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Underground Refining of Fuels in Particular of Oil Shale

Erich Sarapuu

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Introduction

R. Frasch developed in 1890 the first method for mining sulfur without underground appliances and fixtures. By virtue of this method sulfur can be melted "in situ" by introducing superheated pressure-water through a shaft. Liquid and very pure sulfur is pumped to the surface. A patent has been granted for this process in 1891. In U.S. it is widely applied. Thus, sulfur may be obtained from a U.S. presence which could not be mined by any other method....

We meet with a similar situation regarding oil beds. For, by means of the customary pumping operation, only one third or one fourth of the oil extant in a given presence can be obtained. New methods for petroleum production are being developed. At Pechelbronn (Alsace) and at Wietze, underground mining operations have been started decades ago. A presence which has been exhausted by pumping operations is mined by building drifts and galleries. From these spots bore holes are sunk into those strata where oil is still present so that the oil, under the influence of gravitation, may ooze into the galleries. This method increases the amount of oil obtained from a given presence. But this method fails in bringing out the oil quantitatively. Therefore, new methods of operation must be sought for. For example, mining could be replaced by underground distillation. In this case, the derricks being placed very close to one another, the borings may serve as pipes for the removal of the distillation products. It is only open to argument in which manner the oil presence is to be heated. The Russians have suggested to light the oil, which is still present at the drill hole, and to use the hot combustion gases formed for distilling off the oil through another boring.

Experiments have also been made to gasify coal in situ. There is a genuine need for such a process... In Russian undergound gasification is operated on unmineable seams. Russian experiences, however, cannot be directly applied to Western mines, because the geological structures are different.

Russian experts deemed the underground gasification tests to be so successful that several industrial plants have been planned on this basis and some of them are already in operation. Long-distance gas is being produced by underground gasification and brought to Moscow through a 220 km pipe line.

The lignite presences in the neighborhood of Moscow are said to be exploited in the same manner...

Oil shale...must be worked at minimum cost. For, the refining residue is not a valuable distillation product but ashes containing a low rate of combustible components. In Sweden, an underground low-temperature carbonisation process for oil shale has been developed, the Ljungstroem-process, which is being tested on a technical scale at the present time. It is distinguished by the feature that resistance heating-wires mounted on rod-like heating elements are introduced into the borings, thus supplying the bed with the necessary heat. Mr. Esbjornson, too, has recently developed a method of opening up oil shale by means of drill holes. A layer, situated between the two borings is broken up(*) and treated with hot gases...

2.) Underground production of sulfur by the Frasch process

(The Frasch-process as it has been developed in U.S. This section may be translated upon request.)

3.) Underground gasification of coal

(a) Chamber process

Modern research projects regarding the underground gasification of coal have been developed in Russia. In the course of time the various methods have passed through a large number of stages. At the present time we may assume the experimental stage to be concluded.

The objective of the Russian experimentation was to simplify the transportation problem by supplying the consumers with long-distance gas.

Two main lines of ideas were followed in the Russian projects:

1.) Attempts at the gasification of coal without building underground structures.

2.) Attempts at the gasification of coal in special underground chambers (Fig. 4).

In the first case, the sum total the preparations preceding the processing action consist in the sinking of a varying number of borings of different diameters. They are supposed to introduce the air required for the combustion process into the bed and to discharge the evolving gas. Many tests showed the various difficulties involved. It has been found that this method is applicable only under certain conditions.

3.) Reducing the preliminary work to a minimum, since otherwise the advantages offered by underground gasification are lost.

(*) The German expression "sprengen" does not indicate, whether the layer "bursts" under the influence of heat or is blown up by explosives. (M.B.)

