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Bentonite and polymeric support fluids used for stabilization in excavations

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Abstract

Bentonite is a natural and finite mineral resource. Dilute suspensions of sodium montmorillonite clay in water represents bentonite slurries. Suspension and orientation of colloidal clay particles define rheological properties in bentonite slurry (BS). The BS has been used about seventy years to temporarily support the excavations. More recently, polymer support fluids (PSF) gained much popularity and are widely used compared to bentonite support fluids. The PSF are categorized into natural (pure) and synthetic polymers. Physico-chemical properties of PSF are different than BS irrespective of the quite similarity in the mode of action. Synthetic polymer fluids are molecularly engineered fluids that can be a popular alternative of conventional BS deployed as excavation support fluids in different foundation applications such as diaphragm wall panels and pile bores. The synthetically engineered fluids of polymers (water-soluble) are different from conventional BS. The PSF offer additional benefits because their use is cost effective, eco-friendly, and these polymers need smaller site footprint as well as easy preparation, mixing, handling, management and ultimately the final disposal. Nevertheless, synthetic polymers have advantage over bentonite, however, foundation engineers and scientists have also certain concerns about their use because of their performance related issues. For an efficient use of polymers, specific properties and *in situ* behavior of polymers as well as their sorption onto the soils must be recognized because the polymer concentration in the solution is decreased with time during their use. The present manuscript reviewed the relative performance of excavation support fluids and displayed an arranged marriage of physicochemical and rheological properties of natural and synthetic excavation support fluids used in the foundation industry. This information will be highly useful to scientific community for their future ventures and will lay a foundation to understand the mechanisms of stabilization in open and deep excavations.

1. Introduction

Support fluids (sometimes termed as muds or slurries) are referred to the resultant compounds of admixture of manufactured materials and water and that support the sides of open and deep excavations prior to filling of these excavations. Supporting fluids are generally based on bentonite clay (BC), natural or synthetically produced polymers or blending of both bentonite and polymers. Use of excavation support fluids (ESF) in diverse geotechnical and civil engineering operations such as drilling, piling, tunneling (slurry), diaphragm walling, and investigation boreholes (drilling) for stabilizing the excavation until the installment of a permanent element (e.g., liming, concrete etc.) is a common practice in many countries of the world [1].

Bentonite denotes the clays having characteristics of swelling and gel formation upon hydration and dispersion in water. The name 'bentonite' was denoted to such clay (natural sodium bentonite in nature) after its discovery in the 19th century near Fort Benton, USA [2]. Since the trendsetting results reported by Veder [3], bentonite support fluids (BSF) such as bentonite clay (BC) has been widely used for supporting side walls of excavations in permeable and unstable strata prior to concretion while constructing board piles and diaphragm walls [4-5]. Due to distinctive bentonite characteristics (better expansion on hydration, high viscosity, and ability for gel-slurry formation), the BC

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(e.g., aluminum silicate clay) is commonly applied for making drilling fluid in mud rotary drilling process of water wells. During well development, use of low-quality BC can clog the aquifer due to formation of thick wall cake that can be difficult to remove compared to the wall cake formed by high quality bentonite because such cake can be easily removed.

Similarly, polymer support fluids (PSF) have also gained tremendous success in the foundation industry since their use form early 1990s [6]. Polymers can be categorized as naturally occurring polymers and synthetically produced polymers. Natural polymers are naturally the derived products whereas synthetic polymers are the blending products of different polymers. These polymer fluids are more ecological and operational friendly due to their easy mixing, easy handling, and low cost compared to BSF [1, 7-9]. Nevertheless, polymer use is associated with pile bore stability and soft toe risk at the pile base due to less particle holding capacity and fast settling compared to BC [10]. Although, both bentonite (mineral) and polymer (synthetic) slurry function in almost similar mode/fashion and same testing procedures such as pH, viscosity, density, and sand contents are applicable on both ESF, however, synthetic slurries have advantage due to lack of gel strength. Although, both fluids function in a similar way by exerting a hydrostatic pressure on the excavation side walls to ensure its stability; however, their composition and characteristics are quite different. The present manuscript will review the excavation support fluids used in civil and geotechnical applications and will provide valuable information to the engineers and scientist community working in the foundation industry.

2. Types of excavation support fluids

Two types of excavation support fluids are commonly used in many applications. Figure 1 depicts these two types of supporting fluids used in excavations.

