Exploration of potassium chloride from Khur Playa

***Esmail Aflaki*[1]**

Prieskum chloridu draselného v Khur Playa

The Great Kavir is located in the centre and extended to the eastern part of Iran. The low rainfall (86.5 mm/yr) and high evaporation (2857 mm/yr) in this region have led to the presence of a number of playas. This study summarizes the most important and economical minerals such as halite and potash which are deposited in the Great Kavir, especially in Khur Playa. There is thus a strong motivation for extracting this material. The evaporate minerals precipitating from the playa brine are influenced by the progressive change in brine salinity and its composition.

Research was then undertaken to elaborate a common extraction method based on a programmed scheme. A series of test-pits and boreholes were drilled in the playa to a depth of maximum 63 m to produce brine. The pre-constructed ponds were then used to extract KCl by evaporation of water under the sun. Our investigations show that the average content of potassium at Khur Playa is at least 2600 ppm.

***Key words**: Evaporate minerals, Great Kavir, Khur Playa*

Introduction

The term "Great Kavir" refers to the central and lower part of an extensive drainage basin in the eastern part of Iran. Although the Great Kavir occupies the lower part of this interior basin, it is the main part of an elevated plateau which is 650 to 850 m above sea level. Thirty seven percent of its area is composed of intricately folded Mio-Pliocene sediments which have been eroded to a peneplain surface. Interfingering within the peneplain surface are salt-encrusted depressions which also occupy thirty seven (37) % of the area of the Great Kavir.

Based on statistical information, the area covered with salt crust in Khur Playa is about 1000 km^2, which includes a large amount of crystallized and semi-crystallized salt with some clay, silt and sand. The thickness of the salt crust is between 2 to 17 m with an average of 6 m. The salt content is about 5 % and cavity portion of 10 %. The total existence of brine that is able to be used for winning potash salt can be calculated as $6*10^{10}$ MCM. There are certainly additional and considerable amount of brine below the explored deposits that eventually can be used too.

This paper summarizes our investigation to achieve the above objectives.

Geography of the Khur Playa

Khur Playa is located approximately 380 kilometres east of Naiin City and 40 kilometres along Tabas road, at the $E54°16'$ to $55°03'$ longitude and $N33°28'$ to $34°10'$ latitude. The area of this playa is 2000 km^2 and is triangular in shape [4]. The location of this playa is shown in Fig. 1.

Geology of the Khur Playa

In this study, it has been observed that, the western, southern and eastern boundaries of the Great Kavir are sharply defined by the toes of coarse alluvial fans and prominent sand dune fields. The northern boundary between Moalleman and the alluvial fan of the Rud-e-Mureh is delineated by an alluvial apron. In this sector, the topography is transitional from peneplain surface to pediments to low mountain slopes, composed of Miocene rocks and salt domes whose structures are clearly exposed. The Great Kavir may be subdivided into eastern and western basins which are separated by a broad peneplain cut into Miocene rocks. The divided peneplain is marked by three salt crust basins in a north-south direction.

[1] *prof. Dr. Esmail Aflaki,* In Engineering Geology and Geotechnics, Department of Civil and Environmental Engineering, Amirkabir University of Technology, Tehran, Iran eaflaki@aut.ac.ir
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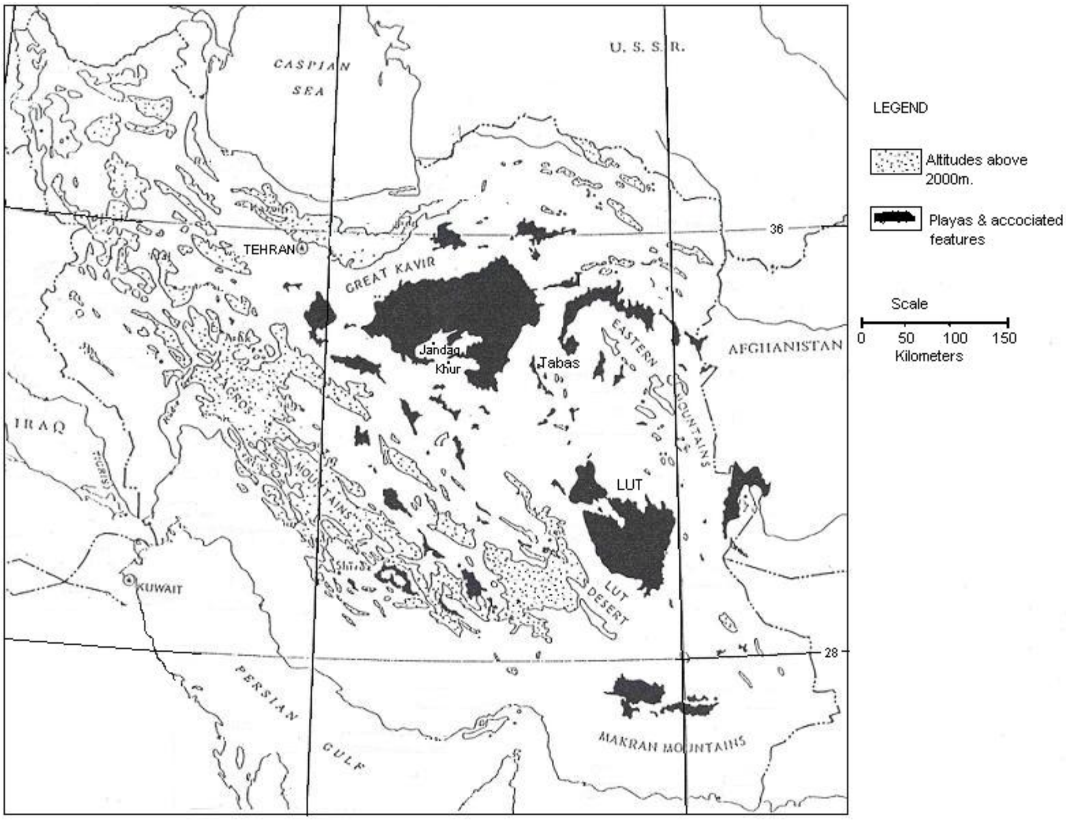

