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BENEFICIATION OF NIGERIA LOCAL CLAY TO MEET API STANDARD SPECIFICATION FOR DRILLING FLUID FORMULATION. (A CASE STUDY OF ABBI CLAY DEPOSIT, DELTA STATE)

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ABSTRACT

Prior to the government's initiative to develop local content, the cost of importation of Bentonite for drilling activities in Nigeria runs to millions of dollar annually which has been detrimental to the economy of the country considering that about 5 to 15% of the cost of drilling a well which ranges between $1 million to $100 million accounts for drilling fluids .Therefore, it is imperative to locally outsource these clay materials in order to conserve foreign exchange, create employment and to enhance Nigerian content development in the drilling component of oil and gas industry. The objective of this study is to investigate the rheological properties of local clay from Abbi town of Delta State, Nigeria, in other to ascertain its substitutability for foreign (Bentonite) clay. This research work was carried out by analysing the in-situ properties of the local mud sample and beneficiating it with 1.0g of potash and the result was compared with imported Bentonite using the API (American Petroleum Institute) specifications. It was established from analysis of Abbi local mud sample that the parameters such as the sand percentage composition, power law index, density, marsh funnel viscosity, etc of the local mud met the minimum required specifications, while other few rheological properties such as viscosity was seen to be slightly below the standard requirement of 30cp and pH of the local mud fell below the standard range of 9.5 to 12.5 and therefore needed some additive treatment for favourable comparison with the foreign clay mud properties. This study will enable the performance of Nigerian clay to be benchmarked against the imported Bentonite and also ascertain that the utilization of this clay for any industrial application will pose no harm to surface and surface facilities and will in turn represent a value added to the Nigeria's economy by the total prevention of the importation of high quality activated foreign Bentonite clay.

Key-words: API, Rheological properties, Viscosity, Additives, Potash.

INTRODUCTION

The history of near modern drilling mud appeared in literature after the use of drilling mud in drilling Lucas well at spindle top in 1901. The modern history of drilling mud began in 1921 with the first attempt to control mud properties through the use of that purpose. Drilling operations in Nigeria began in the mid-fifties and local additives and clays were used on drilling fluids. Later in the early sixties, the use of local additives and clays for drilling in the petroleum industry subsided in Nigeria as a result of the introduction of imported commercial additives and Bentonite (Bindei, 1987).

Drilling fluid is made up of the solid part (i.e. clay), liquid part (i.e. water or oil), and additives Mud is referred to as a suspension of solid clay in water or oil. The kind of fluid that is mostly used in the field today is water-based mud (i.e. the suspension of solid particles in droplet of oil with little dispersed water). The drilling fluid consists of all the components of clay and additives which enable the removal of rock cuttings crushed in the subsurface during drilling operations.

The composition of any drilling mud depends on the requirement of a particular operation. Holes are always drilled through different types of formations that require drilling mud. Factors such as contamination, available make-up water, Temperature, pressure and many others are all significant in the choice of drilling fluid. An ideal drilling fluid must have rheological properties that enable the drilling fluid to lift the cuttings from the subsurface to the surface. This will depend on certain functions of the drilling fluid, which will be emphasized on subsequently

There are two primary types of drilling fluids: Water based fluids (WBFs) and Non-aqueous drilling fluids (NADFs). WBFs consist of water mixed with Bentonite clay and barium sulphate (barite) to control mud density and thus, hydrostatic head. Others substances are added to gain the desired drilling properties. These additives include thinners (e.g.lignosulphonate, or anionic polymers), filtration control agents (polymers such as carboxymethyl cellulose or starch) and lubrication agents (e.g. polyglycols) and numerous other compounds for specific functions. WBF composition depends on the density of the fluid. An example, WBF composition (in wt %) for a 1,190 kg/m (9.93 lb/gal) fluid is: 76wt% water, 15% barite, 7% bentonite and 2% salts and other additives. (National Research Council (US), 1983). NADFs are emulsions where the continuous phase is the NABF with water and chemicals as the internal phase. The NADFs comprise all non-water and non-water dispersible base fluids. Similar to WBFs, additives are used to control the properties of NADFs. Emulsifiers are used in NADFs to stabilize the water-in-oil emulsions. As with WBFs, barite is used to provide sufficient density. Viscosity is controlled by adjusting the ratio of base fluid to water and by the use of clay materials. The base fluid provides sufficient lubricity to the fluid, eliminating the need for lubricating agents. NADF composition depends on fluid density. The United States Environmental Protection Agency (USEPA) (1999a) presented an example NADF composition of (in wt %) 47% base fluids, 33% barite and 20% water. This example does not reflect a 2-5% content of additives such as fluid loss agents and emulsifiers that would be used in a NADF.

MATERIAL & METHODS

Sample collection and preparation

The clay sample used for this project work was collected at the appropriate depth of about 5ft and at appropriate horizontal strata where sodium, calcium and magnesium base elements tend to accumulate. The clay sample for this work was collected from Abbi town which is located in Ndokwa West Local Government Area of Delta State, Nigeria. It is located within Latitude 6.45^{0}E and Longitude 5.30^{0}N. Sample of Aqua gel clay from Abbi was then prepared using Multi-Hamilton Beach mixer, drying oven, triple beam balance/weighing balance, graduated measuring cylinder, spatula, mixer cup, tray, hand mortal and pestle, sieve, beakers and reagents like; Distilled water, sample, masking tape, recording book e.t.c.

The clay sample collected from Abbi was dried under moderate temperature spread out in a plastic tray in a drying oven. The dried clay sample was then subjected to pulverization by pounding it in a mortal. The pulverized clay sample was sieved to obtained fine powdered clay particles. The sieved clay sample was collected in a beaker and labeled appropriately using a masking tape. Then 17.5g, 21.0g and 24.5g of the fine clay sample was weighed using a spatula into separate mixer cups with the help of weighing balance and labeled appropriately. Then 350ml of distilled water is measured using a 500ml measuring cylinder into the already weighed clay samples. The mixture of the clay and water was stirred with the aid of multi-beach mixer for (2-5) minutes to obtain homogeneous mixture. The homogeneous mixture obtained was aged for 24 hours for proper hydration. After 24 hours of aging, the mud was re-stirred to re-agitate the mud for characterization.

Results:

Summarily, the above weighed sample was prepared accordingly with the addition of 350ml of water as indicated below:

i. A high concentration mud contains 24.5g of clay plus 350ml of water
ii. Medium concentration mud contains 21.0g of clay plus 350ml of water
iii. Low concentration mud contains 17.5g of clay plus 350ml of water.

EXPERIMENTAL PROCURE FOR DETERMINATION OF DRILLING MUD PROPERTIES

API RP-13B Standard procedures were employed throughout the laboratory work to determine rheological and fluid loss properties. All the sample mud are based on the formulation of 350 ml of fluid that contains only fresh water

DETERMINATION OF VISCOSITY

This test is done to obtain the marsh funnel viscosity of the different mud samples using a marsh funnel viscometer and a graduated cup using OFITE 900 MODEL viscometer and the following materials; freshly prepared sample, masking tape, recording book and biro.

