COMMON WELL-AQUIFER MAINTENANCE CHEMICALS AND THEIR INFLUENCE ON AQUIFER PERMEABILITY - A LABORATORY ASSESSMENT

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ABSTRACT The Sustainable Water Well Initiative (SWWI) was created in 1996 by the Prairie Farm Rehabilitation Administration (PFRA) to address concerns of declining well yield, water quality deterioration and reduced well lifespan with a goal to provide advice on the diagnosis, prevention, and rehabilitation of well problems. SWWI has focused on the microbiological aspects of deterioration as diagnosis and rehabilitation of this problem are not as established as those for physical and chemical problems in water wells. A review and evaluation of well maintenance chemicals currently employed to restore well - aquifer efficiencies is being conducted by PFRA at their Technical Adaptation Facility in Regina, Saskatchewan, Canada. In order to accomplish this, PFRA are conducting permeameter column studies on aquifer materials and swell - consolidation tests on clays to assess the effects of commonly-used chemicals on aquifer permeability. These techniques can also be used to design an efficient and cost - effective treatment process which may be applied to domestic and farm wells.

Résumé: L'Administration de rétablissement agricole des Prairies (ARAP) a entrepris le Projet de puits d'eau durables (PPED) en 1996 afin de répondre aux questions soulevées par la baisse du débit de production, la détérioration de la qualité de l'eau et la réduction de la durée de vie utile des puits d'eau. L'objectif est d'offrir des conseils pratiques quant à l'analyse, la prévention et la résolution des problèmes par rapport aux puits d'eau. Le PPED s'est penché sur l'aspect microbiologique de la détérioration des puits d'eau puisque l'analyse et la résolution de ce problème n'est pas aussi avancée que pour les problèmes d'ordre physique et chimique. L'étude et l'évaluation des produits chimiques qui servent actuellement à restaurer l'efficacité des puits-aquifères se poursuivent au Centre d'adaptation technique de l'ARAP à Regina (Saskatchewan) Canada. À cette fin l'ARAP poursuit des analyses perméamétriques de diverses matières aquifères ainsi que l'examen de la consolidation et du gonflement des argiles afin d'évaluer les effets de produits chimiques communs sur la perméabilité de la nappe aquifère. Ces techniques servent également à la conception d'une méthode de traitement qui est valable et efficace par rapport au coût et qui s'applique aux puits comme source d'eau pour l'exploitation agricole et l'usage domestique.

1. INTRODUCTION

The performance of, and yield from, water wells often decline over the life of the well. This decline can be due to one or more of several factors such as decreasing aquifer water levels, worn or broken pumping equipment, failure of well structure, mechanical blockage of screen openings, or plugging of the completion interval by chemical precipitates or by the growth of microorganisms. Wells that exhibit declining water yield or deteriorating water quality are often abandoned and new wells are drilled in their place. At times, this may be the appropriate solution, particularly when problems can be diagnosed as resulting from the lowering of aquifer water levels or failure of well structure. Often, however, attempts to rehabilitate wells by means of chemical treatments and re-development techniques result in only temporary improvement in well performance. The costs associated with the replacement of such wells can be significant, and therefore, there is a need to research cost-effective rehabilitation and preventative maintenance methods that will reduce potential problems and maximize investment in water well infrastructure.

In 1996 the Prairie Farm Rehabilitation Administration (PFRA) created the Sustainable Water Well Initiative (SWWI) to address aspects of water well performance with an emphasis on addressing the deterioration of water wells resulting from groundwater microbiological activity, commonly called biofouling. Symptoms of biofouled wells include a gradual deterioration in water quality, a reduction in well yield, and equipment failures due to corrosion or encrustations. Eventually, the completion interval of the well will clog, leading to a dramatic decline in both water yield and quality. Traditional treatments (eg. shock chlorination and acidization) stress the bacteria and biofilms and result in temporary improvement in well performance, however, once the stress is removed, conditions rapidly revert to pre-treatment levels. In recognition of these limitations the UAB™ treatment process was jointly developed by Droycon Bioconcepts Inc. and PFRA, specifically to penetrate, reduce and remove biofilms from water wells.

