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JORDAN'S EXPERIENCE IN OIL SHALE STUDIES EMPLOYING DIFFERENT TECHNOLOGIES

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Jordan's long experience in dealing with oil shale as a source of energy is introduced and discussed. Since the 1960s, Jordan has been investigating economical and environmental methods for utilizing this indigenous natural resource, which, due to its high organic content, is considered a suitable source of energy either by direct burning to generate electricity or by retorting to produce oil and gas. More than three decades of comprehensive engineering and economical studies, and test experiments for both retorting and direct burning carried out in co-operation with several international oil shale companies provide a solid foundation for a future oil shale industry in the country. Oil shale utilization in Jordan should be pursued because it will result in significant savings in foreign exchange, improve Jordan's energy supply security and create new jobs.

Introduction

Oil shale resources being next to coal and tar sands are considered one of the world's largest fossil energy reserves.

As Jordan is a non-oil-producing country deeply affected by the world energy situation it has a clear economic interest to develop the utilization of oil shale as a future energy source. Its large deposits are widely distributed all over the country. As confirmed by geological surveys, the existing oil shale reserves cover more than 60 % of Jordan's territory. Some of the major oil shale deposits are underlain by phosphate beds. The Hashemite Kingdom of Jordan possesses enormous indigenous source of energy in its vast low-grade oil shale. These reserves of extractable oil are virtually equivalent to those of crude oil of the USA.

Exploitation of oil shale deposits in Jordan could potentially lead to initiation of Jordan's self-sufficiency.

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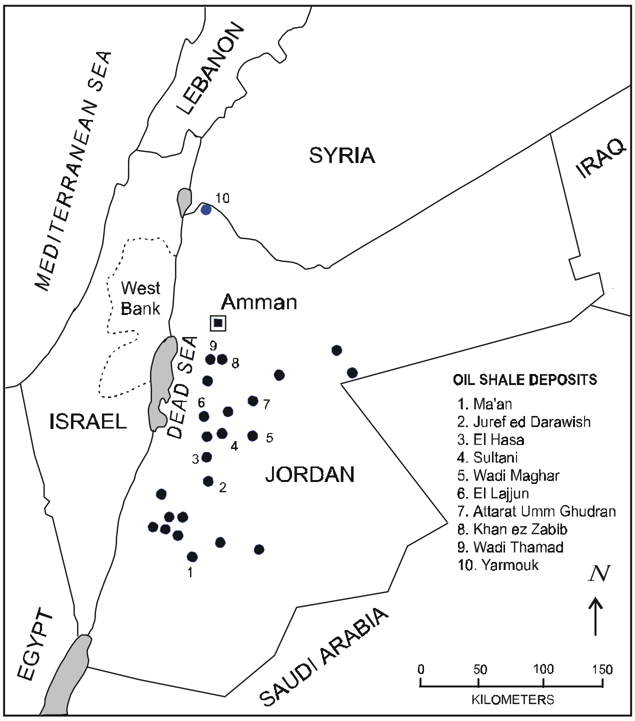
Oil Shale Reserves in Jordan

Oil shale is a 50-70 million year-old sedimentary rock. Its kerogen (from Greek meaning 'oil generator') is basically represented by fossilized algae, which had been formed during deposition of sediments that had been transformed into a hydrocarbon-bearing rock under effects of time, pressure and temperature.



Oil shale locations in Jordan

Oil shale is considered mainly as a source of raw material of fossil origin for energy production having a high content of ballast material, this being the reason why oil shale has seldom been employed as an alternative fuel in the past. Oil shale kerogen is generally present as fine inclusions in the mineral substance. By thermal treatment it can be converted to oil, which can be used for production of liquid fuels and chemicals, gas and coke being formed simultaneously. Oil shale organic matter is basically "immature" oil that had not been subjected to enough heat and pressure effect in the Earth to be converted into liquid crude oil. Consequently, to obtain petroleum from oil shale by retorting, some amounts of heat energy should be applied to extract the kerogen.