(b) The current-process

In contrast to the prior plan of gasifying coal reduced to small pieces, the experiments in question aimed at the gasification of compact masses of coal. The equipment of the experimental plant was very simple, (Fig. 5). The Russians chose a dichlotomous vein of slight thickness. The vein is made accessible by cutting a gallery sole. The access to the vein serves as a kindling pass and is separated from the rest of the mine by an impervious bank. All the underground structures are secured with wood. The timbering serves only for the preparatory work. In large distances of 200-300 metres of length, borings pierce the bed which is also 200-300 m long. Through the two flanking shafts or borings the gasifying agent, such as air or hydrogen, is introduced. Through the central boring the gas flows upwards and is sucked off. In the bottom sole combustible material is kindled electrically. By introducing the blast through a boring the gasification process is started. The blast passes through the vein and keeps the coal burning. The heat of combustion generates the zones of reaction characterized in Fig. 6. As gasification proceeds a cavity is generated which is again accluded partly by the pressure of the cap rocks, partly by the collapsing roofs, so that the current passes through is always of a limited diameter. By adjusting the oxygen-enriched blast which contained about 27-30% of O_2, a gas of the following composition was obtained:

CO_2 - 10-12%
CO = 12-15
H 2-3
CH_4 43-47

The heating values of the gas varied between 1000-1300 k cal. The nature of the gas depended primarily upon the rate of oxygen contained in the blast a property which was utilized later on for controlling the gasification processes above ground.

By the addition of oxygen to the blast the quantity of bombustible constituents in the gas and, thus, its heating value are enhanced.

Since 1935, this process is applied at the Gorlorka mine on a larger scale. It has been found that on using a blast consisting of a mixture of air and oxygen, the evolving gas penetrated also into the adjacent rocks. By virtue of the great differences in the specific gravity of the individual gaseous components, hydrogen was more quickly diffused. The adjacent rocks had thus a kind of filtering effect. The gas which penetrates into the rocks is enriched with hydrogen. When the blast was discontinued and the pressure decreased, the gas was rediffused from the adjacent rocks into the channel on fire and was discharged together with the gas evolved. On this phenomenon the underground generation of special synthesis gases required for the production of various chemical products, such as ammonia and hydrocarbons, has been based.

It is said that at times the beds are worked in a periodical mode of operation, by alternately blowing in the gasifying agent and sucking off the gas. The length of the blowing period varies between 4 and 6 hours. According to the literature, the optimum for the blast period and for the oxygen concentration has not yet been established. When the blast contains 25% of O_2, the composition of the gas is as follows: 18% CO_2, 15% CO, 49% H_2, 4% CH_4 and 14% N. As we know a gas of such composition cannot be obtained in a gas generator, even though the blast contains 35% O_2. It would be necessary to operate with a blast containing 50% O_2 and to convert the nascent CO immediately with steam, in order to produce such a type of gas in a generator.

The underground gas generator combines three processes:

1.) Working the coal
2.) Gasifying the coal
3.) Producing the steam, since the underground gasification method does not require the addition of steam.

This combination of several processes is a great economic advantage. Gas produced by underground gasification is much less expensive than the same type of gas generated in an above-ground gas generator. The heating value of this gas was 1,225 k cal and its composition as follows:

18% CO_2, 15% CO, 20% H, 3% CH_4, 44% N

These results show the practicality of the "current method" of gasifying coal in a compact bed. The installation is very simple and inexpensive.

(c) Regenerative and cracking process

A similar method has been used in the Koutznetsk Basin with horizontal veins. Semenoff and Galinker have developed the regenerative method for the underground generation of gas in the first-line water gas. The coal is gasified by the "current" process, with this difference that the oxygen blast-apparatus alternates in blowing air vapor and oxygen vapor.

The regenerative method has been tested in a laboratory using an underground gas generator model. Anthracite was used as a fuel. It has been found that the vapor would cause an important activation of the coal which would quickly react with O_2. The gas obtained consisted of:

15% CO_2, 5% O_2, 26% CO, 53% H, 0.7% CH_3

The Russians have also developed another process for level seams. Starting from 2 driftings, several holes ("clefts") of about 100 mm diameter are bored at a distance of 5 m for a length of about 100 m.

These holes play the same role as the bottom fire drift in the "current" process. There is this difference, however, that the cleft is surrounded on all sides by gasifiable coal thus undergoing a different type of change in its cross-section. Fig. 7 shows the principle on which this process is based.