PROCEDURE:

The cord of the viscometer was connected to the power source and the instrument switched on. The freshly prepared was poured into the sample cup of the viscometer

The ENTER button pressed and the rotor was allowed to rotate for few seconds for stabilization. The rotor sleeve was then immense until the mud touched the scribed line of the rotor sleeve. The mud button was pressed and the viscometer automatically carried out the measurement of the θ600rpm and θ300rpm. The equipment calculated the 10seconds and 10minutes gel strength. It was observed that at the end of the 10minutes, the machine displayed the value of plastic viscosity (PV), and the yield point (YP) along with 10 seconds and 10 minutes gel strength were displayed. These values were recorded in the table of result respectively.

pH DETERMINATION

The degree of acidity or alkalinity of mud is indicated by the hydrogen ion concentration, which is commonly expressed in terms of *pH*. A neutral mud has a *pH* of 7.0. An alkaline mud has PH readings ranging from just above 7 for slight alkalinity, to 14 for the strongest alkalinity, Acid mud range from just below 7 for slight acidity, to less than I for the strongest acidity.

pH measurements aid in determining the need for chemical control of the mud, and indicates the presence of contaminates such as cement and gypsum. The appropriate *pH* of drilling mud sample was determine using: Multi-Hamilton beach mixer and materials like; freshly prepared sample, phydrion dispenser paper, masking tape, recording book and biro

PROCEDURE

The freshly prepared mud was re-stirred to obtain homogeneous mixture. About one inch strip of the phydrion dispenser paper was removed and placed gently on the surface of the mud. Sufficient time was allowed to elapsed (about few seconds) for the paper to soak up filtrate and change colour. The soaked paper strip was matched with chart on the dispenser from which the strip was taken. The pH range of the mud was read and the value recorded in the table of result respectively. The procedure was repeated for other concentration of the mud.

DETERMINATION OF THE MUD WEIGHT

The mud density test was conducted in order to determine the weight per unit volume of the mud. Mud density must be great enough to provide sufficient hydrostatic heat to prevent influx of formation fluids, but not so great to cause loss of circulation, damage to the drilled formation, or reduce the rate of penetration (ROP). This test is done to determine whether the prepared local mud samples possess API minimum required weight for oil well drilling by using Multi-Hamilton beach mixer, Bariod mud balance with the following materials; Freshly prepared sample, rag, water, masking tape, recording book and biro.

PROCEDURE

The instrument base was set up so that it was approximately leveled.The freshly prepared mud was poured into a clean, dried mud balance cup. The lid was placed on the cup and set it firmly but slowly with twisting motion. It was ensured some mud spilled on the outside of the cup through the vent. Then the reading of the mud balance scale is taken and recorded properly against the mud type. The mud cup is then emptied, washed, dried and properly kept away for future use.

DETERMINATION OF SAND CONTENT

By definition, solid particles larger than 74 micros (200 meshes) are classified as API sand. (A micron is one (million) inch of a meter there are about 25, 400 microns to an inch) regular determination of the sand content of drilling mud is necessary because these particles can be highly abrasive, and can cause excessive wear of pump parts, drill bits, and pipe connections, excessive sand may also result in the deposition of a thick filter cake on the walls of the hole, or it may settle in the hole around the tools when circulation is temporarily halted, interfering with the operation of drilling tools of settling casing. The sand content test for set is used in the test for sand content determination using Bariod sand content set and freshly prepared sample, rag, water, and spatula

Procedure

The Baroid sand content tube was filled to mark "MUD TO HERE" with the formulated mud sample. Water was then added to the mark "WATER TO HERE". Then the tube was covered with thumb and shaken vigorously. The mixture of the mud and water was poured out through the screen, the held back sand were carefully washed to ensure that the mud sample was out in a gently running tap. The sand left in the screen was then washed back into the tube through a funnel that is fitted over and inverted slowly into the mouth of the tube. The quantity of the sand that settle in the calibrated tube was then read and recorded as the sand content of the mud in percentage by the volume of mud.

API Standard Tests and Analysis Values of Drilling Mud

When the mud is characterized or tested, the figures recorded down are compared with known standard values. The American Petroleum Institute (API) standard specification for all the montmorillonite clay family as contained in API practices 13A section 5 are as follows:

DriIlling Fluid Property	Numerical Value Requirement
Mud density (lb/gal)	8.65-9.60
Viscometer dial reading @600rpm	30cp
Plastic viscosity (cp)	8 – 10
Yield point (Ib/100ft2)	3 x plastic viscosity
Fluid loss (Water)	15.0ml maximum
pH level	9.5min – 12.5max
Sand content	(1 - 2)% maximum
Screen analysis	4 (maximum)
Moisture content	10% (maximum)
Ca 2+ (ppm)	2.50 (maximum)
Marsh funnel viscosity	52 – 56 sec/q+
Mud yield (bbi/ton)	91 (maximum)
API filtrate (ml)	30 (minimum)
Montmorillonite	70 – 130
Vermiculite	100 – 200
Illite	10 – 40
Kadinite	3 – 15
Chlorite	10 – 40
Marsh funnel viscosity for	26 sec/q+ ± 0

water	
N-Factor (power law index)	1 (maximum)
Yp/pv ratio	3.0 (maximum)

Table 3.0: API standard numerical value requirement for drilling fliuds

Beneficiation of Drilling Mud

For the prepared mud to be beneficiated it has to be aged and this aging will enable the mixture to hydrate properly and form homogeneous mixture, ready for characterization. Beneficiation is the treatment of the prepared drilling mud with enhancers such as viscosifiers, weightier polymer, thinners and pH raiser to improve the fluid properties for enhanced performance. The blending of the additives (beneficiation) can be done wet or dry. Dry blending can be achieved by mixing the dry clay sample with the additives in right proportion to enhance the properties of the mud (i.e. the blend plus water). For wet blending, accurate measurement of dry clay is blended with 350ml of fresh water and allowed to hydrate. If the wet blend is not adequately hydrated, the mixture will lack homogeneity.

