POTENTIAL ENVIRONMENTAL PROBLEMS ASSOCIATED WITH IN SITU GASIFICATION OF THE ANTRIM SHALE

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ABSTRACT

Present and planned in situ development activities of the Michigan Antrim (Devonian) shale are examined for possible impacts on air, water, and land resources. Current environmental monitoring and baseline collection efforts for various drilling, fracturing, and combustion programs associated with this project are discussed. Local hydrogeological characteristics are used to analyze the effects of disposal materials and wastewaters on surface and groundwater supplies. Other environmental parameters examined include subsidence, air quality, and surface disturbances.

Anticipated results from the Antrim environmental monitoring program are summarized as are statements of specific research needs.

INTRODUCTION

Since March 1977, the Environmental Research Institute of Michigan has been collecting baseline environmental data and monitoring current activities at the in situ Antrim shale gasification project site in southeastern Michigan, sponsored by the state's Department of Energy. This project is a four-year experimental effort, conducted by Dow Chemical Company, as a continuation of their previous work with the Antrim shale.

The Antrim shale deposit covers the entire lower peninsula of Michigan in a layer 60 to 120 meters thick, lying below the surface at depths up to a maximum of 1,000 meters at the center of the Michigan Basin geologic structure. Outcropping occurs near Alpena, Michigan. At the present shale test site, the shale lies 400+ meters below surface.

The goal of the experiment is to evaluate in situ production of energy values (mainly low Btu gas) by partial combustion of the organic matter in the Devonian Antrim shale. Current experimental activity includes two parts: evaluation of various ways to fracture the shale in preparation for burning; and, evaluation of ways to initiate and maintain combustion that will provide the desired energy products.

This paper will: 1. describe the environmental setting of the study site; 2. briefly discuss the experimental activities; and 3. document the current and planned environmental monitoring efforts for air, water, and land resources.

ENVIRONMENTAL SETTING OF THE MICHIGAN SHALE SITE

The study site for the Antrim Shale experimental activities is an 80-acre (32 ha) parcel in eastern Michigan's Sanilac County in what is referred to as the "thumb" of Michigan. Current land use in this area is over 80-percent active or inactive agriculture; the remaining area largely consisting of scattered woodlots. Fields in this area have traditionally been used to raise field crops or as pasture lands for dairy herds. The site itself is a former dairy farm whose current vegetation cover consists of woody and herbaceous old field vegetation. This area is economically poor with a predominantly rural population. Population density is low with only 35 residences within two kilometers of the study site. No significant urban populations are within 30 kilometers. The shale site is in the Seymour Creek watershed of the Black River Basin, which has a total drainage area of 1,820 sq kilometers (fig. 1).

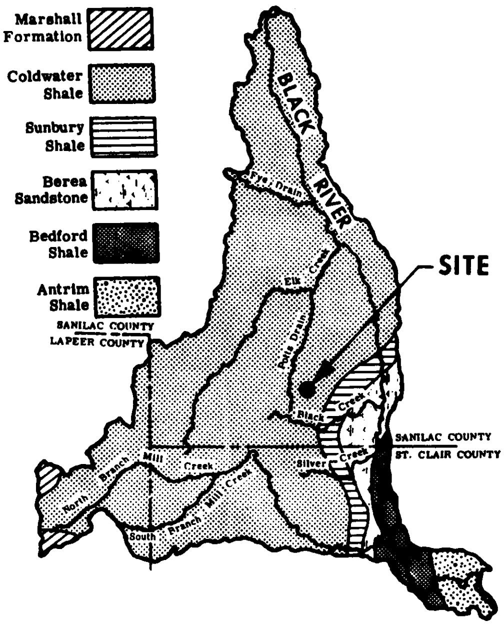

Figure 1. Bedrock geology.

Antrim shale is one strata of extensive sedimentary material deposited during the Paleozoic era. At the study site, 70 meters of glacial drift were deposited on these sedimentary layers during the Pleistocene. Bedrock formations which subcrop the drift in this area include, from youngest to oldest: Marshall sandstone, Coldwater and Sunbury shales, Berea sandstone, Beford and Antrim shales.

