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The use of Oil Shale for Road Coating

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General Introduction and Background- The world's strong economic growth and increasing populations have generated a remarkably growing demand for resources, especially energy. Current conventional sources cannot meet the future needs. Efforts are being focused on renewable energies, deep-sea oil and the development of new techniques to value heavy oils, tar sands and oil shale. This could bridge the gap between energy demand and supply. Several countries with oil shale deposits have launched projects to examine the possibility of exploiting these deposits. Morocco is one of these countries, with significant oil shale deposits in the Middle Atlas (Timahdit), Tarfaya, Tangier and Grand Atlas regions (Fig. 1) [1].

Morocco has a reserve of around 53 billion barrels of oil shale, in addition to a rich capacity for shale gas and oil. The exploration works for these unconventional hydrocarbons, which began several years ago, has proved highly encouraging. The first research into the development of oil shale in Morocco began in Tangier, with the creation of the oil shale company of Tangier. The company built a pilot plant with a daily capacity of 80 tons of oil shale. The Timahdit and Tarfaya deposits were discovered in the 1960’s.

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THEUSEOFOILSHALEFORROADCOATING

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The use of Oil Shale for Road Coating

Mohamed Amine Alouani [α], Dennoun Saifaoui [σ], Abdelkader Alouani [ρ] & Younes Alouani [Ѡ]

I. General Introduction and Background

The world's strong economic growth and increasing populations have generated a remarkably growing demand for resources, especially energy. Current conventional sources cannot meet the future needs. Efforts are being focused on renewable energies, deep-sea oil and the development of new techniques to value heavy oils, tar sands and oil shale. This could bridge the gap between energy demand and supply. Several countries with oil shale deposits have launched projects to examine the possibility of exploiting these deposits. Morocco is one of these countries, with significant oil shale deposits in the Middle Atlas (Timahdit), Tarfaya, Tangier and Grand Atlas regions (Fig. 1) [1].

Morocco has a reserve of around 53 billion barrels of oil shale, in addition to a rich capacity for shale gas and oil. The exploration works for these unconventional hydrocarbons, which began several years ago, has proved highly encouraging. The first research into the development of oil shale in Morocco began in Tangier, with the creation of the oil shale company of Tangier. The company built a pilot plant with a daily capacity of 80 tons of oil shale. The Timahdit and Tarfaya deposits were discovered in the 1960's. These last two deposits have been the subject of several geological and mining studies, laboratory studies, as well as pyrolysis and direct combustion tests. Their oil shales have been tested by several pyrolysis processes throughout the world mainly in the United States, Europe, the former USSR, Canada and Japan. They have been the subject of numerous technical and economic feasibility studies.

This geological, mining and laboratory work, which began in 1975 and continues to this day, has enabled us to identify the characteristics of these reserves in the deposits of Timahdit and Tarfaya oil shales. These studies showed that Moroccan shales could be upgraded by pyrolysis to produce hydrocarbons. This led Morocco to launch its own experiment and develop the T3 process (Acronym of the three deposits of Tangier, Tarfaya and Timahdit) [2].

Morocco has significant oil shale resources, ranking 6th worldwide after the USA, Russia, the Democratic Republic of Congo, Brazil and Italy, with a potential of 53 billion barrels of oil in field. This includes over 37 billion barrels in the two main deposits of Timahdit and Tarfaya.

Oil shale is used for a number of purposes, including conversion into hydrocarbons through the chemical process of pyrolysis and low-grade combustion for power generation. It is equally used as a raw material (chemical industries, agriculture, construction) for heavy oils particularly suited to diesel engines, lubricating oils and tar used in the manufacture of sealants and asphaltites.

At the international level, oil shale is exploited at a limited scale despite how important the reserves are. This is related to a double-fold problematic. The first one concerns economic challenges; the production of petroleum from oil shale does not become economically viable unless the price of a barrel is at a profitability threshold. The second issue is related to environmental challenges: the combustion and thermal processing of oil shale generate waste and emit carbon dioxide into the atmosphere.

In our studies and research program, we have developed solutions to exploit oil shale deposits within the framework of sustainable development, using renewable energy sources, unconventional waters and carbon dioxide collection techniques. In addition, we integrate other uses, to make the overall exploitation of oil shale deposits profitable, by reducing the impact on the global environment in a remarkable manner.

To make the exploitation of oil shale deposits profitable, our research has been directed towards the development of other possible uses, such as road and runway coating, cement production and the manufacture of carbon plates. In this article, we develop the use of shale for road coating.

