

MEASUREMENT OF EXCHANGEABLE CATIONS IN BENTONITES*

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Abstract—High swelling bentonites cannot be analyzed for exchangeable cations with exactly the same technique as most soils. To resolve varied techniques used in the past and to establish a reliable procedure, the effects of sample size, the number of saturations, washes and extractions, and the volume of extracting solutions were determined on three high-swelling bentonites.

Small samples must be used to insure complete extraction of exchangeable cations, and the 0.5 g weight was the best size of those tested. Most exchangeable cations were removed in three extractions with 25 or 33 ml volumes of ammonium acetate. More extractions could result in excessive solubilization of minerals. Centrifugal force must be sufficient to prevent loss of sample during decantation. This varied from 4500 to 7500 *g* for 10–20 min, depending on particle size and sample dispersion.

The proposed CEC method requires little time, but still compared closely with Frink's more extensive method and showed no significant difference between treatment means. The procedure was used to analyze high-swelling bentonites from fourteen locations in six Western States. Chemical properties changed within each deposit and with geographical location, but in general the bentonites contained high amounts of exchangeable Na, moderate amounts of exchangeable Ca and Mg, and low amounts of exchangeable K. Total exchangeable cations and CEC agreed well, demonstrating the reliability of the proposed method.

INTRODUCTION

HIGH-SWELLING bentonites are now widely used in science, industry and agriculture. It is expedient to use proper methods of analysis in order to characterize each clay and subsequently predict its behavior.

Because of their unusual properties, high-swelling bentonites cannot be analyzed for exchangeable cations with exactly the same technique as most soils. Using sample weights of 4–5 g as recommended for fine-textured soils (Okazaki *et al.*, 1962 and U.S. Salinity Laboratory Staff, 1954) impedes extraction of the exchangeable cations. Bower and Hatcher (1966) recognized this when working with clays and used 0.5–1 g samples for cation exchange measurements. Frink (1964) has recently completed extensive work on cation exchange of bentonite using 0.2 g samples, while Rich (1961) used even smaller clay samples of 0.1 g in his work.

The number of saturations, washes and extractions and the volume of solutions used on soils and clays have also varied among workers. USDA

Handbook 60 (1954) recommends saturating with the index cation four times and extracting three times to remove it, using 33 ml solutions in 50 ml centrifuge tubes. Okazaki *et al.* (1962) recommend eight saturations and six extractions, using 30 ml solutions in 100 ml centrifuge tubes. Frink, working with high swelling bentonite, used five saturations, washes and extractions with 25 ml solutions in 32 ml centrifuge tubes (personal communication).

Index cations have also differed in CEC studies. Sodium and ammonium have commonly been used. Frink (1964) and Rich (1961) used Ca while Okazaki *et al.* (1962) used Ba. The presence of Ca (CO₃)₂ and CaSO₄ in the sample however, complicates the use of these cations as the index cation. Seven of the 16 bentonites measured in our study contained such salts.

Frink concluded that loss of adsorbed ions, attributed to hydrolysis in other studies (Bower *et al.*, 1952, and Greene-Kelly, 1955), was due to loss of sample during decantation after washing. He attributes such losses to low centrifugal forces. Frink prevented loss of his bentonite samples by using centrifugal forces of 10,000–20,000 *g* for 10–20 min. But he did not check on shorter times and lower speeds.

The purpose of this investigation was to resolve these differences in procedure and to establish a

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reliable method for measuring exchangeable cations and CEC of high-swelling bentonites. This was done by selecting and characterizing samples of commercial bentonites from three locations in the Western United States. The effects of variations in volume of solutions, sample sizes, number of extractions and centrifugal forces were measured on these 3 bentonites. The resulting procedure was then used to measure exchangeable cations from 14 bentonite deposits in the Western U.S.

MATERIALS AND METHODS

Extractable cations

Volume of extracting solutions. Two high-swelling, granular, Wyoming bentonites were used to determine the effect of solution volume on the amounts of cations extracted from samples. They were: Sample 2 and Sample 13 (see Table 1 for sample location). A comparison was made between 25 ml and 33 ml volumes of 1.0 N ammonium acetate (pH 7) by extracting triplicate 0.5 g weights from the whole sample of each bentonite in 35 ml centrifuge tubes.