(4) The filter process or the method of the "natural cleft" which has been developed by the Energetic Institute of the Academy of Science (ENIN) requires a minimum of mining operations in preparation of the processing operations. Fig. 8a and b show that borings each provided with two concentric tubes are sunk in the centre and on the periphery of a circle. They are kindled by introducing incandescent charcoal into the centre boring and blowing in a blast of air and

oxygen. The gas discharge is repressed to such an extent that a gauge pressure evolves, sufficient for preventing the trickling in of water. Thus, at first, cavities are formed, the coal dries out and clefts are generated. Finally, a natural rift will be formed extending to one of the peripheral borings which have been prepared in the same manner; there, the issuing gas will be discharged. When the gasification goes on the central boring is given up and the blast is introduced into one of the peripheral borings and the gas discharged at a boring situated in an adjacent ring.

The basic ideas of this process have been described in 1909 in the British Patent 21.674. The first experiments with a coal block 300x200x200 mm have been conducted in the gasification laboratory of the Energetic Institute of the Moscow Academy of Science. In the meantime a large-scale technical investigation has been carried out.

Disadvantages of this method are: the height and very great variability of the pressure and the lack of uniformity in the output of gas. This defect can be partly overcome by operating a greater number of borings at the same time. Scorification of the coal and deflagration of the inserted tube are prevented by the cooling effect of water or steam being introduced...

The basic idea of the Russian method of gasifying coal is at the present time being tested with respect to oil-shale mining. Experimental plants have been erected in Sweden, Wurttemberg and Esthonia. The low-temperature carbonization process of oil shale is already in the operational stage in Sweden and the major part of the oil needed by the Swedish Navy has thereby been supplied.

(4) <u>Shale-oil production by the Ljungstrom method</u>

According to the Ljungstrom-method (Fig. 11a) the cover layer is not removed any more from the oil shale. Electrical rod heating-elements and degasification tubes are inserted in the oil-bearing rocks. In accordance with the temperatures attained by the rocks, gases and oil vapours are freed and distilled. Owing to the differences in pressure and temperature, they are flowing through the horizontal rifts which correspond to the natural stratification of the rocks, to the condenser, where the vapors are condensed and the gases sucked off...

A year ago a large-scale experimental plant has been built at Norika. The oil-bearing bed is there about 17 to 18 m thick. The content of oil is about 6% by weight. The experimental equipment consists of a metal tube driven into the ground, the sides of which are provided with a great number of longitudinal slits. Above ground it is connected with a condenser by means of a gas discharging tube. The subatmospheric pressure, which of course prevails in the condenser contributed a great deal to the extraction of the vapors from the ground. Around the "working tube" six metal tubes are driven into the ground. They are equipped with electric heating resistance elements of 22 KW each. To each of these six rod heating-elements belongs an area of 10 m^2, that is, a volume of about 175 m^3 or a quantity of 400 tons. That is, the heating performance was 0.126 KW/m^3 or 0.055 KW/ton of rocks. After two and a half months of heating, the rocks had attained a temperatur of 400°C, and 75% of the fuel contained in the shale had been extracted. A part of the rest has probably been lost through the rifts. The distillate contains 24% of benzine.

On the basis of the data in question we may calculate tha t about 2,200 KWH/ton of oil produced have been consumed. 40,000 tons of oil per annum could be p produced with 10,000 KW. We may assume the lower limit of the heating value of the fuel oil to be about 6,600 k cal/kg. Thus the ratio of heat produced : current consumed is about 3.5:1. .

This favorable result may be explained by the fact that there are not any vertical rifts in the oil-bearing rocks, through which gases and vapors could escape, or that they are sealed when the rocks expand in the heat. In the horizontal direction, however, corresponding to the natural stratification, the rocks remain pervious to gas or vapor. That this method yields such a good heat effect is certainly due to the good insulation of the ground and to the favorable ratio of surface area to volume of the large quantity of heated rocks.

Swedish experts calculated that the Nerika shale alone may yield about 30,000 tons of oil per annum. Sulfur and other valuable by-products are also obtained.

(5) My own investigations on underground low-temperature/carbonization of oil shale.

The survey (1)* shows that there are many oil shale presences in the world...

The Esthonian oil shale Kuckersit consists of paleozoic shale and limestone containing 20% of bitumen. This oil-shale presence lies in Northern Esthonia. Along the Northern shore, there are outcrops of long-stretched beds of oil shale under a comparatively thin cover of quarternary sediments.

