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a
report

from the Texas A&M
RESEARCH FOUNDATION

College Station, Texas

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ABSTRACT

The Petroleum Engineering Department at Texas A&M University (TAMU) has conducted field tests on in situ gasification of lignite first at the Easterwood Site near the main campus during 1978 and more recently at the Rockdale Site adjacent to the Sandow Mine near the town of Rockdale in Milam County, Texas. The present project is related to the gasification trials at the Rockdale Site. The objective of the current study is to investigate those geotechnical factors that may influence the performance of the in situ gasification process. These factors include: 1) pre-existing fracture patterns in the lignite and their influence on permeability, 2) strength and deformability of the overburden materials and how these properties are changed by the gasification process and their relationship to subsidence, and 3) the size, shape, and orientation of cavities produced by the process and their relationship to local fracture patterns and geologic structure. The current study is necessarily site specific and related to the Rockdale Site. Ultimately, the goal is to develop models that would be adaptable to any site with a minimum amount of site-specific investigation.

Tasks for the first year of the project include (along with their status): 1.1 Site Characterization (nearly complete), 1.2 Material Properties (nearly complete for well 4LP from an unburned area), 1.3 Fracture Mapping (just starting, air photos are in hand), 1.4 Geotechnical Coring (will start this summer), and 1.5 Geophysical Mapping (preliminary work with sonar is complete, seismic work not started). Tasks 1.1, 1.2, and 1.5 are reported in detail in Appendices 1, 2, and 3.

Overall the project is on schedule and progressing well. Two areas of potential near-term difficulties have been identified as 1) lack of personnel for field mapping during the coming summer and 2) potential lack of availability

of geotechnical coring equipment. Both of these short-term potential difficulties are receiving attention and we are optimistic that they can be overcome. In the longer term, the only identified problem is the possibility that the gasification tests may be moved to a new site thus removing the opportunity to test our models at the site where the data have been collected. If a decision to move the gasification tests is made, it will be reported as soon as possible in order that DOE may have input into possible revisions in schedule and work scope of the geotechnical investigations.

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1. Introduction

1.1 Background

In situ lignite gasification field studies have been conducted in Texas by the Department of Petroleum Engineering of Texas A&M University. The primary objective of these field trials has been the development of the technology required to exploit the deep-basin lignite resources that are too deep to be mined economically by the strip mining methods presently in use.

The deep-basin lignite resources of Texas are probably greater than 100 billion tons depending on the cut-off depth, minimum seam thickness, etc. It is unlikely that this resource will be developed by underground mining methods as they are now practiced primarily because of the low energy content of the lignite when compared with available sub-bituminous and bituminous coals in other states and the expected high cost of deep mining in the unconsolidated sediments of the Gulf Coast province.

The proximity of the lignite resource to the energy-intensive industries of the region and the high cost of transporting coal from other states provide additional incentive to develop the necessary technology.

The field experiments run by TAMU have utilized the linked-vertical-well gasification approach with a backburn followed by forward gasification with air injection. The process variables are the lignite composition, injection-air flow rate and pressure, amount of water in the system, and the system back pressure. Product gas is monitored for composition and heating value.

Field experiments have been conducted at two sites: the Easterwood site on the TAMU campus in 1978 and the Rockdale site adjacent to the Sandow Mine owned by Alcoa in 1979 and 1980. No difficulty was encountered in igniting the lignite at either site. However, it was not possible to maintain combustion

at the Easterwood site. The difficulty was thought to be due to water intrusion from an overlying sand. The Easterwood site was then abandoned in favor of the Rockdale site that offered an impermeable clay-shale roof over a relatively thick (3 - 4 m) section of higher quality Wilcox formation lignite at a depth of about 70 m.

Results from the Rockdale site trials have been encouraging. Gas quality at the onset of forward gasification is approximately of the same quality as that produced in laboratory experiments at TAMU. The gas quality then deteriorates as the burn progresses leading to relatively poor resource recovery. This deterioration of gas quality seemed to be beyond the control of the process variables in the 1979 tests. In the 1980 test, multiple wells were used in an attempt to sweep the burn through a region and increase resource recovery. Unfortunately, premature failure of the well casing in several wells prevented the completion of the test.

