Suitability of Agricultural Drainage Water of the Safi Area for Potash Production

Nizar Abu-Jaber[1] Sultan Abu-Orabi[2] Sameh Gharaibeh[1] Hanan Malkawi[3] Idrees Momani[2] Mohammed Qudah[2] Nigem Din Yousef[1]

Abstract

The nature of drainage waters from agricultural fields in the Safi area and their potential for use as process water in the potash production plants was evaluated. Five triplicate samples were taken during a ten day period from the drainage waters in the area. The samples were analyzed for chemical, physical and microbiological characteristics.

Thermodynamic equilibrium models indicated that no change in the quantity of carnallite produced could be expected as a result of using these waters. These thermodynamic models indicate that $CaSO_4$ will not precipitate in the cold extraction facility, but it is not possible to determine whether this might happen in the high temperature plant. If this should become a problem, it can be minimized or eliminated through various simple options. A slight increase in scaling and corrosion is also expected.

The physical properties of the waters were inferior to those of the currently used process waters. Suspended solids and organic material could be easily removed through the use of rapid sand filters. Biological hazards are present in some samples. These need to be taken into consideration when handling and using the water.

In conclusion, preliminary sampling and analysis suggested that the waters may be used as process water in the plants, following the simple treatment methods that were recommended in this study. Further sampling and experiments are needed to reach a definite conclusion.

Introduction

Water shortage in Jordan is a well-known issue. Because of this, it is clear that water resources should be used in the most effective manner possible. This is particularly true for the Arab Potash Company (APC), which uses over 6 million cubic meters (MCM) per year in the production process (Abu-Jaber and Wafa, 1996). Coupled with this is the fact that the production facilities are at the southern end of

[1] Department of Earth and Environmental Sciences, Yarmouk University, Irbid, Jordan
[2] Department of Chemistry, Yarmouk University, Irbid, Jordan
[3] Department of Biological Sciences, Yarmouk University, Irbid , Jordan

the Dead Sea, where rainfall averages less than 100 mm/yr, which makes the most effective management of water resources even more important.

The major source of water in the area is the Safi aquifer, which lies at the terminus of Wadi Hassa. The water in this aquifer is replenished by recharge into the floor of the wadi from surface runoff (Parker, 1970). The highly permeable sediments of the course-grained alluvium at the end of the wadi provide an excellent shallow aquifer. The water quality is good, although salination of the outer margins of the alluvial fan aquifer has been noted, which been attributed to the dissolution of evaporative sediments from the Lisan Formation in this area (Abu-Jaber and Wafa, 1996).

Water in the area is used for agriculture, potash production and for domestic purposes. Runoff from the open trenches draining agricultural fields in the Safi area is typically drained towards the Dead Sea from two locations. These are the Sammar and Ain Younis areas. Waters at these locations are not suitable for domestic or agricultural reuse, and so the APC has expressed interest in using this drainage water as process water in its plants to augment its existing resources.

Process waters are used for decomposition of carnallite, dissolution of NaCl in crystallizer feed, washing of the sylvanite cake (belt filter) and cooling of pump seals and other general purposes (washing, cleaning, etc.).

Low quality waters may result in an inferior quality of potash, diminished production, or lower life expectancies and higher maintenance costs for plant equipment. Monitoring and detection of indicator and disease-causing microorganisms are major parts of sanitary microbiology. Bacteria from intestinal tract generally do not survive in the aquatic environment. They are under physiological stress and gradually lose their ability to form colonies on differential and selective media. Their die-out rate depends on the water temperature, the effect of sunlight, the population of other bacteria present, and the chemical composition of the water.

A wide range of viral, bacterial, and protozoan diseases result from the contamination of water from human fecal wastes. Although many of these pathogens can be detected directly, environmental microbiologists have generally used indicator organisms (*E.coli*) as an index of possible water contamination by human pathogens.

One aspect of the project is to understand the health aspects involved in using this water. In order to understand this, chemical and biological analysis of water samples collected from the above sites were carried out. The purpose of the microbiological analysis was to evaluate the potential hazard to the health of people exposed to this water during handling and processing of the water.

The scope of the work involved collecting water samples and determining the physical, chemical and biological characteristics of these samples. The possible

effects of using this water as process water on the quality and quantity of the products as well as the possibility of scaling, corrosion and erosion of plant equipment were assessed. Recommendations for possible treatment options, if needed, were given.