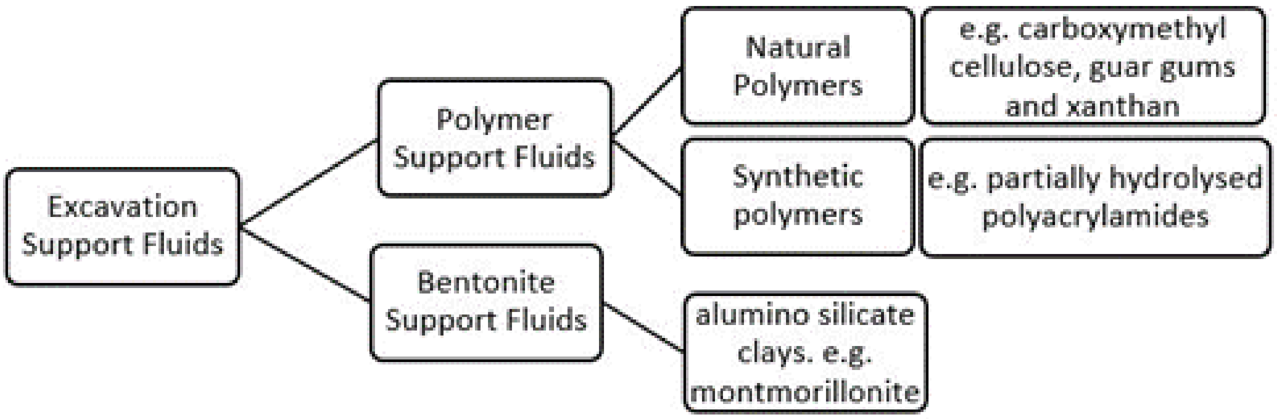

Figure 1. Types of excavation support fluids used in different operations

2.1. Bentonite support fluids

The BSF are broadly used in different engineering applications such as (i) panel excavations sides for diaphragm walls are supported by producing a barrier or a filter cake (FC) on the sides to avoid/prevent fluid loss into the ground, and by providing a surface mat to resist external pressures, (ii) for constructing large diameter bored piles, (iii) for making boreholes of small diameter for site

Investigation activities in unstable strata, (iv) for constructing cut-off walls below ground to generate barriers to groundwater. Bentonite slurry (BS) has been used for more than six to seven decades to support the excavations temporarily such as bored piles and diaphragm walls.

The excavation concept by deploying BS to form a continuous structural wall was advanced by Veder [11-12] in well drilling by using supporting muds known from earlier times [1]. Hajnal et al. [13] reported that relatively smooth diaphragm walls were obtained in 1950 and concrete diaphragm wall concept was established by the late 1950s. In earlier applications, excavation support was carried out by the fluids of clay nature, particularly montmorillonite (bentonite) clay of swelling form enriched with high sodium (Na). Types of silicates and bentonites are represented in Figure 2. The BC is a special clay originating from weathered ash that can swell approximately ten times higher than its original volume upon complete mixing with water or when fully hydrated.

Most bentonites available on commercial scale are hydrated alumino silicates containing the predominant mineral montmorillonite i.e., derived from a clay type discovered near Montmorillon in France. Most common types of bentonites include (i) natural Na-bentonite, (ii) natural Ca-bentonite, (iii) Na-activated bentonite. The cation exchange capacity (CEC) of these bentonites is much higher than other clays e.g., ball clays, china clay, and attapulgite. Although expensive, natural Na-bentonite has high swelling capacity than natural Ca-bentonite. To overcome the cost factor, with similar characteristics of Na-bentonite, Na-activated bentonite is produced by replacing Ca ions with Na ions in natural Ca-bentonite with the addition of soluble Na_2CO_3. Today, Na-activated bentonites are widely used in foundation industry. Nevertheless, in case of bentonite applications, large ancillary plant is needed for different process steps such as mixing, cleaning etc.