Fig. 1. Map of location of Playas in Iran [4].

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Around the margins of the Great Kavir, higher eroded surfaces have been cut into the Miocene rocks. These surfaces are now only scattered remnants due to uplift and erosion. The eastern and western basins receive their drainage from the Rude-e-Mureh and Rude-e-Shur rivers which, originate from the Alburz Mountains. These streams debouch from narrow valleys into the broad flats of the Great Kavir where they have formed into extensive alluvial fans [4, 1]. Other map units (Fig. 2) in the Great Kavir with their distribution are described as follows:

Unit	Area [km^2]	Area [%]
Alluvial fans	2,892	5.5
Wet zone	3,106	5.9
Salt crust	1,9676	37.2
Clay flat	895	1.7
Eroded surface of the Miocene rocks	19,314	36.6
Sand dune	6,942	13.1
Total	52,825	100.0

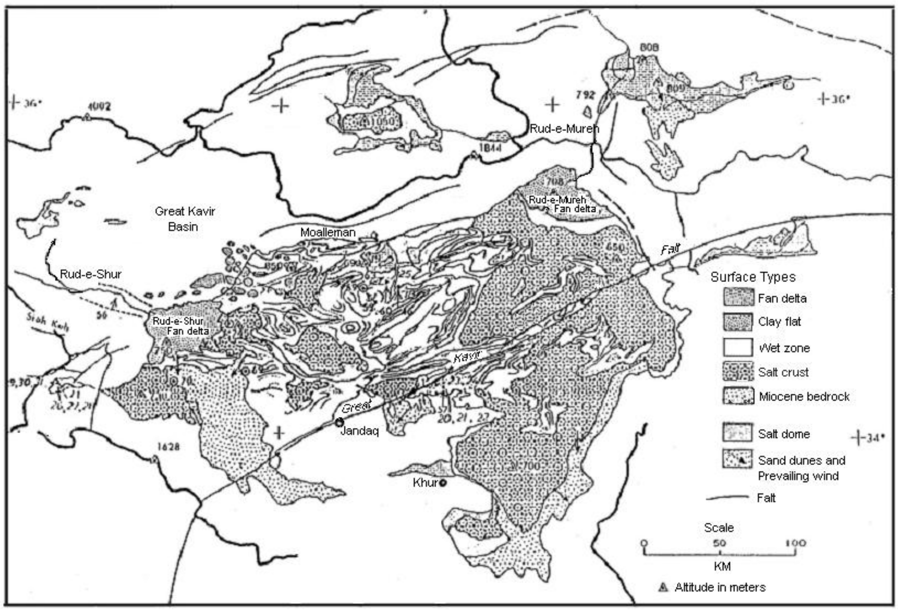


Fig. 2. Map of the Great Kavir of Iran [4] as well as author's observations.

Alluvial fan

Alluvial fans in this region were formed by the rivers Rud-e-Mureh and Rud-e Shure. Rud-e Mureh has cut a narrow gorge through volcanic rocks northeast of its alluvial fan in the Great Kavir. Rud-e Mureh maintains its axial position through the fan with only two tributaries. Its alluvial fan occupies an area of 1.392 km^2 in the northern part of the Great Kavir. There are adjacent alluvial fans at its north-east and north-west sides. It has been separated from the nearby salt crust by a wet zone which ranges in width from 2 to 12 km, along its 70 km length southwest periphery (Fig. 2).