Jordanian oil shale consists of kerogen-rich bituminous limestone and calcareous marls whose color varies within brown, gray or dark-gray being typical bluish light-gray when weathered. Its kerogen originates from the fossil remains of microplants and animals accumulated in the seas and lakes that covered most of Jordan some 80 million years ago.

Geologically, Jordanian oil shale belongs to the upper Cretaceous and lower Tertiary formations. Thickly bedded or concretionary limestone, and sometimes dolomite and chert are interlaced in the oil shale sequence, phosphate layer occurs usually under the oil shale deposits.

It is believed that the existence of oil shale in Jordan has been known for centuries. Records from the outcrop of Shallaleh deposits have indicated that villagers had used shale for many years to heat water and to lime their homes and wells. Since World War I oil shale occurrence had been known in the main part of the country, east of the Jordan River, but no intensive investigations had been conducted. A more detailed geological study of the El-Lajjun deposit was made by the German Geological Mission directed by professor Bender. After World War I British geologists investigated the oil shale of the general region where samples were taken and retorting tests made.

According to geological investigations carried out by the Natural Resources Authority (NRA), Jordan has sizable oil shale reserves exceeding 50 billion tons (Figure). These quantities are capable of yielding 50 billion barrels of crude oil. The average oil content is about 10 % (by weight) with a calorific value of oil shale ranging within 1200–2000 Kcal/kg.

More than twenty oil shale deposits classified as shallow and near-surface and accessible for open-pit mining are known in the central part of the country, seven of them having been studied in detail. Major deposits of commercial-scale interest are located about 100 km south of Amman (the capital of Jordan). These deposits are regarded as the richest in organic bituminous marl and limestone that occur at shallow depth. They are easily accessible from the highway and traversed by a high-voltage power transmission line, so that a substantial part of the infrastructure requested for development is already in place. Other deeper-lying deposits, which are located in the northern and eastern part of Jordan, are exploitable only by underground mining operation.

Preliminary studies on Jordan oil shale began in the late 1960s but no actions were taken at that time because the level of oil prices was far too low for a viable shale oil development program. However, since the 1980s the Government of Jordan (GOJ) has conducted extensive studies for the exploitation of oil shale reserves mainly of two deposits: El-Lajjun (typical oil yields within 100–180 liters per metric ton) and Sultani. Their geological conditions e.g. thickness and structural settings, as well as chemical and mineralogical composition, are favorable for open-pit mining. These factors in combination with the low mining and infrastructure costs render the deposit quite suitable for industrial utilization. Production of oil and electricity using oil shale could be a viable option even at today's oil prices. With these potential benefits, it is important to continue R&D efforts toward resolving the remaining technical and environmental issues.

The GOJ has recently invited many interested and qualified developers to submit their proposals to develop this source commercially.

Of oil shale deposits with low overburden concentrated in six main sites, deposits in central Jordan were selected for detailed study based on the following aspects (see the Table):

- Favorable conditions for surface mining and presence of phosphate raw materials.
- Adequate reserves with oil shale of good quality and sufficient quantity.
- Availability of good infrastructure including adequate ground water for future commercial utilization.

Main Characteristics of the Studied Oil Shale Deposits

Indices	El-Lajjun	Sultani	Juref Ed-Darawish	Attaraat Um-Ghudran	Wadi Maghar	El-Thamad	Khan Ezzabib
Geologic reserves, billion tons	1.3	0.99	8.6	11.3	32	11.4	n.a.
Surface area, sq. km	20	24	150	226	29	150	n.a.
Overburden, thickness, m	31	69	47	47	40	142–400	66
Oil shale thickness, m	29	32	68	36	40	72–200	39–45
Number of drilled wells	135	57	50	41	21	12	–
Organic matter, %	28	25	18	29	20	25	n.a.
Average oil content, %	10.5	9.7	5.7	11.0	6.8	10.5	6.9
Moisture content, %	2.1	5.5	4.5	3.25	2.9	2.5	n.a.
Ash content, %	54.7	55.5	58.4	53.2	57.5	54.7	n.a.
Sulfur content, %	3.1	2.4	2.4	2.6	2.6	3.2	n.a.
Density, g/cm^3	1.81	1.96	2.1	1.8	2.03	1.8	n.a.
Calorific value:							
Kcal/kg	1650	1526	1100	1730	1090	1800	n.a.
KJ/kg	6906	6380	4603	7235	4773	6903	n.a.