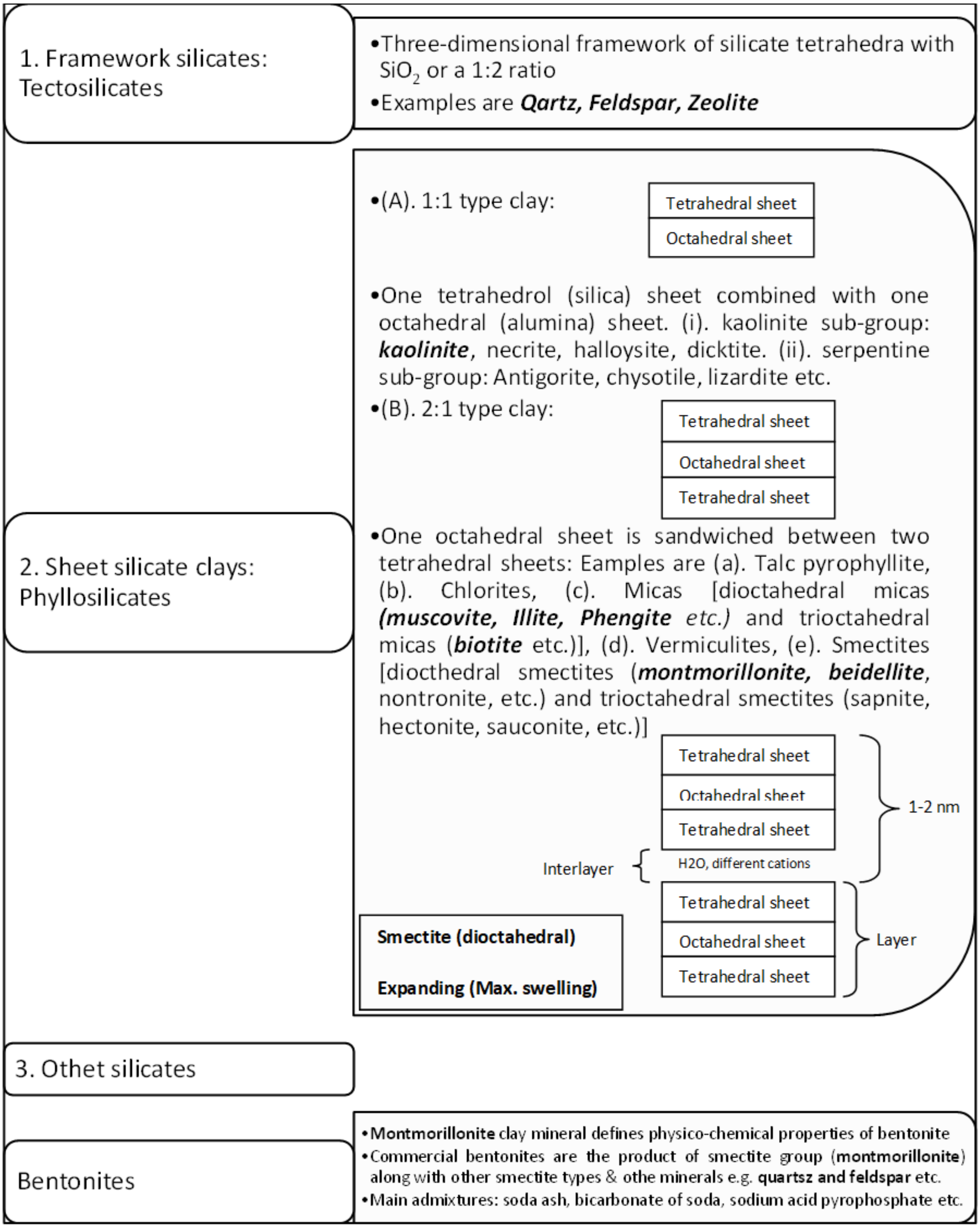

Figure 2. Types of silicates and bentonites

2.2. Polymer support fluids

With the passage of time, polymer modification of bentonites has been emerged to meet the requirements of geotechnical and civil engineering industry and many bentonites that are significantly polymer modified are available today. With polymer modification, properties of moderately active bentonites can be developed to use in excavation supports and with high rheological properties (e.g., viscosity and gel). Addition of polymers to BC can be carried out during their production or at the time of their use. Polymer addition to bentonite at the time of using the polymer/bentonite system should be done by keeping in view the slurry formulations; otherwise, their effectiveness is questionable. Imprudent mixing of bentonite/polymer in the field does not give the desired results. Furthermore, for effective use of these polymers, their use is warranted with specification as well as with an expert's advice. Polymer fluids have advantages in terms of smaller site footprint, easy mixing of fluids, and better concrete-sand interface resistance [5, 7, 14].

2.2.1. Natural polymers and natural modified polymers

Earlier used polymers are termed as pure polymers that are naturally derived products e.g., guar gums, hydroxypropyl guar (HPG- gum derivates), xanthan gum (additive), carboxymethyl cellulose (CMC), polyanionic cellulose (PAC) lignite, hydroxyethylcellulose (HEC) [1, 15-20]. The CMC in the form of its Na salt is used to modify the rheological properties of aqueous liquids. Natural polymers were used sporadically since four to five decades. These pure polymers were used alone or in combination with bentonite and/or natural clay dispersed into the slurry from the excavated formation. As natural polymers are biodegradable, therefore, their use is limited only to those processes/operations in the construction industry where biodegradation is desirable such as in permeable reactive barriers and deep drainage trenches [21]. Due to biodegradable nature of naturally derived polymers, these materials should be used generally with biocide. In addition, dispersion of fine clays (clays into excavation) is not inhibited by natural polymers like bentonite, thus, necessary cleaning is required prior to their re-use.

2.2.2. Synthetic polymers

Advanced development of fluid systems has been achieved with the invention of synthetic polymers by blending of different types of polymers. Many synthetic polymers used in the construction or foundation and geotechnical industry are simply partially hydrolyzed polyacrylamides (PHPAs). The PHPAs bring the breakthrough in deep foundation construction industry in the early 1990s. Earlier, PHPAs have been used in oil and gas industry as bentonite additives for inhibition of swelling of water-sensitive shales and reduction of fluid loss in permeable formations [22-24]. The PHPAs fluids gain popularity by replacing BS in civil engineering due to less site requirement for fluid management and easy and readily operation of excavation. The PHPAs are water soluble synthetic polymers of high molecular weight typically between 12 and 17 million g/mol [25] with negatively charged molecules and can form non-Newtonian solution when dissolved in water [24]. The density of these high-molecular-weight polymers is almost similar to water, but their viscosity is much higher than water. Unlike bentonite, these polymer fluids are gel less when these fluids are not disturbed (nonthixotropic), display low yield stress and high viscosity (10^5 MPa · s) when shear rates are low [24, 26]. If proper slurry management is done, then synthetic polymers can be repeatedly reused till the completion of the operation. Nevertheless, the addition of fresh polymer is required because the polymer concentration is decreased with time due to their potential sorption onto soil surfaces. Due to resistant nature of synthetic polymers to biodegradation, these materials can be used without biocide [1].