The strata dip very gently southward at about 3°. Within the Lower Silurian two horizons with strikingly low contents of bituminous components have evolved, the so-called Dictyonema shale; containing 5-7% of oil. This stratum lies directly at the Coast, but it is not rich enough in oil to be exploited.

The Esthonian fuel shale-Kuckersit - has attained an increasingly important position in the economy of Esthonia since the world war. It forms several brownish strata of marls and shales 0.1 m thick, up to a maximum of 1 m, alternating with strata of limestone. A horizon, 130 km long by 30 km wide has been proven, said to contain 5 billion tons of material worth working. This oil shale has mainly evolved from saprophagous vegetable matter and contains 30-70% of combustible material. The rocks themselves are combustible and have a heating value of 2,300 to 3,500 k cal, so that the shale has been used as fuel, at times even for locomotives, without any further treatment.

The major part of the shale mined is subjected to low-temperature carbonization. The output of crude oil amounts to 18 to 20% of the gross weight. The refined benzine is of a high quality. The distillation residue, which contains

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(*) May be copied upon request. (M.B.)

yet 8-17% C has not yet been utilized. Enormous dumps of residue accumulate in the vicinity of the plants. About 10% of the presence is mined in open working, 90% in deep workings. In 1939, 1.700.000 tons of shale were mined. The contents in organic substances varied with the individual seams. They averaged 43%, and the upper heating value was 8.300 k cal.

The average composition of Kuckersit, calculated on the basis of air-dried shale, is

Specific gravity	1.2096
H_2O	1.59%
C org.	39.78%
H_2	5.72%
N	0.30%
O	8.03%
Total S	1.27%
SO_2	8.61%
SiO_2	14.00%
Al_2O_3	6.35%
Fe_2O_3	1.98%
CaO	11.15%
MgO	0.63%
$Na_2O + K_2O$	0.88%

On heating, the undecomposed shale evolves gas at about 200°C, the formation of oil beginning at 350°C. The formation of gas and oil becomes more intensive when the temperature goes up to 400-460°C. The end point for the formation of oil lies practically at 600°C. It is interesting to observe that the shale melts like pitch on being slowly heated to 330-350°C. The nature of decomposed shale differs from that of normal shale. This difference in behavior caused many of the mistakes made in prior observations.

Under normal conditions, the low-temperature carbonization process yields an output of about 60-60% of the organic substance contained in the oil shale. This output can be enhanced to 75% by adding steam in the course of the operation. By the Fischer carbonization-analysis, the following results are obtained, based on air-dried shale:

Low Temperature Tar	29.7%
" " Coke	55.0%
Water of distillation	6.3%
Low Temperature Gas (without H_2S)	6.0%
H_2S	0.32%

The low temperature tar is of a specific gravity of 0.9735. Its elementary analysis is:

C	78.22%
H	10.57%
N	0.34%
S	1.21%
O	9.66

Analyzing the oil shale residue we found:

Mineral substance	63.61%
CO_2 (Carbonate)	15.66%
C org.	18.20%
H_2	0.99%
N	0.23%
O_2	0.56%
S	0.75%

In the course of time various types of low temperature carbonizing furnaces have been developed in Esthonia. Only a few of them have stood the test because Kuckersit sinters readily. In 1927, after experimenting for many years, the Esthonian Oil Shale Consortium succeeded in constructing a tunnel furnace, the basic principles of which are still maintained in new installations. A plant comprises the following units:

(Sillamäe low temperature carbonization plant:)

1.) Mining installations
2.) Tracks for the conveyance of shale from the mine
3.) Elevated tracts for discharging the shale, and shale storage places
4.) Breaking up unit
5.) Screening unit and shale bunkers
6.) Nodulization unit
7.) Drying furnace for nodules
8.) Low temperature carbonizing furnace
9.) Circulation tracks for the low-temperature carbonization trucks
10.) Carbonization truck tipper
11.) Elevator and bunker for low-temperature carbonization coke
12.) Condensers
13.) Receivers for the different oils
14.) Benzine removal unit for light oil
15.) Refining and rectifying units and receivers
16.) Ditch for pipelines and waste water
17.) Tank farm
18.) Boilerhouse and power plant
19.) Bitumen blowers
20.) Administration and laboratory
21.) Repair workshop
22.) Drum shop for shipping the bitumen
23.) Storehouse
24.) Benzine filling unit

These plants are very spacious. If we could succeed in introducing underground gasification processes, great simplifications would be possible, resulting in important savings in investment and labor.