Marshall formation subcrops are found only in the extreme western portions of the Black River basin. Because this sandstone is very porous, wells yield large amounts of water. Coldwater shale is a relatively thick layer and subcrops a large portion of the basin, including the site area. This shale has very low permeability as well as an inability to store water. Wells completed in the Coldwater formation yield less than 10 gpm, and the water is often highly mineralized. The Sunbury, Berea, and Beford formations are thin as compared to the Coldwater shale. Of these units, only the Berea sandstone is capable of storing and yielding water which will generally be brine. The Antrim shale is the oldest subcropping formation; it generally produces little water and whatever is produced is always mineralized. At the site, only drift wells produce fresh water. Bedrock strata all contain highly mineralized water or brine.

In the southeastern portion of the Black River basin, including the site, glacial lake beds are predominantly clay and generally not good sources of water. In this area, wells completed in the drift yield less than 10 gpm. The site bears evidence of being formed by glacial-lake bed deposits. It has little relief and is poorly drained. The site itself has several marshy depressions, one with a standing body of water. Soils in this area have developed from the glacial deposits through weathering, oxidation, and leaching. Because of the variation in parent materials and changes in these materials, a complex of soil types exists. Surface soils are chiefly silt loams and sand loams and are often well sorted and structured. State well-logs and water wells in and around the shale site show the upper alluvial structure consists of alternate clay and loam layers. Infiltration rates are generally less than 5 centimeters per hour so that heavy rainfall produces significant storm runoff.

The topography of the Seymour Creek watershed basin is very flat with average slopes of less than two meters per kilometer. Because drainage is very poor, numerous channels and ditches have been added to enhance draining and prevent ponding in the fields. Many of these ditches are intermittent and free-flowing during the period of spring runoff and often in late fall season. Flows in the Black River are quite variable. The United States Geologic Survey (USGS) gauging station at Fargo, which receives water from about two-thirds of the basin, has a typical annual minimum discharge of 10 cfs, an annual maximum discharge of 5,000 cfs and an average of 200 cfs. Because clay is the dominant soil in the Black River drainage basin, infiltration is very low and stream flow has great variability. Depth to the water table can fluctuate by more than five meters from wet saturated to dry periods when surface ground water sources are depleted. Annual average precipitation in this area is 76 cm of which 19 cm are observed as runoff and 51 cm are lost as evaporation; only 6 cm infiltrates the clay soils to recharge groundwater supplies.

No broad water quality monitoring program has been undertaken in the Black River basin. However, some water quality data are available from the USGS and the Michigan Department of Natural Resources. It may be inferred from the data that surface waters are hard, with calcium concentrations as high as 100 mg/1 and magnesium concentrations of about 25 mg/1. These waters can also be high in sulfate (100-150 ppm) and chlorides (30-100 ppm). Total dissolved solids vary widely in the surface waters but are usually in excess of 400 ppm (Knutilla 1969). Wells completed in the drift in the vicinity of the site are also quite hard, having calcium concentrations from 40 to 80 ppm, magnesium from 25 to 30 ppm; sodium and chlorides occurrence, however, is low: less than 10 ppm. In the southern portion of the Black River basin, deeper wells may yield water with chlorides in excess of that recommended for drinking. Many wells completed in bedrock are very mineralized, high in sodium and chloride, and having total dissolved solids in excess of 1000 ppm.

Water used to supply drilling operations and general needs at the site has been obtained from two sources; a one-hectare pond located on the site and a supply well (24 m deep) completed in the drift. Records of water use and disposal are being maintained. Since water resources in this area are substantial, they can easily meet the requirements for shale development without infringing on present domestic and agricultural needs.

At present very little information is available on possible environmental contaminants from in situ gasification. Some preliminary results have been obtained from surface retort tests of the Antrim shale conducted by the Laramie Energy Research Center (Martel and Harak 1977).

Concentration of sulfur in Antrim shale is notably higher than in typical Colorado shales according to results from retort effluent analysis.

Retort waters from both shales were also analyzed for trace elements. Table 1 compares concentrations of several trace elements in the retort effluent with levels in the raw shale and with national interim drinking water standards. Raw shale data were obtained from two sources but comparisons of the trace element concentrations may be useful (Fergus 1977, for Antrim, Shendrikar and Faudel 1978, for Colorado). Arsenic and selenium, identified by Klusman and Ringrose (1977) as potential problems in mining western shale, do not appear to be a problem for the Antrim shale. Manganese, on the other hand, was found in much higher levels in the retort water from the Antrim than from the Colorado shale and also at a concentration almost six times that accepted for domestic water supplies. Boron, fluoride, and mercury, also identified as potential problems in Colorado, may not have the same significance for the Michigan Antrim shale. This preliminary examination of trace element contaminants from retorting the Michigan Antrim shale indicates little potential for environmental problems from the gasification process. Many of the above parameters will be examined during the Michigan experiment in attempts to confirm this supposition.