3. Testing protocols for support fluids

Properties of support fluids are interdependent and require a range of tests rather than a single test. Serial simple tests reflecting the rheological properties are conducted because on site rheological properties are rarely measured. Different support fluids are listed in Table 1.

Table 1. Testing protocols for supporting fluids

Parameter	Unit/Basis	Instrument /Protocol
Density (ρ)	g/ml	Mud balance or protocol for precision weighing
Sand content	% vol.	Protocol for sand content measurement
Rheological characteristics-Viscosity	s/qt	Fann viscometer (hand cranked and electrically driven viscometers), flow cones-Marsh funnel
Gel strength	lb/100 ft^2 (N/m^2)	Shearometer
pH		pH meters or litmus or pH papers
Filtration/fluid loss	ml after 0.5 hr	American Petroleum Institute standard fluid loss protocol
Thickness of filter cake	mm after 0.5 hr	American Petroleum Institute standard fluid loss protocol

4. Formation of bentonite slurry and its reuse

Figure 3 represents the layout of BSF in terms of bentonite types, slurry formation, characteristics, functions, and reuse of BS. The BS is prepared form bentonite powder by achieving maximum hydration. The use of salt water or water containing Ca or Mg should be avoided otherwise the desired dispersion will be inhibited. However, the Ca can be removed as a precipitate of $CaCO_3$ by using an appropriate amount of Na_2CO_3, and Mg can be removed with an alkali such as NaOH. The amount of bentonite powder to make slurry depends on the bentonite quality and desired viscosity of the slurry. Generally, concentrations between 4 to 6% on weight basis are used in many applications [2]. Swelling of bentonite particles takes place by absorbing water after dispersion phenomenon. Viscosity and gel strength of the slurry is linearly related to the mixing and agitation. The slurry should be stored at least 12 hours prior to its use; however, it can be immediately used even after mixing if the properties are suitable for its use. Important parameters need to be tested for BS includes rheology, density, sand contents, pH, and segregation processes of slurry such as filtrate loss (fluid loss), settlement, bleed (separation of water from solids) and syneresis.

By careful monitoring and controlling the characteristics of BS, it can be reused. Whatever system of the excavation is used, loss of slurry will be occurred. The lost slurry should be replaced and blended with fresh slurry. Accumulation of clay and silt sized particles can increase the density and Marsh viscosity (measured viscosity with marsh funnel). The pH of slurry can be changed due to contamination with cement, acids, or acidic groundwater. To adjust the properties, bentonite powder can be added to the slurry or admixtures and pH can be readjusted by the addition of $NaHCO_3$ (if pH ↓) or Na_2CO_3 (if pH ↑), viscosity and flocculation can be corrected by organic thinners or polyphosphates, and fluid loss can be reduced by using CMC. At completion of the operation, the BS can be disposed of safely in an appropriate landfill because bentonite is a non-hazardous waste. Nevertheless, care should be taken into account so that BS should not be released into an aquatic environment, otherwise, it could be highly polluting for aquatic biodiversity.