It has been calculated that theoretically 181 k cal are required for the low temperature carbonization of oil shale.

The heat balance in the tunnel-kiln is as follows:

Evaporating moisture	78 k cal
Superheating vapor	26 "
Heating up shale to 400°C	104 "
Heating up shale truck to 500°C	60 "
Heating up low-temp. carbonisation products to 500°C	60 "
Heating up shale coke to 500°C	11 "
Radiation of the kiln	33 "
Radiation of the hearths, exhaustors and circuit lines	40 "
Losses	40-403 k cal

This carbonization kiln consumes 2.2 times the amount of heat theoretically necessary, that is, it is of very low efficiency. However, all the heat necessary is supplied by the carbonization gases, only during wintertime 1-2% of oil must be used for additional heating.

The investigation of the electrical properties of Kuckersit

If we should directly apply the Russian underground gasification process to Kuckersit, we should be obliged to desist from producing oil and should obtain only cracking gas. Such tests have already been made in Wurttemberg, yielding a 1,000 k cal power gas. In the Esthonian tests a yield of about 7% of oil has been obtained, that is, about 30% of the total oil production by the Fischer method. The experiments have not yet been terminated. At any rate, the yields of oil are low.

There is another possibility of melting oil shale without mining in the bed by applying electroheat to the bed. Low-temperature carbonization by menas of electric energy has been the object of thorough investigations for a long time. The first patents have been granted in US:

6-18-1918: Method of and Apparatus for Treating Oil Shale, No. 1,269,747

4-25-1921: Improvement in or relating to the Recovery of Oil from Substances such asBitumen and Shale, No. 162,337 (sic!)

10-7-1924: Process of Subterranean Distillation of Volatile Mineral Substances, No. 1,510,655

Up to date, these patents have been without practical meaning. They differ only in minor details from the Ljungstrom process...

Underground low-temperature carbonization processes may offer the following advantages:

1. Fast rise in the temperature of the shale.
2. Suitable conversion of the electrical energy, into combustible gases and oils.
3.

Low-temperature carbonization with electroheat is distinguished by the following properties:

1. Simple construction.
2. Low costs of maintenance.
3. Quick and easy adjustment of the temperature.
4. High thermal efficiency.

The objective of my investigation was the establishment of the type of electrical heating most suitable for Kuckersit. Systematically three types had to be tested: resistance heating, (luminous) arc heating, and inductive heating.

For this purpose, we had to study the electrical properties of the shale. By laboratory tests only, the economically most suitable type of heating could not be established with accuracy. Pilot tests are necessary for this purpose.

We based our tests on direct electrical resistance heating, data for indirect heating being given by Ljungstrom.

On studying the electrical resistance of Kuckersit, it has been found to be 6.10^9 in the sample. The test was conducted by placing the sample between two electrode plates and passing through the current. The voltage was about 2,000 V and the intensity of the current about 100 m A. After a few minutes the rock became warm. Thus we proved that high voltage will heat Kuckersit.

Our next task was the reducing of the electric resistance of shale. One means to this end was to effect a change in the nature of the shale. If we succeed in carbonizing the combustible matter contained in the shale from the inside, as it occurs in the formation of a bridge, thus generating a bridge, we should have achieved this objective.

Basically there are four ways of generating a bridge by means of high tension, namely, by

1. The transforming of the high tension
2. Generating the high tension with condensers (shock tension-migratory wave)
3. Generating the high tension by shock currents
4. Applying high frequency.

The first tests run were conducted with transformed high tension (Fig. 9) current. The equipment available made it possible to conduct tests with 4,000 V and 0.5 A. The iron electrodes were of a 10 mm diameter, bored into the shale 3 cm deep at a distance of 10 cm (Fig. 4 and 5).