The causes of the declining gas quality with the progress of the 1979 tests are not known for certain. One explanation is the possibility of the fire front moving to the top of the seam (over riding) where there is no fresh lignite to fall into the fire and maintain the process temperature. Another explanation is that the fire front may be encompassing the entire link simultaneously thus preventing the secondary reducing reactions from occurring. These endothermic reactions use the sensible heat from the combustion, the CO_2 , and the H_2O as follows to produce CO and H_2 .

and

From the above discussion, it is apparent that post-test evaluation is required to attempt to determine which, if either, of the possible explanations

discussed above is the reason for declining gas quality. An extensive post-test evaluation program will be carried out during the 1981 field season.

Also from the above discussion, it can be noted that the geologic factors given consideration for siting have been: 1) lignite thickness should be greater than about 2 m to prevent excessive heat loss, 2) roof and floor strata should be impervious and thick to prevent water movement and gas escape, and 3) the seam to be gasified should be deep enough to allow the required process pressure flexibility. With respect to orientation at the site, the 1980 burn was oriented to progress in the direction of maximum permeability. In view of the experience to date, it is logical to inquire, what other geological factors may be influencing the behavior of the in situ lignite gasifiers? Further information on the TAMU gasification tests is available in the references given in Sec. 1.4.

1.2 Objective

The objective of the current study is to investigate those geotechnical factors that may influence the performance of in situ gasifiers. Because these geotechnical factors are site-specific, the emphasis of this study is on the in situ gasification trials at the TAMU site near Rockdale, Texas.

1.3 Scope

The scope of this project includes field, laboratory, and numerical modeling studies of the role of geotechnical parameters related to in situ gasification trials in Texas lignite. The emphasis of this project is on the completed trials at the TAMU Rockdale site, however, information gathered will also be related to planned sites whether at Rockdale or at some as yet unchosen site.

Topics to be studied include, but may not be limited to: 1) strength, deformation, permeability, and porosity of lignite seams and overburden materials,

2) regional and local geological structure with particular emphasis on the orientation of joints and faults and their relationship to strength, deformation, and hydrogeologic parameters, 3) regional and local groundwater hydrology particularly as it relates to the geologic structure, and 4) changes in 1, 2, and 3 induced by the in situ gasification process. These changes may include subsidence, fracture, and flow in both the overburden and the lignite. It is important to note that these changes are probably time dependent and may influence the gasification process if they occur quickly. If the changes occur more slowly, they may not influence the process but will affect the post gasification environment which must be considered in the overall feasibility of in situ gasification under conditions prevailing in Texas.

The present project scope does not include the design, construction, or execution of in situ gasification tests but is complementary to the TAMU In Situ Gasification Project which is funded by a consortium of companies and the Texas Engineering Experiment Station, Jennings (1979). Other related work on the subsidence over in situ gasification tests is being conducted by the principal investigators with funding being provided by the Texas Petroleum Research Committee and the Texas Engineering Experiment Station.

1.4 References

Jennings, J. W. (1979), "Underground Conversion of Texas Lignite", presented at the 5th Underground Coal Conversion Symposium, Alexandria, VA, June 18-21, 1979.

2. Research Plan and Project Status

2.1 Research Plan

Our overall research plan is shown in Table 2.1.

Table 2.1 Overall Research Plan

Year		
1	2	3
1) Site Characterization <ul style="list-style-type: none"> - stratigraphy - lithology - environment of deposition - potential new site 2) Material Properties (Burned and Unburned Locations) <ul style="list-style-type: none"> - triaxial comp. strength - deformation - index tests 3) Fracture Mapping <ul style="list-style-type: none"> - air photo - fracture mapping of lignite mine faces 4) Geotechnical Coring <ul style="list-style-type: none"> - vertical - inclined 5) Geophysical Mapping <ul style="list-style-type: none"> - definition of cavity size and shape: sonar, high-resolution seismic 	1) Geophysical <ul style="list-style-type: none"> - further cavity definition studies 2) In Situ Permeability <ul style="list-style-type: none"> - define anisotropy and relate to fractures 3) Lab Testing of Lignite and Overburden Core 4) Modeling <ul style="list-style-type: none"> - develop conceptual models - initiate code development and modification 	1) Modeling <ul style="list-style-type: none"> - complete code modification and development - code verification and testing - simulation of gasification tests 2) Synthesis 3) Final Report

2.2 Project Status

The overall project is on schedule and progressing well. Task 1.1 from Table 2.1 is essentially complete and reported in Appendix 1.