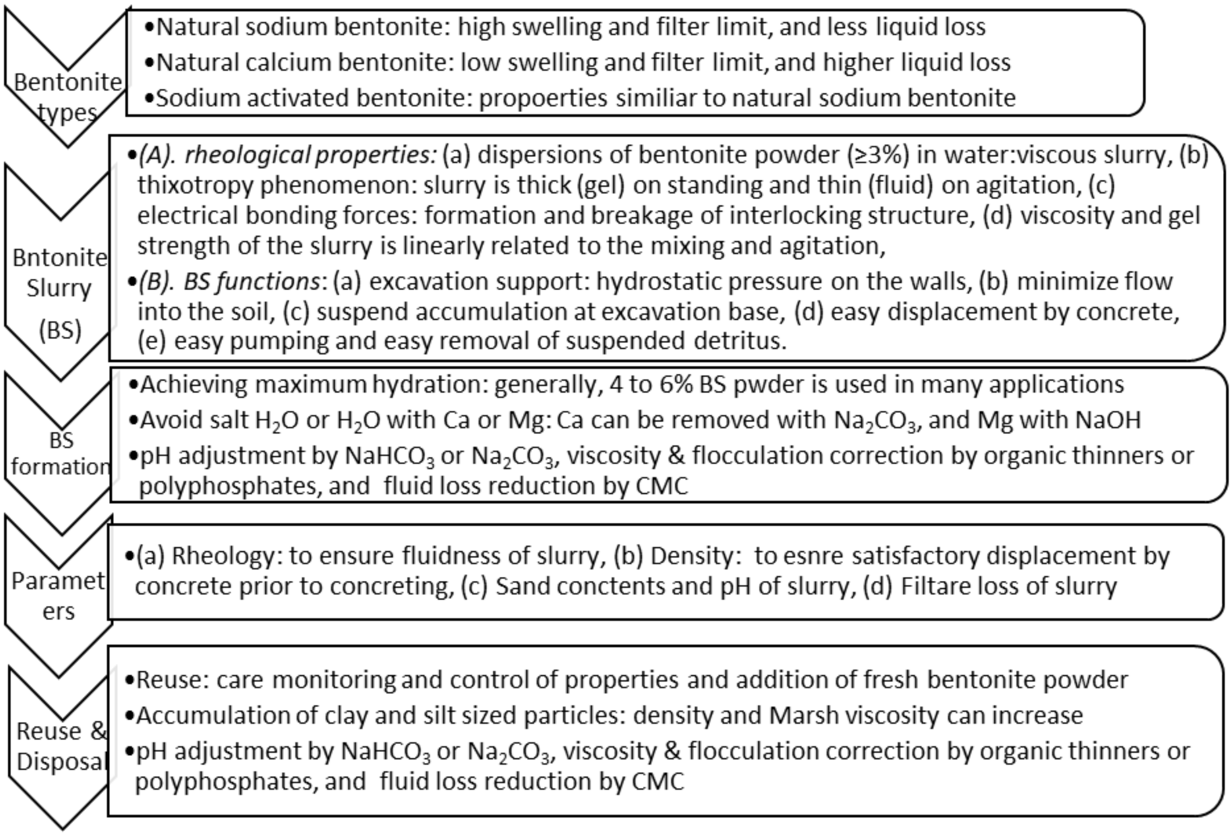

Figure 3. Bentonite support fluids: bentonite types, slurry formation, characteristics, functions, and reuse of BS

Formation of a filter cake (FC) on the side walls as a stabilizing mechanism in permeable soils (gravel and sand) is a well-documented phenomenon in pertinent literature. For stability of coarse unconsolidated soils, the slurry induced hydrostatic pressure is applied against a barrier/membrane created by the slurry [27]. The slurry penetration into ground until the gel strength of the slurry acting over the penetrated area of soil particles is enough to prevent further slurry penetration that can be ascribed to FC assisted by rheological blocking [5]. Bentonite slurries should have characteristics to perform functions such as (a) exert hydrostatic pressure on the walls to support the excavation, (b) minimize flow into the soil, (c) suspend accumulation at the base of excavation (d) easy displacement by concrete, (e) easy pumping and easy removal of suspended detritus. In permeable soils, formation of BFC with bentonite slurry is important for stabilizing the excavation because bentonite platelets create viscosity and gel strength and shingle off to form BFC. Low permeability of BFC results in the reduction of fluid loss into the ground and stabilizes the excavation by providing a membrane/barrier against the applied hydrostatic slurry pressure [28].

The rheological properties of bentonites define their fitness for use in different engineering applications. Upon dispersion in water, natural Na bentonite and Na-activated bentonite formed minute plate-like particles with positive charges on the surfaces and negative charges on the edges. Dispersion of bentonite powder (≥ 3%) in water results in the formation of viscous slurry displaying thixotropic phenomenon (i.e., slurry is thick on standing and thin on agitation) due to plate like particle orientation in the slurry. Formation and breakage of interlocking structure due to electrical bonding forces results in the formation of gel from slurry (on standing) and fluid from slurry (on agitation), respectively [2]. Nevertheless, constant buildup of BFC with time can be a concern in terms of skin friction and load bearing capacity of the shaft.

In BS, bentonite concentration generally ranges between 2.5 to 5% on weight basis with fluid density ranges between 1.014 and 1.028 g/cm^3, while the concentrations of synthetic polymers in mix water ranges between 0.05 to 0.2% on weight basis with ρ

(density) of a clean polymer fluid is effectively the same as that of water because of low polymer concentration used [1, 5]. Contrarily, long molecular chains in synthetic slurry produce viscosity in water with little to no gel strength and gel membranes are created in and near borehole pores [27]. Solid surfaces absorb the segments of long molecular chains and chemical net is created due to bridge formation across the soil's grains. Highly viscous solution is produced by synthetic polymers (mainly PHAPs) due to the interaction of molecules of high molecular weight having functional side groups with ionic charges through hydrodynamic and electrostatic forces that bind soil particles. However, molecular induced viscosity is sensitive to different external influencing factors such as ground contaminants, shearing of pumping, and *in situ* physico-chemical interactions [9, 29-31]. Synthetic slurry gel membrane is broken easily with high alkalinity and $CaCO_3$ contents of cement [27]. Cement can displace synthetic slurry in the shaft and slurry can be pumped for reuse after proper testing.