EXPERIMENTAL ACTIVITIES

Currently, the Antrim shale gasification program is in several stages of

Table 1. Comparison of trace element composition.

Element	Colorado Shale(ppm)[1]	Antrim Shale (ppm)[2]	Colorado shale Retort Water (ppm)[3]	Michigan shale Retort Water (ppm)[4]	Water Supply Standard (ppm)[5]
Arsenic	61.7	15.3	5.90	0.011	0.05
Barium	---	488	0.012	0.012	1.0
Baron	74.0	---	5.2	2.0	0.750[6]
Cadmium	1.35	13.8	---	---	0.01
Chromium	43.3	91.6	0.011	0.020	0.05
Floride	1017	---	31.0	7.6	2.0
Manganese	213.7	---	0.042	0.280	0.05
Mercury	---	---	0.100	0.0002	0.002
Nickel	23.4	101.0	1.10	0.005	(0.01)
Selenium	12.2	1.80	0.010	0.001	0.01
Zink	64.2	69.3	0.260	6.90	5.0

1. Colony Mine. Piceance Creek Basin
2. Drill Core Analysis, Sanilac County, Michigan
3. Anvil Points, Rifle, Colorado
4. Huron Cement Co., Alpena, Michigan
5. National Interim Primary Drinking Water Regulations
6. Michigan Standard For Agricultural Use

development. The well pattern on the northern (or front) forty-acre (16 ha) portion of the site, developed in earlier Dow shale experiments, has been revitalized. Several attempts have been made to initiate in situ combustion in these wells. A substantial, self-sustaining combustion has not yet been achieved. There are no plans to use the gas produced in this stage of development. Gases obtained will be passed through a gas/liquid separator and a demister to collect solid and liquid wastes. Gas will be flared on site in a ten-meter flare system. Brine from dewatering has been stored in a rubber-lined pit. On the southern forty-acre (16 ha) portion, plans call for drilling 37 new wells, fracturing of three well patterns by different methods and then attempting to initiate combustion in the pattern exhibiting the best fracturing. Open pits have been used for disposal of drilling muds. Drilling brines, used during the winter months, have been contained in surface storage tanks.

Three techniques will be used to fracture the shale: hydrofracing, explosive fracturing, and acid under-reaming. All will be followed by various types of explosive fracturing. In situ gasification entails raising the fractured shale to a sufficiently high temperature to achieve a self-sustaining burn. Once this is achieved, injection rate is regulated to control the burn rate, and by-product gas is recovered from surrounding wells. Since there is a substantial overburden of bedrock and glacial deposits above the Antrim shale, separating combination products from potable aquifers, chances of environmental contamination from migration of in situ gasification are expected to be minimal. Therefore, examination of environmental impacts from gasification will be concentrated on those associated with site development and disposal of materials brought to the surface.

Principal concerns and potential impacts resulting from the in situ gasification program are summarized in table 2.

Table 2. Potential environmental problems from in situ processing and energy extraction of Michigan Antrim shale.

Activity	Concerns	Potential Impacts
Site Preparation	Increase surface runoff due to grading, generation of dust and noise, removal of upper soil horizons	Increased sedimentation to surface waters. Nuisance conditions Loss of soil productivity
Well Drilling	Leachate from drilling mud pits, brine leakage surface disturbance	Reduce quality of local ground water supplies. vegetation loss
Fracturing and Acid Underreaming	Spillage, vertical cracks, explosive fracturing of overlying strata. subsidence	Leaks from resource zone, change in local drainage pattern
Dewatering	Disposal, leakage from holding ponds	Reduce quality of local ground water
In Situ Combustion and Product Recovery	Air emissions, disposal of retort and backflood waters, deep groundwater contamination, subsidence	Impacts on local air and groundwater quality, change of local drainage patterns
Site Restoration and Reuse	Soil residuals, long-term pollution of local aquifers by slow migration of solutes	Contaminants prevent agricultural use unsuitable groundwater for domestic water supplies

While current activities are expected to have limited impacts on the environment, monitoring and analysis of their magnitude may allow a more complete assessment of an operational in situ gasification program.

