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PRODUCING ELECTRICITY FROM ISRAELI OIL SHALE WITH PFBC TECHNOLOGY

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Results of Israeli oil shale combustion at atmospheric pressure in the AFBC commercial boiler manufactured by Foster Wheeler Energia OY (Finland) and in the pressurized test facility of ABB Carbon AB (Finspong, Sweden) confirm suitability of fluidized-bed technologies in case of oil shale. The results approve possibility to use the PFBC technology in case of oil shale after solving of some problems connected with great amounts of fine fly ash.

Introduction

Oil shale is so far the only large indigenous fossil energy source in Israel. Shale deposits have been found all over the country and proven reserves are estimated at 12,000 million tons. The exploitable reserves, concentrated in several major deposits in the Northern Negev desert region in Southern Israel, are about 1,200–1,500 million tons. To develop the oil shale utilization a special company named PAMA (Hebrew for Energy Resources Development) LTD. was formed at the beginning of the 80's.

The Israel Electric Corporation Ltd. (I.E.C.) – the only utility in Israel, operating about 8,000 MWe, which accounts for more than 96 % of total generating capacity in the country – is one of the PAMA's founders and the main stockholder. There were two major research subjects: extraction of oil and direct combustion of the oil shale. Due to decrease in oil prices, the main development effort since 1985 has been concentrated mostly on electric power production from oil shale.

Since 1989, PAMA has been operating a semi-commercial 40 MWth demonstration plant producing electricity for the national grid and steam for local industry. Much experience has been acquired from operation of this demonstration plant in mining, oil shale handling, the combustion process, atmospheric boiler design, ash handling and disposal. The boiler, which has an atmospheric fluidized-bed combustor (AFBC) manufactured by Ahlström Corporation (now *Foster Wheeler Energia* OY) has an impressive record of availability and reliability – an equivalent availability factor above 90 % during the last few years.

In 1995, I.E.C. decided to examine another combustion technology – pressurized fluidized-bed – which had been developed by ABB Carbon AB. ABB Carbon, now a part of ABB STAL, is an engineering unit within the Power Generation Segment of the ABB Group, with its headquarters in Finspong, Sweden. Pressurized fluidized-bed combined-cycle (PFBC) is a core product of ABB STAL for the production of heat and power from solid fuels. Within the ABB Group, ABB STAL has the worldwide responsibility for development, marketing, sales, supply and service of the PFBC technology.

This technology promised some advantages compared to the atmospheric technology, including significant efficiency improvement. In 1996 The Frame Agreement between IEC and ABB Carbon was signed and an implementation of The Verification Programme was begun. Special agreements have been signed between PAMA Company Ltd and each side of The Frame Agreement, which permit the use of the proprietary information acquired by PAMA for The Verification Programme.

Characteristics of Israeli Oil Shale

Oil shale from the Northern Negev (Rotem deposit) is a friable, porous and dusty material [1]. Its characteristics and composition change with the deposit depth. Typical composition is presented below (wt.%):

Organic matter	9–15
Carbonates (as CO_2)	19–22
Moisture	16–20

The average organic matter content is 14.3 % (dry basis), the *in-situ* moisture in the deposit is constant at about 20 %. The sulfur content is high, about 10–15 % by weight of combustible content. The low heating value of the oil shale for the average composition is only 700–740 kcal/kg (1260–1330 Btu/lb.).