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II. Definition and Characterization of Bituminous Shale

The distribution of oil shale deposits in Morocco is shown in the figure (Fig. 1) below:

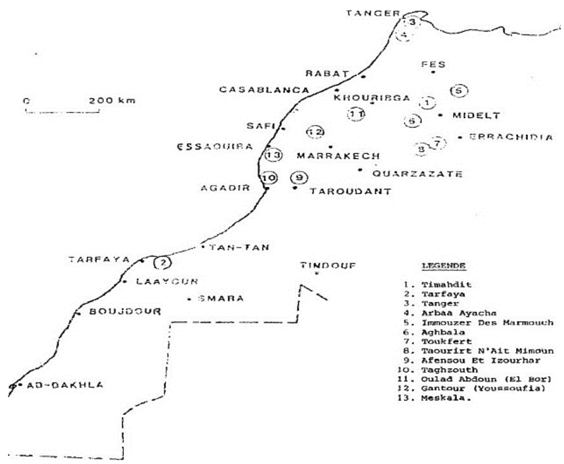

Fig. 1: Distribution of oil shale deposits in Morocco [1]

a) General Definition of Bituminous Shale

Bituminous shales are rocks capable of producing oil in commercial quantities when subjected to pyrolysis. A sedimentary rock containing an insoluble organic substance is referred to as pyro schist, pyrobitumen shale, kerogen rock or, more commonly, bituminous shale. It releases an oil with a general appearance similar to crude oil by non-oxidizing heat treatment at a temperature of between 400 and 500°C [3].

b) Nature and Composition of Bituminous Shale

- Organic and mineral matter. Despite certain similarities, the composition of the organic matter contained in oil shale varies from one deposit to another.
- Kerogen is a mixture of high-molecular-weight compounds containing mainly carbon, hydrogen, nitrogen, oxygen and sulfur. The oxygen and nitrogen content are generally higher than crude oils.

The organic matter in oil shale is richer in aromatic sulfur compounds (benzothiophene derivatives) and above all in resins and asphaltenes. They are normally heavy but constitute minority constituents in conventional oils (0 to 2% by weight), and a majority in shale.

c) Chemical Reactions Produced during Shale Combustion

The chemical reactions that occur during shale combustion can be presented as follows [1]:

For organic matter

$$C_nH_n + \left[\frac{5n}{4}O\right]_2 \rightarrow nCO_2 + \frac{n}{2}H_2O + Q \text{ (Exothermic)}$$

For terrigenous matter:

$$SiO_2 \rightarrow Si + O_2$$

For carbonate matter:

$$CaCO_3 \rightarrow CaO + CO_2 - Q \text{ (Endothermic)}$$

For other elements:

$$2FeS_2 + 11/2\, O_2 \rightarrow 4SO_2 + \left[Fe_2O\right]_3 + Q \text{ (Exothermic)}$$

III. Global Experience and General Properties of Bituminous Shale

a) Oil Shale Experience Worldwide

Oil shales are fine-grained sedimentary rocks containing sufficient organic matter. They can be used to produce oil and fuel gas. Oil shale can be converted into liquid hydrocarbons by pyrolysis. It may be burned directly as a low-grade fuel for power and heat generation, or used as a base material in the chemical industries.

Figure 2: Example of an oil shale operation in Estonia (Eesti Energia)

Bituminous shale (also oil shales, pyro schists, Kero bituminous) are fine-grained sedimentary rocks containing enough organic matter, kerogen, to provide oil and gas fuel. Oil shales vary considerably from one another, in terms of their chemical composition, mineral content, age, type of kerogen and manner of deposition. The existing kerogen in oil shale can be converted into oil through the chemical process of pyrolysis; the decomposition of organic matter under the effect of heat. In fact, the kerogen in oil shale is a kind of "unfinished oil" that has not been exposed to the sufficient temperature and pressure conditions to be transformed into petroleum.

Oil shale can also be burned directly as a low-grade fuel for the supply of electricity and heating. It can be used as a raw material in the chemical industries for subsequent extractions (Sulfur, Ammonia, Sealants, Road Bitumen, Cement or Bricks). Oil shale contains kerogen, which must be processed before oil can be obtained, whereas tar sands and shale gas are directly exploitable, containing trapped bitumen and gas respectively. The following products can be obtained from oil shale oil:

- Conversion to hydrocarbons through the chemical process of pyrolysis
- Low-grade combustion for electricity generation
- Use as raw materials (chemical industries, agriculture, construction).