MONITORING PROGRAM

To assess negative impacts from site development and combustion activities, a monitoring program has been initiated which includes the collection of baseline data on air, water, and land resources. Additional data will be collected throughout the period of site development, well drilling, fracturing and combustion trials for comparison with baseline data. Adverse effects should be indicated by changes in one or more environmental parameters that can be related to the presence of released materials, subsidence or other site activities. The following sections document in greater detail current monitoring activities.

Air

Air quality measurements are being conducted to determine baseline concentrations of air pollutants in the vicinity of the in situ oil shale test site and to isolate impacts of site activities. Pollutants measured include: carbon monoxide, oxides of nitrogen, sulfur dioxide, hydrocarbons and particulates.

The air quality impact of the experimental in situ test facilities is significantly different than the impact of an operational program. The flare stack is one of the major features of this test site and would not be present in an operational oil shale project. Therefore, emissions from the flare stack are only applicable to determine the impact of the experimental process; not an operational one.

Ambient air monitoring equipment was installed in a Coachman trailer equipped with a portable electrical generator. Instrumentation included: a Hi-Vol particle sampler; a gas chromatograph for measuring methane, carbon monoxide, and total hydrocarbons; a dual-channel chemiluminescent analyzer for measuring NO and NO_x; and a flame photometric detector for measuring SO_2. The trailer was located at the edge of the test site, approximately two hundred and fifty meters downwind from the flare stack. Ambient air sampling has been performed from July 1977 to April 1978 except for a period in December and January.

The prevailing winds during the time period of testing were from the southwest. Wind speed and direction were continuously recorded as were the concentrations of gaseous samples. Twenty-four hour particle samples were normally collected every other day on pre-weighed filters that were subsequently desiccated and weighed to determine particle concentrations. Results were then correlated with site activities, wind speeds and directions, and ambient air quality standards to determine the air quality impact of test site activities.

Background concentrations of air contaminants at the in situ oil shale test site (table 3) are in the following ranges:

Table 3. Air quality baseline monitoring.

SO_2, 0-10ppb	Particulates, 10-100 mg/m^3
NO_x, 5-10ppb	Methane, 1.0-4.0 ppm
CO, 0.3-0.8ppm	Non-Methane Hydrocarbons, 0.0-0.2 ppm

These concentrations are well below ambient air quality standards.

Soil samples, upwind and downwind from the combustion stack, were collected before current combustion tests. Additional samples will be obtained after conclusion of a successful combustion test. These samples will be analyzed for the elements in table 4 to complement the data collected by the air quality van and to examine heavy particulate fallout near the stack and gaseous materials at the area of expected maximum ground concentration.

Table 4. Water quality parameters.

Potassium	Total Carbon, TC	Barium
Sodium	Total Organic Carbon, TOC	Strontium
Calcium	Carbonate/Bicarbonate	Bromide
Magnesium	Phenolics	Arsenic
Chloride	Sulfate	Zinc
Suspended Solids	Aluminum	Copper
pH	Silicon	Nickel
	Iron	Manganese
	Lead	Chromium
	Mercury	Vanadium
		Boron
		Beryllium
		Lithium

Water

The water monitoring program will gather water quality data on surface and ground water from the site and surrounding area. Samples are being analyzed for several parameters on each sample and selectively for trace elements (table 4). Surface disposal materials such as brines, drilling muds, retort condensate and backflood water, will be examined for trace elements. Baseline measurements will establish levels in soils, stream sediments, surface and ground waters.

The hydrologic system will be monitored to improve understanding of surface drainage patterns and flows. Smaller flows, near the site area, are seasonal and fluctuate greatly with the passing of storms. Flows in smaller channels are being monitored with small weirs fitted with hydrographic recorders. Flumes may also be installed to examine small flows from the site. Precipitation data is being gathered by a recording gauge at the shale site.

Groundwater monitoring has involved the collection of samples from area domestic wells and study site water supply wells. It is anticipated that the drilling mud pits will be monitored by installing several shallow wells both up and down gradient from the pits. Results will be interpreted and analyzed for concentration and movement of constituents laterally and vertically from the disposal site. A rubber-lined pit, holding brine, is also being monitored via a shallow well. Bedrock ground water, located above the retort zone, will not be monitored before combustion is established. Once combustion is established, product condensate, residue oils, and spent shale backwaters will be analyzed for organic chemical constituents and trace elements. If significant contaminants are found, it may be necessary to drill observation wells into formations located above the combustion zone to monitor any upward migrating groundwater.