RESULTS AND CONCLUSION

Results

For analysis of mud weight from table 4.6: The mud weight of the 24.5g clay concentration of sample mud was 8.60lb/gal before beneficiation took place. This is a little short of API minimum numerical value standard (8.65lb/gal). The mud weight of the foreign Bentonite sample was 8.70lb/gal. While on beneficiation with both 1.0 g Drispac and 1.0g potash the sample mud weight increased from 8.60lb/gal to 8.70lb/gal which now fell within API numerical value standard for drilling mud (i.e. 8.65lb/gal-9.60lb/gal). From table 4.5: The mud weight of the 21.0g clay concentration of sample mud was 8.60lb/gal before beneficiation took place. This is a little short of API minimum numerical value standard (8.65lb/gal). The mud weight of the foreign Bentonite sample was 8.70lb/gal. While on beneficiation with both 1.0 g Drispac and 1.0g potash the sample mud weight increased from 8.60lb/gal to 8.70lb/gal which now fell within API numerical value standard for drilling mud (i.e. 8.65lb/gal-9.60lb/gal). From table 4.4: The mud weight of the 19.5g clay concentration of sample mud was 8.60lb/gal before beneficiation took place. This is a little short of API minimum numerical value standard (8.65lb/gal). The mud weight of the foreign Bentonite sample was 8.70lb/gal. While on beneficiation with both 1.0 g Drispac and 1.0g potash the sample mud weight remained constant at 8.60lb/gal this is due to the fact that it's a low concentration mud. For analysis of mud pH from table 4.6: The mud pH of the 24.5g clay concentration sample mud was 6.0 before beneficiation took place. This showed that the sample mud was a little acidic and hence fell short of API minimum numerical value standard (i.e. 9.5). The pH value of the foreign Bentonite mud sample was found to be 9.0. While on beneficiation with 1.0g potash, the sample mud pH increased from 6.0 to 12.0 which then conformed to API numerical value specifications (i.e. 9.5-12.5). From table 4.5: The mud pH of the 21.0g clay concentration sample mud was 6.0 before beneficiation took place. This showed that the sample mud was a little acidic and hence fell short of API minimum numerical value standard (i.e. 9.5). The pH value of the foreign Bentonite mud sample was found to be 9.0. While on beneficiation with 1.0g potash, the sample mud pH increased from 6.0 to 12.0 which then conformed to API numerical value specifications (i.e. 9.5-12.5). From table 4.4: The mud pH of the 19.5g clay concentration sample mud was 6.0 before beneficiation took place. This showed that the sample mud was a little acidic and hence fell short of API minimum numerical value standard (i.e. 9.5). The pH value of the foreign Bentonite mud sample was found to be 9.0. While on beneficiation with 1.0g potash, the sample mud pH increased from 6.0 to 12.0 which then conformed to API numerical value specifications (i.e. 9.5-12.5). For rheological properties analysis, from table 4.6: The viscometer reading of the 24.5g clay concentration sample mud @600rpm was 2.70cp, this is a far cry from the 30cp API minimum numerical value standard for drilling mud. This showed that the viscosity of our local sample mud is very low. The viscometer reading for the foreign mud sample was 31.4cp. While on beneficiation with 1.0g Drispac, the mud sample viscometer readings improved from 2.70cp to 35.50cp. The gel strength @10mins also decreased from 1.0 lb/100ft² to 0.6 lb/100ft² when it was beneficiated with 1.0g of Drispac. From table 4.5: The viscometer reading of the 21.0g clay concentration sample mud @600rpm was 2.60cp, this is a far cry from the 30cp API minimum numerical value standard for drilling mud. This showed that the viscosity of our local sample mud is very low. The viscometer reading for the foreign mud sample was 21.1cp. While on beneficiation with 1.0g Drispac, the mud sample viscometer readings improved from 2.60cp to 33.20cp. The gel strength @10mins also decreased from 0.8 lb/100ft² to 0.4 lb/100ft² when it was beneficiated with 1.0g of Drispac. From table 4.4: The viscometer reading of the 19.5g clay concentration sample mud @600rpm was 1.70cp, this is a far cry from the 30cp API minimum numerical value standard for drilling mud. This showed that the viscosity of our local sample mud is very low. The viscometer reading for the foreign mud sample was 17.0cp. While on beneficiation with 1.0g Drispac, the mud sample viscometer readings improved from 2.40cp to 33cp. The gel strength @10mins also increased from 0.0 lb/100ft² to 0.4 lb/100ft² when it was beneficiated with 1.0g of Drispac. For sand content analysis from table 4.6: The sand content of the 24.5g clay concentration local sample clay mud was constant at a value of 0.38% which was within API numerical value standard of between 0.3%-1.0%. The sand cont of the foreign Bentonite mud sample was 0.3%. From table 4.5: The sand content of the 21.0g clay concentration local sample clay mud was constant at a value of 0.25% which was within API numerical value standard of between 0.3%-1.0%. The sand cont of the foreign bentonite mud sample was 0.3%. From table 4.4: The sand content of the 19.5g clay concentration local sample clay mud was constant at a value of 0.25% which was within API numerical value standard of between 0.3%-1.0%. The sand cont of the foreign bentonite mud sample was 0.3% For power law index analysis from the table 4.6: The "n"- factor value for the 24.5g clay concentration sample mud was 0.43. Upon beneficiation with 1.0g Drispac, the value increased from 0.43 to 0.80. The value for the "n"- factor for the foreign bentonite clay mud was 0.76. From the table 4.5: The "n"- factor value for the 21.0g clay concentration sample mud was 0.38. Upon beneficiation with 1.0g Drispac, the value increased from 0.38 to 0.80. The value for the "n"- factor for the foreign Bentonite clay mud was 0.56. From the table 4.4: The "n"- factor value for the 19.5g clay concentration sample mud was 0.50. Upon beneficiation with 1.0g Drispac, the value increased from 0.50 to 0.76. The value for the "n"- factor for the foreign Bentonite clay mud was 0.79.

CONCLUSION

From the above analysis, it was obvious that most of the parameters of the local clay mud such as: sand content, consistency index and power law index met the minimum required specification. While others such as: rheological properties, mud pH and mud weight needed little treatment with additives for favourable comparison with API standard for drilling fluid.

Local clay sample was successfully treated with readily available additives to improve its properties to meet API minimum specifications. A significant economic opportunity exists for large scale production of local clay in formulating drilling mud. But the clay must however be acquired at the right depth and strata to ensure good laboratory response to treatment.

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Clay concentration in 350ml of water (g)	Mud Weight (lb/gal)	Viscometer Reading (cp)		Mud pH	Mud gel strength (lb/100ft²)		Mud sand % volume	Mud PV (cp)	Mud AV (cp)	Mud YP (lb/100ft²)	"n" factor	"k" Factor @511
		θ600	θ300		10secs	10mins						
17.5	8.60	2.40	1.70	6.0	0.00	0.00	0.25	0.7	1.2	1.0	0.50	1.24
21.0	8.60	2.60	2.00	6.0	0.80	0.80	0.25	0.6	1.3	1.4	0.38	0.94
24.5	8.60	2.70	2.00	6.0	0.90	1.00	0.38	0.7	1.4	1.3	0.43	0.54

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APPENDIX

Table 4.0: result of sample mud without beneficiation after 24hrs of aging

Clay concentration in 350ml of water (g)	Mud Weight (lb/gal)	Viscometer Reading (cp)		Mud pH	Mud gel strength (lb/100ft²)		Mud sand % volume	Mud PV (cp)	Mud AV (cp)	Mud YP (lb/100ft²)	"n" factor	"k" Factor @511
		θ 600	θ 300		10secs	10mins						
17.5	8.60	33.00	20.90	12.0	0.30	0.40	0.25	14.6	17.8	6.3	0.76	1.58
21.0	8.70	33.20	19.00	12.0	0.30	0.40	0.25	14.2	16.6	4.8	0.80	1.15

24.5	8.70	35.50	18.90	12.0	0.50	0.60	0.38	14.1	16.5	4.8	0.80	1.14

Table 4.1: result of sample mud with beneficiation after 24hrs of aging using 1.0g drispac and 1.0g potash

Clay concentration in 350ml of water (g)	Mud Weight (lb/gal)	Viscometer Reading (cp)		Mud pH	Mud gel strength (lb/100ft²)		Mud sand % volume	Mud PV (cp)	Mud AV (cp)	Mud YP (lb/100ft²)	"n" factor	"k" Factor @511
		θ 600	θ 300		10secs	10mins						
17.5	8.70	17.70	10.20	9.0	0.10	1.50	0.30	7.5	8.9	2.7	0.79	0.65
21.0	8.70	21.10	11.60	9.0	0.20	5.10	0.30	9.5	10.6	2.1	0.56	3.27
24.5	8.70	31.40	18.50	9.0	0.70	12.10	0.30	12.9	15.7	5.6	0.76	1.39