The values measured are recorded in synopses 1 and 2, the graphs are in Fig. 10.

The graph consists of two parts. The first part shows the course of the current in overcoming the major resistance. When the break-through between the two electrodes has occurred, the resistance goes down, and 10 V and 100 A are sufficient for heating purposes.

The initial tension was much higher when the electrodes were not pressed snugly enough into the borings; for, the resistance of the air lying between the boring wall and the electrode had to be overcome. For overcoming this defect, t we sealed the electrodes with graphite. Thereafter, the curve was much flatter.

Of particular interest were the observations made regarding the so-called bridge formation, which is comparable to a resistance break through. With lower tensions of about 300 to 500 V, at first, no appreciable change will take place in the shale. But when the tension exceeds 1000 V, sparks evolve, searching for a path between the two electrodes, comparable to resistance- and luminous-arc heating phenomena. The force of the current remains very low, being about 0.06 A. Increasing tension will result in the increased formation of sparks, the force of the current rising slowly, until finally a conductor-bridge has been evolved between the two electrodes. The rate of formation of this bridge may be readily observed by watching the changes in the force of the current. When the conductor-bridge has been formed, the tension goes down substantially and the force of the current goes up. Bridges can be formed at various magnitudes of tension. We have observed that this phenomenon takes place the faster, the more moisture is held in the rocks and the higher the tension. The minimum rate of tension necessary for a break-through varies between 1000-5500 V.

The process of bridge formation effects in the rocks various changes of a chemical nature. Moisture is driven out by spark formation. When this process takes place rapidly at high tension, many small cracks are made by the formation of vapor. The rock becomes more pervious for gas and will finally burst. The current takes its path along these tiny fissures, which are carbonized from the inside by the sparks. These carbonized areas offer very low resistance to the current, forming a conducting bridge between the electrodes. When the bridge has been terminated, the regular 220 voltage will be sufficient. It is important that the voltage used for making the bridge is sufficient for driving out moisture and carbonizing the surfaces of the fissures. Low voltages may be applied only afterwards (Fig. 6). It must be noted that sparks are not only formed between the two electrodes but also at their outer side. Fig. 7 shows that the low-temperature current follows the lines of force.

The type of heating chosen by us combines features of resistance and luminous-arc heating, differing from the direct light-current heating by the feature that the electrodes enter directly into the rocks and are surrounded by them.

Corresponding investigations on Wurttemberg oil shale (posidonia shale) gave the same results, excepting that arc formation sometimes required higher performances up to 4 KW, because at 0.5 A the bridge formation had not advanced to an extent sufficiently so that operation could have gone on at 220 V.

But even though a bridge would not evolve, the rocks would rather quickly reach a temperature of 140°C. The conductivity of the rocks is to a very great extent dependent upon the amounts of moisture contained in the shale. Subsequent to the evaporation of the water, conductivity went down. In the experimental specimen it was not possible to raise the temperature above this value. In the meantime, tests had been started on shale in situ, which could be heated to low-temperature carbonization ranges owing to the higher amounts of moisture contained in it. In situ, namely, moisture is not driven out but superheated. This fact may explain the differences in behavior mentioned.

For the low-temperature carbonization tests proper, a kiln and its equipment for the processing of about 1.5 kg of shale were constructed (Fig. 8 and 9). Alternating current of 220 V and 380 V was available. The current was transformed over two transformers. It was possible to switch on

0-220 V and 0-60 A, or
0- 20 V and 0-800A.

The high intensity of the current resulted in the generation of heat within a short period of time. The condenser-unit, however, was too small to take care of the rapidly evolving oil vapors, so that we could not study the effects resulting from the rapid heating-up of the shale. We operated in the following manner: the block of shale was reduced to a size of about 16 x 9 x 8 and the bridge formed with high voltage. Then, the block was built in into the carbonizer. The carbonization process was adjusted in such a manner that oil was formed at a uniform rate and that the oil vapors were quantitatively separated in the electrofilter.

At some tests powdery shale was processed (Fig. 10 and 11). These tests showed the current to form a conducting bridge in this case, too; powdery shale could be heated to low-temperature carbonization-temperatures like solid shale.