Methodology

Water sources and sampling

Two locations near the APC production plant contain water collected from agricultural drainage. These are the Sammar and Ain Younis locations. The Sammar location is at the south edge of the Dead Sea (Figure 1), and consists of a reservoir where the agricultural drainage water is collected.
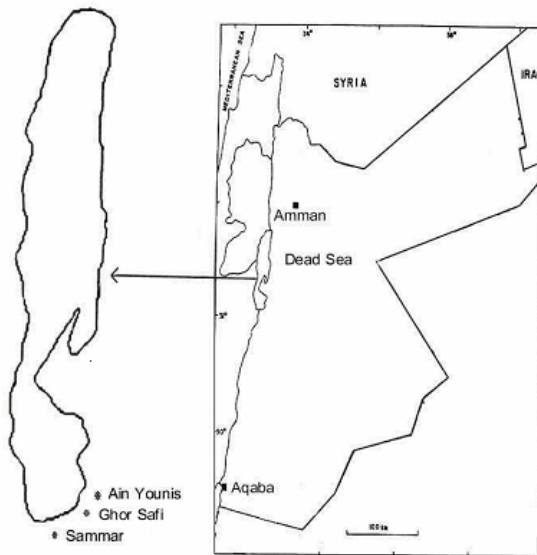
Figure 1. General location map.

The Ain Younis water is more dispersed, and in reality consists of four separate channels which ultimately flow into a pool of Dead Sea brine on the southeastern coast of the Dead Sea. A general sketch of the area and the sampling locations is given (Fig. 2). The studied area is located at the southern end of the Dead Sea and includes four main drainage channels in Ain Younis and a pool in Sammar in which drainage water is collected.

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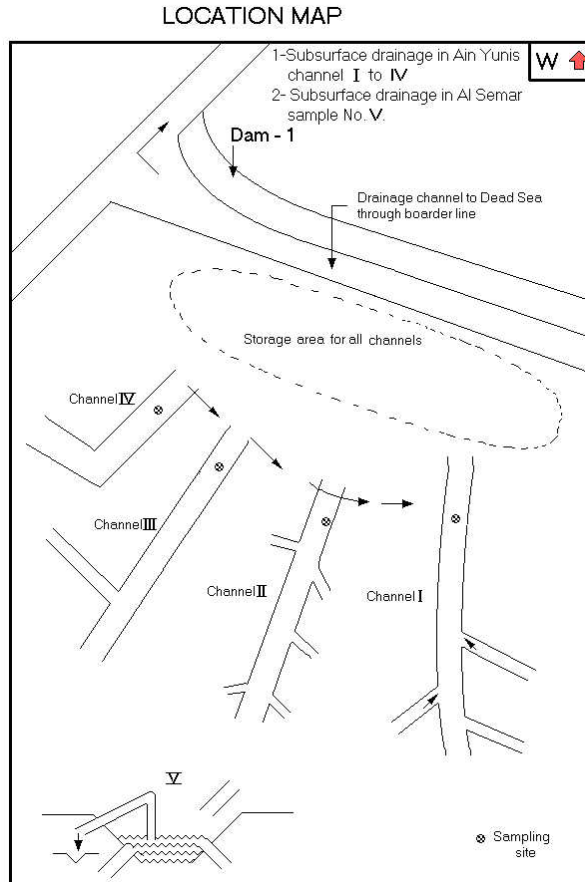
LOCATION MAP

Figure 2. Location of the sampling sites at Ain Younis.

The water samples were taken from fixed sample sites located at the head of each main channel. The sampling was conducted three times over a period of ten days and included each time four water samples in order to determine the major and trace element constituents, phosphate content, fat, oil and grease (FOG), and microbiological characteristics. Samples were taken on June 27, July 2 and July 8, 2001.

Analysis of samples

All samples were analyzed at the Royal Scientific Society laboratories according to their standard procedures (Franson et al., 1998). The fifteen samples taken and one control sample were analyzed. The control sample was taken from the water

currently used in the plants. Samples I-IV were from Ain Younis, sample V was from Sammar.