5. Rheological characteristics of PHPAS polymer support fluids (PSF)

Rheological properties of BSF are reported in pertinent literature [32-34], but Rheological properties of PSF are scarcely documented [24]. The rheological characteristics of PSF might also affect the fluid loss from the excavation and influence its stability. Although, the mode of action of both supporting fluids (i.e., BSF and PSF) is quite similar and both fluids exert pressure for stabilization against the side walls and base of the excavating structure, however, they display differential impacts on the excavating structure and completed foundation element primarily due to their differential rheological properties. During excavation, BS forms a FC layer on soil surface that is exposed while PSF do not form a FC layer, rather than PSF fluids flow continuously into surrounding soil formations because of pressure head difference of >15 kPa between groundwater and the surrounding soil formations [24, 26]. The fluid flow rate is dependent on PSF shear viscosity [35]. Because soil particles settling velocity in fluid depends on viscosity and elasticity, therefore, reasonable amount of detritus accumulation takes place at the basal part of excavation or at the upper (top) part of fresh concretion as it is termied into the hole [36-37]. Sedimentation of soil particles occurs in creeping flow regime (Reynolds number, $R < 1$) without influencing by fluid elasticity in agreeing with [38] who also reported no effect of fluid elasticity on the particle drag when Deborah number (De) < 0.1. The De number defines the ratio between fluid's characteristic time of and process's characteristic time. For steady state flows, De = 0. Although, settling of the large sized particles occurs with high R and De numbers and fluid elasticity has an influence on the dragging force that tends to increase it. Nevertheless, settling process of the large sized particles is fast and the sediment removal is easier prior to concretion. Therefore, in case of soil sedimentation process, steady state viscosity is more important than the fluid transient viscoelasticity. Lam et al., [24] also investigated these parameters (steady shear viscosity and transient viscoelasticity) of a PSF by performing serial oscillatory tests and reported that the viscoelastic characteristics of PSF are quite different from the counterpart BSF. These authors reported that PSF used in construction showed non-Newtonian activity at shear rates relevant to the construction work and recommended that the obtained results are useful to investigate the related issues during excavation such as sedimentation of particles in fluids and soil liquefaction mitigation.

6. Wise use and misuse of polymers: advantages and drawbacks

Advantages/benefits through proper use and failures/drawbacks through abuse of polymers are depicted in Figure 4. Polymer use within the specification of manufacturers and suppliers gives the satisfactory results. Polymers display their full effectiveness if they use within specifications and as per instructions of the expert's advice. Furthermore, in case of bentonite/polymer mixture use, imprudent mixing or injudicious use in the field does give satisfactory results.

7. Polymer chemistry: sorption mechanisms, flipping effect, and residual concentrations

Generally, the world polymer refers to molecules with repeating structural units such as rubber, plastics, DNA etc. In foundation industry, polymer is used for synthetic polymers commonly known as partially hydrolyzed polyacrylamides (PHPAs) (repeating units of acrylamides and acrylates belonging to family of acrylamide copolymers) or their derivatives [25]. The general formula of PHPAs is $[-(CH2CHCONH2)x-(CH2CHCOOH)y-]n$, where, subscript x = proportion of the acrylamide, subscript y = proportion of acrylic acid, and n = number of repeating units in a polymer molecule. In addition, certain additives are also used to improve the functions of the system such as fast settling of suspended soil particles, control of fluid loss, and fluid weighting for enhancing stability of the excavation. Fluid loss additives or modified additives resistant to high temperature such as 2-acrylamido-2-methylpropane sulfonic acid (AMPS) multi-copolymers are preferable choice in drilling fluid deployed for deep foundations (e.g., oil and gas exploration) because they contain more aromatic units in their structure [39-42]. Different aromatic polymers available as commercial polymers include polyesters, aromatic polyamides, heterocyclic polymers, polyimides, polysulfones [43-46]. Furthermore, synthetic polymers as fluid loss additives can improve interaction between polymer and bentonite via adsorption group (–CONH2, –SiOH, –OH, other cationic groups) and can enhance dispersive properties of bentonite via hydration groups (–COO– and –SO3–) [47-48]. Traditionally, PHPAs have been effectively used in different applications such as drilling of oil well, stabilization of soil for erosion control and treatment of water. Recently, these are also effectively deployed in geoenvironemntal and geotechnical applications.