Material Properties Testing, Task 1.2, is nearing completion. All available core from an unburned area and from one well in a burn area has been tested. These data are summarized for the unburned area core in Appendix 2. Further laboratory testing will be done when core becomes available.

Task 1.3 on Fracture Mapping has been initiated after a delay in obtaining air photos of the test site. These photos are now in hand and interpretation will begin soon. Field fracture mapping will begin during the coming field season on freshly mined lignite faces at the Sandow Mine which adjoins the field site.

Task 1.4 on Geotechnical Coring will be initiated during the coming summer. The Department of Petroleum Engineering has acquired a drilling rig which is currently being refurbished in Houston. This rig should be available by this summer for the required coring that will provide: 1) data on fracture orientation and spacing, 2) core for further laboratory testing, and 3) size and shape of the burned-out cavities which we will attempt to relate to the fracture patterns in the area.

Task 1.5 on Geophysical Mapping has been initiated and results to date are reported in Appendix 3. The objective of this task is to delineate the burned-out cavities as accurately as possible using remote techniques. The size and shape will then be analyzed to determine if any correlation exists with geologic structure, fracture patterns, etc.

2.3 Potential Difficulties

As noted above, the project is progressing well. However, there are two potential areas of difficulty during the upcoming field season. Of the three graduate students currently working on the project, one (Charles Forster) is graduating in May and the other two (David Becker and Donn Mohrman) will be

working in industry for the summer but will return in the fall. We have not yet identified the person or persons who will be doing the field mapping and core logging during the summer.

The second area of potential near-term difficulty is the availability of a drilling rig for coring. If the Petroleum Engineering Department rig is completely refurbished and available for this summer, we have no problem. However, if for some reason the department rig is not available, we will probably have to go to a contract driller. The local demand for drilling rigs is high and costs would probably be higher than using the department rig. If we have to go to a contract driller, the amount of coring will probably be reduced which will impact the remaining schedule.

Both of the above potential near-term difficulties are receiving our attention and hopefully they can be resolved before they impact the rest of the project.

There is a possibility that the TAMU gasification tests will be moved to a new site nearer to the university which would facilitate the involvement of students in the field work. Another factor in moving is that the permit area (about 3 acres) at the Rockdale site has been subjected to several trials and there is some concern that remnant effects of the previous trials may influence future trials. The coming summer months will be used to perform post-test evaluations on the Rockdale site. No gasification experiments are planned for this summer. The decision on a move probably will not be made until after the post-test evaluation is completed in the fall.

The primary impact of a move to a new site on our present geotechnical project would be that it removes the opportunity to test our hypotheses and models at the site where the most characterization has been done that formed the bases for the models. Much of the work would need to be repeated for a test at a new site because of the site-specific nature of geotechnical work.

This work would be beyond the existing work scope. New gasification tests are desirable to test the models because time dependent sloughing and caving may significantly alter the size and shape of gasification cavities particularly in the unconsolidated sediments at the Rockdale site.

We will have input into any decision to move, but other factors may prevail. We will inform you if a decision to move is made.

3. Project Organization and Personnel

This project is organized under the Texas A&M Research Foundation which works through the Texas Engineering Experiment Station and the Departments of Geophysics and Petroleum Engineering. Technical direction and project management are provided by the co-principal investigators, E. R. Hoskins and J. E. Russell. During the reporting period, three graduate students have contributed greatly to the progress of the project. David Becker (Geophysics Department) has worked on the Geophysical Mapping of cavities as reported in Appendix 3. Charles Forster (Interdisciplinary Engineering) has been partially supported by this project and partially by the subsidence project funded by the Texas Petroleum Research Committee. Mr. Forster has collected and analyzed most of the data reported in Appendices 1 and 2 while working with undergraduate students in the Mining Engineering Program in the Petroleum Engineering Department. Notable among the undergraduate students are Paul Griffin who prepared the computer programs for data reduction and plotting and Arnie Hammock who assisted with maps and drafting.

Donn Mohrman (Interdisciplinary Engineering Graduate Student) has done a small study of potential future sites. If the gasification project is moved to a new site, we want to try to find a site that has already been explored in detail in order not to impact our geotechnical project any more than necessary. Mr. Mohrman's contribution is given in Appendix 4.