Rud-e-Shur cuts through the Miocene sedimentary rocks before reaching the western part of the Great Kavir where its alluvial fan occupies an area of 1.500 km^2. The north and west sides of the alluvial fan which, each has 40 km length, border the alluvial fan from the adjacent mountains. Narrow wet zones separate the alluvial fan from salt crust basins along the east and south-west perimeters (Fig. 2).

Wet zone

The wet zone contains clay and silt, and frequently halite (NaCl) and gypsum ($CaSO_4$, $2H_2O$). It is a transitional zone which is periodically inundated and always wet at or near the surface, but may be superficially dry in summer. Its width may change from year to year, and it may be shifted outward by an expanding playa. In the Great Kavir, two types of wet zones can be distinguished. The more common occurs at the toes of the alluvial fans. Extensive wet zones border the alluvial fans of the Rud-e-Shur and the Rud-e-Mureh (Fig. 2). The wet zone is actually higher than the adjacent salt crust, although the vertical distance may be less than one meter except for the larger salt crust basins. The wet zone receives its water from the alluvial fans and the supply is visibly superficial during the wet seasons. In the dry period, the wet zone is supplied by ground water which lies closer to the surface at the margins of the playa basin.

The second type of the wet zone occupies a narrow trough within the area underlain at shallow depth by Miocene rocks. Many of these zones are too narrow to be mapped. In the central part of the Great Kavir, three extensive narrow wet zones with a northeast-southwest trend have been developed (Fig. 2). The surface gradients of these troughs are less than one degree and are characterized by a thin salt crust.

Salt crust

The salt crust, overlying the basins of the Great Kavir, occupies areas in the east, west and the centre. The eastern basins are generally continuous, but are locally interrupted by Miocene outcrops with the northeast-strike ridges. The two salt crust basins in the western area of the Great Kavir lie adjacent to the alluvial fan of the Rud-e-Shur. The southern basin, which receives additional drainage from a small playa from the west, is three times the size of the northern basin. It contains more moisture and has a continuous salt crust. All these observations indicate that the north-west part of the Great Kavir has been uplifted relative to the south part. The data concerning altitudes indicate that the salt surfaces of the Great Kavir basins are at different levels. The surface of the southern basin is 50 meters higher than the salt surfaces adjacent to the Rud-e-Mureh alluvial fan. There is thus a significant gradient northward towards the alluvial fan. Three salt crust basins in the central part of the Great Kavir occupy down warps in the Miocene rocks. The salt crusts of these basins lie at different levels and they are probably hydrologically independent. It is estimated that the middle basin surface lies at an altitude of approximately 850 m. There are numerous smaller salt-crust depressions within the Great Kavir which can't be shown on the map with the scale of 1:2,500,000 (Fig. 2).

The salt crusts are mainly derived from the weathering and erosion of the Miocene evaporates rocks which comprise almost all of the bedrock underlying the Great Kavir. Several salt domes are also outcropping in the north-east part of the Great Kavir. Analysis of a piece of unweathered Miocene siltstone indicated that it contained fourteen percent of the salt content of Kavir salt crust. The transportation of salts in solution occurs through runoff and associated ground-water discharge during the wet season, and by capillary movement toward the surface throughout the entire year.

Playa fills are composed of fine-grained materials. The surfaces of the playa are cracked due to desiccation. The cracks perpendicular to the upper dried surface generally assumed to have polygonal patterns. These cracks are the conduits of water periodically flooding the surface or raising the ground water and also determine the pattern of cracks in the salt crust which may develop over them. Frequent inundation prevents the accumulation of surface salt and removes salts that accumulate in the cracks. The cracks themselves usually disappear with the next flooding (Fig. 2).

Toward the centre of the basin and further from the wet zone, the polygonal cracks persist and more salt accumulates in them than can be removed by additional flooding. Moreover, the salt crust persists and grows by accretion during each period of evaporation following inundation. It can be suggested that, the rate of evaporation depends upon the wind direction and the edges of the salt plates facing the wind, grow faster than those on the leeward side. Therefore, the faster growing windward edges override the slower growing leeward edges (Fig. 3). This mechanism creates an illusion of laterally expanding polygonal plates which appear to overthrust each other, or it could be suggested that the polygonal plates grow due to continuous crystal growth of halite from brine in contact with subsurface of the plates [7, 9]. However, in the absence of evaporation beneath the plates, there is no mechanism to concentrate the brine and crystallization of the salt is not possible.

