GENESIS OF OIL BY HIGH RADIAL AXIAL PRESSURE

By

Kunio UWATOKO

With 1 Text-Figure

CONTENTS

INTRODUCTION

Pressure experiments on the bituminous rocks have been performed, previously, by many investigators, but all the tests were conducted under shearing pressure, so that they yielded by either fracture or flow representing flowage experiments. But the present experiments were done by radial axial pressure under which the test piece has not been forced into flowage structure, possibly shearing pressure being avoided.

Oil shale which had been defined by the present writer(1), contains two kinds of bitumen (1) Petrol-bitumen (2) Coal-bitumen, from which so-called oils (gaseous, liquid, and solid states of hydrocarbon compounds soluble in solvents) may be obtained by certain methods of treatment. Of these two kinds of bitumens, it is the first which is mainly contained in California oil shale and partly in Colorado oil shales, while the latter is largely contained in Fushun oil shale and coal and slightly in Colorado oil shales. By high

(1) KUNIO UWATOKO: The Fushun Oil Shale Deposit, Manchuria. Jour. Faculty of Science, Hokkaidô Imperial University, Series IV, Vol. 1, No. 2, p. 129, 1931.

radial axial pressure these bitumens in the rocks converted into oils at room temperature, soluble in benzol at temperatures up to its boiling point.

The pressure experiments have been made in the Riehle's testing machine at the Civil Engineering Institute Laboratory under the kind courtesy of Professor K. OGAWA, Assistant Professor K. SHINGO, and Assistants OHTANI and HATA of the Institute, and the steel apparatus in which the test pieces had been compressed, were arranged at the Mechanical Engineering Institute Laboratory under the kind direction of Professor M. KUJIME, at the Hokkaido Imperial University.

The present investigator is greatly indebted to the staffs mentioned for their kindness during the work.

PREVIOUS WORKS

Pressure metamorphism of bituminous rocks has been discussed by many authors. WHITE(1), STRAHAM(2), FULLER(3), RUSSEL(4), MOULTON(5), TARR(6), and DORSEY(7), mentioned, essentially, the stage of pressure metamorphism of the bituminous rocks, showing their causal connections to the ocurrence of oil and gas and to the carbon-ratios theory.

BAILEY WILLIS(8) and JOHN L. RICH(9) also noted the large scale distillation of petroleum as an incident of mountain making crustal

(1) DAVID WHITE: Some Problems of the Formation of Coal. Economic Geology, Vol. 3, No. 4, 1908.

(2) A. STRAHAM and W. POLLARD: The Coals of South Wales, with Special Reference to the Origin and Distribution of Anthracite. Mem. Geol. Surv., England and Wales, London, p. 1, 1908, reviewed in Econ. Geol., 1909, by David White.

(3) M. L. FULLER: Relation of Oil to Carbon-Ratios of Pennsylvanian Coals in North Texas. Econ. Geol., Vol. 14, 1919. Carbon-Ratios in Carboniferous Coals of Oklahoma and their Relation to Petroleum. Econ. Geol., Vol. 15, 1920.

(4) WILLIAM L. RUSSEL: Relation between Isocarbs and Oil and Gas Production in Kentucky. Econ. Geol., Vol. 20, 1925.

(5) GAIL F. MOULTON: Carbon-Ratios and Petroleum in Illinois. Illinois State Geological Survey, Rept. of Investigations, No. 4, 1925.

(6) RUSSELL S. TARR: Oil May Exist in Southeast Oklahoma. Oil and Gas Journal, Dec. 17, 1925.

(7) GEORGE EDWIN DORSEY: Present Status of Carbon-Ratio Theory. Bull. Amer. Assoc. Petrol. Geologists, Vol. 2, No. 5, 1927.

(8) BAILEY WILLIS: Geologic Distillation of Petroleum. Mining & Metallurgy, No. 157, 1920.