This treatment method involves three phases of chemical application to 1) shock bacterial cells and biofilms, 2) disrupt the biofilms, and 3) disperse the biofilms and other material in the immediate aquifer environment and completion interval of the well. The procedure involves application of heated water, disinfectant and a wetting agent (surfactant) to penetrate and kill bacterial cells followed by applications of strong acid and alkaline solutions to disrupt the biofilms. Removal of biofilms and other clogging material is then accomplished by traditional redevelopment techniques.

As part of the effort to improve understanding of current

TABLE 1
Inventory and classification of evaluated chemicals

Name	Chemical Formula	Classification
hydrochloric acid (muriatic)	HCl	mineral acid
sulfamic acid	H_2NSO_3H	mineral acid
oxalic acid	HO_2CCO_2H	organic acid
acetic acid	CH_3CO_2H	organic acid
commercial product	proprietary	organic acid
calcium hydroxide	$Ca(OH)_2$	caustic
potassium hydroxide	KOH	caustic
sodium hydroxide	$NaOH$	caustic
calcium hypochlorite	$Ca(OCl)_2$	chlorine compound
sodium hypochlorite	$NaOCl$	chlorine compound
hydrogen peroxide	H_2O_2	oxidant
commercial products	ClO_2, O_3, $HOCl$	mixed oxidant
commercial products	proprietary	dispersant
commercial products	proprietary	surfactant

chemical treatments, and to select new means to improve on such treatments, PFRA established laboratory methods to measure and evaluate the influence of common treatment chemicals on the permeability of samples of biofouled aquifer materials.

2. LABORATORY TESTING AND ANALYSIS

The suitability of potential treatment chemicals was evaluated in the laboratory by means of swell-consolidation and permeameter column tests on aquifer samples obtained from several municipal well fields in Saskatchewan. Swell-consolidation tests were designed to evaluate the effect of various concentrations of compounds on the swelling of clays which exist in small proportions in most aquifer materials.
Permeameter column tests compared the initial (pre-process) permeability of aquifer materials with that following a chemical treatment (post-process) at varying temperatures, concentrations and residence times. An inventory and general classification of well-aquifer treatment chemicals evaluated in this project is given in Table 1. In most instances these compounds were generic, however a number of commercial products were also evaluated.