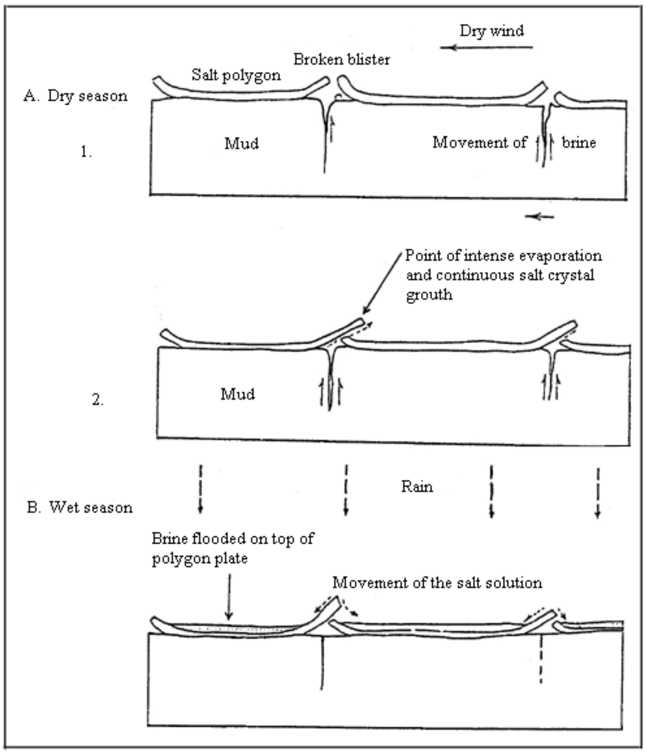


Fig. 3. Laterally growing salt plates [7] *as well as author's observations.*

Clay flat

Clay flats occur in four zones along the margins of the Great Kavir (Fig. 2). They lie adjacent to the wet zones with which they are lithologically similar. Consequently, they are distinguished from wet zones on the basis of their higher elevation above the water table in dry season.

Eroded surface of the Miocene rocks

The Great Kavir is underlain by Miocene rocks which are clearly distinguishable from the outcrops. The present surface which cuts across the Miocene beds (Fig. 2), is characterized by a peneplain locally dissected as a result of tectonic activities, low domes and anticlines (some of which have been gullied) and through which most of the erosional debris have been transported to the adjacent basins. The Great Kavir is the flat surface covering thousands of square kilometres veneered by puffy ground, an integral part of most true playas. Puffy ground is a mixture of clay and silt with up to forty seven percent halite which has been churned as a result of salt crystallization upon the evaporation of surface water, following winter soaking or summer evaporation of capillary water [1, 7].

Sand dune fields

Longitudinal sand dunes are present in three zones along the southern and south-eastern margins of the Great Kavir (Fig. 2). The western sand dunes, the Rig-i-jin (Sand of the Ghost) encompassing an area of 3855 km^2, is the second largest dune field in Iran, next to that in the Lut Desert. Along the north-eastern margin of Rig-i-jin, the sand system forms a series of honeycomb structures loosely connected into longitudinal dunes and separated by sheets of sand which thicken to the southwest. Honeycomb structures in this area are roughly triangular in plan. The distinct northeast-southwest direction of series of connected structures indicates that the prevailing wind is from the northeast. Disintegration of the Miocene rock as it is abraded by blowing and churning sand provides a ready source of additional sand. At the north-western margin of the Rig-i-jin (Fig. 2), the longitudinal dunes composed of the honeycomb structures have been shifted to a generally north-south direction. Of great interest are the wet dunes which are all oriented northeast-southwest and indicate great wind intensity from merely the northeast prior to their partial inundation by the encroaching salt crust from the west. The exact margin of the salt crust is saw-tooth shaped as it follows the contour line around the dunes. Next evidence that the ground water level is rising may be found at the northern margin of the Rig-i-Jin where a narrow extension of the west zone projects between the Miocene rocks and the sand dune. If sand transference were currently dominant over wet zone and salt crust expansion, this narrow zone crosswise to the prevailing winds should have been quickly filled with sand.

All of these observations suggest that the Rig-i-Jin formed during a period of intense wind activity greater than that is prevailed today. At that time strong northeast winds shifted the west margin of the sand dune field into the western basin where it encroached upon the salt crust. More recently the atmospheric pressure system has changed locally in both direction and intensity; although the prevailing winds are still from the northern quadrant, the intensity appears to have diminished so that the components of east and west winds are able to construct opposing systems which manifest themselves in the honeycomb structures. At the same time, these counteracting winds prevent strong movement of the sand dunes in any direction. Two hundred and thirty kilometres of the south-eastern marginal basin is bordered by a zone of sand dunes which has at least 10 km width.

Meteorology of the Khur Playa

The Great Kavir is characterized by the prevailing northeast-southwest wind and monsoonal rainfall and temperature. In Jandaq area which is located adjacent to Khur, a meteorological unit exist which, measures the meteorological parameters as are shown in Tab. 1, 2 and 3.

Tab. 1. Average temperature (in centigrade) of this station [7].