Land

A concern related to most in situ extractive activities is surface subsidence. The possibility of subsidence resulting from the current Antrim shale activities is believed to be very unlikely because of the limited materials involved, the depth at which activities occur, and the integrity of the strata above the Antrim shale. In order to detect any elevation change, however, forty-three subsidence monuments were installed during the past year and an additional eleven monuments will be installed in the next. Most of these monuments were placed on three radial lines from the three centers of site activity; several were installed beyond the limits of any possible subsidence. The monuments consist of a three meter long, ten centimeter inside diameter plastic pipe and a three and one-half meter long, two centimeter inside diameter steel pipe. An auger is used to dig a hole for the plastic pipe and the steel pipe is then placed inside the plastic pipe and driven into the ground until both pipes extend approximately fifteen centimeters above the ground surface. The space between the pipes is filled with foam chips. The outer plastic pipe should protect the inner pipe from movements due to frost heave. Baseline vertical elevations of the metal pipes were collected, using a laser theodolite. Additional elevations will be obtained at least annually during the experiment and possibly beyond the experiment to identify delayed surface subsidence.

The principal observable impact during the first year of activity was ground surface disturbances. These disturbances have resulted from increased traffic on the property, road construction and drilling activities - particularly disposal of drilling muds. These activities have caused compaction of the soil; removal of much (in some cases all) of the "A" horizon of the soil; removal of vegetative cover, thus increasing the amount of surface water runoff; soil contamination from the drilling muds, brine used in winter drilling; acid and soda ash from the acid underreaming; and miscellaneous spills of gas and oil. These impacts are common to many construction activities - particularly other drilling operations - and may only be unique to the Dow activity because of the density of the experimental wells.

Color infrared and normal color aerial photographs were taken before current experimental activities. This record of site conditions can be compared to subsequent photography to determine location and magnitude of surface disturbances or changes in land cover resulting from the site activity.

A survey of vegetation, conducted during the past year, consisted of a qualitative assessment of types on the Dow property. This assessment was conducted in two stages: (1) an analysis of recent aerial photography for primary cover types, and (2) a field examination of the site. Primary-type ground cover on the property is old field vegetation; others are scattered rock islands, fencerows, and several wetlands. A list was made of the most common plants in each of these cover types. A more detailed vegetative analysis, using sample plots, will be conducted this spring. The aim of the vegetative survey is to document the extent of removal or damage from pollutants and also to examine rate of recovery of vegetative cover after the experimental activity is concluded.

DISCUSSION

Baseline monitoring of potential impacts on air, water, and land resources from the Antrim shale gasification experiment will be continued throughout the development phase. During most of that time, activities will involve drilling, hydrofracing, and permeability tests. Combustion trials on the south forty acres (16 ha) are not scheduled until July 1979. With combustion attempts on the north forty acres (16 ha) scheduled to stop soon, there is little chance of examining specific components from combustion until late 1979 or early 1980.

This past year's main accomplishment has been establishing baseline information against which future data can be compared. The validity of such baseline data has been compromised, in some cases, by various activities that took place on-site before the current effort began. These activities include well drilling, fracturing, brine leakage and surface disturbances. In some cases, these activities have affected the environment at the site to the extent that impacts of the current operations will not be evident or quantifiable from the current monitoring effort. In such instances, only conjectural or, at best, qualitative assessments of the affects of the site activities may be possible.

Among the greatest concerns for potential impact are the long term effects of the extensive surface disruptions, especially mud pits, associated with drilling operations. These disruptions may seriously impair use of the land after the shale energy beneath it is extracted and could have major implications affecting the use of the shale resource in areas like Michigan. Procedures to reduce or eliminate the need for extensive surface disruption should be considered.

Perhaps the potential impact of greatest uncertainty is created by the vertical fractures developed by hydrofracing. If such fractures extend into the shale caprock, they may increase permeability. Gas pressure generated during in situ gasification may then cause displacement of void water in the caprock. Plans are being formulated to analyze this possibility, although it is presently considered remote. While the need to address this issue is recognized, a method is sought which will avoid the necessity of drilling a number of observation wells.

Another area of uncertainty and concern is the possibility that there are occupational hazards and toxic substances associated with oil shale development for which standards have not been established. Practical guidelines are needed on concentration levels observed in raw materials and on combustion products which can be tolerated in various environments.

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