Oil shale is still minimally exploited despite the size of its reserves. This is due to a double fold issue. Oil production from oil shale becomes economically viable once the price per barrel reaches the profitability threshold.

As for the environmental challenge, the combustion and thermal processing of oil shale generate waste and emit carbon dioxide into the atmosphere. Despite these constraints, industrial processing has already been launched, such as:

- Liquid hydrocarbon production in Estonia, Brazil and China
- Electricity production in Estonia, China, Israel and Germany
- Cement production in Estonia, Germany and China.
- Chemical industry in China, Estonia and Russia.

b) The Timahdit Oil Shale Case in Morocco

The oil shales of Timahdit (Morocco) may constitute significant hydrocarbon resources, amounting to more than nineteen billion tons of raw rock. This is equivalent to around 8.9 billion barrels [1]. These argilo-carbonate sedimentary rocks were formed at the end of the secondary period.) They are essentially made up of [3]:

- 30 to 75% terrigenous (clayey) material: aluminosilicates predominate
- 25-50% carbonate matter: calcite is the main constituent
- Organic matter from 12 to 24%. One part is soluble in organic solvents, the other is insoluble in the same solvents and constitutes kerogen.

The mineral composition of an average sample of Timahdit oil shale [1] is shown in Table 1 below:

Table 1: Mineral composition of the Timahdit shale

Mineral	Pourcentage (%)
Dolomite (CaMg $(CO_3)_2$)	15,9
Calcite ($CaCO_3$)	41,5
Quartz (SiO_2)	19,5
Illite ($(OH)_4K_2$ (Si_6Al_2) Al_4O_{20})	13,4
Pyrite (FeS_2)	1,8
$FeCO_3 + FeO_3$	1,8
TiO_2 + Phosphate	2,4
Other elements	3,7

The concentration of dolomite is low when compared with that generally found in the Colorado shale in the USA. Thermal decomposition of dolomite and calcite is a highly endothermic reaction. Maximum temperatures in the combustion zone are, therefore, higher for Timahdit shales than for Colorado shales when the applied process is direct heating. Similarly, the

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kerogen composition of a sample of Timahdit shale [1] is shown in Table 2.

Table 2: Elemental composition of Timahdit and Colorado kerogen

Elements	% for Timahdit kerogen	% for Colorado kerogen
Carbon	69,2	80,5
Hydrogen	6,5	10,3
Azote	2,9	2,4
Sulfur	8,4	1,0
Oxygen	12,9	5,8

IV. Synthesis of the Simulation of the Use of Oil Shale as a Road Coating to Replace Road Bitumen

a) Application Techniques for Bituminous Shale

The sub-base course must be produced in strips, in accordance with the following procedure:

- Scraping soil in order to decompactify it and detect any mining waste, afforestation or scrap metal.
- A tractor-mounted stone crusher is used to size the largest schist blocks to 60 mm.
- Adjustment of water content by sprinkler and paver
- Binder spreading by spreader.

b) Summary of the Study on the Application of Oil Shale for Road and Runway Coating

On the basis of various reserve evaluation studies, geophysical, geological, mining, geochemical and chemical work studies, we have characterized the deposits according to the zones with profitable exploitation. In addition to the use of bituminous layers as a source of energy, we have identified their use in road coating by replacing road bitumen which is a residue of crude oil processing in an oil refinery.

Drawing on similar experience [5] and simulation results, the results obtained are encouraging, with very competitive repair costs.

c) Results Obtained from Studies, Simulations and Pilot Tests carried out on the Application of Bituminous Shale for Road and Runway Coating

Parameter optimization was based on experimental design techniques applied in a similar optimization case [4]. In addition to the economic advantages and local availability, the results obtained lead to the following conclusions:

- The products studied show reduced dry densities compared with other types of coating.
- Swelling is virtually non-existent
- The products show very good resistance to direct shearing, particularly in terms of very high angles of internal friction.
- Impact and wear resistance comparable to reference materials
- Oil shale-based materials have low degradability and fragmentability under hydric and mechanical stress.

A third phase was devoted to studying the technical feasibility and economic viability of industrial applications over long stretches of runways or roads to be coated. The study showed that surfaces covered with oil shale have comparable characteristics to those of asphalt roads usually covered with petroleum bitumen. The physico-chemical characteristics obtained were in line with required standards. Economic profitability was confirmed as well.

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