the slurry to a very low bentonite content might prove to be a good management alternative. However, dilution would be meaningful only if the treatment (*ie*, addition of gypsum and settling) of the diluted slurry produces higher solids content in the settled slurry than that of undiluted slurry. As, higher solids content implied less volume of waste slurry for final disposal. Maximum values of final solid content in the settled slurry obtained have been shown in Table 2. The experimental results revealed that the

Table 2 Final maximum solids content

Initial bentonite content, %	Final maximum solids content, %
4	11.53
5	12.59
6	12.84
7	15.81
8	16.32
9	16.38
10	16.54

final solid content increased with increase in the initial bentonite content. Thus, dilution of the slurry prior to treatment was not advantageous, as it would result in an increase in the final volume of slurry to be disposed. For example, slurry when diluted from 10% to 5% bentonite prior to treatment would increase the volume for final disposal after treatment by 34.3%. That is, viscosity reduction in the working range of bentonite in the slurry has not reduced the volume of waste slurry for final disposal. This fact further reinforced the reasoning that the dominant mechanism in this treatment was the expulsion of interlayer water, with almost no contribution of classical settling mechanics.

Final Disposal

The final disposal of slurry has to be environmentally sustainable. Once, the aim of increasing the bentonite content of the slurry was achieved, the volume reduced, thus making handling easier. Also the final sludge was apparently semi-solid and contained a large number of other inorganic particles like silt and sand, apart from bentonite.

One of the effective methods of disposal would be using the slurry as a daily cover material in sanitary landfill

operation. Landfilling requires a daily cover of 100 mm to 150 mm of native soil^{2,8}, which might be advantageously replaced by the bentonite slurry. A small landfill site of about 0.1 acre would accommodate the entire volume of 50 m³/day as daily cover from a typical construction site taken up in this study. The final sludge containing bentonite clay might also be used in water treatment for the removal of heavy metals from the water⁹. The supernatant fluid generated after volume reduction was clear water having suspended solids less than 30 mg/l, was well within the local standard of disposal in public sewers of 600 mg/l and of disposal in inland surface waters of 100 mg/l⁸.

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