Evaluation of the drainage water

The evaluation of the drainage waters consisted of three separate tasks. The first was a chemical modeling of the thermodynamic equilibrium relationships between the water and the various mineral phases relevant to potash production. The second was an evaluation of the corrosion potential of the waters in question on the pipes of APC plant. The third was an evaluation of the microbiological contamination of the waters in question.

Chemical modeling

Chemical thermodynamics can provide appropriate criteria for predicting mineral dissolution and precipitation under various conditions. Given this, it is appropriate to explore the implications of the use of the subject waters on the quality, and quantity of potash if used in the extraction. Another issue is the problem of scaling (mineral precipitation) in the pipes of the potash plant.

In order to determine the saturation state of a solution with respect to the various solid phases, it is important to be able to determine the activity coefficients (α) for the various solutes. This is relatively simple in dilute solutions and becomes more difficult in brines. Until recently, the use of chemical equilibria to model water evolution of brines has been considered difficult. The modified Debye-Hückel equation is suitable to salinities of about 0.1M, but deviates strongly from observed behavior after that (Stumm and Morgan, 1981: Domenico and Schwartz, 1990).

Pitzer and Kim (1974) proposed a new set of relationships that are based on empirical observations of interionic behavior, which became known as the Pitzer equations. This set of relationships was largely deemed to be difficult to apply, and hence impractical (Domenico and Schwartz, 1990). However, Plummer et al. (1988) developed a code integrating the Pitzer equations into the already well-known chemical equilibrium software program known as PHREEQE, creating a new program known as PHRQPITZ. The use of PHRQPITZ allows for chemical equilibrium and mass balance modeling for extremely high ionic strength solutions. This is ideal for modeling of chemical evolution of waters to be used in potash production, where the ionic strength of the solution often exceeds 8M. PHRQPITZ has been used in the past in studying the chemical evolution of the Dead Sea (Abu-Jaber, 1998).

Modeling steps

The extraction of sylvite (KCl) from carnallite ($KMgCl_3.6H_2O$) can be viewed as a two-step process, that is, the dissolution of carnallite and the precipitation of sylvite. Hence, the modeling of these processes was done in two stages. The first stage was as follows:

$KCl.MgCl_2.6H_2O + H_2O$ (including the major solutes) $\rightleftharpoons K^+ + Mg^{2+} + 3Cl^- +$ other solutes

It is recognized that NaCl is also dissolved in this process and precipitated with KCl. NaCl was not included in the model because its relative proportion and its relative rate of dissolution and precipitation is not known and can't be modeled. The effect of ignoring NaCl on the results is that these results will contain over estimates of carnallite dissolution and sylvite precipitation. The purpose of the model is to show how the results of the extraction process might change as a result of using the proposed waters in processing. It is not intended to give the exact yields.

This modeling allows us to estimate the chemical composition of the resulting water, the mass of carnallite dissolved into solution, and the equilibrium relationships of a large suite of minerals that precipitate in the brine environment.

The second stage was as follows:

$K^+ + Cl^-$ + other solutes in the solution $\rightleftharpoons$ KCl + other solutes.

This modeling allows us to estimate the chemical composition of the final water, the mass of sylvite precipitated, and the equilibrium relationships of the final water.

It is recognized that the plant conditions are not designed to allow the brines to reach supersaturation with respect to carnallite. However, comparison between water currently in use with the results of runoff waters may be indicative. Reaction temperatures were assumed to be 25°C, which is the optimal temperature for these simulations because of the nature of the thermodynamic database available.

Microbiological analysis

Microbiological analysis for the water used in this study was done according to the procedures prescribed by the US Environmental Protection Agency (Franson et al., 1998). The results were compared with the Jordan National Standard for drinking water (No. 286, 1990) and for waste water (No.893, 1995), Ministry of Water and Irrigation.

Corrosion Study

The corrosion study was conducted at the laboratories of the Department of Chemistry at Yarmouk University. The electrochemical behavior of steel in the different aqueous samples can be summarized as follows.

The corrosion characteristics of the different water samples were assessed by using the potential current technique. The working electrodes (steel) were successively abraded with emery paper up to 100 grade and then cleaned with acetone. A platinized platinum electrode served as a counter electrode while the reference electrode was a saturated calomel electrode. The three electrodes were connected to a glass cell as described Gassen et al. (1986). This was done by applying anodic potentials starting from the open circuit potential. The corrosion systematics of the samples were analyzed. All electrochemical measurements were performed using computer controlled IM5D digital equipment (Zahner Elektric, Germany).