Mrs. Anita Fickey is serving as the project secretary.

4. Conclusions

The project is on schedule and progressing well. Areas of potential near future difficulty have been identified and are receiving attention. A potential future difficulty related to possibly moving the in situ gasification project to a new site has also been identified. If the gasification site is moved to a new location, we will not be able to test our models against the results of future gasification trials at the Rockdale site. Because of the site-specific nature of our investigations, much of the work done at the Rockdale site would have to be repeated at the new site for an adequate test of our models. These additional activities are beyond the scope of the current grant. Although we will have input into any decision to move, it is likely that other considerations will prevail.

A1. Site Characterization (Charles Forster)

A1.1 Introduction

The TAMU In Situ Lignite Gasification Project has conducted field tests at the Rockdale Site since 1978. No detailed description of the stratigraphy, lithology, and environment of deposition had previously been made. The present geotechnical investigations require such a detailed description for interpretation and input to the future numerical modeling.

The Rockdale Site is located in Milam County, Texas, USGS Alcoa Lake Quadrangle, adjacent to the Sandow Mine as shown on the location map, Fig. A1.1. The major and local stratigraphic units are shown on Fig. A1.2. The lignite seam gasified is shown as Unit 5 on Well No. 2 which is located approximately one mile east and one-fourth mile north of the TAMU site as shown on Fig. A1.1. The lignite seam designated as Unit 5 is about 4.3 m thick and dipping about 150 ft/mile at the permitted-test site. The area of the test site for which a Texas Railroad Commission permit was obtained is about 3 acres. The surface is characterized as Post Oak Savannah with the most recent previous land use being as pastureland.

Well number 4LP was drilled and partially cored during June of 1980 in a location within the permit area that had not previously been burned.

Core from well 4LP was examined for texture, composition, and sedimentary structure in an attempt to determine the environmental conditions present during the period of lignite accumulation and associated sediment deposition. This interpretation is important because the environment of deposition is a major controlling factor of the formation, extent, and quality of the lignite.

A1.2 Description of Core from Well 4LP

The 54 foot section of core available for observation was cut from the Calvert Bluff member of the Wilcox group at depths of 177-231 feet. In terms of the divisional units described in the Railroad Commission Permit Application

FIGURE A1.2
GEOLOGIC SECTION
AT
ROCKDALE WORKS
 BASED ON DATA FROM
 TEST DRILLING

1000 0 1000 2000 3000 4000 5000
 SCALE IN FEET

(RRCPA), 1978, this section of core from top to bottom is comprised of Unit 3 (lignite 177' - 180'), Unit 4 (silty clay grading to a plastic brown clay 180' - 228'), and Unit 5 (lignite 228' - 231'). Units 1, 2, and 6 described in the RRCPA were not available. See Fig. A1.2.

The lignites of Units 3 and 5 are relatively massive and apparently uniform in texture and composition. From an interpretative standpoint they represent a marshy, reducing, low-energy environment. The associated silty clay of Unit 4 is a key unit for the interpretation.

A1.3 Texture

Unit 4 is composed of predominantly silty clay at the top of the unit which grades into an organic rich clay at the base. The section is relatively uniform with a slight decrease of particle size with depth.

A1.4 Composition

The majority of Unit 4 is composed of alternating siltstones with high matrix content and clay laminations. Carbonaceous root traces are common at the top of the section and organic rich clays are characteristic of the basal portion.

A1.5 Sedimentary Structure

Primary sedimentary structures of the silty clay at the top of Unit 4 are partially destroyed by rooting. Throughout Unit 4 very fine, parallel, even, continuous laminations generally partially or completely destroyed by small scale bioturbation (polychaete worm tubes) are observed. Bioturbation decreases downward to nonexistence in the clays at the bottom of Unit 4. These clays retained their primary deposition feature of very fine, parallel, even, continuous laminations. As previously indicated, bioturbation was not present.

Curved, truncated, parallel laminations or ripple lenses were very rarely observed. Small-scale soft sediment deformation features due to loading are common throughout the silty clay fraction of Unit 4 and have contributed to

the destruction of the primary sedimentary structures. There is a one foot section (195' - 196') of CaCO_3 cemented silty sandstone which contains relatively large scale and extensive bioturbation. This section contained the ripple structure described above.