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
8.2	13.7	20	25.6	30.7	32.5	30.4	26.7	20.6	12.8	7.2	5.7	19.5

Tab. 2. Rate of evaporation measured in millimetres [7].

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
67	103	191	272	401	497	465	337	231	142	87	64	2857

Tab. 3. Rate of rainfall in millimetres [7].

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
11.4	14	14.3	6.2	0.6	0.3	---	---	2.8	8.6	12.3	16	86.5

Seasonal rainfall at Khur station is 24 mm (26.7 %) in spring, 1 mm (1.1 %) in summer, 23.7 mm (26.3 %) in autumn and 41.4 mm (45.9 %) in winter.

Hydrology

Surface water

The Khur Playa is mainly fed by the rainwater during the monsoon months, but remains dry for the rest of the year. The low precipitation (86.5 mm/yr) and high evaporation (2857 mm/yr) have resulted in a negative water budget in the region and formation of a number of economically important, hydrologically closed, saline playas. The amount of water obtained from the rainfall in the Khur region is about 22.2 MCM which mainly penetrates into the ground or evaporates. Also, the ephemeral rivers and streams flowing from the surrounding high lands bring the clastics and major solutes to these playas.

Based on the records of the above-mentioned information prepared by the Ministry of Power of Iran, the general rate of Khur water flow is as follows:

- Flow from rain in mountains: 13 MCM.
- Flow from rain in the plain (very low): zero
- Flow from flood and surface water in the plain: 2 MCM.
- Flow from irrigational water and sewage in the plain: 1.4 MCM.

Underground water sources in the Khur Playa

The Khur Playa extends widely but due to the shortage of rainfall and evaporation, there are not enough underground water sources. Water sources of the region include 11 deep wells with maximum depth of 63 m, a momentary debit of 13 l/s and an annual evacuation of about 2.624 MCM. There are 65 semi-deep wells with an average depth of 23 m and a momentary debit of 21 l/s and also 38 Qanats. The total annual extraction from this plain is recorded at 35.4 MCM/y.

For precise calculation, information about aquifer hydrodynamic coefficients, exploration boreholes for measuring water levels and preparation of isopieze maps and determining the parameters such as the coefficient of permeability of soil is necessary. Again based on the recording information prepared by the Ministry of Power of Iran, the general rate of Khur underground water is as follows:

- Evacuation from underground water by pumping: 10.5 MCM.
- Evaporation from underground water of the Khur Playa and Kavir: 6 MCM.

Maximum debit of the wells

Debit in any test-pit which includes a part of the thickness of salt crust can show an approximate estimation of debit rate of the total thickness. According to the field observations during sampling, the rate of each test-pit debit was described as low, medium and high. The most debits are related to the western and central regions, the least is related to the eastern and south eastern areas and the average debit is more than 20 l/s.

Considering the condition of the test-pits debit, it is suggested that extraction from the Khur underground brine should be carried out by excavating radial channels to the length of 100 m. It is obvious that the western, eastern and a band in the southern margins of the plain are the most suitable points for extracting the underground solution in the Khur salt crust.

In the second phase, in the autumn and winter of 2005, about 2000 samples were taken from the test-pits on the main playa, in order to measure the amount of potassium “K” by flame photometer. For acceleration of the work, a flame photometer unit was installed and commissioned in Khur. The average grade of “K” in autumn 2005 was about 3166 ppm, and in winter 2005, 2975 ppm [7]. The average grades of “K” in the Khur Playa are shown in Tab. 4.

Tab. 4. Average grade of K in the Khur Playa in each season [7].

Autumn 2005	Winter 2005	Spring 2006	Summer 2006	Annual grade
3166 ppm	2975 ppm	3387 ppm	3042 ppm	3150 ppm

Bulk density of the sampling test-pits was measured in autumn and winter 2005 and in spring and summer 2006. It is very important to consider and correlate the bulk density of different basins. Bulk density of the samples in spring 2006 was about 1.22 $gr.cm^{-3}$ and in the summer of that year, was about 1.21 $gr.cm^{-3}$. The studies indicate that from the centre of the salt crust to the margins of the Great Kavir, the grade of “K” decreases to 2000 ppm with respect to tab. 4. Also, in some parts of the salt crust where the accumulation of salt is more, the porosity will decrease and the amount of "K" brine increases. Therefore, defining the reservoir coefficient and knowing about the debit of aquifer, it was proceeded to design a network of deep wells to be drilled. 28 wells with an average depth of 10-12 m (30 cm. diameter) and 10 piezometer wells (15 cm. diameter) with an average depth of 9 m were drilled. Pumping tests were carried out to define the amount of debit. The exploration profiles results are as follows:

- The grade of "K" is equal in different seasons at any profile of the surface network.
- In some of the profiles, the grade of "K" is linear and stable but suddenly the grade of "K" increases. From this point of view, "K" changes monotonously at a high grade which is probably due to the existence of a fault in the salt plain.
- It is necessary that the debit of the drilled wells in southern block to be less than the debit of the wells in the middle and northern blocks. Thus, it can be stated that the lower part of the Khur Playa is nearly isolated and separated from the other parts by the underground obstacles.
- Existence of marly tongues at the plain surface has caused some pieces to be separated from the salt crust. Those samples from the salt crust surrounded by marly tongues have "K" with higher grade and density.