Sample size and number of extractions. These same 2 bentonites plus Sample 15 were used to study the effect of sample size and number of extractions. Three weights (3 g, 1 g, and 0.5 g) from the whole samples of each bentonite were extracted six times with 25 ml of ammonium acetate. Triplicate analyses were made on each weight.

Centrifugal force. Samples were centrifuged at 4500–7500 g for 10–20 min to obtain a clear supernatant liquid. Centrifugal force and time varied within these ranges, according to particle size and sample dispersion. Samples were weighed to check for sample loss when extraction was concluded. If loss was greater than 5 per cent the measurement was taken again at a higher centrifugal force. Losses from the 0.5 g samples were commonly less than 2 per cent, losses from smaller samples were slightly higher. Centrifugal forces were not investigated further when it was found that our method compared favorably with Frink's CEC method which employed higher forces.

Cation exchange capacity

Proposed method. Samples of 0.5 g were saturated with Na as the index cation with four 25 ml volumes of 1.0 N sodium acetate. Excess sodium acetate was removed with 3 washings (25 ml each) of 95 per cent ethanol. The index cation was then extracted with three 25 ml volumes of 1.0 N ammonium acetate. All saturations, washes and extractions were done in succession with no time lapse, except to disperse thoroughly the samples in each volume of solution. The samples were dispersed with a vortex mixer, then shaken on a

reciprocal shaker for 5 min. The centrifugal force varied between 4500–7500 g for 10–20 min. Samples were weighed to check for sample loss when measurements were completed.

Comparison with Frink's method. Frink (1964) used more saturations, washes and extractions on smaller samples under a high centrifugal force than our proposed CEC method. It was, therefore, desirable to compare the two methods to determine if a time and material savings was possible and still obtain equivalent results. He used 0.2 g bentonite samples saturated with 1.0 N $\text{Ca}(\text{NO}_3)_2$, washed with ethanol and extracted with 1.0 N NaCl. Each treatment or wash was repeated five times with 25 ml volumes. The last saturation, wash or extraction was allowed to remain in contact with the clay overnight. He used a centrifugal force of 10,000–20,000 g for 10–20 min prior to decanting each solution (personal comm.). To compare procedures, Frink's procedure was duplicated and the proposed procedure, described in the previous paragraph, was conducted on 0.2 g and 0.5 g samples.

Analytical procedure. Calcium plus magnesium was determined by titration with versenate using Erichrome Black T as an indicator (U.S. Salinity Laboratory Staff, 1954). Potassium and sodium were analyzed with a Beckman model DU flame photometer.

Properties of test samples. Mineral content and physical properties of the 3 commercial bentonites used as test samples are presented in Table 1. The montmorillonite content of the clay and silt sized particles was calculated from surface area measurements according to Carter *et al.* (1965). The percentage of each remaining mineral was estimated from X-ray diffraction patterns as suggested by McNeal (1964). Minerals in the grit (> 0.043 mm) were identified microscopically by the U.S. Bureau of Mines, Reno Research Center.

Montmorillonite in the clay fractions of these samples ranged from 70 to 90 per cent. Other mineral differences in the bentonites probably contributed to differences in physical and chemical properties. (Some chemical properties are presented in Table 5).

Physical properties of the samples were measured using standard procedures for bentonites. Size separates were determined according to Fisk (1946). The filter press loss was measured according to the American Petroleum Institute (1957), and the volume of swell was determined according to the American Colloid Co. (1945). The viscosity and gel strength were measured with a Baroid viscometer, model 35, Fann V-G meter according to its operating instructions. The bentonites were

prepared for viscosity and gel measurements according to the American Colloid Co. (1945).

Sample 13 is typical of Black Hills bentonites in Wyoming and South Dakota. Sample 2 is also a Wyoming bentonite, but located to the west of the Black Hills. This particular clay will reach a maximum volume of swell in 15 min, unlike other bentonites (Rollins *et al.* 1961). These 2 Wyoming bentonites are typical of those used as drilling muds. Sample 15 represents another type of bentonite. Because of its physical properties, it is seldom used as a drilling mud, but is an excellent sealer as verified by the filter press loss.

comparison of the two volumes of (ammonium acetate) extracting solution. There was no significant difference between the two volumes in the amount of Ca plus Mg extracted from either bentonite. The slightly significant difference in the extraction of Na was opposite for each bentonite; i.e. the larger volume extracted more Na from one bentonite, whereas the smaller volume extracted more from the other. Apparently, differences in the volumes of the extracting solution had little effect on amounts of extractable cations, and either 25 or 33 ml solution volumes, whichever is suited to available equipment, can be used.