Summary: Our experiments have established the practicality of electrical low-temperature carbonization, by passing the current directly through the rocks. The length of time required for the low-temperature carbonization process will vary in accordance with the electrical performance, the temperature being 450°C, the minimum rate required in this process. The length of time required for reaching this temperature is also a function of the electrical performance.

In order to test the practical applicability of this method, the following variations had to be investigated:

1. Heating the shale with high voltages and low intensities.

2. Bridge formation with shock tension (migratory wave).

3. Bridge formation with shock currents.

4. High frequency

The mode of heating (1) stood the test up to a 15 m distance of the electrodes; but the experiments applying methods (2) to (4) turned out to be failures.

These were the results of the first 1. - t. carbonization test (Diagram 1).

	Fischer Analysis	Electro-Carbonization
Tar	42.0%	14.9%
Water	6.9"	5.2"
Residue	43.3"	43.1"
Gas Losses	7.8"	36.8"

The electrocarbonization process yielded a very low rate of output of tar, whereas that of the residue agrees with the Fischer analysis. That means that there have been the same yields of volatile components but that the ways of cracking the oil vapors have been widely different. (Summary 3 shows the data.)

Correct conclusions may be drawn from these data only by visualizing the behavior of Kuckersit on being carbonized.

Zeidler's investigations of Esthonian oil shales have shown that the rate of cracking of oil vapors varies with the temperature. Gentler carbonization methods will produce more crude oil containing less benzine (8-10%) or less gentle method will result in less crude oil with higher benzine contents (about 25%). Variations in the carbonization temperature affect this shale much more than lignite, for example.

One may in this case arbitrarily choose between the possibility of generating much higher-boiling oil and little benzine and cracking gas, and much benzine and cracking gas with poor total yields of oil. The latter method will be preferable, whenever the refining of the shale oil is to be avoided (hydration), as in Esthonia. There, one reckons with 1 part of benzine to 2-1/2 parts of oil.

Zeidler compares the operational output of a Wander-tunnel kiln with that of the Fischer low-temperature carbonization analysis as follows:

	Kiln	Fischer
Total Benzine	5.16%	3.69%
Oil Benzine and Gas Benzine Plus in benzine output 5.16% - 3.69% =	1.47%	
The increased yield of benzine corresponds an increase in yield of uncracked oil of 2.5 x 1.47 - 1.47	2.20%	
The Yield of oil calculated for the identical cracking rates	28.46%	27.46%

Converted to the same rate of cracking, the yield of oil in large-scale operation was thus somewhat higher than in the Fischer low-temperature carbonization analysis. This phenomenon may be effected by the lower partial pressure of the oil vapors in commercial-scale carbonization operations involving gas recirculation.

We tried to repress the cracking of the oil vapors at the second experiment by recirculating CO_2. The formation of oil vapor drops sharply after two hours (Summary 4).

The data are, as compared with the Fischer analysis:

	Fischer Analysis	Electrocarbonization
Tar	37.2%	15.7%
Water	3.4	7.0
Residue	50.0	50.2
Gas losses	7.4	23.8
Gas benzine	-	1.8
Losses	-	1.5

The output of gas (Diagram 2) is still very high. The oil output, in comparison to the Fischer output, amounts to 42.3%. If we compute (in accordance with Zeidler) gas and tar benzine as 2.5 times as much oil, the calculation shows an output of 87.3%. The 12.3% of tar which are missing, have been converted into cracking gas. In the Fischer analysis of a normal dry average shale containing about 42% of organic substance, there are yields of about 4% of permanent gas (8,000 k cal) (that is, 320 k cal in gaseous form) per kg of shale. The electro-carbonization yields 23.8% of permanent gas, that is 2,100 k cal. Subsequent investigations must try to increase the oil output and to repress the formation of cracking gas.

6. Investigations on the low-temperature carbonization of oil shale in situ

A few preliminary experiments in the shale bed have been conducted after the laboratory tests had shown that low temperature carbonization by means of electric resistance heating is possible. The experiments were carried out at Dotternhausen, Wurttemberg, where a modern oil-shale carbonization plant is located, which operates by the gas-recycle method. The studies had the objective of finding out, whether the carbonization gases can be sucked off through the tubelike electrodes which introduce the current into the fuel bed. Moreover we wanted to establish the optimum distances of the electrodes in practical operation. And finally, we wanted to see what resistance is offered by the shale bed to the sucking off of the gases. It was neither planned nor possible to run tests with respect to the carbonization period, the oil output and the consumption of current, for, the extensive condenser unit necessary for such an investigation was not available.