Results and Discussion

Chemical, physical and microbiological analyses

Results of the chemical, physical and microbiological analyses of the three sampling events, as supplied by the Royal Scientific Society, are presented in appendix 1 and are averaged and presented in Table 1. Samples I-IV were from Ain Younis (see Fig. 1), and sample V was from Sammar. A sample of the process water currently used was also analyzed as a control.

Comparison of the data from table A, B and C in the appendix show negligible variation in chemical and physical properties during the three sampling events. However, there is notable variation in the biological properties. The number of samples precludes conducting statistical treatment to determine standard deviations. The results showed a high salinity value for sample I. All of the drainage waters have salinity values that are higher than the currently used process water. Heavy metal concentrations were low and near to those in the currently used process water. The only exception was sample I, which has somewhat higher Cr, Zn, Ni and Cu concentrations. These would be ultimately diluted with the other water and may be removed with the suspended organic material as a result of filtration, as recommended later. This should not adversely affect the quality of the final product.

The color, turbidity, and chemical oxygen demand (COD) for these waters were also higher than those of the currently used process water, whereas the fat, oil and grease contents were comparable. The color and turbidity were probably linked to the high COD, indicating a high organic load. These factors may adversely affect the texture of the final product by changing the color or texture of the potash. This can be easily remedied.

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Table 1 : Average values of chemical, physical and microbiological data of the water samples (all 3 Batches).

Parameter	Unit	Result/ Sample Code					
		I	II	III	IV	V	Control
TDS	mg/l	79597	6510	2380	3039	14092	1330
PH	SU	7.4	7.9	8.3	8.2	7.9	7.72
Na	mg/l	16583	1274	362	434	2702	188
Ca	mg/l	5343	376	101	119	689	135
Mg	mg/l	5103	410	182	298	963	80
K	mg/l	918	119	99	114	242	23
Cl	mg/l	50749	3557	572	1339	6454	652
SO4	mg/l	358	391	789	546	24089	168
PO4	mg/l	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
NO3	mg/l	9.0	<3.6	<3.6	4.9	<3.6	13
NH3	mg/l	33.3	<1	<1	<1	6.2	<0.03
HCO3	mg/l	115.0	233.3	429.7	292.0	236.3	206
SiO2	mg/l	8.1	9.2	8.1	7.6	28.0	
Color	PCU	36.7	13.3	18.3	18.3	28.3	5
Pb	mg/l	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
Cd	mg/l	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Cr	mg/l	0.27	<0.1	<0.1	<0.1	<0.1	<0.1
Zn	mg/l	0.1	<0.05	<0.05	<0.05	<0.05	<0.1
Cu	mg/l	0.15	<0.1	<0.1	<0.1	<0.1	<0.1
Fe	mg/l	1.8	0.28	<0.1	0.14	0.49	<0.1
Ni**	mg/1	0.6	<0.1	<0.1	<0.1	<0.1	<0.1
EC	μs/cm	99433	11220	3659	5233	21287	2420
TSS	mg/l	221.7	28.3	7.3	13.7	74.7	<5
Turb.	NTU	21.7	29.9	5.5	10.4	49.7	1
FOG	mg/l	<3	<3	<3	<2	<2	<2
COD	mg/l	*	*	25.7	56.0	*	6
Algae	Count/ml	462	421	104	68	5122	
Fungus	CFU/100ml	35	20	15	20	20	
E.coli	MPN/100ml	<2	740	522	134	328	

* : Could not be analyzed due to high Cl content.

Abbreviations: Turb: Turbidity, TDS: Total dissolved solids; EC: Electrical conductivity; TSS: Total suspended solids; FOG: Fats oils and grease; COD: Chemical oxygen demand; CFU: Colony forming unit; MPN: Most probable number; PCU: Platinum cobalt unit; NTU: Nepheometric turbidity unit; SU: Standard Unit.

Microbiological analyses indicated variable counts of algae, fungi and *E.coli*. The implications of these results will be discussed in the following sections.

Chemical models

Based on the results of the chemical analyses, simulations of the thermodynamic conditions were conducted. The results of the PHRQPITZ models are presented in Table 2. The results suggested that the drainage waters would be as effective in terms of carnallite dissolution and sylvite precipitation as the currently used process water.