Table 1. Character of whole bentonite samples used to develop cation exchange procedure according to mineral content and physical properties

Sample No. and location	No. 2 Greybull Wyoming	No. 13 Belle Fourche S Dakota	No. 15 Cannonville Utah
Particle size	(%)	Mineral content (%)	
Clay	70 montmor. 15 cristobalite 15 chlorite	90 montmor. 10 feldspar	80 montmor. 20 quartz
Silt	10 montmor. 35 mica 35 feldspar 20 cristobalite	40 montmor. 30 cristob. 15 feldspar 15 mica	15 quartz 15 montmor. 15 mica 5 kaolin 5 feldspar
Grit*	Quartz Feldspar Calcite Biotite Hematite	Quartz Feldspar Biotite Calcite Chalcedony Sericitite Zircon Hematite	Quartz Feldspar Magnetite Hematite Muscovite Chalcedony
Size			
Separates Clay	80.7	82.0	75.5
Silt	15.8	15.3	19.4
Grit	3.5	2.7	5.1
Filter press loss (ml)	12.1	15.4	9.1
Swelled volume (ml)†	46	35	15
Plastic viscosity (centipoise)	27	11	5
Gel strength @ 5 min. (lb/100 ft ²)	60	58	1

*Includes particles greater than 0.043 mm. Minerals are listed in their order of abundance.

†Swelled volume from 2 g of air dry sample.

RESULTS

Extractable cations

Volume of extracting solution. Table 2 shows the

Sample size and number of extractions. Sample size and number of extractions were investigated by analyzing each of six successive ammonium

Table 2. Amounts of extractable cations* removed from 0.5 g samples of 2 bentonites with 33 ml and 25 ml volumes of ammonium acetate. Figures are means of three replicates of each treatment

Cations	Bentonite			
	No. 13		No. 2	
	33 ml	25 ml	33 ml	25 ml
Ca plus Mg meq/100 g	54.9†	53.8	22.7	23.6
Na meq/100 g	54.9	52.3	59.7	60.7

*Extractable cations include exchangeable and water-soluble cations.

†Figures underscored indicate no significant difference between treatment means at the 5 per cent level according to the "T" test.

acetate extractions from the 3 bentonites shown in Table 1. Three sample sizes (3, 1 and 0.5 g) were tested for each bentonite. Results are shown in Table 3.

More cations were removed in the first extraction from the 0.5 g sample weights than from the larger weights, except for the sodium extraction from Sample 13. This and successive extractions show that larger masses tend to impede cation removal. The 0.5 g samples were essentially free of Ca plus Mg by the fourth extraction, but the 3 g samples were still releasing an appreciable amount of Ca plus Mg on their sixth extraction. The 1 g samples were intermediate in this respect. Regardless of the sample size, complete removal of Na appears to be more difficult than Ca plus Mg.

Measurable amounts of Na were still removed in the sixth extraction with all weights, but a low plateau was reached at the fourth extraction of the

Table 3. Amounts of cations extracted from three weights of bentonite samples with successive 25 ml extractions of 1.0 N ammonium acetate

Bentonite samples	First	Second	Third	Total of				Total of six
				three	Fourth	Fifth	Sixth	
Ca plus Mg meq/100 g								
0.5 g								
No. 2	15.7	5.05	3.37	24.0*	1.05	0.00	0.00	25.2
No. 13	44.5	8.26	0.67	53.5 _a	0.12	0.00	0.00	53.6
No. 15	18.4	3.72	1.41	23.5	0.62	0.49	0.45	25.1
1 g								
No. 2	12.7	4.73	2.97	20.4 _b	2.36	0.28	0.09	23.1
No. 13	43.3	7.13	2.53	54.0 _a	1.47	0.66	0.64	55.7
No. 15	15.5	4.25	2.04	21.8	1.69	0.96	0.89	25.3
3 g								
No. 2	12.3	5.50	2.68	20.5 _b	2.36	2.26	1.24	26.3
No. 13	36.6	8.58	2.99	48.2	1.72	1.46	1.37	52.7
No. 15	12.1	4.88	2.29	19.2	1.90	1.69	0.86	23.7
Na meq/100 g								
0.5 g								
No. 2	52.2	7.21	1.33	60.7	1.08	0.86	0.92	63.6
No. 13	46.9	4.89	1.14	52.9 _c	0.85	0.85	0.62	55.3
No. 15	61.4	4.86	1.41	67.7	1.10	1.16	1.18	71.1
1 g								
No. 2	49.4	8.43	1.20	59.1 _d	0.70	0.49	0.46	60.7
No. 13	47.2	4.06	0.91	52.1 _c	0.63	0.38	0.64	53.8
No. 15	58.0	4.57	0.71	63.3 _e	0.38	0.38	0.57	64.6
3 g								
No. 2	46.5	9.95	2.19	58.6 _d	1.03	0.64	0.24	60.6
No. 13	40.6	6.18	1.54	48.3	0.76	0.70	0.60	50.4
No. 15	51.4	11.3	1.97	64.7 _e	0.78	0.29	0.14	65.9
Total cations meq/100 g								
0.5 g				282.3				293.9
1.0 g				270.7				283.1
3.0 g				259.3				279.6