Feasibility Studies and Test Programs

During the last two decades, the GOJ has conducted several feasibility studies (FS) and test programs through many specialized international companies either for direct burning or for retorting.

FS in Co-Operation with the Former USSR *Technopromexport* Company

It was held to assess the potential for direct burning in a 300-MW power plant. Suitability of Jordanian oil shale as a fuel for direct burning was proved and construction of an experimental of a 200-MW demonstration plant recommended.

FS in Co-Operation with the German *Klockner/Lurgi* Company

Studies and test programs on oil shale retorting to produce syncrude (50,000 b/d) and on circulating-fluidized-bed (CFB) combustion for power generation were carried out. It was concluded that:

- Geological conditions of El-Lajjun oil shale are reliably proven for a 50,000-b/d oil shale retorting plant operation during 30 years.
- Open-cast mining method is viable both technically and economically.
- El-Lajjun oil shale is rich in sulfur (3.5 %). Hydrogen sulphide produced can be converted to 99-% elemental sulfur.
- The pilot test has demonstrated smooth operation.
- Combustion tests on spent shale proved an almost burn-out of residual carbon at 800 ºC, the residual oil shale being a suitable material for building and road construction.
- Economic assessments indicated that oil production cost is in the range of 20–25 USD/b and electricity production cost is 19 fils/kWh (1988 prices).

FS and Retorting Test Program in Co-Operation with the Chinese *Sinopec* Company

For this research more than 1,000 tons of Jordanian El-Lajjun oil shale was shipped to China. The main results indicated that oil content reaches 10 %, sulphur content is about 3 %, and calcium oxide content in ash accounts for 38 %. It was shown that Jordanian oil shale can be well processed in the Chinese *Fushun*-type retort. There arose no difficulties in connection with ash removal or separation of water from shale oil. The oil yield from the retort reaches 80–84 % of Fischer assay; oil viscosity was 0.98 and amount of impurities 0.06 %. The calorific value of the gas produced was 1,050 Kcal/m^3. Consequently, *Fushun*-type retorts are suitable for different kinds of oil shale and this makes them economically profitable (estimated cost of oil production using *Fushun*-type retorts is within 15–20 USD/b) and especially suitable for shale oil small- and medium-scale production.

Test Program by the Russian *ENIN* Company (Krzhyzhanovski Power Engineering Institute)

Preliminary results of Jordanian shale thermal processing tests conducted by Russian experts from *ENIN* showed that the *ENIN*'s technology enables to use shales of any fractional composition and quality for producing high-calorific liquid and gaseous fuels without preliminary sizing. The solid heat-carrier technology has found its commercial application at two plants which process as much as 140 tons oil shale per hour. It was concluded that Jordan oil shale suites fully for high-efficient use in solid heat-carrier plants which are highly-efficient and environmentally-safe facilities to produce oil and fuel gas in a thermal power station where oil shale is used as a source of fuel.

FS and Test Program in Co-Operation with the Canadian *Suncor* Company

It was objected at testing retorting Jordanian oil shale using Alberta *Taciuk* Processor. Further engineering and economical studies are required to determine whether this project is viable. Technical data of a similar Australian project seem to be positive. The first stage of the project proposed for Jordanian oil shale is the production of 17,000 b/d oil and it is expected that the cost of production for commercial operation would be $11-12.

FS for Direct Burning

In Jordan direct burning to generate electricity has been investigated in co-operation with some international companies. All feasibility studies and test burns have concluded that burning of Jordanian oil shale is very stable even at 40-% loads, SO_2 and NO_x emission levels in the CFB combustor are low, and carbon burn-out is high (up to 99 %).

