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THE SHALE-OIL INDUSTRY IN SCOTLAND 1858–1962. II: OIL-SHALE QUALITY, RESOURCES AND TECHNOLOGICAL ADVANCES

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Scotland had a history of full-scale shale oil production from 1850-1962 and was a key developer of many of the technologies still used in modern-day, above ground retorting processes. The central Scotland oil shale field is only a tenth the size of the Estonian oil shale field (194 km^2) with 7 main oil bearing seams. Remaining resources are calculated at 1,100 million tonnes. The Scottish shale-oil industry mainly produced oil for petrol, lighting and lubricating. In addition extensive use was made of the waste products, like ammonia, that were created in retorting process. The spent shale was typically about 75% of the weight of the raw shale and was tipped onto shale bings (spoil heaps) up to 95 metres high; much of this spoil was also utilised in a range of by-products.

Introduction

Scotland was the global pioneer of the modern oil-industry and, for a few decades in the second half of the 19th century, was the leading oil-producer in the world. The history of the shale-oil industry in the county of West Lothian, Scotland is unique within the United Kingdom [1]. Oil shale production was from deep mined seams and was primarily processed to produce crude oils in the form of paraffin (which was a brand name). In 1850 full-scale commercial processes to retort and refine oil products from oil shale were developed by James 'Paraffin' Young [2].

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Summary of Central Scottish oil-field and shale quality

The shale field in Central Scotland is only a tenth the size of the Estonian oil shale field, 19,400 ha (194 km^2), with seven main oil-bearing seams (Figure). Over a period of 110 years, from 1853, approximately 10 million tonnes of oil were retorted from 140 million tonnes of mainly deep-mined oil shale [3].

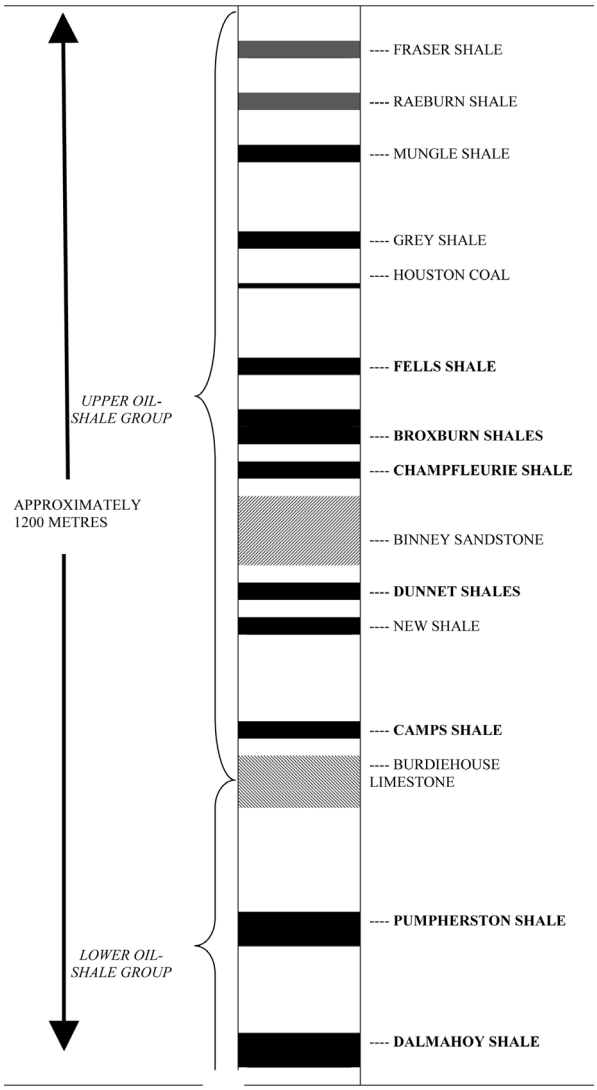

Figure. The main oil seams.