A1.6 Interpretation

Bioturbation by rooting of the clays below the Unit 3 lignite implies an organic deposit of widespread areal extent that accumulated in place. The small scale bioturbation dictates either paucity of burrowing organisms or harsh living conditions. For this reason, anaerobic conditions are suspected. The soft sediment deformation feature and the fine, parallel, even, continuous laminations are characteristic of slow, suspended load sedimentation occurring in a quiet, restricted area.

In addition to the feature observed in the 4LP core, correlation with the borehole log from Ground-Water Development Study at Rockdale Works (GWDS) Well No. 2 provides the complete interpretation. The Simsboro Sand member of the Wilcox Group which underlies the "Units" of the RRCPA is a fluvial sand deposited by a main feeder channel of a deltaic system. Therefore, the evidence suggests a fluvial floodplain lignite deposition updip from the main deltaic system.

A1.7 Conclusion

Interpretation of the paleoenvironment of deposition based on texture, composition, and sedimentary structure indicates a quiet, anaerobic restricted region of wide areal extent. Correlation of 4LP core characteristics with the borehole logs from GWDS Well No. 2 of the RRCPA suggests that lignite deposition occurred in a deltaic floodplain adjacent to a major fluvial feeder channel updip from the main deltaic system.

A1.8 References

Berg, R. A. (1980), "Stratigraphic Setting for Lignite Accumulation in the Texas Gulf Coast", in Lignite, Mathewson, C. C., editor, Texas A&M University Lignite Symposium, April 17-18, 1980, pp. 1.1 - 1.10.

"In Situ Lignite Gasification Project - Rockdale Site", Application to Texas Railroad Commission, Texas Engineering Experiment Station, The Texas A&M University System, July, 1978.

A1.9 Core Description Sheets

The Core Description sheets are on the following three pages.

CORE DESCRIPTION

Field: Rockdale In Situ Gasification Site

Core Name: 4LP

Location: Milam County, Texas

Core Interval: 177 - 231 ft

Depth	Thickness	Description	Environment
177-180	1 1/2 ft	Lignite, Dark Black N1, highly fractured small amounts < 3% sand grains qtz	
180-183	3 ft	Siltstone; Dark Grey N3, clay layers and root traces	
		Light Olive Grey 5Y 6/1 silts - very fine grained, very finely laminated, alternating silts and clays, layers even, continuous, parallel, suspended load sediment Ripples nonexistent Loading features common Small 2-5 mm normal fault displacement from loading Soft sediment deformation Bioturbation by rooting decreasing downward, bioturbation not extensive but common	Rooting indicates coal formed in place and therefore probably extensive in areal coverage
186-195	9 ft	Siltstones with interbedded clays Siltstones Light Olive Grey 5GY 6/1 Clays - Medium Dark Grey N4 to Brownish Grey 5YR 4/1 Very finely laminated silts and clays Suspended load sediment - parallel, even, continuous laminations One small low flow regime ripple set - curved, truncated Much of structure is destroyed by loading and soft sediment deformation Very small scale bioturbation increased downward, worm tubes visible (Polychaete) indicates harsh environment	Anaerobic conditions Quiet water

CORE DESCRIPTION

Field: Rockdale In Situ Gasification Site

Core Name: 4LP

Location: Milam County, Texas

Core Interval: 177-231 ft

Depth	Thickness	Description	Environment
195-196	1 ft	Sandstone, Light Grey N7, very fine grained	
		Few interbedded clays - general appearance	
		is churned	
		Few flow structure present - some small scale	
		ripple cross bedding sets	
		Bioturbation relatively large compared to	
		section described above - environmental	Influx of
		conditions not as harsh	more saline
		Sandstone relatively well cemented by CaCO ₃	water
		cement	
196-226	30 ft	Siltstones with interbedded clays	
		Siltstone Light Olive Grey 5GY 6/1	
		Clays Medium Dark Grey N4 to Brownish	
		Grey 5YR 4/1	
		Very fine grained silts	
		Flow structure all suspended sediment	
		feature or an occasional very low angle	
		ripple cross bed	
		Except where deformed or bioturbated,	
		laminations are parallel, even and continuous	
		Bioturbation scale is smaller than that	
		found from 195-196 (harsh environment)	
		Bioturbation varies in intensity and is	
		intermittent	
		Original structure commonly deformed by	
		loading	
		Bioturbation decreases to insignificance	
		in the last three feet of this section	
		(223'-226')	
		Increasing amount of clay - lamination	
		becoming finer, parallel, even, continuous -	
		only an occasional silt lense	

A1.10 Acknowledgements

We would like to thank Dr. R. Berg of TAMU for his guidance and support during the course of this project.