Table 4.2: Result of Bentonite mud without beneficiation after 24hrs of aging

Clay concentration in 350ml of water (g)	Mud Weight (lb/gal)	Viscometer Reading (cp)		Mud pH	Mud gel strength (lb/100ft²)		Mud sand % volume	Mud PV (cp)	Mud AV (cp)	Mud YP (lb/100ft²)	"n" factor	"k" Factor @511
		θ 600	θ 300		10secs	10mins						
17.5	8.90	246.1	156.4	9.5	30.20	41.50	0.30	89.7	123	66.7	0.65	21.80
21.0	8.70	287.2	160.2	9.5	38.30	59.10	0.30	127	146	33.2	0.84	7.77
24.5	8.70	300.0	179.3	9.5	OR	OR	0.30	OR	OR	OR	OR	OR

Table 4.3: result of bentonite mud with beneficiation after 24hrs of aging using 1.0g drispac and 1.0g potash
***OR-out-of-range**

	Mud weight (lb/gal)	pH level	Viscometer Reading (cp)		Mud gel strength (lb/100ft²)		Sand content % volume	"n" factor
			@600	@300	10secs	10mins		
API numerical value specification (minimum)	8.65	9.5	30.0	30				
Sample mud before beneficiation (17.5g)	8.60	6.0	2.40	1.70	0.00	0.00	0.25	0.50
Foreign mud (17.5g)	8.70	9.0	17.0	10.20	0.10	1.50	0.30	0.79
Sample mud after beneficiation (17.5g)	8.60	12.0	33.0	20.90	0.30	0.40	0.25	0.76

API numerical value specification (maximum)	9.00	12.5					1.0	1.0

Table 4.4: comparison of mud properties with API numerical value specification (17.5g)

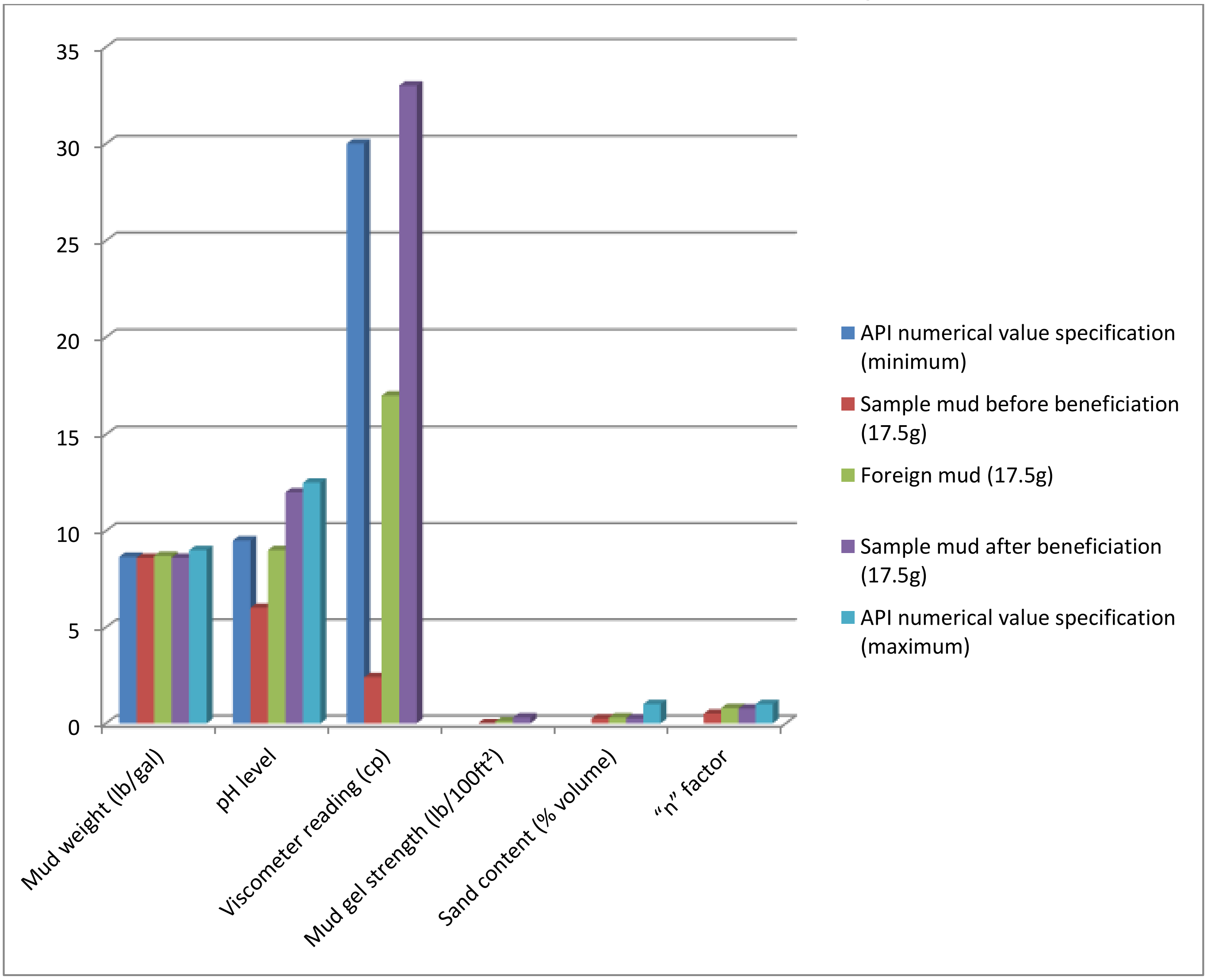

Figure 4.1: graphical comparison of mud properties with API numerical value specification (17.5g)

	Mud weight (lb/gal)	pH level	Viscometer Reading (cp)		Mud gel strength ($lb/100ft^2$)		Sand Content % volume	"n" Factor
			@600	@300	10secs	10mins		
API numerical value specification (minimum)	8.65	9.5	30.0	30				
Sample mud before beneficiation (21.0g)	8.60	6.0	2.60	2.00	0.80	0.80	0.25	0.38
Foreign mud (21.0g)	8.70	9.0	21.1	11.60	0.20	5.10	0.30	0.56
Sample mud after beneficiation (21.0g)	8.70	12.0	33.2	19.00	0.30	0.40	0.25	0.8
API numerical value specification (maximum)	9.00	12.5					1.0	1.0

Table 4.5: comparison of mud properties with API numerical value specification (21.0g)