Combustion Tests

Test in Finland

Based on the results of combustion of 75 tons of Jordan Sultani oil shale by *Pyropower* (Finland) the following can be concluded:

1. Jordan oil shale is acceptable to be fuelled in an *Ahlstrom Pyroflow* CFB where it burns cleanly and efficiently.
2. Combustion efficiency in excess of 98.5 % was demonstrated.
3. Both SO_2 and NO_x emissions, as well as CO emissions were acceptably low. The tests demonstrated that over 90 % of sulfur was absorbed by the inherent calcium present in shale. Typical emissions measured during these tests were:

SO_2	below 20 ppm
NO_x	in the range between 60–120 ppm
CO	below 50 ppm

These values will generally meet the stringent environmental requirements.

Test in Germany

Based on the results of combustion of 75 tons of Jordan Sultani oil shale by *Lurgi* (Germany) the following can be concluded:

1. There were no upsets in the fluidizing behavior of the circulating material and/or in plant operation.
2. Combustion of oil shale was self-sustained.
3. Combustion of oil shale 3-5-mm particles has not posed any problems.
4. Carbon burn-out reached 98 %.

5. $CaCO_3$ present in oil shale ash binds SO_2 and it is not necessary to add limestone for dersulfurization:

$$CaCO_3 \rightarrow CaO + CO_2$$

$$CaO + SO_2 + \tfrac{1}{2}O_2 \rightarrow CaSO_4 \text{ (calcium sulfate like plaster)}$$

6. As combustion temperature is low, the amounts of SO_2, NO_x and CO emissions did not exceed the international standards.

Catalytic Gasification

Research on catalytic gasification of Jordanian oil shale sample was carried out in the former Soviet Union at *Grozneftechnim* laboratory and pilot-scale plants. The catalytic system used proved to be highly selective yielding gas containing 80 % methane against other known hydrogasification processes yielding gas and oil. Results of the research in steam oxygenous gasification have shown that it is possible to obtain synthesis gas used in motor fuel production. The gas obtained was rich in hydrogen (10.5 %) and carbon oxides (64.9 %).

Solvent Extraction

Solvent extraction of organic matter is one of the well-known techniques for dissolving organic matter within rock composite. R&D activities were carried out in Jordan. El-Lajjun oil shale has been investigated using 75 % benzene and 25 % cyclohexane (by volume) solvent mixture. It was found to be the best one among various organic solvents, such as toluene, benzene, cyclohexane, pentane, ethylether and ethylbenzene, to produce as high as 73 % yields of extracted oil in a continuous sterling tank reactor (CSTR).

It was found that extraction yield from fine particles exceeded that from the course particles. Extract amount decreased with the increase in residence time. The higher the temperature to which the oil shale is preheated (less than the boiling point of the solvent) the higher the extraction yield for the same residence time. The impact of extraction time on the yield was much stronger for larger particles (>2 mm) than for smaller ones. The optimum mass of solvent used per 1 kg of oil shale was 0.5 kg.

A joint study by NRA and NERC using Soxhlet extractor was aimed at extracting oil from El-Lajjun oil shale. Different solvents were examined to find out the best solvent and the best technique based on the quality and quantity of the yield and solvent obtained. Maximum oil recovery reaching 23.37% was achieved using carbon disulfide.

Utilization of Oil Shale Ash

Jordan oil shale ash is highly alkaline and requires no limestone to be added for sulfur removal. The pilot test results indicate excellent sulfur capture by the calcium present in oil shale. Preliminary R&D concludes that this high-calcium ash is suitable for manufacturing a wide range of products:

- Construction materials including bricks, tiles and light-weight aggregate cement mixtures for manufacturing concrete products, for construction of road bases, and for use as filler in asphalt mixtures
- Soil stabilizer and fertilizer for liming acid soils
- Foundry cores
- Supplement to animal food

An ash sample from Sultani oil shale combustion was tested at the Jordan Cement Lab in 1988 and the following results were obtained:

- It has a good grinding ability which assists in increasing the earlier cement strengthening
- The cement containing some ash became more strengthed after 3-7 days.
- When the share of ash in the ash-cement mixture exceeds 20 %, some negative impact appeared due to the high content of P_2O_5 in the ash.