*Common subscripts indicate no significant difference between treatment means at the 5 per cent level according to the "T" test.

0.5 g samples. Only Sample 13 had leveled off by the fourth extraction in the 3 g size.

Considering the sum of each major cation removed by 3 extractions, Samples 2 and 15 showed more cations were extracted from the 0.5 g samples than any other sample weight. But Sample 13 showed no difference between the 1 and 0.5 g weights (common subscripts). A comparison of total cations (Ca plus Mg and Na bottom of Table 3) removed in 3 and 6 extractions from each sample weight clearly shows the impedence of cation removal by the larger samples. It is significant to note that slightly more cations were removed in 3 extractions from the 0.5 g samples than in 6 extractions from the 3 g samples.

More than 3 extractions of small samples may result in unnecessary solubilization of minerals found in these bentonites (Bower *et al.*, 1952). Solubilizing effects are shown by the constant amount of cations in the fifth and sixth extractions of Ca plus Mg (0.5 g sample of no. 15, Table 3) and in the fourth, fifth and sixth extractions of Na from the 0.5 g weights of all bentonites. The results in Table 3 show that of the conditions tested, 3 extractions from 0.5 g samples is the best procedure to remove exchangeable cations from high-swelling bentonites.

Cation exchange capacity

Table 4 presents the comparison of Frink's method with the proposed method on 2 sample sizes. The proposed method agreed with Frink's method for 2 of the 3 bentonites using 0.5 g samples, and for the third bentonite (no. 15) using the 0.2 g sample. The reason for this latter agreement could be the slightly soluble Ca mineral in Sample 15 which is shown clearly in each extraction of Table 3. This slightly soluble Ca mineral would increase the cation exchange capacity with Frink's method, since Ca is the index cation used there.

Actually the treatment means (for each method and sample size) showed no significant difference between Frink's method and either sample size of the proposed method. But there was a significant difference (at the 0.02 level) between the 0.2 g and the 0.5 g samples using the proposed method. This is consistent with previous findings on sample size as shown in Table 3. The smaller weights resulted in higher exchangeable or higher cation exchange capacities, whichever were measured.

Exchangeable cations in high-swelling bentonites. Table 5 presents exchangeable cations and CEC of 16 high-swelling bentonites from the Western United States. The exchangeable cations

Table 4. Comparison of the proposed method and Frink's method for measuring the cation exchange capacity of high-swelling bentonites

Sample		Proposed method	Frink's method	Proposed method
No.	Location	(0.5 g sample)	(0.2 g sample)	(0.2 g sample)
2	Greybull, Wyoming	73.3	66.1	75.3
		73.3	71.1	76.2
		71.2	65.6	77.2
		Mean	72.6*	67.6
13	Belle Fourche, S. Dakota	88.2	86.1	106.4
		83.8	89.3	100.3
		83.8	89.8	97.3
		Mean	85.2	88.4
15	Cannonville, Utah	77.9	90.3	91.4
		73.5	89.8	94.5
		75.7	86.7	92.5
		Mean	75.7	89.0
Treatment mean		77.9	81.7	90.1

*Figures underscored indicate no significant difference between treatment means at the 5 per cent level according to the "T" test.