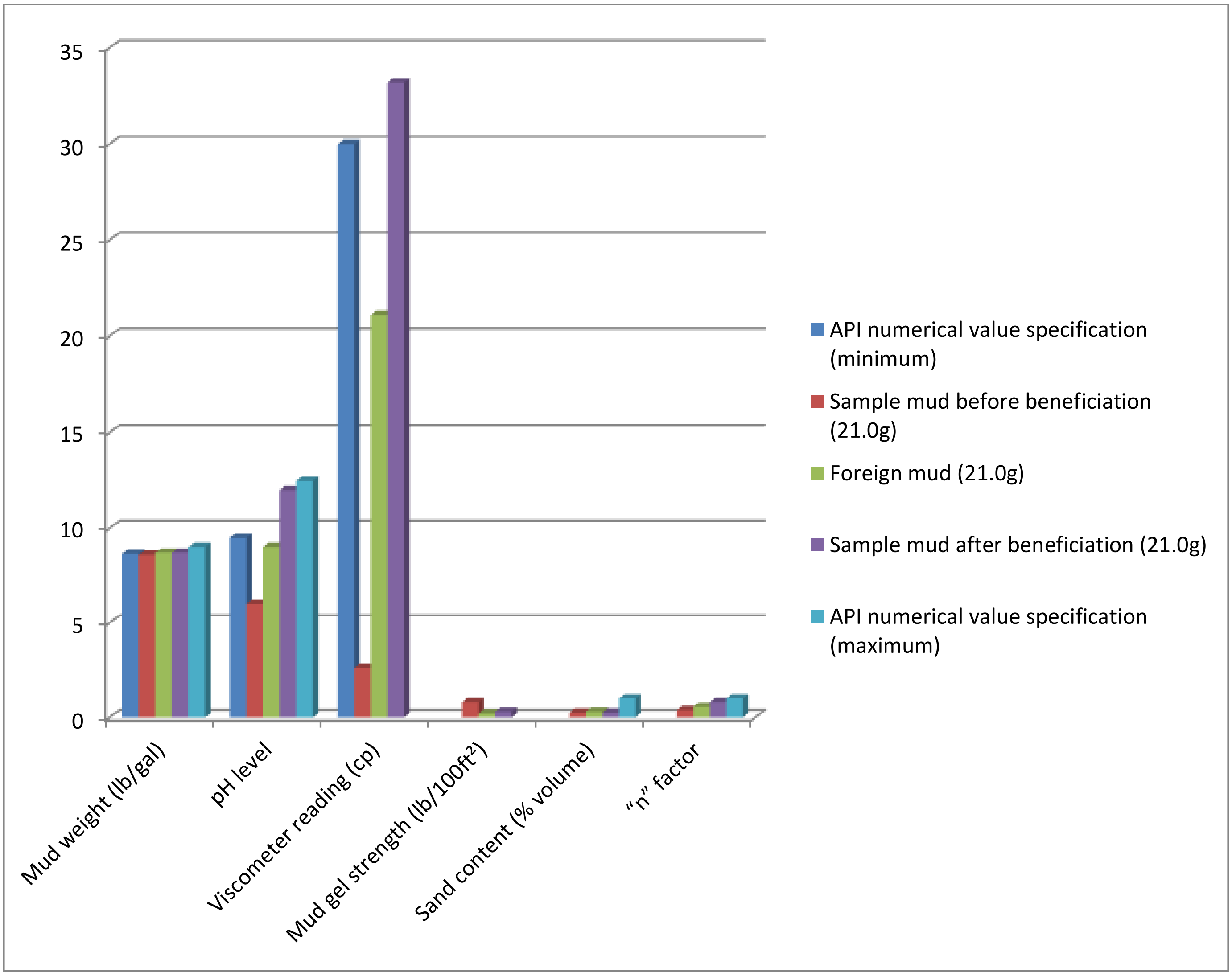

Figure 4.2: graphical comparison of mud properties with API numerical value specification (21.0g)

	Mud weight (lb/gal)	pH level	Viscometer Reading (cp) @600	@300	Mud gel strength (10secs	10mins	Sand Content % volume	"n" factor
API numerical value specification (minimum)	8.65	9.5	30.0	30				
Sample mud before beneficiation (24.5g)	8.60	6.0	2.70	2.00	0.90	1.00	0.38	0.43
Foreign mud (24.5g)	8.70	9.0	31.4	18.50	0.70	12.10	0.30	0.76
Sample mud after beneficiation (24.5g)	8.70	12.0	35.5	18.90	0.50	0.60	0.38	0.80
API numerical value specification (maximum)	9.00	12.5					1.0	1.0

Table 4.6: comparison of mud properties with API numerical value specification (24.5g)

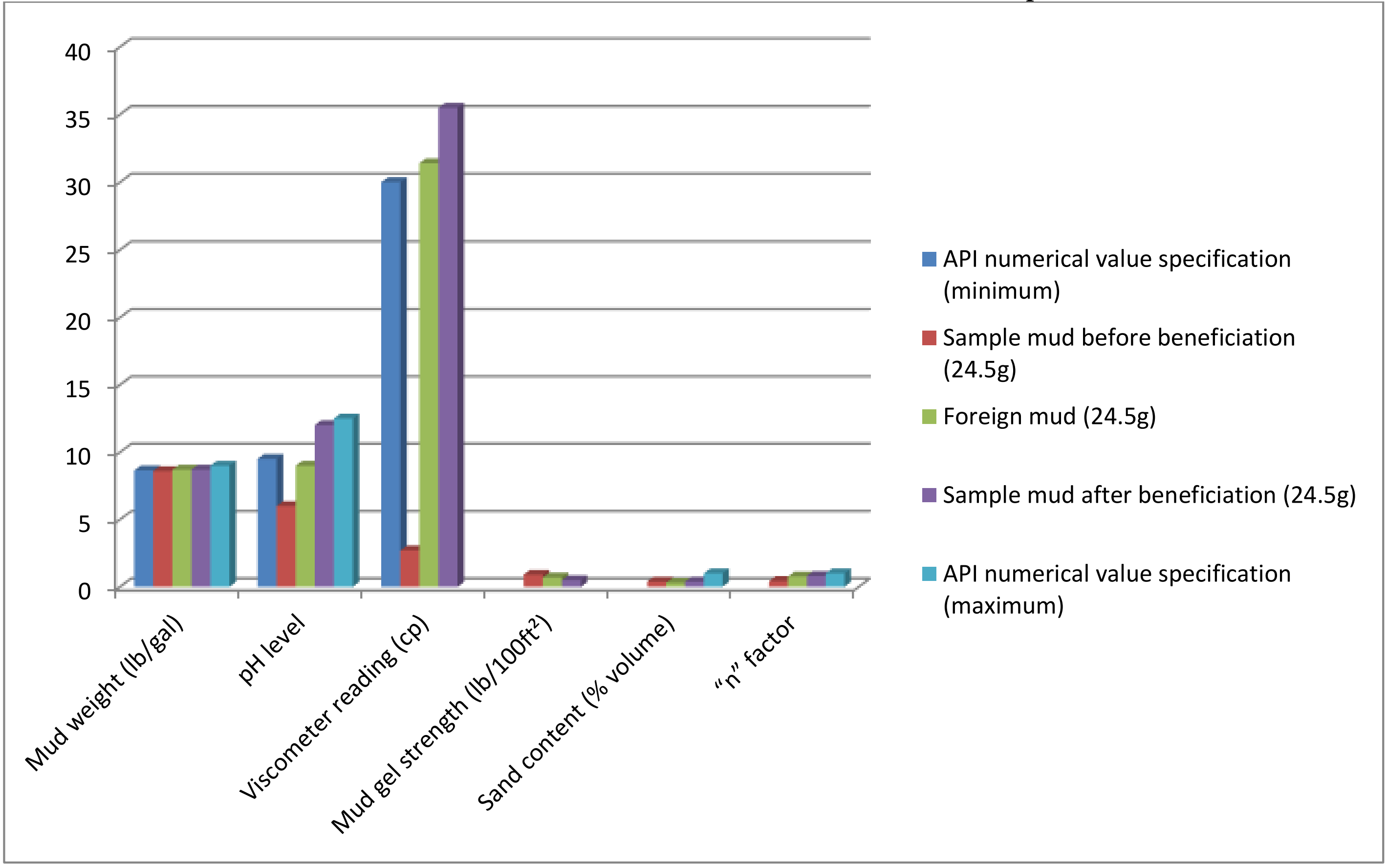

Figure 4.3: graphical comparison of mud properties with API numerical value specification (24.5g)