(9) JOHN L. RICH: Generation of oil by Geologic Distillation during Mountain Building. Bull. Amer. Assoc. Petrol. Geologists, Vol. 2, No. 2, 1927.

movement, and showed that many of the oil fields are related to belts of dynamic metamorphism competent to have been the source of the oil.

Experiments on the shearing compression of oil shales and other bituminous rocks have already been carried on by others. McCoy(1) reported that after flowage compression of oil shales globules of oil could be seen in the shale with a hand lens. He also forecasted that some regions in the Mid-Continent oil fields may contain oil generated in place by dynamic metamorphism of moderate intensity too weak to drive it outward from its source; other regions would contain only such oil as had reached them by secondary migration. TRAGER(2) stated that the fragments of kerogen in the oil shale were completely stained dark brown. This stain was probably due to liquid hydrocarbons produced during the compression. No appreciable heat was developed during the shearing of the shale. TRAGER also suggested that the organic matter in the shales was distilled by the frictional heat of molecular displacement, yielding hydrocarbons.

VAN TUYL and BLACKBURN(3) reported the oil shale cylinder to have yielded to deformation by flowage pressure. But the solubility of the kerogen of the flowed shale was found to be consistently less than that of the original shale. McKEE and LYDER(4) reported the result of the investigation of the thermal treatment of the oil shale, stating that the formation of petroleum oil is the result of the decomposition or cracking of the heavy bitumen, and also that the formation of oil from bitumen is a function of both the time and the temperature. ADAMS and BANCROFT(5) reported the results of experiments of shearing compression of several barren rocks in steel cylinder with pistons, the internal friction in rocks being examined.

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(1) ALEX. W. McCOY: Note on Principles of Oil Accumulation. Jour. Geol., Vol. 27, No. 4, 1919.

(2) EARL A. TRAGER: Kerogen and its Relation to the Origin of Oil. Bull. Amer. Assoc. Petrol. Geologists, Vol. 8, No. 3, 1924.

(3) FRANCIS M. VAN TUYL and CHESTER O. BLACKBURN: The Relation of Oil Shale to Petroleum. Bull. Amer. Assoc. Petrol. Geologists, Vol. 9, No. 8, 1925.

(4) R. H. McKEE and E. E. LYDER: Thermal Decomposition of Shales. Journ. Ind. and Eng. Chem., July, 1921.

(5) F. D. ADAMS and J. A. BANCROFT: On the Amount of Internal Friction developed in Rocks during Deformation and on the Relative Plasticity of Different Types of Rocks. Jour. Geol., Vol. 25, No. 7, 1917.

HAWLEY[1] recently reported the detailed results of shearing pressure experiments on oil shales, stating that additional shearing pressure tests at room temperature all failed to generate oil, and that the increase of bitumen soluble in solvents is believed due mainly to the finer physical state of the highly sheared shale, rather than to any chemical reactions caused by pressure. He obviously stated the negative results of the shearing pressure tests to generate oil from bituminous rocks in his conclusion.

Considering these above mentioned results of high pressure experiments on the bituminous rocks, it may be said that all tests were subjected to shearing pressure with flowage fracture. But in the present experiment, the shearing pressure has been avoided if possible, in compressing oil shales and coal.

PREPARATION OF EXPERIMENTS

The test pieces used in the present experiment were oil shales and coal, among which Colorado oil shales near Rulison, and Californian oil shale at Ventura have been both collected by the present writer in 1927, and Fushun oil shale and coal also collected by him in 1928 and in 1929.

Large blocks of each of the test pieces having been secured, bars of them were sawed into lengths of about two inches. These bars were then very carefully reduced to the exact size required, by being ground down in a lathe by means of revolving carborundum wheels of different degrees of fineness, and were finally highly polished. When completed the columns were of such a size that they would just pass into the steel tubes at room temperature, the tube inclosing the column with an absolutely perfect mechanical fit. The column was in each case about one inch long and twenty three-sixteens inch in diameter. While the column was thus fitted accurately into the tube, it could, by the exertion of a certain amount of pressure, be moved up and down within tube. In preparation of the test pieces, there were needed two kinds of column specimens, one parallel to the plane of sedimentation of the rocks, while the other is perpendicular to it.