Seven major experiments have been carried out:

Test 1

Electrode distances of 0.5, 1.0, 2.0 and 4.0 m have been studied. Two tube-electrodes 2 m long and of 42 mm interior diameter have been used. At a performance of 400 kw a bridge was formed and a few minutes later gas started to evolve briskly. Fig. 11 shows the details of the tube electrode used. Fig. 12 gives the graph...

Test 2

In this test, one electrode only was formed as a tube electrode, whereas the second (Fig. 15) was supposed to effect a point-like radiation. A 1 m distance was between the electrodes. The tube electrode which was supposed to discharge the carbonization gases was only 1 m long, the interior diameter being 42 mm. In the bottom of the bed a bridge was formed at 200 kw. The carbonization gas caught fire immediately (Fig. 13).

Test 3

Tube electrodes of 2 m length at a distance of 15 m have been used in Test 3. In heating up the bed 300 kw were needed. Owing to the magnitude of distance it was not possible for a bridge to evolve. After about (?) minutes appreciable quantities of carbonization gas developed. This test seems to indicate that it is profitable to operate with a wide interspace between the electrodes, thus avoiding the formation of a direct bridge.

Test 4

The same tube electrodes were used as in Test 3, but arranged in the form of a triangle, the side of which is 3 m long. Heating was effected by alternating current. It was found that heating and thus carbonization effects took place only in the interval between two phases. The current chose probably the path of least resistance.

Test 5

In this case tube electrodes threefold connected in parallels have been used (Fig. 15). At a performance of 400 kw it could be observed that carbonization gas was formed at a satisfactory and uniform rate, without the gases taking fire.

Test 6

In this test we investigated the most suitable form of electrodes for the fine-grained shale which is supposed to be carbonized in heaps. We studied electrode-distances of 0.5, 1.0, 1.5, and 3 m. Apparently, the optimum heating conditions were those prevailing at a 1.5 m distance. Plate electrodes at a 3 m distance failed to effect the formation of a bridge so that, in the neat test, tube electrodes were tested also for the carbonization of dustlike shale. The distance chosen was 0.5 and 1 m. No bridge was formed. However, we may assume that the 1 m distance selected was too short, since a break-through occurred.

Indeed, the results of these preliminary tests were so encouraging that carbonization tests are to be carried out on a 500-tons block of oil shale when the necessary condenser unit will have been built.

7. Summary

The carbonization tests in question did not prove anything but that it is in principle possible to produce oil from oil shale by means of direct resistance heating...

Survey 1

Measuring of the Electrical Resistance

Voltage V	87	87	82	82
Deflection	7.3	7.3	6.6	6.2
Zero point	6.0	6.0	6.0	6.0
Sensibility	1.2	1.1	1.2	1.5

$c = 1.073 \cdot 10^{-3}$

1 Skt. $= 10^{-8}$

$$\frac{8}{1.2 \times 10^{-8}} = 67 \times 10^{-8} \text{ Ohm}$$

Summary 2

Flow of Electric Current Between Two Electrodes

(Distance of Electrodes 10 cm)

U_V	J_{mA}	J_{mA}	J mean $_{mA}$
1000	8	9	8.5
1500	10	10	10.0
2000	12	12	12.0
2500	13	14	13.5
3000	15	20	17.5
3400	25	30	27.5

(Distance of Electrodes 5 cm)

1000	10	22	16
1500	20	30	25
2000	20-40	35	32
2500	20-60	60	60

(Distance of Electrodes 10 cm)
Electrodes sealed with graphite

1000	121	123	122
1200	151	154	153
1400	171	160	165
1600	235	200	217
1800	265	221	243
2000	282	241	261

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Patents:

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(The graphs and photos referred to in the text can not be traced but may be photostated upon request.)

M. Beth
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ds: All Divisions