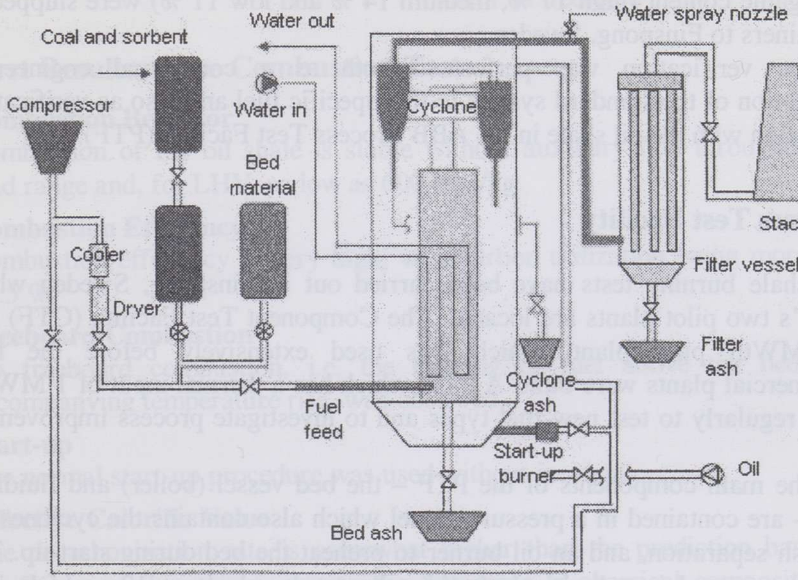
Ash produced from a boiler consists mainly of different compounds of calcium.

PFBC Technology

The PFBC technology, which has been developed within the ABB Group for the last twenty years, is based on combustion of fuel in a pressurized fluidized-bed at a pressure up to 16 bar [2].

Power generation using a combined cycle is based on the joint use of a gas turbine and a steam turbine for extra efficiency. PFBC is the only technology using a coal-driven gas turbine. The steam turbine generates approximately 80 % of the output, and the gas turbine another 20 % of the output. PFBC has a 15-% lower fuel consumption than conventional technologies.

Prior to combustion, the solid fuel is crushed and then mixed with limestone (due to the high content of calcium in the Israeli oil shale there is no need for limestone to absorb sulfur). The fuel is injected into the fluidized-bed and burned. The temperature in the bed is kept constant at approx. 850 °C. The boiler is pressurized with air from the gas turbine compressors. The flue gas from the combustion is taken to the turbine, where it expands and drives the compressors used to pressurize the combustion air and the generator for electrical generation.



Scheme of the PFBC technology

The heating value of oil shale is determined under atmospheric conditions and varies over a wide range. At these conditions the limestone in the fuel either captures sulfur or is converted to free lime. As calcination of limestone is an endothermic chemical reaction, it takes away heating value from the fuel and reduces the indicated energy content in the oil shale by some 15 %. Combustion under pressurized conditions means a higher partial pressure of CO_2, which prohibits the calcination of limestone and thus eliminates the formation of free lime. The consequence is that the effective heating value of the fuel under pressurized conditions is up to 15 % higher than for atmospheric combustion conditions.

The PFBC combined cycle has an efficiency advantage of about 4 percentage points over an atmospheric fluidized bed where ordinary coal is used. A consequence of burning oil shale under pressure is that the apparent efficiency advantage of the PFBC power plant increases drastically. In the case of Israeli oil shale with a high content of calcium compounds, the efficiency advantage increases by some 4–6 extra percentage points, resulting in a total superiority of about 8–10 percentage points over atmospheric combustion.

Objectives of the Verification Programme

The overall objective of the Verification Programme was to verify process behaviour and system adaptation for combustion of the Israeli oil shale under pressurized conditions. Some 800 tons of the Israeli oil shale at three levels of organic content (high 17 %, medium 14 % and low 11 %) were shipped in containers to Finspong, Sweden.

The verification was performed both as a conceptual engineering adaptation of the standard system to this specific fuel and also as verification operation with the oil shale in the ABB Process Test Facility (PTF).

Process Test Facility

Oil shale burning tests have been carried out in Finspong, Sweden where ABB's two pilot plants are located. The Component Test Facility (CTF) is a 15 MWth pilot plant, which was used extensively before the first commercial plants were built. A PTF, which has a thermal input of 1 MW, is used regularly to test new fuel types and to investigate process improvement [3].