(1) J. E. HAWLEY: Generation of Oil in Rocks by Shearing Pressure. Bull. Amer. Assoc. Petrol. Geologists, Vol. 13, No. 4, 1929; Vol. 14, No. 4, 1930.

Two kinds of round bars of chrome nickel steel four inches and six inches in diameters were secured. These were then reduced to the pressure apparatus as is shown in Figure 1, in the Mechanical Engineering Institute Laboratory of the Hokkaido Imperial University under the care of Professor M. KUJIME. The pressure to which the test pieces was submitted was obtained by a Riehle's testing machine set up in the Civil Engineering Institute Laboratory of the Hokkaido Imperial University. This machine has a capacity of four hundreds tons.

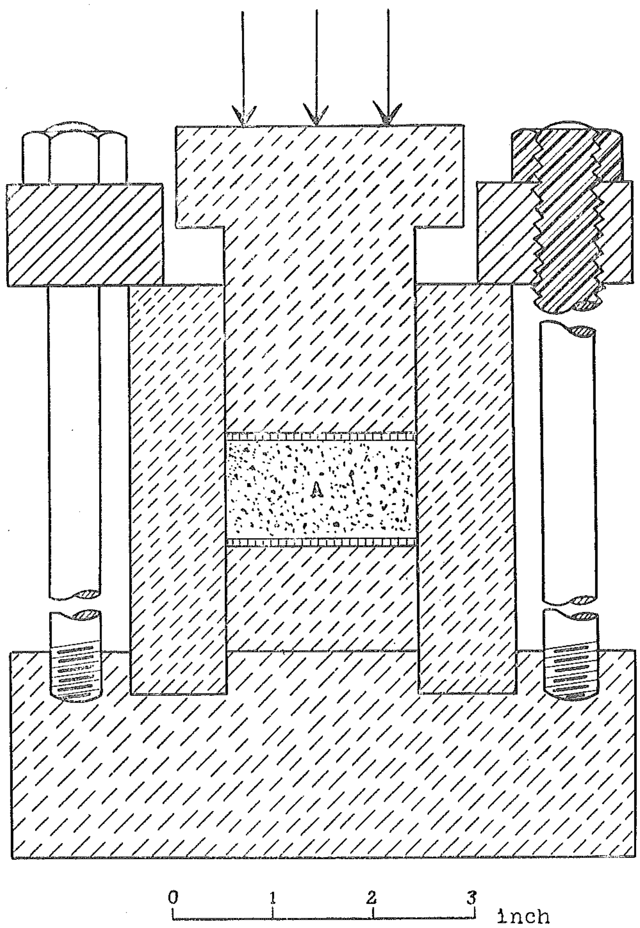

Figure 1. Longitudinal section through steel cylinder with a plug inserted and inclosing a column of test piece.
A, test piece between packing papers.

If all equipments of pressure experiments and test pieces are properly arranged, it is important carefully to clean the test specimen and the pressure apparatus with benzol to remove fatty and oily substances on them before setting them up. When the test piece was put into the apparatus, several round pieces of blotting paper of the same diameter as the steel tube were packed at both the upper and lower ends of the test specimen to prove liquid oil generated from the bituminous rocks by pressure.

TYPE OF PRESSURE EXPERIMENTS

Previous investigators mentioned in the above pages, generally, have considered the shearing pressure to compress the bituminous rocks, but in the present experiment, the radial axial pressure was required; if it could be obtained hydraulic pressure would be much better to compress the rocks. That is, the specimen is really compressed by high pressure without deformation of the rocks by fracture and flowage. All surfaces of the test piece were strongly compressed without deformation, that is, the result was almost similar to that of a hydraulic pressure experiment.