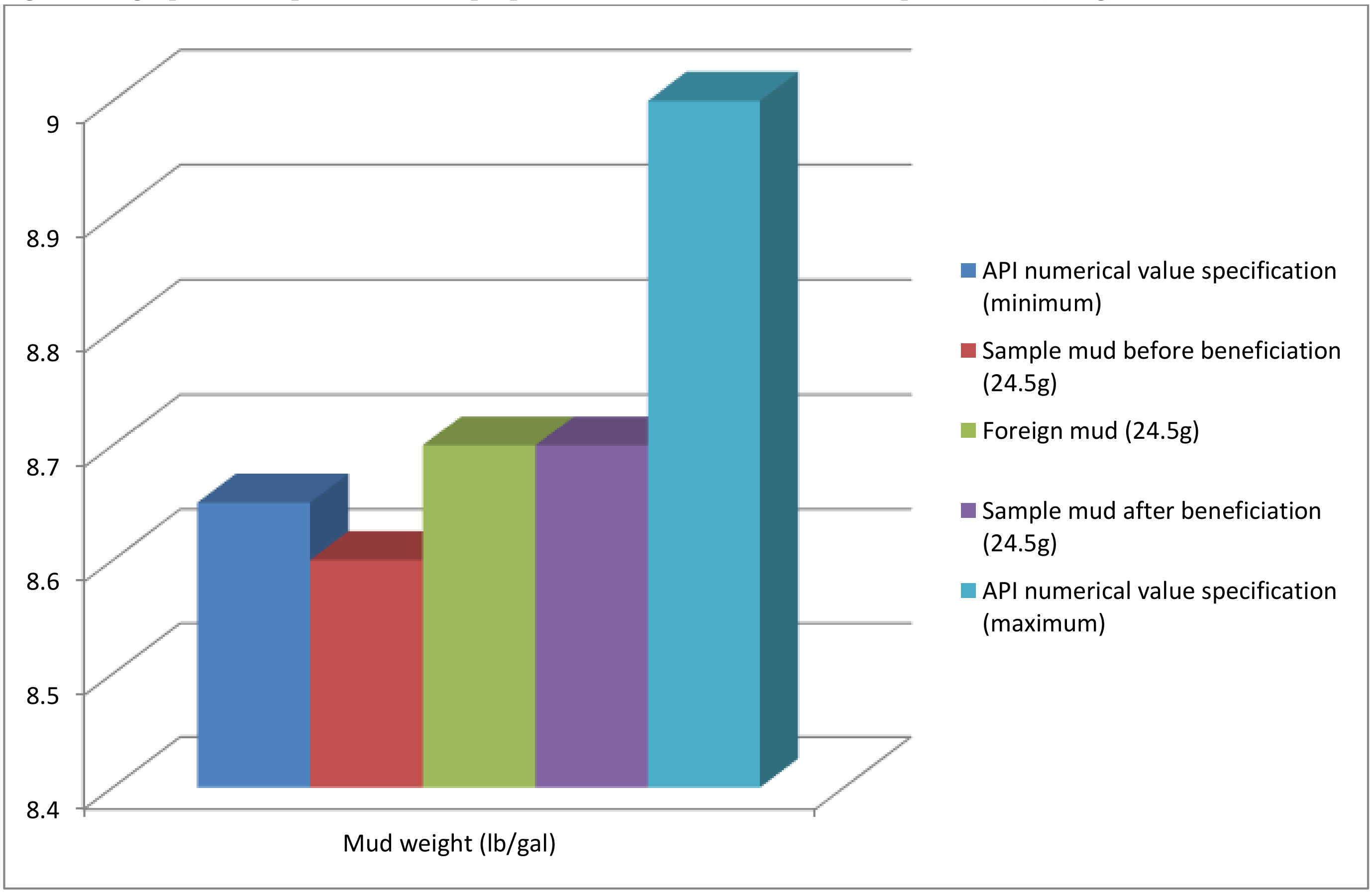

Figure 4.4: graphical comparison of mud weight (lb/gal) with API numerical value specification (24.5g)

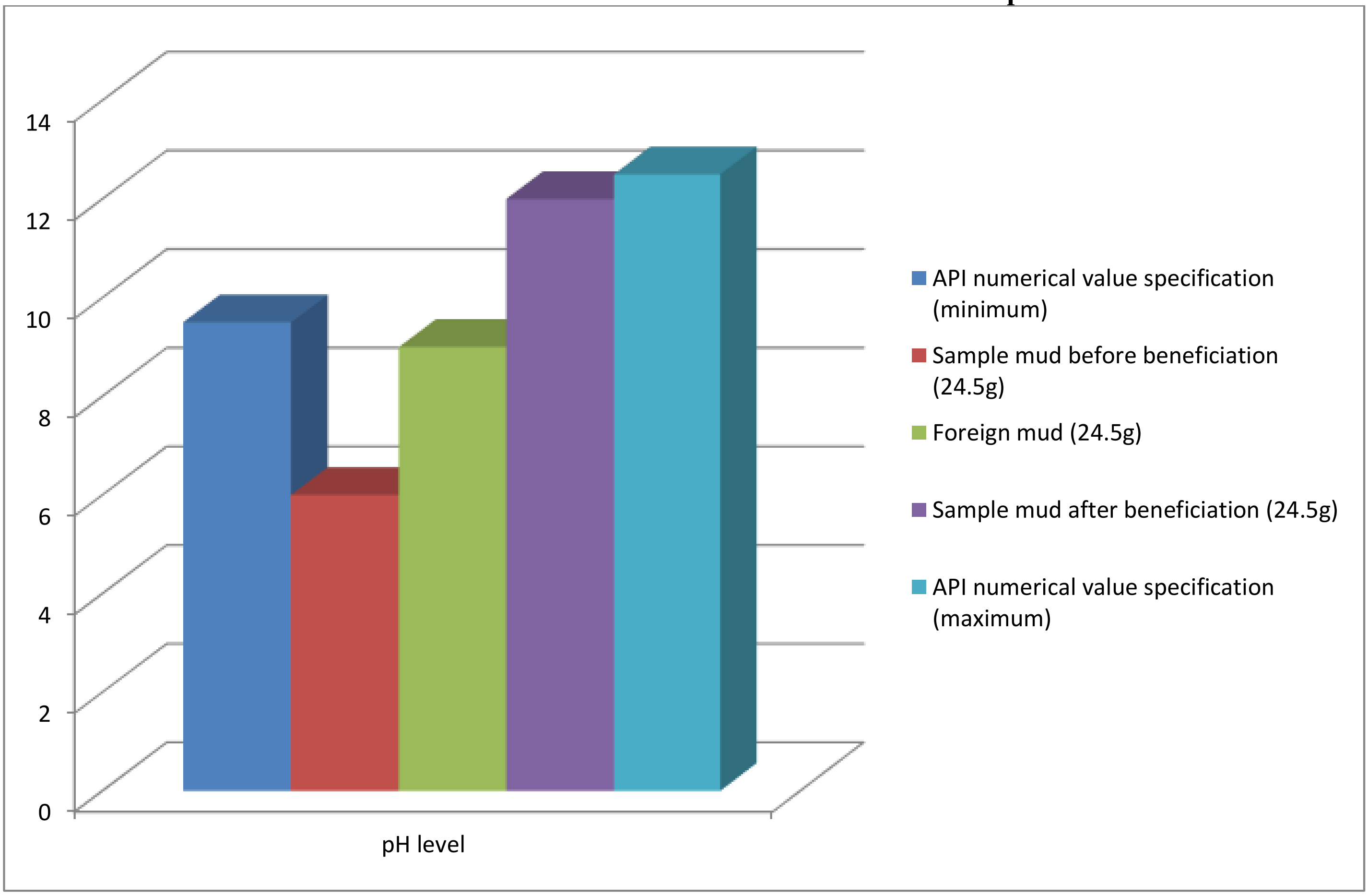

Figure 4.5: graphical comparison of pH level with API numerical value specification (24.5g)