The main conclusions that could be reached from Table 2 are:

- Most samples can be expected to have the same efficiency in dissolving carnallite and precipitating sylvite. The notable exception was sample I, which was clearly inferior on both counts.

- Mineral phases expected to precipitate into the final sylvite cake may be dolomite and magnesite. Sample I may precipitate calcite as well. No exotic minerals are expected to appear as the result of using this water at ambient temperature.

Table 2: Results of the thermodynamic modeling with respect to carnallite dissolution and sylvite precipitation at 25°C.

Sample	Mass carnallite dissolved (Mole/l)	Mass sylvite precipitated (Mole/l)	Final mineral phases supersaturated
	25°C	25°C	25°C
Currently used water	3.14	2.08	Dolomite, magnesite
I	2.69	1.75	Calcite, magnesite, dolomite
II	3.13	2.07	Dolomite, magnesite
III	3.14	2.08	Dolomite, magnesite
IV	3.14	2.07	Dolomite, magnesite
V	3.10	2.05	Dolomite, magnesite

APC technical engineers have expressed concern that sulfate precipitate may occur at high temperatures. This could not be done because the computer software used in modeling high ionic strength water was based on a thermodynamic database that is applicable at 25°C. No thermodynamic database has been developed for both high temperature and high salinity waters so far in the literature, thus experimental work will be needed to explore anhydrite precipitation at higher temperatures.

Scaling

Samples of proposed input waters were all more supersaturated with respect to calcite than the currently used water (table 3). This suggests that increased scaling may be a problem.

TABLE 3 : Calcite Equilibria Relationships and Estimated Change in Calcite precipitation over current levels.

Sample	Log IAP	Log IAP/K
In use water	-7.9594	0.4468
I-1	-7.0468	1.3594
II-1	-7.2318	1.1745
III-1	-7.0991	1.3071
IV-1	-7.2391	1.1671
V-1	-7.1249	1.2813

Biological hazards

Since the water source in question is not intended to be used for drinking purposes, we recommend considering the potential health hazards that could be associated with handling such water in the production system. The group of people that could be exposed during the production procedures is mainly engineers and laborers. Therefore we should consider mainly the guidelines of using and handling wastewater in general as stated by the national guidelines.

The results of microbiological analysis indicated that for batch I, samples I-1, III-1, IV-1 and V-1 contained *E.coli* population below the standard limits according to the Jordan National Standard for drinking water (No, 286, 1990 and No. 893, 1995 and therefore would not impose a hazard to health. Sample II-1 contained 1,700 MPN/100 ml, which was higher than the limits by 1.7 times, therefore protective and safety measures should be used. Sample I-1 was considered very low in the number of *E.coli* population, which is obviously due to the inability of *E.coli* to survive in the highly salty water in I-1.

The results of batch 2; samples III-2 also contained *E.coli* higher than the recommended limits. The third batch did not contain any microbial number higher than the recommended acceptable limits.

The national standards do not consider fungi or algae as indicators for water contamination as health hazard. Therefore, the presence of algae or fungi in these water samples will not impose a heath hazard.

Corrosion

As a result of applying the anodic potentials, small amounts of current densities were measured. The current density increases as potential increases in the same solution. Upon investigating the effect of the percent of chloride ions, a shift toward the active direction (less anodic) was observed as the concentration of chloride ions increased. In all solutions a notable increase in the values of current density was measured at potentials greater than +100 mV. Also, at the same applied anodic potential, current density increased as the concentration of chloride ions increases.

Initially, a protective passive film was formed through the formation of passive oxide film, which is dependent on the alloy (steel) constituents. At potentials greater than 100 mV, chloride ions broke the passive film and current densities increased through increasing the surface area of the electrode (steel). i.e. the passive film was destructed and the passive region disappeared. Most pitting corrosion has been attributed to chloride ions. Chloride ions can penetrate through the oxide films and cause localized attacks on the passivated surface (nonuniform breakdown of passivity).

Whereas the chloride ions exist in an aqueous medium, and the relative humidity is at least 5%, then corrosion takes place. The chloride ions are the most harmful ions by which pitting corrosion occurs, and prevents the formation of a passive film at the surface of the alloy. The results of the polarization process of the carbon steel sample in different aqueous samples, are shown in Table 4.