As before stated, it is also one of the remarkable points of the experiments that the time of compression is so long that no thermal change of the test piece by internal friction could be recognized during compression.

Pressure tests of two kinds have been made to determine the effect of compression on the bituminous substances at room temperature. These include compressing (1) perpendicular to the plane of sedimentation of the rock, (2) parallel to it.

EFFECT OF COMPRESSION

Density of the samples, as indicated in Table I, increased a little with a small decrease of their volume. The Colorado oil shales, generally, are so compact in texture that the volume change was very small by compression. Change of density of the test piece by compression has a close relation to the orientations of plane of sedimentation of the rock; if the main pressure, axial up and down, is loaded parallel to the plane of sedimentation, the density change is smaller than that of the test piece compressed perpendicularly to the plane of it, as is shown in Table I. The density change of

TABLE I. Summary of Results of High Pressure Tests

Source of shale and coal	Time of compression in m.	Load in pounds	Pounds per square inch	Density	Genesis of liquid oil	Percent extract from compressed shale	Percent extract from uncompressed shale	Difference in percent extract	Increase of extract in percent	Size of grains in mesh	Remarks
Colorado velvet shale	—	Nil	Nil	1.590	—	—	0.86	—	—	170	—
Colorado velvet shale	—	Nil	Nil	1.590	—	—	1.05	+0.19	22.09	200	—
Colorado velvet shale	—	Nil	Nil	1.590	—	—	0.86	—	—	170	—
Colorado velvet shale	13+20	300000	191083	1.603	Yes	1.59	—	+0.73	84.88	170	*
Colorado velvet shale	13+20	300000	191083	1.603	Yes	1.94	—	+1.08	125.58	200	*
Colorado velvet shale	—	Nil	Nil	1.590	—	—	1.05	—	—	200	—
Colorado velvet shale	13+20	300000	191083	1.603	Yes	1.94	—	+0.89	84.76	200	*
Colorado velvet shale	13+20	300000	191083	1.590	Yes	1.14	—	+0.09	8.57	200	**
Colorado mahogany shale	—	Nil	Nil	1.857	—	—	4.20	—	—	200	—
Colorado mahogany shale	13+20	140000	89172	—	Yes	4.48	—	+0.28	6.66	200	*
Colorado mahogany shale	14+20	400000	254000	1.860	Yes	5.55	—	+1.35	32.14	200	*
Colorado mahogany shale	14+20	400000	254000	1.858	Yes	4.59	—	+0.39	9.28	200	**
Colorado paper shale	—	Nil	Nil	1.747	—	—	1.32	—	—	200	—
Colorado paper shale	13+20	400000	254000	1.748	Yes	2.26	—	+0.94	71.21	200	*
Californian shale	—	Nil	Nil	—	—	—	0.53	—	—	200	—
Californian shale	14+20	400000	254000	—	Yes	0.47	—	−0.06	−11.32	200	*
Fushun oil shale	—	Nil	Nil	1.746	—	—	0.49	—	—	200	—
Fushun oil shale	14+20	400000	254000	1.886	Yes	0.57	—	+0.08	16.32	200	*
Fushun coal	—	Nil	Nil	1.213	—	—	1.19	—	—	200	—
Fushun coal	13+20	400000	254000	1.219	Yes	2.16	—	+0.97	81.51	200	*

* Compressed perpendicularly to the plane of sedimentation of the test specimens.
** Compressed parallel to the plane of sedimentation of the test specimens.

Fushun oil shale by compression is the most remarkable among those oil shales tested, although the measurement of that of Californian oil shale unfortunately failed in part. Fushun coal is so elastic that the volume change by pressure is quickly recovered after being freed from pressure, and its density change after compression is not so large; this is also shown to Table I.

Colour of the test piece after compression, generally, became darker on the polished surface as compared with that before compression. Particularly, Californian and Colorado oil shales showed a strong dark colour after compression.

The test piece, after compression, also showed some changes of luster representing more resinous or greasy luster on the polished surface than before compression.