2.1 Swell-Consolidation Tests

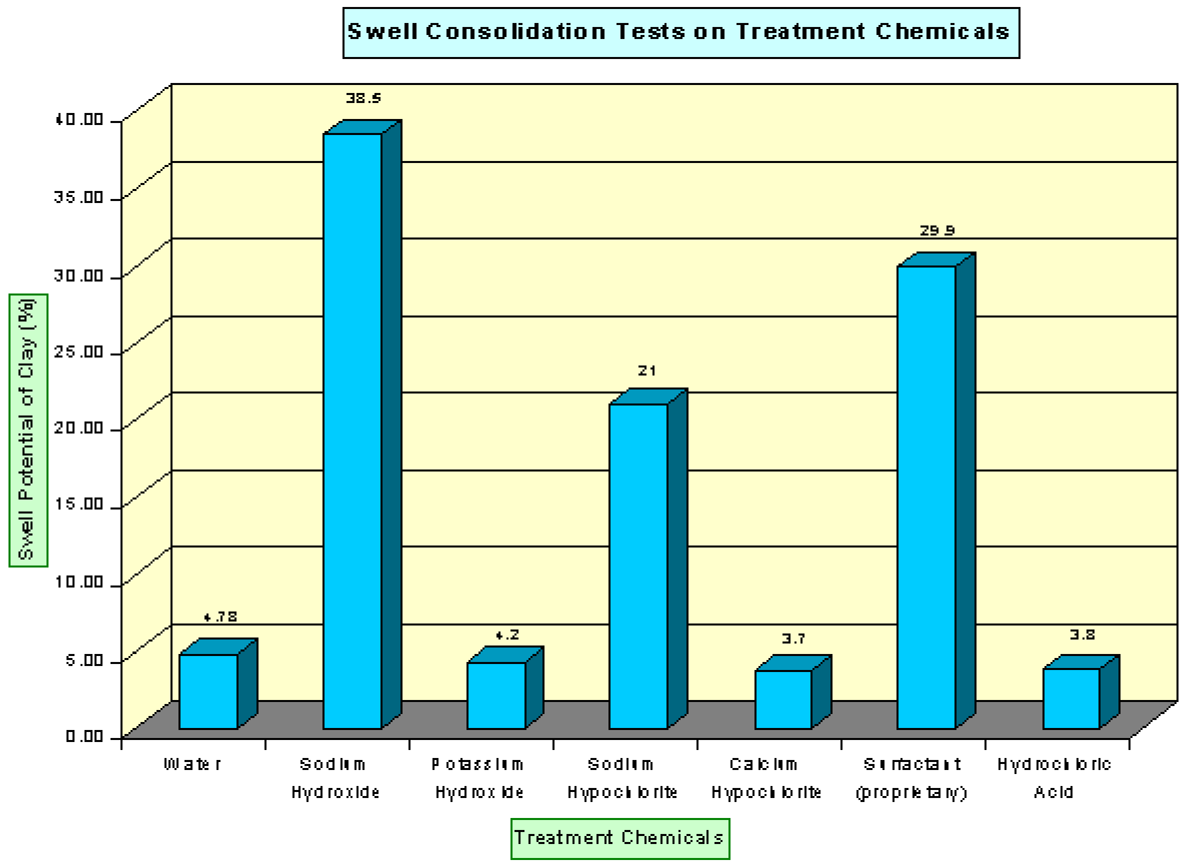
The one-dimensional swell potential of cohesive soils (ASTM D:4546) is a test method to determine the magnitude of swell of compacted, cohesive earth materials under a known axial pressure. A calcareous, oxidized clay from the Morden-Portage area in Manitoba was employed in all cases as the test specimen. In each case the clay was trimmed and placed within a consolidometer under a specified pressure (4.6 kPa) and inundated with a chemical at a specified concentration. A continuous readout of the results provided a comparison of the percentage of swell to that of a control consisting of clay in distilled water. The results of this series of tests is provided in Table 2.

TABLE 2
Swell-consolidation test results

AGENT	CONC	SWELL(%)	TIME (MIN)
WATER		4.78	10000
NaOH	1%	8.82	1500
NaOH	5%	29.55	6500
NaOH	1%	38.5	20000
NaOCl	12.50%	21	6000
CB4	1%	9.47	23000
CB4	1%	13.1	49000
CB4	100%	1.2	18000
CB4	50%	2	10000
CB4	est<1%	29.9	10000
HCl	10%	3.8	7000
KOH	2g/l	4.2	10000
HTH	2g/l	3.7	10000
CH_3CO_2H	10%	3.2	4000

Distilled water generated about a 5% swell in the clay over a period of 7 days. Sodium hydroxide at a 1% concentration indicated a swell approaching 40% and, on the basis of this test, this chemical was not considered for further testing. Sodium hypochlorite caused a swell of 21% during the 4-day test period. Calcium hypochlorite (HTH) showed a swell of 3.7% over 7 days. An anionic polyelectrolyte surfactant, the chemical formula of which is proprietary, was tested at an initial concentration of 1%. A swell of 13.1% over 3.5 days was measured. As a follow-up test, a pure 100% solution of the surfactant was tested with the result being a 1.2% swell over 12.5 days. On the basis of this test it was concluded that water was necessary to induce swelling and the solution was diluted to 50% with water. Swelling increased to 2% over 7 days and ultimately to 29.9% at a very dilute concentration. Tests on hydrochloric acid (HCL) at 10% and potassium

Figure 1



hydroxide (KOH) at 2g/L indicated swelling at rates less than water over 7 days. A 10% solution of acetic acid (CH_3CO_2H) produced a 3.2% swell over 2.75 days.