Stylised diagram of the oil-bearing shale strata, adapted from Kerr (1994) and Cameron & McAdam (1978). The seven most productive seams are highlighted in bold.

Shale quality

The inorganic materials in Scottish shales are mainly alumina and silica, and the organic material is of mainly plant origin [1, 5]. Individual shale seams vary from high to low quality (see Table).

- Oil yield could be as high as 12% by weight of shale extracted but averaged 8% over the 100 years of production;
- Crude oil produced had a set point of 87 °F (30.6 °C / 304 K) and a specific gravity of 0.88;
- Maximum annual output was in 1913 when 3 million tonnes of shale was extracted yielding approximately 250,000 tonnes of crude oil;
- During the retorting process 13.5 kg of naphtha was produced per tonne of raw shale;
- Naphtha produced had a boiling point range from 48–242 °C (118–468 °F / 321–515 K);
- Average ammonium sulphate, $(NH_4)_2SO_4$ (soil fertiliser) , production was more than 25,000 tonnes per year.

More than 150 million cubic metres of spent shale (industrial waste) was also produced during the 100 years of shale-oil production. This sterile ash was composed of 3% carbon, 49% silica, 25% alumina, 12% iron oxide and contained no organic matter [5].

Table. **Crude oil and ammonium sulphate content per tonne of shale**

	high-quality seams	low-quality seams
crude oil	110–200 litres	70–90 litres
ammonium sulphate	9–16 kg	13–32 kg

Present resources

Remaining resources of oil bearing shale seams are calculated at 1,100 million tonnes [3], mostly from the Pumpherston shales although accurate figures are difficult to calculate. Only approximately 12 million tonnes of this could be extracted by open cast or strip mining in areas where the surface cover (overburden) is less than 30 m. In most of the shale field the surface cover is upwards of 60 m. The remaining resource could be deep-mined but would probably require many small mines and/or multiple shafts because of the extent of discontinuity in the seams from faulting of the shale beds, although there are many workable seams 1.25–3.75 m high. In addition extraction of the shale-oil would require the building of new on-site retorting and distillation plant and would produce considerable environmental disturbance for a relatively low yield. It is therefore unlikely that this resource will be exploited.

Inventions and innovations

In 1851, James Young opened Britain's first commercial mineral oil refinery in Bathgate and patented his retorting process in both the UK and US [6]. Young's other major contribution was to the refining processes. Paraffin wax was produced during distillation along with various grades of fuel: naphtha (or petroleum spirit) 6%, burning oil (kerosene) 23%, wax and lubricating oil 56%, the remaining heavy residue, sent to the coking stills, 15%.

Throughout the history of the oil-shale industry in Scotland company engineers developed a wide range of novel engineering products to maximise the production of multiple grades of oil, waxes and numerous others products from the crude shale oil.

Retorting and refining

The 1850s oil was extracted from the shale using a horizontal gas retort that typically held and retorted about 50 kg per day. However, within two years a vertical retort was introduced that gave increased yield and better-quality oil. The two types of retort worked in tandem for many years because the horizontal retort produced burning oil for lighting and the crude oil did not need to be distilled before refining. A local engineer, N. M. Henderson, improved the retorts used by the industry by developing the Henderson retort in 1873.

The Scottish retort was perfected by 1895 when the Pumpherston retort was developed by James Bryson, an engineer / manager at Pumpherston Oil Company. This retort consisted of an externally heated continuous vertical retort of cast iron and firebrick construction; it was the only type of retort in use by 1938. No other retort was as efficient at giving maximum yield of oil and ammonia from Scottish shale [3]. Further new retorts were developed throughout the twentieth century, including a development in which air as well as steam was introduced into the base of the retort that was evaluated around 1937, but although oil quantity and quality were not affected, none of them had the high yield of ammonia and other by products that were essential to keep the costs of shale-oil production in Scotland competitive.