Description of exploration activities

Drilling test-pits

A regular exploration network was carried out in the playa. This network includes 3 northwest and 4 east west profiles on which 70 exploration test-pits at 70-100 cm depth were drilled for systematic sampling from the brines of the surface salt crust. 30 exploration test-pits were also drilled out of the mentioned network in different parts of the salt crusts.

Deep drilling with coring

In this phase 9 boreholes were drilled to the depth of 40.45 m and samples were collected at different locations. Borehole logs indicate that the existing lake deposits in this playa were formed of upper and lower parts. The average thickness of the upper part reaches to 20m and is composed of three major salty layers such as surface layer or salt crust with an average thickness of 7 m, middle layer with an average thickness of 3m and lower layer with an average thickness of 2m. In any of the three salty layers, saturated inter-crystal brine exists between salt crystals with rather high potash, magnesium, and nitrate ions. The lower part of lake deposits is generally formed of brown lake marl overlaying the folded Miocene sediments.

Sampling

Samples were collected from the boreholes over three years in different seasons. In each phase, pots of brine from the test-pits were taken. These brines contain ions of Na^+, K^+, Mg^{2+}, Ca^{2+}, Cl^- and SO_4^{2-}. Tab. 5 summarizes the potassium and other ions content of the Playa.

Tab. 5. Average of these ions, obtained through mineralogical studies [7].

Na^+	K^+	Mg^{++}	Ca^{++}	Cl^-	SO_4^{--}
34952 ppm	5496 ppm	15028 ppm	75808 ppm	238244 ppm	124 ppm

Method of extraction of potash

The first part of our investigations was the research for an applicable solution for the extraction of potash from the brine. Among different procedures, the possibility of locating the evaporation ponds inside the salt crust was considered. Pond dimensions of 3*2 meters with a depth of 1-2 m were dug and some pits were drilled in the salt crust inside the Kavir. Field studies showed that the brine can't evaporate inside the salt crust to increase the potash grade, therefore construction of artificial ponds utilizing clay or cement ponds for producing the concentrate of potash salt is necessary [7].

The second part was the partial evaporation and subsequent concentration of the brine. Metallic pans were used and the tests carried out inside them with dimension of 59*159 cm and a depth of 20 cm. During the studies, the pans were laid on the Kavir salt crust in direct sunshine. The salt concentration would then pass from density of 1.20 $gr.cm^{-3}$ to 1.50 $gr.cm^{-3}$ without separating the lower salt from the upper brine. In the second part after taking away the residual NaCl, the brine with a density of 1.36 $gr.cm^{-3}$ was poured in the pan and testing continued.

The process allows for a complete evaporation of brine, giving a density of 2.37 $gr.cm^{-3}$, and producing a matrix which is a mixture of NaCl, KCl, $CaCl_2$ and $MgCl_2$. A sample was taken from the total brine and the final matrix was tested, in which the average grade of KCl was sixteen percent.

The next part of the process scheme aims to construct the experimental evaporation ponds for extraction of the concentrated materials. Two ponds were constructed, one for separating the NaCl from the brine and the other for extraction of potash salt in an area of 900 m^2. The dimensions of the big pond are 28*26 m with height of 75 cm and the small pond with dimensions of 18*9 m and height of 85 cm.

After establishing the ponds, concentrate extraction started. In order to have 3 tons of concentrated materials, the brine from different parts of the Kavir were mixed and poured into the ponds. The height of water inside the pond reached to 40 cm; 270,000 litres of brine in which the percentage of "K" was 3.6 $g.l^{-1}$ and a density of 1.20 $gr.cm^{-3}$, was poured in the first pond. After 20 days (in summer) the percentage of "K" was increased to 11 $g.l^{-1}$. When the density reached to 1.36 $gr.cm^{-3}$, the percentage of "K" in the brine reached to its maximum grade. Therefore, potash rich-brine was evacuated into the second pond. At this step, there should remain about 35 % or 90,000 litres of brine. But due to unforeseen incidents such as, intensive storms, strong winds and thunderstorms, only 42,000 litres of brine was transferred to the second pond. After 8 days, the density of brine reached to 1.47 $gr.cm^{-3}$ and its volume decreased to about 3000 litres so the grade of "K" in brine was about 1.9 $g.l^{-1}$ and the amount of KCl reached to 16-20 % [7].