To prove the fluidity of such rigidities of the test pieces as oil shales and coal against high pressure, the ridge of the test piece was partly truncated before compression, but the truncated surface of the specimen which had been free from direct external compression was merely crushed by fracture without showing any flowage structure.

Also no deformation of the sample was recognized in texture by pressure, even if it was observed either with naked eyes or under microscope in thin section, it showed its original structure as before compression.

Generation of liquid oil generated in the oil shales and coal was the most important and remarkable effect of high compression in the present experiment. Qualitative determination of liquid oil generated in the rocks was proved by staining of the blotting paper packed between the test piece and the pressure apparatus. The upper packing paper did not include so large an amount of oil as the lower paper did, but the papers, either upper or lower have been stained very much by the liquid oil generated by pressure along their edges. The stained margin of the round paper looks like a translucent body, just like paraffin paper, while the central part shows rather a semi-translucent appearance with a small quantity of oil.

Quantity of oil generated in the test pieces had also a close relation to the arrangement of the specimen. That is, if the plane of sedimentation of the rock were arranged to be perpendicular to the long axis of the plug of the pressure apparatus shown in Figure 1, much oil was generated in quantity in the rock, while in the other case, if the plane of sedimentation of the same rock were arranged to be parallel to the plug's long axis, the amount of oil generated in the rock was small in quantity.

All the test pieces of oil shales and coal compressed in the present experiment have produced some liquid oil which stained the packing paper. Among the test specimens, Californian oil shale produced the largest quantity of liquid oil by pressure.

Soluble organic matter of oil shales and coal after compression was extracted in Soxhlet extractors modified by the present investigator(1) with benzol at any temperature up to its boiling point continuously for forty eight hours. As is shown in Table I, the amount of bituminous substance in the oil shales and coal which is soluble in benzol at its boiling point before and after pressure treatment was ascertained. Generally, the increase of extract of soluble matter after compression is recognized compared with that of it before compression, except in case of Californian oil shale.

The amount of extraction of soluble matter in oil shales increased with the increase of pressure loaded on them, and also it increased with the increase of mesh of grains in mesh.

The test piece compressed perpendicularly to the plane of sedimentation of the specimen, as before noted in case of generation of liquid oil produced much more soluble matter than that of the test piece of the same sample compressed parallel to the plane of sedimentation. Particularly, Colorado oil shales and Fushun coal produced the largest quantities of soluble matter.

It is also a remarkable result that Fushun coal which contains the most coal-bitumens produced much quantity of soluble matter in benzol by pressure. Californian oil shale which contains the petrol-bitumens shows conversely negative results of extraction as is shown in Table I, although the liquid oil generated by pressure is recognized in large quantity stained in the packing blotting paper.

SUMMARY

High radial axial pressure experiments of oil shales and coal have been made to generate oil in the rock without deformation of the test piece by fracture and flowage.

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(1) Kunio Uwatoko: Op. cit.

Liquid and solid oils produced in the rocks which largely contain either coal-bitumen or petrol-bitumen are recognized as the effect of high compression.

The amount of oil generated in the rock has a close relation to the intensity of pressure, showing the increase of amount of oil with the increase of pressure loaded on the test piece.

Quantity of oil generated in the rock has also a close relation to the arrangement of the test piece. That is, if the plane of sedimentation of the rock is arranged perpendicular to the orientation of the axial pressure, up and down, a large amount of oil is generated in the rock; while if the plane of sedimentation of the same rock is placed parallel to the orientation of the axial pressure, the amount of oil generation in the rock is small in quantity.

The amount of oil extraction increased with the increase of mesh of grains in mesh.

Density of the specimens increased a little with a small decrease of their volume as an effect of compression.

Colour of the test piece after compression, generally, became more dark on the polished surface, and also it shows some changes in luster showing more resinous or greasy surface in the polished specimen.

It is said, judging from the results of the present experiments above stated, that the axial pressure is greater than the radial pressure in intensity.