2.2 Permeameter Column Tests

Several permeameters were designed and constructed for the purpose of investigating the effect of well treatment chemicals on the permeability (k) of biofouled aquifer materials from cores or disturbed samples. Each permeameter cell was constructed of a 160 mm length of 63.5 mm I.D. clear acrylic tubing sufficient to contain approximately 425 to 445 cc of earth materials. The contents of each cell were saturated for a minimum of 24 hours prior to any tests of pre-process permeabilities. In all cases, falling head tests were conducted through use of 19.45 mm diameter riser tubing with an initial one-meter head and a fall of 0.75 m to a residual head 0f 0.25 m. In keeping with an objective to make laboratory results transferable to practical applications in the field, absolute K-values were considered to be less important than the determination of changes in the value of K over the course of testing. For this reason, a municipal water supply source was used in all falling head tests rather than distilled, de-aired water. In all cases, 500 ml solutions of compounds were applied to the contents of the cell for evaluation.

The variables for evaluation of each treatment process included the compound being tested, its concentration and input temperature, its input order relative to other tested compounds on the same test, and the residence (contact) time of the compound within the cell. In most instances, tests were performed on unmixed compounds, however, some mixtures were also evaluated. The results of permeameter column tests on several of the chemicals evaluated are provided in Table 3, and results of two treatment processes are given in figures 2 and 3. A number of compounds at varying concentrations and temperatures were evaluated with respect to their influence on aquifer materials. One compound initially considered for study was sodium hydroxide (NaOH). However, this chemical was eliminated due to a demonstrated swelling potential of clay (see section 2.1). Calcium hydroxide ($Ca(OH)_2$) was also considered, however, this chemical compound could not be dissolved in water without forming a heavy floc which would severely reduce K-values. This problem could be resolved if the compound were to be dissolved in distilled, degassed water, but its use in field conditions would be impractical. Therefore, no further consideration was given to testing this compound.

A commercial surfactant was tested at three different concentrations and at temperatures of 20°C and 65°C. In all instances, the post-process K-valus increased following a 5-hour contact time with the surfactant. In all instances, considerable volumes of fines were released from the cells and higher temperatures and solution concentrations increased the amounts released. The average increase in K-value for all concentrations at a flush temperature of 20°C was 12% and for 65°C the increase was 27.3%. However, testing indicated that the lower the concentration of surfactant, the better the result may be in terms of maintaining or increasing aquifer K-values, as indicated in Table 4.Calcium hypochlorite ($Ca(OCl)_2$ (or HTH) solutions were flushed through the permeameter cells at concentrations of 2g/L and 5g/L with mixed results. The higher concentration solution resulted in a 5.5% increase in K-value while the 2g/L solution resulted in a 3.8% reduction in K-value. A 1% solution of sodium hypochlorite (NaOCl) was also tested resulting in a 7.1% increase in permeability. However, in combination with a 1%concentration of surfactant neither of the hypochlorite solutions provided improvements in the permeability of aquifer materials. A 12.5% solution of sodium hypochlorite in a 1% solution of surfactant reduced the permeability by 18% and a 5g/L concentration of calcium hypochlorite in a 1% solution of surfactant resulted in a 25% reduction in permeability over a 5-hour time period. The sodium hypochlorite-surfactant combination did result in significant removal of fine material. No such effect was observed for the calcium hypochlorite-surfactant combination and, furthermore, a precipitate was produced when these two chemicals were mixed. On the basis of these preliminary results, and in consideration of practical field applications, sodium hypochlorite appears to promise greater benefits over calcium hypochlorite in well-aquifer rehabilitation programs. Hydrochloric acid (HCL) was tested at concentrations of 1% and 5%. The permeability of the aquifer material increased 200% with the 1% solution and 137% with the 5% solution.