For analysis and evaluation of the available data about potash content, it was necessary to enter the above data into a calculation program and process it according to the required results. There are two kinds of data to be analyzed; the first group consists of data taken from surface boreholes; the second, from deep boreholes in the region of the Khur Playa.

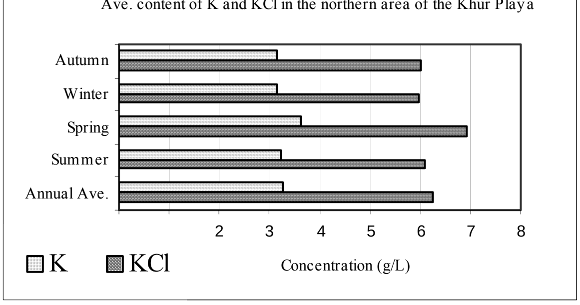
It must be emphasized that the area of the Khur Playa has been divided into the northern, central and southern parts provided that the collected data interpreted properly. The results of the analysis are shown in Tab. 6.

Tab. 6. Average content of K and KCl in three parts of the Khur Playa [7].

Season	Northern		Central		Southern		Whole Playa	
	K^+_{ave} [$g.l^{-1}$]	KCl_{ave} [$g.l^{-1}$]	K^+_{ave} [$g.l^{-1}$]	KCl_{ave} [$g.l^{-1}$]	K^+_{ave} [$g.l^{-1}$]	KCl_{ave} [$g.l^{-1}$]	K^+_{ave} [$g.l^{-1}$]	KCl_{ave} [$g.l^{-1}$]
Autumn 2003	3.152	6.009	3.742	7.135	4.153	7.918	3.571	6.808
Winter 2003	3.141	5.988	3.914	7.462	3.898	7.432	3.621	6.903
Spring 2004	3.634	6.929	4.245	8.094	4.105	7.828	3.979	7.587
Summer 2004	3.204	6.109	4.029	7.682	3.912	7.459	3.673	7.003
Annual average	3.283	6.259	3.982	7.593	4.017	7.659	3.771	7.075

These data clearly show that in the central and southern parts of the Khur Playa, the "K" and KCl content of the brine is about 1.3 $g.l^{-1}$ higher than in the northern part (Fig. 4). It can be stated that the highest concentration of potash is reached in spring in the central and southern region of the Khur Playa.

The deep boreholes lead to the result that we can expect an average salt layer of 7.5 to 7.7 m. Potassium content in individual boreholes changes between 1500-4000 ppm whereby the average of 9 boreholes is about 2844 ppm. This means that at an average density of 1.19 $g.cm^{-3}$ the average potassium concentration is about 3388 $mg.l^{-1}$ and the average KCl concentration is about 6.5 $g.l^{-1}$. In summery, it can be estimated that, according to this data the average content of potassium at the Khur Playa does not fall below the estimated 2600 ppm. Tab. 7 shows the results of average potassium concentration obtained from deep boreholes. It can be seen that the content of potassium chloride which has been determined from the surface sampling is not essentially different from the average of deep borehole sampling.



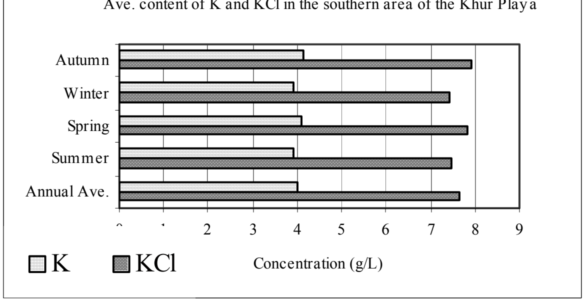
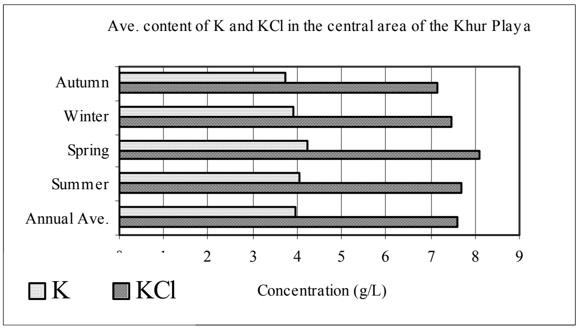


Fig. 4. Calculated averages for K and KCl for the seasons in three regions of the Khur Playa.