Table 4 :Expected corrosion rates from the different samples on carbon steel pipes.

Sample	Corrosion rate (mm/yr) at 8 °C
Control	0.029
I	0.77
II	0.17
III	0.26
IV	0.053
V	0.34

When this study was extended to other alloys (Monel 400, Stainless Steel 316 and Inconel 625) at higher temperatures (up to 80°C) in different aqueous solutions, the following results were obtained:

The Inconel alloy was more passive in chloride solutions than the Monel alloy, where the polarizing resistance (RP) was very high for the Inconel alloy. The activity of Monel was similar to that obtained for steel. Corrosion rates increase in the presence of chloride ions with increasing temperatures for all the alloys. These results were consistent with earlier published work (Abdallah and Said, 1995; Abdallah, 1996).

Proposed treatment options

The major obstacles to using these waters for processing are as follows:

1- The relatively high suspended solid concentration.
2- The relatively dark color.
3- The relatively high turbidity.
4- The occasional presence of *E.coli*, fungi and algae in some samples.
5- Possible supersaturation with respect to anhydrite in some of the samples at high temperatures.

The proposed treatment needed for the water in question is to use rapid sand filters. This is because of the high efficiency in removing the suspended solids, the moderate efficiency for removing color, turbidity, microorganisms and the organic material, and heavy metals adsorbed onto organic or clay materials. NH_3 or NH_4^+ will be reduced or eliminated due to air stripping in such a filter. The microorganisms are not a problem regarding the process of potash production, but waters containing unacceptably high concentrations of microorganisms should not be used for washing, cleaning or human consumption.

It is also recommended that the open reservoirs of APC should be covered with plastic or polystyrene spheres (balls) in order to:

1- Reduce evaporation and salt concentrations.

2- Reduce algal and other microbial growth.

Such covering materials are of low cost and do not affect the pumping of water from the reservoirs. In case the APC feels that the sulfate concentrations are too high for whatever reason, this can be lowered using ferrous chloride. Sulfate removal will result in the lowering or eliminating of any anhydrite precipitate. The increase in chloride concentrations may lead to reduced efficiency of the extraction process, however.

Water should be mixed with the currently used waters in order to maintain anhydrite ($CaSO_4$) IAP below the supersaturation level. If this is not possible, water might be heated prior to entering the carnallite dissolution process. This will allow the anhydrite to precipitate. The suspended anhydrite can then be removed by filtration or settling.

Final Notes and Recommendations

It should be noted that the samples taken represent the state of the waters at the time of sampling. There is no explicit or implied assumption that the results of the analyses or the conclusions based on them are valid during other seasons of the year. Therefore, it is recommended that further sampling throughout the year be conducted in order to validate these results.

The results of the chemical models are based on incomplete knowledge of reaction kinetics and the possibility of reaction poisoning by unrecognized solutes. In effect, the best way to understand the potential effects of the use of the proposed waters is to build a pilot plant to test these results. Given the time and financial

restrictions of the project, this work has not been done. Nevertheless, we believe that the theoretical models will provide accurate indications of what to expect in the event that the water is used.

Given these restrictions, the following are the recommendations of this study:

1- The use of the drainage water will not affect the quantity of potash produced in the plant. Water at one location (Sample I) at Ain Younis will result in a small decrease in production efficiency, and this will not be noticeable when mixed with the other drainage waters and with the waters currently being used. The rest of the waters show similar results to the water currently being used.

2- Turbidity, suspended solids and organic materials should be removed before using the proposed water in the plant, as they may affect the color and texture of the final product. It is recommended that a low-cost and simple sand filtration system be installed in order to reduce these impurities.

3- Waters should be mixed with low sulfate waters currently used in order to minimize or prevent the precipitation of anhydrite, especially in the industrial grade potash. No anhydrite is expected to precipitate if the water is used in the cold crystallization facility.

4- The proposed water will probably result in an increase of calcite precipitate in the pipes of the plants.

5- Corrosion of the pipes due to the use of the proposed water may increase from current levels, especially in pipes channeling water before carnallite dissolution.

6- It is not recommended to use some of the water for cleaning or washing purposes, as they may contain certain pathogens. However, the number of these pathogens will be reduced or eliminated in the sand filtration system and any later treatment option. Moreover, the microorganisms will not survive in the sylvite extraction facilities.