The main components of the PTF – the bed vessel (boiler) and fluidized bed – are contained in a pressure vessel which also contains the cyclones for fly ash separation, and an oil burner to preheat the bed during start-up. The pressure vessel is cylindrical, 1 m in diameter and about 12 m high. The height of the bed vessel is the same as that of a full-size plant, but the bed cross-sectional area is smaller. The bed height at full-load operating conditions is about 3.5 m (see the Scheme).

Combustion air supplied to the pressure vessel enters through nozzles at the bottom of the bed. An electrical compressor delivers the air for fluidization and combustion.

Oil shale is pneumatically fed into the bed. The fuel preparation consists of units for crushing and drying.

Bed ash is removed from the bed bottom cone and is transported to the ash disposal silo. There are separate systems for bed ash and cyclone ash removal.

A high-pressure turbine guide vane (HPTGV) rig was installed downstream of the cyclones specially for the Israeli oil shale tests.

The power output from the plant is basically controlled by the bed height. The bed temperature, which is normally 850 °C, is controlled by varying the speed of the fuel feeder.

There are some 120 measuring points in the process test facility. These are either local, transmitted to the control room or connected to a logging computer.

PTF Plant Data

Combustor pressure	up to 17 bar
Bed temperature	up to 900 °C
Fluidizing velocity	1 m/s in freeboard
Thermal output	up to 1 MW
Bed height	up to 4.5m
Bed area	0.09 m^2 at distributor
	0.09 m^2 in freeboard

First Results of the Combustion Tests

Combustion Behavior
Combustion of the oil shale is stable without auxiliary fuel throughout the load range and, for LHV, as low as 600 kcal/kg.

Combustion Efficiency
Combustion efficiency is very high, with carbon utilization being more than 99.5 %.

Freeboard Combustion
No freeboard combustion, i.e. the burning of fuel above the bed with accompanying temperature rise, was observed.

Start-up
The normal start-up procedure was used without incident.

Effective Calorific Value
The decarbonization rate is somewhat higher than the prediction based on the CO_2 partial pressure, due to the difference in chemical composition of the mineral matter of the oil shale and limestone. Although the calcination rate was higher than expected, the effective calorific value of the oil shale is about 10 % higher than for atmospheric conditions.

Ash Behaviour in the Furnace
Bottom ash accounts for more than 55 % of the total ash.

Heat Transfer Coefficients
Heat transfer within the bed was as expected and is not be expected to be a problem in a commercial unit.

Fouling
The in-bed tube bank of boiler and cyclones remained clean despite the extremely high ash production. Hard deposits were, however, formed on the blade of the HPTGV test section. The deposits and their formation rates would not be acceptable in a commercial unit without a functioning on-line cleaning system.

Emissions

There are no detectable SO_2 emissions due to high calcium content in the oil shale. NO_x emissions are relatively high and would require the installation of an ammonia injection system in a commercial unit.

Technical Results

The main conclusion after the first stage tests was that the combustion of the Israeli oil shale does not have any process difficulties. The phenomenon of hard deposit formation on the HPTGV rig during the first phase requires a solution.

Changes were implemented at the PTF to prevent the hard deposit formation through increasing the efficiency of the gas collecting system.

A petroleum coke and an asphalt residue were used for some tests as a supplementary fuel because of its extremely low costs. A supplementary fuel portion of about 10 % by weight was chosen for these tests.

A device for on-line cleaning was installed between the cyclones and the HPTGV rig.

These changes proved to be very effective and significantly decreased the phenomenon. Further verification, however, is needed on a commercial scale.

Conclusion

Both companies – I.E.C. and ABB STAL – consider the combustion tests to be an important step, which has proved the technical feasibility of a PFBC plant fired by the Israeli oil shale.

In order to consider such a plant in I.E.C., the generation cost has to compete with other potential units considered for the Israeli generating electricity expansion programme. The economic feasibility of the concept is the subject of further co-operation between I.E.C. and ABB.

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