Private Investment Through a Build, Own and Operate and Build, Operate and Transfer Schemes

The energy sector is considered an infrastructure service sector, which is crucial to economic growth. In 1985, the Jordan Council of Ministers took a decision to adopt privatization and outlined the ideas and actions to convert a number of public corporations to shareholding companies that work on commercial basis and to allow the private sector to participate in the ownership of some public corporations and participate in its management. Jordan has also adopted the economic reform program, which includes the restructuring and privatization of a number of public enterprises including the power sector.

In 1996, a new electricity law was issued that allows the private sector to participate in building, operating and owning power generation facilities to highlight potential investments in Jordan with special emphasis on the new investment ventures such as Build, Operate and Transfer (BOT), and Build, Own and Operate (BOO).

Through the modification of investment and electricity laws Jordan aimed at creating a suitable environment to attract private investment within the country and from abroad in financing and operating the proposed infrastructure projects including oil shale projects. This approach injects elements of new source of capital and enhances competition in the sectors to provide lower costs, better levels of services and transfer of financial and technical risks, which the private sector is better able to handle.

Oil shale utilization processes require large financial expenditures beyond Jordan's means, therefore the BOO or BOT schemes seem to be the perfect solution. The project concept is that the investor/contractor constructs a facility that utilizes oil shale through the known technologies mainly: by direct burning for power production or by retorting for oil and gas production. This will require the GOJ to provide necessary guarantees to enable the contractor to sell the output products for a period of time.

Jordan's Strategy Toward Oil Shale Utilization

The GOJ has adopted a new policy for the development of oil shale resources with minimum risks to the country. The Ministry of Energy and Mineral Resources (MEMR) has invited qualified companies to submit their proposals with proven technology and experience in oil shale to establish privately owned oil shale projects based on the BOO scheme to produce oil and electricity. The requested proposals shall include comprehensive feasibility study, basic financial terms and conditions along with total benefits to Jordan. A decision is to be made after the most attractive and acceptable offers received by the MEMR from interested parties after a transparent evaluation process. This will be followed by good faith negotiations on concluding oil shale agreements.

Oil shale technologies have been rapidly developed to accommodate oil shale utilization economically and cleanly to a point where the cost of extraction and processing of oil shale is competitive with conventional crude oil. Suncor has developed the technology of extracting and processing oil shale at about $ 10 per barrel. Consequently, at the current level of conventional crude oil of $ 25/bbl, producing oil from shale becomes economically viable.

With this improvement in technology, Jordan will be able to become self-sufficient in oil production, consumption and exporting. The GOJ has taken essential measures to encourage foreign investments in oil shale processing and utilization. The new investment law and the new electricity law will provide equal opportunities to capable developers to establish privately owned oil shale projects.

The GOJ is becoming more aware of the critical energy situation and the associated environmental problems related to the conventional oil that are considered a pressing factor toward searching for various alternative options to suit Jordan's economy. The focus of attention will be directed towards the practical issues of the offer that will be submitted by the Canadian *Suncor* company for implementing a retorting oil shale project rated 17,000 b/d. If this initial stage demonstrated success along with the first operational oil shale project in Australia rated 4,500 b/d, the GOJ will look favorably on granting the development firms the right to continue expanding in other projects based on the BOO scheme.

Conclusions

- Due to the importance of oil shale to Jordan as the only major proven indigenous energy source, extensive studies were carried out with an objective to assess the quality, quantity and suitability of using oil shale as a reliable energy source.
- The studies have indicated that Jordan possesses a large quantity of good-quality oil shale. All tests have proven the environmental, technical and economical feasibility, and the studies have suggested constructing pilot demonstration plants prior to embarking upon any commercial-scale project.
- The Government of Jordan believes that oil shale utilization for power generation and retorting should be pursued because it will result in significant energy supply security and savings in foreign exchange, and create new jobs.
- The oil shales in Jordan are considered by international standard highest-grade oil shales, which are available at shallow overburden near the existing infrastructure needed for an oil shale industry.

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