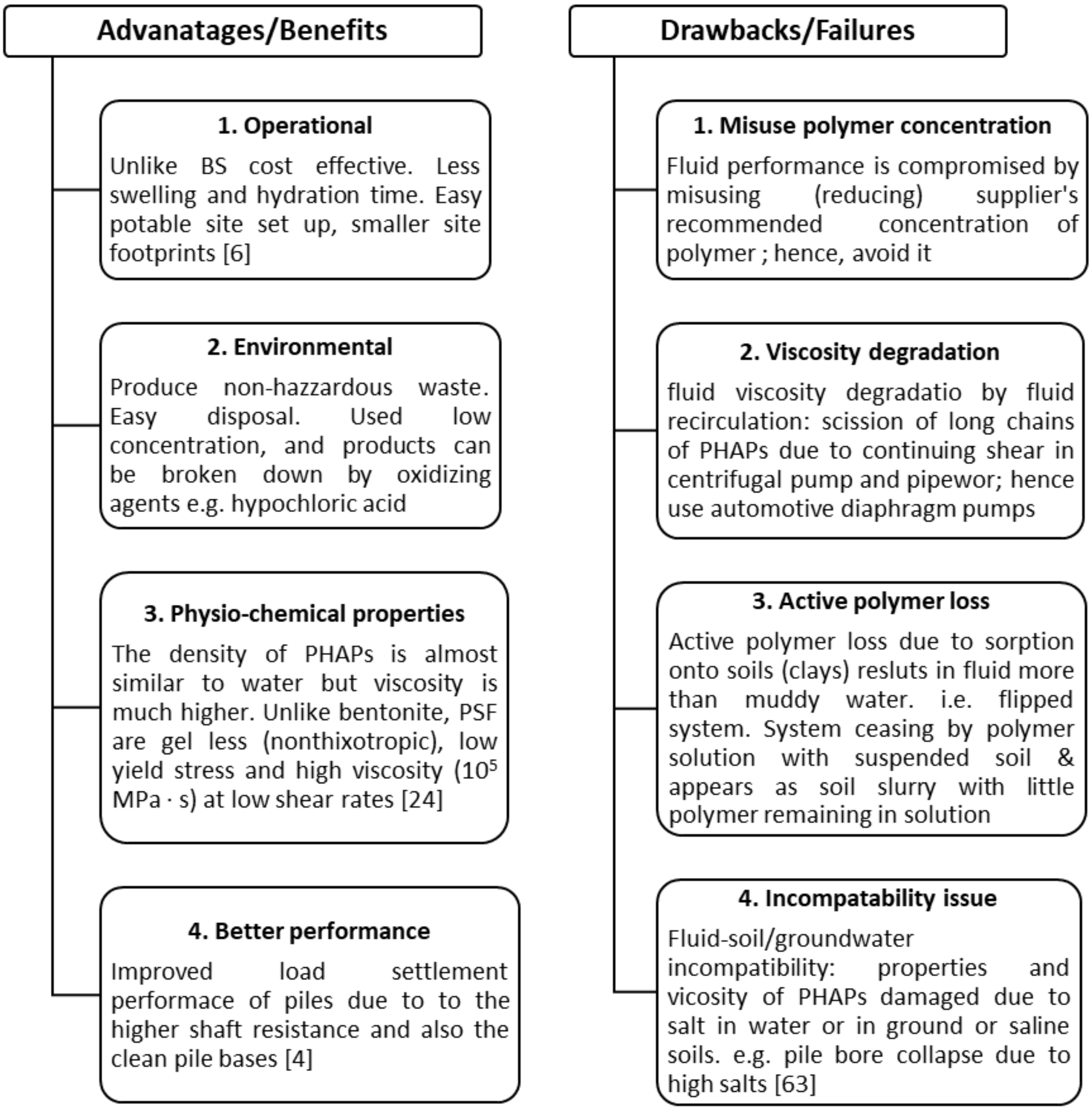

Figure 4. Advantages/benefits through proper use and failures/drawbacks through misuse of polymers

In a polymer supported excavation, polymer soil interactions are generally ignored and lacking detailed information about this subject. After repeated use, polymer fluids contain substantial amounts of suspended soil with no or polymer residual concentration in solution that can be ascribed to the action of digging equipment that can bring *in-situ* soils into fluid suspension. This is due to the relative settling velocity rates i.e., the fast-settling rate of larger particles compared to the slow settling rates of smaller particles (< coarse silt particles) that tend to remain in the fluid relatively for longer time periods due to high fluid viscosity.

In addition, surfaces of soils especially clay soils display sorption sites where sorption of polymer molecules can take place and the functional groups of these polymer chains can aggravate this sorption mechanism. The binding ability of the polymer molecules to soil particles is one of the important characteristics of the polymer fluids that allows interaction between molecules and soils at the excavation side walls and tend to reduce the swelling amount in clay soils or slaking in argillaceous rocks [49-51]. The interface shear strength between soil and foundation element seems to be not affected because there is no formation of FC during the process [30, 52-53]. The cut soil can be encapsulated as lumps by polymer molecules to prevent disintegration into smaller pieces apart from the coating effect. Therefore, the cut soil can fall out of suspension more rapidly so that the polymer fluids can remain relatively free of suspended soil [5, 54]. Because of polymer removal from the solution due to sorption onto the soils, their functions (the soil-binding & side-wall coating) can be reduced or even lost unless the suspended soil particles are removed, and fluid is reconditioned after its use by supplying the fresh polymer [55]. Fluid properties can be maintained by using sedimentation tanks and addition of the desired amount of new polymer materials to ensure that the cut soil settles without dispersing into the slurry. Nevertheless, fluid's filtration capacity can be improved by the addition of fluid loss additives [42, 56-58].