Portions of the work described above were sponsored by the Texas Petroleum Research Committee under Project AM #23.

A2. Material Properties (James Russell and Charles Forster)

A2.1 Introduction

The strength, deformational, and water flow related properties of the overburden materials are required as input for analysis and modeling. Material properties were determined from the well 4LP core described in Appendix 1.

A2.2 Grain-Size Analysis and Clay Analysis

The lithologic description of the 4LP core indicates the presence of silts and clays in much of the overburden material. This is confirmed by the data shown on Table A2.1 where percent of the material finer than 200 (0.075 mm) mesh ranges from 35.8 to 65.6 with an average of 50.4.

X-ray diffraction clay analysis tests were run on 42 samples at 1 ft intervals in order to determine what clay minerals are present in the overburden and if there is any significant change with depth. Results of the X-ray diffraction analysis are shown on Fig. A2.1.

Different clay minerals are expected to behave differently when exposed to the high temperature environment immediately adjacent to the burning cavity. For example, montmorillonite is very water sensitive. If the water is driven out of this mineral, one would expect a large decrease in volume probably accompanied by caving of the roof rocks. Vermiculite is characterized by marked exfoliation when heated above 150°C which would also seem to promote roof caving. Kaolinite is used in making ceramics and may become stronger in the repository environment. Naturally, the amount of time the clay minerals are exposed to the elevated temperatures as well as other environment parameters may affect the way in which the roof material responds to the gasification environment. At the present time we have inadequate data to come to any firm conclusions but it would seem that the drying and subsequent shrinkage of the clay which would promote caving and subsidence may be of primary importance because caving provides pathways for gas escape and water movement.

WELL 4LP

<u>Depth Interval</u>	<u>% Finer than 200 (0.075mm) mesh</u>
180 - 183	44.4
192 - 195	43.6
201 - 204	65.6
211 - 213	58.3
219 - 222	54.8
226 - 229	35.8

AVE. % FINER than 200 mesh $302.5/6 = 50.4\%$

CONCLUDE that approximately one-half of the dry material between 180 and 229 ft is silt and clay.

Table A2.1 Percent Material Finer than 200 (0.075 mm) Mesh in Core from Well 4LP, Rockdale Site.

CLAY ANALYSIS BY X-RAY DIFFRACTION
WELL NO. 4LP

<u>DEPTH</u> (ft)	<u>PREDOMINATE CLAY MINERALS PRESENT</u>
180	<div> Mixed-layer montmorillonite-illite clay Illite Kaolinite Quartz </div>
190	
200	
210	
214	
220	Mixed-layer vermiculite-illite clay
222	Mixed-layer vermiculite-illite-montmorillonite clay, illite, and kaolinite. Quartz
230	Lignite

NOTES:

- 1) 42 samples at 1 foot intervals
- 2) Change in clay composition at 214 ft may be characterized as minor and not unexpected in sediments such as these.

A2.3 Index Tests

Atterburg limits are index tests run on fine-grained soils to provide an indication of how the soil might react to changes in the moisture content. The lower portion of Fig. A2.2 shows the stages of consistency that fine grained soils can assume with changes in moisture content. The Atterburg limits are the points of transition from one consistency to another: the shrinkage limit (SL) is the boundary between the solid state and the semisolid state, the plastic limit (PL) is the boundary between the semisolid state and the plastic state, and the liquid limit (LL) marks the transition from the plastic state to the liquid state. The plasticity index (PI) is $LL - PL$.

Fig. A2.2 shows the LL, PL, and PI along with the as-received moisture content as they change with depth. The liquid limit increases with depth while the plastic limit undergoes a slight decrease leading to an increasing plasticity index with depth.

The relatively low plasticity index of the material near the top of the section considered indicates that only a small increase in moisture can transform the material to the liquid state where it has no structural strength. This is potentially significant if fractures open or caving occurs that allows flowing water to contact this material.