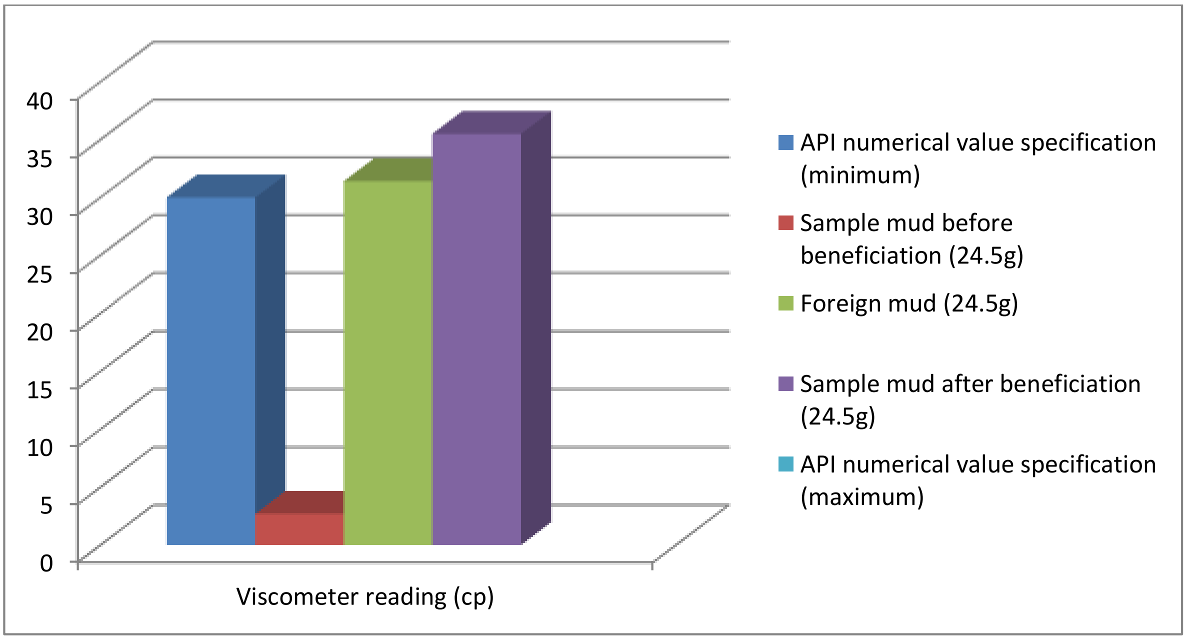

Figure 4.6: graphical comparison of viscosity reading (cp) @600 with API numerical value specification (24.5g)

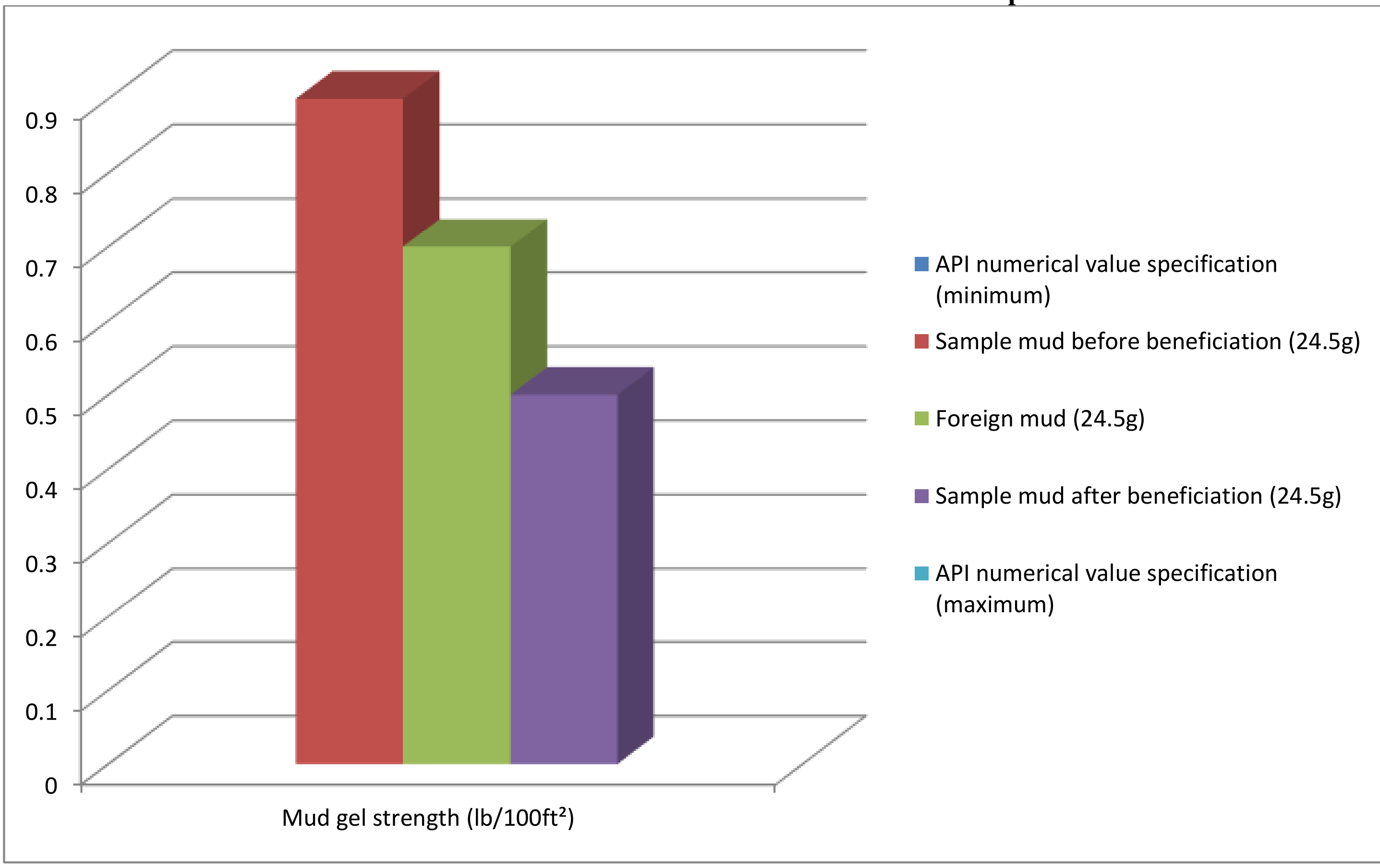

Figure 4.7: graphical comparison of mud strength (lb/100ft^2) with API numerical value specification (24.5g)