If the above stated steps are neglected, a mixture of water and native soil with no active polymer (absence of free polymer for development of solution properties including bonding to soil particles) will be formed. This phenomenon is referred as 'flipping effect' and the exhausted polymer fluid system is referred as a 'flipped' system [54]. When the fluid becomes flipped, then polymer becomes nonfunctional. Hence, a soft native soil FC can be formed in permeable soils and the slurry needs more efforts for functions as well as additional equipment are required for completion of the operation. Reversal of flipping fluid system is cost expensive and dispersion of soil cutting will take place. In such system, much more amount of polymer is required to satisfy the exposed bonding sites compared to a non-flipping fluid system (system with coarser lumps) [55]. Therefore, by considering the above scenario, there is a dire need for functional and practical methods/protocols for determination of residual polymer concentration (RPC) to access the flipping risk.

Polymer sorption onto the soil particles is an important phenomenon influencing their functional ability [59]. In this context, with the passage of time, different methods have been developed for estimating RPC after soil-polymer interactions. Taylor and Nasr-El-Din [60] reported seventeen different testing protocols/methods such as turbidimetry (simple) and electron spin resonance spectroscopy (advanced) techniques for measuring RPC. Bae and Inyang [61] used thermogravimetric analysis successfully for estimating RPC. However, these testing protocols have substantial variations in terms of accuracy of the results and complexity and equipment requirements. Jefferis & Lam [62] suggested the criteria for a testing protocol to satisfy the requirements of the industry. The authors reported that the testing procedure should be compatible with different polymer chemistries ranging from basic to complex polymer blends, avoid hazardous and radioactive materials, the equipment used in process should be the electrical dependent and potable, perform analysis in minimum time, and procedure should display the tolerance against the contaminates entering the polymer fluids from the excavation ground. The authors also tested three candidate techniques out of seventeen methods reported by Taylor and Nasr-El-Din [60] that were thematically based on total organic carbon content, fluid viscosity and absorption of ultraviolet light. Among these methods, technique based on the viscosity and density measurements showed the superior performance for polymer loss detection by sorption compared to other two methods. However, mud balance device used for onsite density measurements gives poor resolution, especially this device is not suitable for polymer fluid concentration control for both freshly prepared and/or re-used polymer concentrations [63], hence; more precise methods are needed for onsite density measurements. Nevertheless, new approaches for steady state flow (also based on modeling) are direly needed to describe the stabilizing mechanism of PSF. Mechanics and industrial processing of PSF can be robustly and accurately simulated by improved constitutive modeling [64].

7. Conclusion

Application of excavation support fluids (ESF) in the construction of deep bored piles and diaphragm walls is a well-known practice around the globe. Bentonite slurry (BS) is in practice around 60 to 70 years to temporarily support the excavations such as bored piles and diaphragm walls. Due to distinctive bentonite characteristics such as better expansion on hydration, high viscosity and ability for gel-slurry formation, bentonite clay (alumino silicate clays e.g., swelling type montmorillonite clay enriched with high Na) is commonly applied for making drilling fluid in mud rotary drilling process of water wells. In permeable soils, formation of bentonite filter cake with bentonite slurry is important for stabilizing the excavation because bentonite platelets create viscosity and gel strength. Viscous slurry is formed due to dispersion of bentonite powder in water by displaying thixotropic phenomenon. Gel viscosity and strength has linear relationship with mixing and agitation. Bentonite properties can be readjusted such change in pH by $NaHCO_3$ or Na_2CO_3, viscosity and flocculation by organic thinners or polyphosphates, and fluid loss by CMC.

The physico-chemical properties of modern polymer support fluids (PSF) are quite distinct from BSF irrespective of the similar mode of action displayed by both polymer fluids and bentonite slurries. Use of PSF has both advantages and drawbacks. The PSF could be the possible alternative for BS especially in case of site space limitations. Advantages recommend their use due to simplicity of site operations, minimum environmental disturbance (eco-friendly) and improvement in foundation performance. Drawbacks impel our attention on the altered (reduced) fluid characteristics due to continued shear in re-circulating system, sorption of polymers onto soils and altered (lost) properties in saline soils/salty water. To combat the alterations in fluid properties and to minimize significant degradation in fluid performance, fresh polymer should be regularly augmented. Further research is needed for complete understanding of soil-polymer interactions, on site density measurements, direct measurement of residual polymer concentrations in solution, and to identify the mechanisms that determine the preferential use of PSF over BS. New approaches/protocols (that also include modeling) based on steady-state flow are direly needed to explain the stabilizing mechanism of PSF.

Conflicts of interest

The authors declare no conflicts of interest.

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