Table 3:
Permeameter Column test results of well-aquifer treatment chemicals

Agent	Conc.	Time (hr)	Temp (°C)	*K (cm/s)	K-DIFF	%DIFF	Remarks
surfactant A	0.75%	5	20	8.70E-03	1.00E-04	1.1	Fines released. Heat gives better fines removal. Gas production observed with high temperature surfactant solutions
surfactant A	1%	5	20	8.40E-03	1.30E-03	18.3	
surfactant A	2%	5	20	7.50E-03	5.00E-04	7.1	
surfactant A	0.75%	5	65	8.70E-03	2.90E-03	50	
surfactant A	1%	5	65	1.10E-02	2.00E-03	22.2	
Surfactant A	2%	5	65	9.50E-03	9.00E-04	10.4	
HTH	5g/L		19	1.90E-02	1.00E-03	5.5	
surfactant B	1%	5	20	2.20E-02	0	0	no fines removed
HTH	2g/L	5	19	2.50E-02	-1.00E-03	-3.8	
surfactant B	1%	5	65	2.20E-02	0	0	no fines removed
HCl	1%	5	20	1.20E-02	8.00E-03	200	
Sulfamic	3g/L	5	20	1.20E-02	5.60E-03	87.5	
KOH	2g/L	5	20	1.70E-03	-5.00E-04	-22.7	floc observed in riser pipe
Sulfamic	3g/L	5	20	3.60E-03	1.40E-03	6.4	
KOH	2g/L	5	20	8.00E-03	-1.70E-03	-17.5	floc observed in riser pipe
HCl	5%	5	20	2.30E-02	1.33E-02	137	
Sulfamic	1g/L	5	20	3.30E-02	1.10E+00	28.4	
NaOCl	1%	5	20	3.00E-02	2.00E-03	7.1	yellowish cloudy liquid
surfactant A	1%	5	22	4.40E-02	2.40E-02	124	
iHCl	1%	5	22	1.70E-02	1.16E-02	215	
acetic acid	10%	22	65	1.5E-02	9.1E-03	154	effervescence, some clay
surfactant A	1%	5	22	1.80E-02	1.27E-02	240	
NaOCl	1%	65	1.75	5.9E-03	-1.00E-04	-2	no fines removed
surfactant A	1%	5	22	9.00E-03	2.00E-03	-18	fines removed
acetic acid	10%	65	16	1.7E-02	1.3E-02	347	effervescence
surfactant A	1%	5	22	1.20E-02	4.00E-03	-25	no fines removed

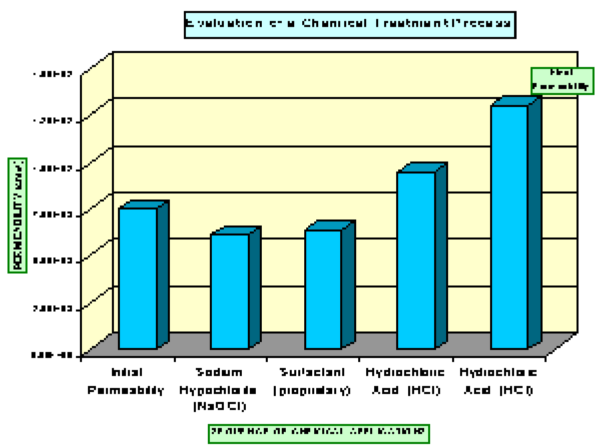
* - denotes post-process K-value

Table 4:
Surfactant A concentrations vs permeability (k)

concentration of surfactant (%)	Average increase in K-value (%)
0.75	30.5
1	20
2	8.5