Table 5. Exchangeable cations and cation exchange capacities of bentonites from the Western United States

Bentonite sample	Exchangeable cations meq/100 g				Exchangeable Na percentage	CEC meq/100 g	
	No. Location	Ca + Mg	Na	K			Total
Wyoming							
2 Greybull*		24.6	45.9	1.22	71.7	64.0	72.6
21 Greybull†		25.0	39.7	0.05	64.7	61.3	72.5
6 Casper		13.9	62.7	1.46	78.1	80.3	78.1
Black Hills (Wyoming & S. Dakota)							
4 Colony, Wyo.		48.1	40.4	1.71	90.2	44.7	90.2
8 B. Fourche S. Dak‡		61.8	31.2	1.27	94.3	33.4	90.4
13 B. Fourche S. Dak‡		51.5	34.2	1.57	87.2	39.1	85.2
18 Moorcroft, Wyo.		22.2 ^b	58.9	1.76	82.9	71.1	82.9
Nevada							
10 Nixon		10.8 [†]	72.8	3.79	87.4	83.3	87.4
11 Thorne§		24.7	34.7	1.05	60.5	57.4	56.0
12 Thorne§		27.5	27.2	0.88	55.5	48.9	53.6
16 Baker		29.4	30.7	1.50	61.6	49.8	61.6
Utah							
14 Ivie-Aurora		14.2	44.4	1.54	60.2	73.8	60.2
15 Cannonville		7.6 [†]	65.7	2.40	75.7	86.8	75.7
20 Woodside		28.0	26.6	2.27	56.8	46.8	60.3
Idaho							
5 Nampa		65.1	11.2	0.50	76.8	14.6	78.5
Colorado							
19 Salida		53.4	27.5	2.63	83.6	32.9	83.6
Means \bar{x}		31.7	40.9	1.60	74.1	55.2	74.3

*Sample received in 1958.

†Sample received in 1964 from the same company as above sample.

‡Samples are from different bentonite companies.

§Samples are from different locations in the same deposit.

^bThese bentonites contained additional Ca and Mg salts not soluble in water but were solubilized by the ammonium acetate extraction. These were most likely carbonate or sulfate salts.

Note: Samples omitted were found to be other clay minerals or poor sealers and, therefore, were not of interest in this study.

were calculated by subtracting water-soluble cations from extractable cations. These bentonites contain high amounts of exchangeable Na, moderate amounts of exchangeable Ca and Mg, and low amounts of exchangeable K. Only 1 bentonite measured less than 30 per cent exchangeable Na,

this was Sample 5; 3 bentonites had 80 per cent, or greater, exchangeable sodium, these were Samples 6, 10, and 15.

Chemical properties of the bentonites varied with geographical area, with deposit within a geographic area, and with location within a

deposit. This latter variation is shown by the deposit in western Nevada (Samples 11 and 12). Williams *et al.* (1954) conducted a more extensive study on this subject and found substantial changes with change in depth of overburden.

CONCLUSIONS

The proposed method for measuring exchangeable cations and CEC of high-swelling bentonite gave reproducible results on these clays. Total exchangeable cations and CEC agreed well in most cases, further showing the reliability of the proposed method.

An important advantage of this method is that it requires little time. This procedure is similar to the CEC procedure for soils outlined in USDA Handbook no. 60 with several important changes. With bentonites, smaller samples of 0.5 g must be used to insure extraction of cations, and a higher centrifugal force must be used to avoid sample losses. The lack of these 2 changes could result in serious error when working with bentonites.

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Résumé—L'analyse des cations échangeables ne peut être effectuée sur les bentonites à fort gonflement, exactement selon les mêmes méthodes utilisées pour la plupart des sols. Afin de prendre une résolution sur les techniques variées employées par le passé et d'établir un procédé sûr, on a déterminé les effets de la taille du prélèvement, le nombre de saturations, les lavages et les extractions et le volume des solutions d'extraction pour trois bentonites à fort gonflement.

Il faut utiliser de petits prélèvements pour assurer l'extraction complète des cations échangeables, et le meilleur poids enregistré sur les prélèvements choisis était de 0.5 g. La plupart des cations échangeables ont été enlevés en trois extractions avec de l'acétate d'ammonium en volumes de 25 ou 33 ml. Un nombre plus élevé d'extractions aurait pu donner une solubilisation excessive des minéraux. La force centrifuge doit être suffisante pour empêcher la perte d'échantillons pendant la décantation. Ceci varie de 4.500 à 7.500 × G pour 10–20 minutes, selon la taille des particules et la dispersion des échantillons.