Acknowledgments

دراسة ملائمة مياه الصرف الزراعية في منطقة غور الصافي لاغراض انتاج البوتاس

نزار ابوجابر، سلطان ابوعرابي، سامح غرايبة، حنان ملكاوي، ادريس المومني، محمد القضاه و نجم الدين يوسف

ملخص

لقد تم تقييم مياه الصرف من المزارع في منطقة الصافي و امكانية استخدام هذه المياه لاغراض مصانع البوتاس.

فقد تم اخذ خمس عينات (ثلاث مرات) من مياه الصرف في المنطقة. اربعة من عين يونس و الخامسة من السمار على فترة عشرة ايام. تم تحليل العينات كيميائيا و فيزيزيائيا و احيائيا في مختبرات الجمعية العلمية الملكية.

تم نمذجة كيميائية المياه اثناء العمليات داخل المصنع باستخدام افتراضات الاتران الثرموديناميكي، وذلك لتقدير كمية اذابة الكارنالايت و انتاج كلوريد البوتاسيوم في حالة استخدام هذه المياه. و قد بينت هذه النتائج بان كمية الانتاج لن تتغير في حال استخدامها. و من الممكن ايضا ان يكون هنالك زيادة طفيفة في التكلس و تآكل الانابيب.

ان الخصائص الفيزيائية للمياه هي اقل جودة من المياه المستخدمة حاليا. ولكن من السهولة االتخلص من المواد الصلبة العالقة و المواد العضوية بواسطة فلاتر رمل سريعة. هناك اخطار بيولوجية في بعض العينات، لذا يجب مراعاة ذلك عند استخدام هذه المياه.

وفي الختام، البيانات تشير الى جدوى استخدام هذه المياه في المصنع شرط استخدام اساليب المعالجة البسيطة المقترحة في هذه الدراسة.

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Appendix. Results of the analyses of the three samples

Table A : Results of Chemical, Physical and Biological Analyses of the Water Samples (Batch No. 1, Sampling Date: 27/6/2001).

Parameter	Unit	Result/ Sample Code					
		I-1	II-1	III-1	IV-1	V-1	Control
TDS	mg/l	81106	6426	2236	2808	12188	1330
pH	SU	7.72	8.02	8.58	8.47	8.19	7.72
Na	mg/l	18050	1283	362	427	2410	188
Ca	mg/l	5359	361	85	111	598	135
Mg	mg/l	5365	409	171	275	855	80
K	mg/l	936	117	91	108	212	23
Cl	mg/l	51953	3494	527	1218	5645	652
SO4	mg/l	361	394	750	512	2210	168
PO4	mg/l	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
NO3	mg/l	7.3	<3.6	<3.1	6.3	<3.6	13
NH3	mg/l	33	<1	<1	<1	4.9	<0.03
HCO3	mg/l	109	224	348	250	212	206
SiO2	mg/l	24.4	27.5	24.4	22.9	83.9	
Color	PCU	40	15	20	20	30	5
Pb	mg/l	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3**
Cd	mg/l	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1**
Cr	mg/l	0.24	<0.1	<0.1	<0.1	<0.1	<0.1**
Zn	mg/l	0.1	<0.05	<0.05	<0.05	<0.05	<0.05**
Ni**	mg/l	0.6	<0.1	<0.1	<0.1	<0.1	<0.1**
Cu	mg/l	0.17	<0.1	<0.1	<0.1	<0.1	<0.1**
Fe	mg/l	1.9	0.56	<0.1	0.12	0.64	
EC	s/cm	102300	11070	3420	4900	18940	2420
TSS	mg/l	119	58	7	10	118	<5
Turb.	NTU	14	82	3.5	4.3	70	1
FOG	mg/l	3	3	3	2	4	<2
COD	mg/l	*	*	26	46	*	6
Algae	Count/ml	546	210	127	32	9021	
Fungus	CFU/100ml	36	27	11	7	34	
E.coli	MPN/100ml	<2	1700	26	22	4	

* : Could not be analyzed due to high Cl content.

** : Analysis was done at Yarmouk University.

Table B :   Results of Chemical, Physical and Biological Analyses of the Water Samples (Batch No. 2, Sampling Date: 2/7/2001).