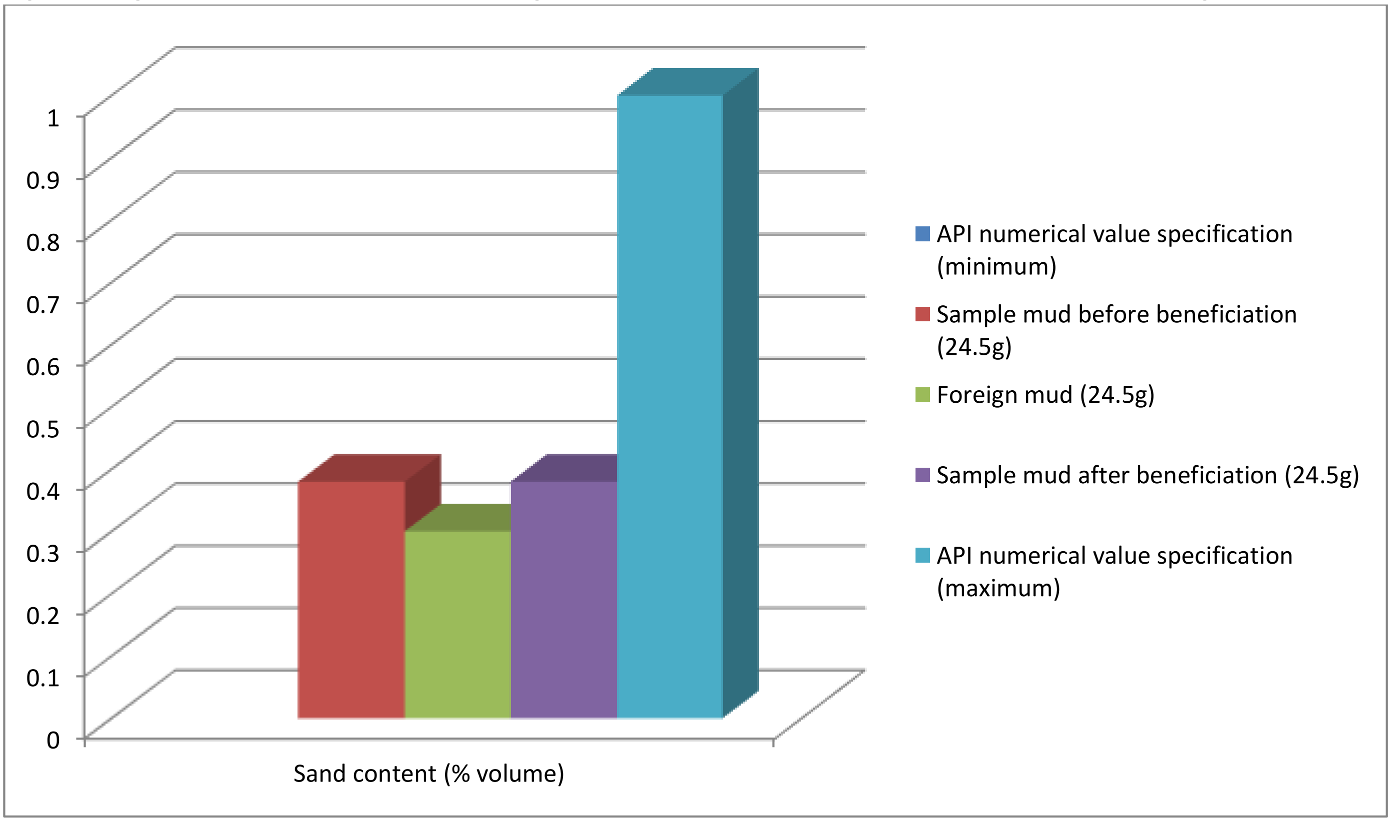

Figure 4.8: graphical comparison of sand content (% volume) with API numerical value specification (24.5g)

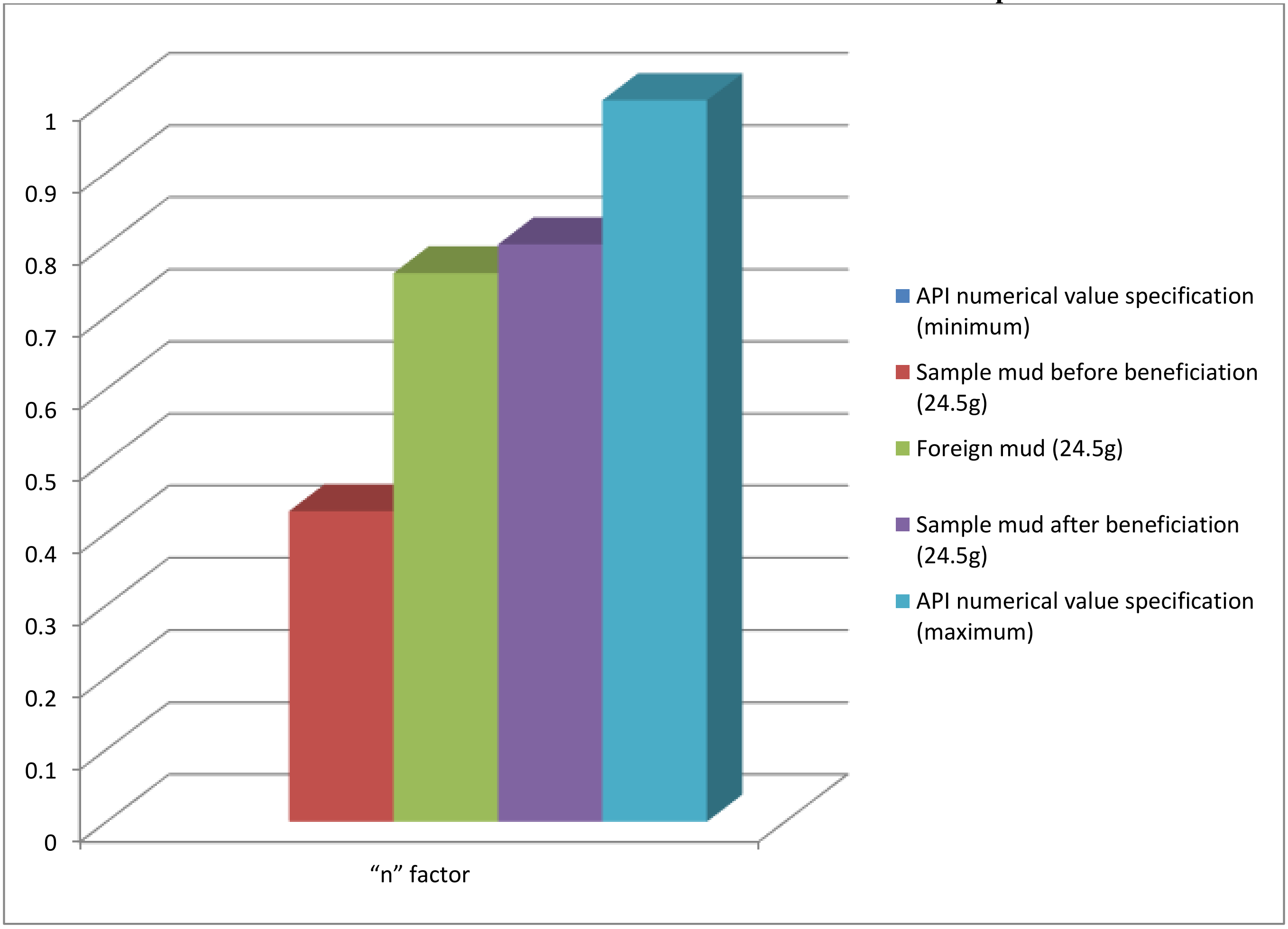

Figure 4.9: graphical comparison of "n" factor with API numerical value specification (24.5g)