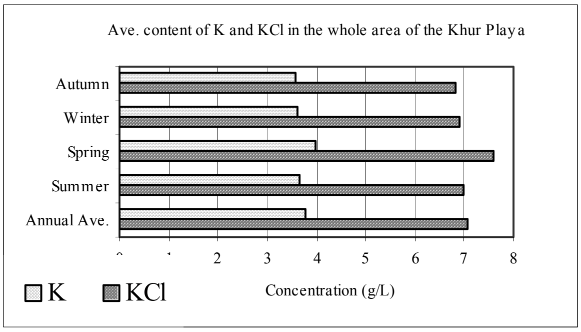


Fig. 4 (continued). Calculated averages for K and KCl for the seasons in three regions of the Khur Playa.

Tab. 7. Average content of K and KCl from deep sampling of the Khur Playa [7].

Sample	Content of K and KCl at the Khur Playa		
	K^+ ppm	**K^+** [g.l^{-1}]	**KCl** [g.l^{-1}]
Surface data	3564.9	4.307	8.200
Deep data	2844.0	3.388	6.500
Deep data	3473.0	4.122	7.900
Average	3239.0	3.895	7.431

The outcome of calculations for estimating the proven and probable reserves of brine of the Khur Playa is considered in the next section. Note that the calculation was done on the basis of KCl existing in the salt crust.

Estimation of reserve

Proven reserve

Actual parameters are measured as follows:

Area of salt crust A = 1,000,000,000 m^2
Average thickness of salt crust H = 6 m
Volume of salt crust Vs = 6,000,000,000 m^3
Reserve coefficient S = 5 %
Volume of brine V_b = 300,000,000 m^3
Average grade of KCI in brine G = 6 gr/l
Average grade of K is G = 3.14 gr/l
It is concluded that the amount of KCl = $M = G * V_b$
It is concluded that the amount of K = $MK = G * V_b$
M = 6*300,000,000 = 1,800,000 t
MK = 3.14*300,000,000 = 942,000 t

Probable reserve

Brine of the two layers (middle and lower) of the Khur Playa.

Middle layer with an average thickness of 3 m and lower layer with an average thickness of 2 m exist under the salt crust.

The average grade of their brine is about 5.5 gr.l^{-1}, KCI. If the reserve coefficient is 4 %, then:

Area of the layers A = 1,000,000,000 m^2
Total thickness of the two layers H = 5 m
Volume of the two salty layers V_s = 5,000,000,000 m^3
Reserve coefficient of two layers S = 4 %
Volume of brine in two layers V_b = 200,000,000 m^3
Average grade of KCI in brine G = 5.5 g/l
It is concluded that the amount of probable KCl = $M = G * V_b$
M = 5.5*200,000,000 = 1,100,000 t

Brine of northern playa
Approximate area of salt crust A = 400,000,000 m^2
Average thickness of salt crust (rough) H = 5 m
Approximate volume of salt crust V_s = 400,000,000*5 =2,000,000,000 m^3
Approximate reserve coefficient S = 4 %
Volume of brine V_b = 80,000,000 m^3
Average grade of KCI in brine G = 5 g/l
It is concluded that the amount of probable KCl = $M = G * V_b$
Probable reserve: M = 5*800,000,000= 400,000 t

Therefore the total probable reserve of KCl would be 1,500,000 tonne.

Summary and conclusion

The Khur Playa is a part of the Great Kavir, located in the centre of Iranian plateau, with the total area of about 2000 km^2. The area that is covered by a salt crust is about 1000 km^2. This is the region which is used for calculating the reserves.

The Khur Playa sediments are comprised of clastic and nonclastic minerals such as clay, silt, and sand, mainly derived from the weathering and erosion of the Miocene bedrocks. The assemblage of these components and a variety of evaporative crystallized minerals indicates transportation from the surrounding region by eolian and fluvial mechanisms.

The presence of a thin layer of polygon-shaped halite occurring on the surface of playa is attributed to the process of evaporative pumping of the sediment pore brine to the playa surface and precipitation during the summer.

Based on the drilled boreholes in different parts of the region and the study of the borehole logs, the average depth of the porous salt layer from which the brine can be obtained has been stated as 6 m.

For exploitation of potassium and potassium chloride, construction of evaporating ponds with low height on the salt crust can be carried out where the crust is more than 2 m thick. For construction of the evaporation ponds, the best material on site is the mixture of clay and gravels, which have good compaction characteristics. It is suggested that the injection of clay and mixture of clay and lime for creating impermeable walls under the pond walls would substantially decrease the permeability of the surface layer. The brine in the ponds is exposed for evaporation.

In summary, it can be estimated that according to the obtained data, the average content of potassium at Khur Playa does not fall below 2600 ppm. This is clearly proven by the existing data which is summarized in Tab. 6 and 7. Also the large number of results across the region of the Khur Playa (through all seasons shown in Tab. 6) indicates that the content of an average of 6 g.l^{-1} potassium chloride in the brine that has been used for the feasibility studies can be regarded as safe.

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