Cracking

An early version of the cracking process (heating oils under pressure) was invented to increase lamp oil production and patented in 1865 by Young's son, also James. The process was developed in the 1920s to increase petrol production. These same processes are used in the modern refining industry to produce low-boiling oil products.

Fractionation

In 1885 local engineer N. M. Henderson patented continuous boiler stills, a system that allowed different grades of oil to be fractionated in a single

process by using a linked series of stills. These were used across the world until 1936 when engineers from Scottish Oils designed a new system based on pipe stills. Some of the first of these were installed in the new refinery at Grangemouth.

Industrial refrigeration

The first practical air compression refrigerator in the world was developed and built by Young's chief engineer, Alexander C. Kirk in 1858 for the cooling process that allowed the paraffin to crystallize out of the oil (industrial-scale refrigerators were then produced in Glasgow and exported all over the world for ice-making).

By products

Although free-flowing oil had been discovered in Pennsylvania, U.S.A. by 1859 (and was refined using Young's patented process) it was some time before the imported oil was cheaper than the home manufactured product as the shale distillation process was now more efficient [7] and the industry in Scotland also successfully utilised a range of by-products.

Retorting in the Scottish shale-oil industry was always carried out in such a way that maximum production of other materials was included in the process to keep down the production costs of the oil [3]. The use and reuse of all of the waste products resulted in a highly complex and cost effective oil-production system although oil could have been produced more efficiently by concentrating on oil extraction only.

Steam and natural gas

Steam, oil and gas were drawn off the retorts. Heat was recovered from the gases via exchangers heating boiler feed water, suction being maintained by a steam driven turbine exhauster. The condensed crude oil and ammonia liquor passed through separators into separate storage. The gases were scrubbed with water to remove any remaining ammonia then with light shale oil to remove solvent naphtha (3 gallons of the light naphtha hydrocarbons were removed per ton of shale). The stripped gas was used to supplement gas from coal to power the retorts. The steam also reacted with carbon to produce a combustible gas that was used to light the oil works, at no cost, and supply the local towns.

Paraffin

Candles were a major paraffin wax product. In 1858, five tonnes of paraffin wax per week was sold to candle makers but by 1902 Young's Addiewell plant was cutting out the middle man by producing 100 tonnes of candles per week. "Paraffin Oil" was a brand name and other uses of the wax included

waterproof papers, wound dressings (like Vaseline) and in matches. A third of Britain's paraffin wax supply continued to come from West Lothian until the industry closed down in 1962.

Ammonia and fertilisers

Ammonia, which was formed by hydrogen in the steam reacting with the nitrogenous material in the shale, was extracted from the steam fed through the raw shale during retorting. About 80% of the nitrogen content was recovered in this way. Although initially treated as a waste product, by 1865 the ammonia waste was being used to produce ammonium sulphate fertiliser that was exported to plantations throughout the British Empire [4].

Chemical industry

Other by-products of the oil extraction process included 4,000 litres a week of lubricants and naphtha (manufactured for the paint and rubber industries). Shale oil was also used at the chemical works in Broxburn and Bathgate to produce petroleum jelly, wax for beekeepers, fluid for powering lighthouse lamps, detergent, sulphuric acid, mothballs, paints, rubber goods and candles, [5, 8–10].

Spent shale

The spent shale was typically about 75% of the weight of the raw shale and was tipped onto shale bings (spoil heaps) up to 95 metres high. This was used to produce bricks in the Scottish Oils Plant at Pumpherston, and by 1938 production reached 30 million bricks per year, many of them used to build Oil Company housing.

The lasting legacy

Technology and personnel were exported from West Lothian to develop shale oil industries in other countries, including Australia. The influence of the engineering, refining and mining expertise from the shale-oil industry is evident throughout the modern oil industry in Scotland and across the world. To quote FM Cooke in 1970; "all of the basic refining processes used in a modern oil industry were in place in the oil-works of West Lothian in the 1860's" [4].

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