A concern for the stability of the nylon screening and the possibility of spurious results due to breakdown under acidic conditions required an examination of the screens after the cells were dismantled. Microscopic examination of the screens showed they were intact, and therefore, the HCL results are deemed valid. Although the 1% solution resulted in a greater increase in K-value than the 5% solution, both trials resulted in dramatic increases in permeability. The reason for the disparity in results is due to the fact that the stronger solution of HCL was significantly neutralized by KOH

Figure 2

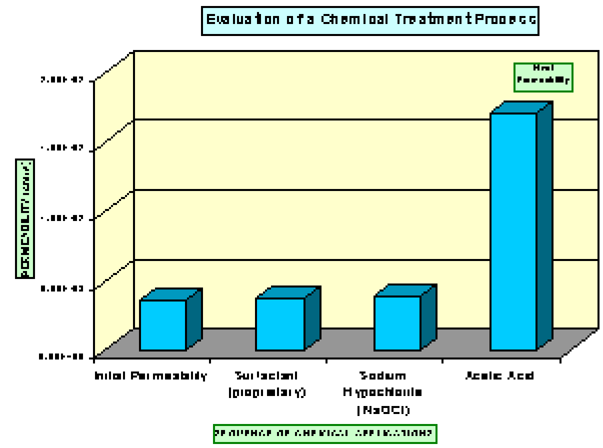


which remained in the cell following an earlier test. Inhibited hydrochloric acid (iHCl) was also tested at a 1% concentration and at a 1% concentration surfactant solution. Permeability increases in excess of 200% were observed, with the acid-surfactant combination providing the best results.

Sulfamic acid (NH_2SO_3H) was also evaluated as a possible alternative to the use of hydrochloric acid. A solution of 1g/L increased material permeability 28% and a solution of 3g/L improved permeability 64%. In combination with surfactant, sulfamic acid at a 21g/L concentration increased permeability about 124%. The screens were also examined to ensure the results were valid.

Two trials of potassium hydroxide (KOH) solutions, both 2g/L were also conducted to determine the effect of this compound on aquifer material. The use of this compound has been considered to provide a pH adjustment during well servicing instead of compounds such as sodium or calcium hydroxides which do not have favourable characteristics. Swelling tests on KOH have shown it to have favourable attributes in this

Figure 3



regard. Unfortunately, in both instances, the solution formed a floc while in the riser tube and the results of K-testing were unfavourable. Significant decreases in K-values were observed, likely because of plugging at the top of the column in each cell. These decreases were 17.5% and 22.7%, as shown in Table 3.The formation of a floc with KOH solutions may be similar to problems experienced with $Ca(OH)_2$ solutions. Unless this problem can be adequately managed under field conditions, it is unlikely that potassium hydroxide compounds will be used in well-aquifer treatments.

3.0 Discussion of Swell Consolidation and Permeameter Test Results

The results of swell-consolidation tests and/or permeameter tests indicate that hydroxide compounds should be avoided for water well servicing. Sodium hypochlorite has greater promise than calcium hypochlorite, but it may swell clay if not sufficiently removed from aquifers following treatment.

Increasing the temperature of treatment fluids results in increased efficiencies of fines removal, dissolution of organics and better overall increase in the permeability of aquifer materials. The optimum temperature for treatment has not been determined and further testing to determine optimal temperature for water well treatment will be required.

Surfactant A effectively dispersed clay particles and its use increased the permeability of aquifer materials. Tests suggest that solutions should not exceed 1% by volume in water and that residence times in the aquifer should be minimized, otherwise clay swelling may be a problem.

Permeameter tests of sulfamic, hydrochloric and acetic acid solutions indicate that these acids increase the permeability of aquifer materials more effectively than any other agent that has been evaluated in this study. Acetic acid proved to be the best of the organic acids evaluated in terms of clay swelling potential and increases in permeabilities. The evaluation of other acids and combinations of acid types for water well treatment will be considered in future laboratory studies. Further information on laboratory testing and field applications of new treatment methods cann be found on the PFRA web site at **http://www.agr.ca/pfra/water/swwie.htm**.

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