Parameter	Unit	Result/ Sample Code					
		I-2	II-2	III-2	IV-2	V-2	Control
TDS	mg/l	78832	6840	2402	3404	15244	1330
pH	SU	7.06	7.7	7.9	7.84	7.42	7.72
Na	mg/l	16150	1298	365	488	2995	188
Ca	mg/l	5244	397	111	129	749	135
Mg	mg/l	5010	412	184	335	1033	80
K	mg/l	806	110	93	121	240	23
Cl	mg/l	49161	3627	618	1574	6956	652
SO4	mg/l	352	417	816	585	2542	168
PO4	mg/l	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
NO3	mg/l	6.6	<3.6	<3.1	3.8	<3.6	13
NH3	mg/l	34	0.28	<0.03	<0.03	7.4	<0.03
HCO3	mg/l	117	254	461	314	247	206
SiO2	mg/l	17.8	17.8	20.2	20.2	51.3	
Color	PCU	40	10	20	15	30	5
Pb	mg/l	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3**
Cd	mg/l	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1**
Cr	mg/l	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1**
Zn	mg/l	0.29	<0.05	<0.05	<0.05	<0.05	<0.1**
Cu	mg/l	0.15	<0.1	<0.1	<0.1	<0.1	<0.1**
Ni**	mg/l	0.6	<0.1	<0.1	<0.1	<0.1	<0.1**
Fe	mg/l	1.50	0.13	<0.1	0.18	0.43	
EC	μs/cm	94200	11320	3710	5853	22540	2420
TSS	mg/l	161	12	10	24	45	<5
Turb.	NTU	13	2.6	9	14	36	1
FOG	mg/l	<2	<2	<2	<2	<2	<2
COD	mg/l	*	*	30	77	*	6
Algae	Count/ml	537	963	34	91	3416	
Fungus	CFU/100ml	23	9	21	21	13	
E.coli	MPN/100ml	<2	300	1400	300	900	

* : Could not be analyzed due to high Cl content.

**: Analysis was done at Yarmouk University.

Table C : Results of Chemical, Physical and Biological Analyses of the
Water Samples (Batch No. 3, Sampling Date: 8/7/2001).

Parameter	Unit	Result/ Sample Code					
		I-3	II-3	III-3	IV-4	V-5	Control
TDS	mg/l	78854	6264	2502	2906	14846	1330
pH	SU	7.27	8.07	8.28	8.26	8.07	7.72
Na	mg/l	15550	1242	360	388	2700	188
Ca	mg/l	5425	370	108	118	719	135
Mg	mg/l	4935	408	192	284	1002	80
K	mg/l	1013	130	112	112	274	23
Cl	mg/l	51133	3551	570	1226	6760	652
SO4	mg/l	360	362	801	541	2474	168
PO4	mg/l	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
NO3	mg/l	13	<3.6	<3.6	4.6	<3.6	13
NH3	mg/l	33	0.8	<0.04	<0.04	6.4	<0.03
HCO3	mg/l	119	222	480	312	250	206
SiO2	mg/l	17.1	17.1	27.1	19.2	48.1	
Color	PCU	30	15	15	20	25	5
Pb	mg/l	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3**
Cd	mg/l	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1**
Cr	mg/l	0.27	<0.1	<0.1	<0.1	<0.1	<0.1**
Zn	mg/l	0.1	<0.05	<0.05	0.05	<0.05	<0.1**
Cu	mg/l	0.15	<0.1	<0.1	<0.1	<0.1	<0.1**
Fe	mg/l	2.0	0.14	<0.1	0.13	0.41	<0.1**
Ni**	mg/1	0.6	<0.1	<0.1	<0.1	<0.1	<0.1**
EC	µs/cm	101800	11270	3846	4947	22380	2420
TSS	mg/l	385	15	5	7	61	<5
Turb.	NTU	38	5	4	13	43	1
FOG	mg/l	3	2	2	<2	<2	<2
COD	mg/l	*	*	21	45	*	6
Algae	Count/ml	304	89	152	82	2931	
Fungus	CFU/100ml	46	23	14	14	13	
E.coli	MPN/100ml	<2	220	140	80	80	

* : Could not be analyzed due to high Cl content.

** : Analysis was done at Yarmouk University.