La méthode CEC proposée demande peu de temps, mais se compare d'assez près à la méthode plus extensive de Frink et montre une différence non significative entre les moyens de traitement. Le procédé a été utilisé pour analyser les bentonites à fort gonflement prélevés en 14 points différents des six états de l'ouest. Les propriétés chimiques ont changé à l'intérieur de chaque dépôt selon la situation géographique, mais en général les bentonites contenaient de grandes quantités de Na échangeable, des quantités plus réduites de Ca et Mg échangeables, et de faibles quantités de K échangeable. Le total des cations échangeables et CEC s'accordaient bien pour démontrer la fiabilité de la méthode présentée.

Kurzreferat—Stark quellende Bentonite können nicht mit der genau gleichen Methode wie die meisten anderen Bodenarten auf austauschbare Kationen untersucht werden. Zum Zwecke der Vereinheitlichung verschiedenartiger, in der Vergangenheit angewandter Methoden und der Aufstellung einer

verlässlichen Arbeitsweise wurde die Wirkung der Probengrösse, der Anzahl der Sättigungen, Spülungen und Extraktionen sowie des Volumens der Extraktionslösungen auf drei stark quellende Bentonite untersucht.

Um sicherzustellen, dass eine komplette Extraktion der austauschbaren Kationen stattfindet, mussten kleine Proben verwendet werden, und unter den untersuchten Probegrößen erwies sich die 0,5 g Probe als die günstigste. Die meisten austauschbaren Kationen konnten in drei Extraktionen mit 25 oder 33 ml Volumen Ammoniumazetat entfernt werden. Eine grössere Anzahl von Extraktionen könnte zu übermässigem Löslichmachen der Minerale führen. Die Zentrifugalkraft muss genügen, um einen Verlust an Probesubstanz bei der Dekantierung zu verhindern. Dieser schwankte zwischen 4500 und $7500 \times G$ für 10–20 Minuten, je nach Teilchengrösse und Probendispersion.

Die angeführte CEC Arbeitsweise erfordert wenig Zeit und ist trotzdem durchaus mit der umfassenderen Methode von Frink vergleichbar und zeigt keine wesentlichen, durch Verschiedenheit der Behandlungsmittel hervorgerufenen, Unterschiede. Die Arbeitsweise wurde zur Untersuchung von stark quellenden Bentoniten von 14 Lagerstätten aus sechs westlichen Staaten verwendet. Die chemische Eigenschaften waren je nach Lagerstätte und geographischer Lage verschieden doch zeichneten sich die Bentonite im allgemeinen durch hohe Gehalte an austauschbarem Na, mittelmässig Ca und Mg, und wenig K aus. Die Gesamtmenge der austauschbaren Kationen stimmte gut mit CEC überein und bewies dadurch die Zuverlässigkeit der vorgeschlagenen Methode.

Резюме—Сильно набухающие бентониты не подвергаются анализу на обмениваемые катионы, пользуясь точно теми же методами, как в случае других почв. Для разрешения вопроса пригодности различных применяемых в прошлом методов и для определения надежной процедуры, определяли эффект воздействия на три сильно набухающих бентонита: размера, образца, количества насыщений, промывок и извлечений, а также объема извлекающих растворов.

Для обеспечения полного извлечения обмениваемых катионов, следует пользоваться малыми образцами; катионы весом 0,5 г оказались наилучшим размером из подвергаемых испытаниям. Большинство обмениваемых катионов удалялось за три извлечения ацетатом аммония объемом 25 или 33 мл. Большее количество извлечений может повлечь за собой чрезмерное растворение минералов. Центробежная сила должна быть достаточной для предотвращения потери образца во время декантации. Дентробенсная сила меняется от 4500 до $7500 \times G$ для 10–20 мин, в зависимости от размера частиц и дисперсии образца.

Предлагаемый метод СЕС не требует много времени, но все же тесно следует более подробному методу Фринка и не показывает значительной разницы между средствами обработки. Процедура применялась для анализа сильно набухающих бентонитов из 14 местонахождений в шести западных штатах. Химические свойства были разными в каждом образце и менялись в зависимости от географического местоположения, но в общем бентониты содержали крупное количество обмениваемого Na, умеренное количество обмениваемых Ca и Mg и малые количества обмениваемого K. Общее количество обмениваемых катионов и СЕС хорошо согласовывалось, демонстрируя тем самым надежность предлагаемого метода.