A2.4 Strength and Deformation Tests

Triaxial compression tests have been run on the 3 inch (75 mm) diameter core from well 4LP. These tests were run at a confining pressure of 85 psi (0.59 MPa) and results for three different depth ranges are shown on Figs. A2.3, A2.4, and A2.5. In the three cases shown, the stress difference at failure ranges from 150 to 160 psi (1 to 1.1 MPa). The samples also exhibited considerable ductility which increases with depth probably with the increase in clay content. The sample from depth interval 194 - 198 ft (59 - 60 m) was strained over 20% and still maintained about the same stress difference. This is a very plastic material.

SEC. 3.6

FIGURE A2.2. LABORATORY DATA SUMMARY WELL 4LP

4LP/180-183

Fig. A2.3. Stress Difference vs Strain for Depth 180-183 ft

4LP/194-198

Fig. A2.4. Stress Difference vs Strain for Depth 194-198 ft

4LP/216-219

Fig. A2.5. Stress Difference vs Strain for Depth 216-219 ft

These triaxial tests were run in the rock mechanics laboratory of the Mining Engineering Program at TAMU on the Soil Test 20,000 lb capacity, screw-driven testing machine. Strain rates were about 10^{-4} per second. These tests were run during the summer of 1980 with funding provided by the Texas Engineering Experiment Station and the Center for Energy and Mineral Resources.

Previous laboratory results on overburden materials from the Sandow Mine have been published by Thompson et.al. (1977) and are shown on Fig. A2.6. Our results compare favorably with those of Thompson. Thompson's results indicate some anisotropy but no increase in strength with confining pressure probably indicating a considerable amount of clay in the samples tested. The modulus of elasticity has been calculated for each of the samples tested. These results are being checked and will be presented in the next report.

A2.5 References

Thompson, T. W., et.al. (1977), "In Situ", 1(2), pp. 171-190.

A2.6 Acknowledgements

Several TAMU students participated in the work reported in this appendix. Curtis Conrad performed the clay analysis, Gil Boyd and Russell Thomas performed the triaxial compression tests, and Paul Griffin prepared the computer programs and plots. Work reported in this appendix was partially supported by the Texas Petroleum Research Committee and the Center for Energy and Mineral Resources.

Fig. A2.6. Mohr's Envelope for Wet Overburden from the Sandow Mine; Ref: Thompson, T. W., et. al, 1977, In Situ, 1(2), pp. 171-190.

A3. Geophysical Mapping (David Becker)

A3.1 Introduction

Preliminary tests have been performed at the Rockdale coal gasification site to determine the viability of sonar probing as a tool to map the post burn environment of a gasification site. Some of the variables in the test included: transducer beamwidth, pulse duration, amplifier gain and the coupling of the transducer to the ground. These tests produced repeatable reflections to a depth of approximately 20 meters. The depth to the top of the lignite bed (and the top of the cavity produced by the burn) is approximately 68 meters (from drilling results). Therefore, it is evident that further work needs to be done to determine if sonar probing can be used to penetrate greater depths. This may be accomplished by lower frequency transducers and/or possibly by using nonlinear sonar techniques.

A3.2 Testing Procedures and Results

To improve coupling of the transducer with the ground, approximately one half meter of top soil was removed from two sites located at opposite ends of the cavity (Fig. A3.1). This produces a square meter depression in the ground. Two types of coupling fluid were tried, glycerin and water. It was found that by filling the depressions with water and allowing the ground under the transducer to be saturated produces a greater improvement in the signal than using glycerin. The water was allowed to soak into the subsurface for a couple of hours before the depression could maintain a water puddle (which indicates a large degree of saturation). The increase in signal quality due to water saturation is due to the removal of gas (air) in the soil. Partial gas saturation is known to have a first order effect on the degree of attenuation incurred by acoustic waves traveling in a medium. Water saturation also produces better coupling between the transducer and the subsurface. Therefore, it is evident that total saturation is a desirable situation to increase signal quality and amplitude, in turn

Fig. A3.1. Location of test sites with respect to the gasification wells. Location of transducer given by capital letters inside outline of water saturation sites.

giving greater penetration. In the Rockdale area, the water table is approximately 3 - 5 meters deep. Therefore, only the upper 3 - 5 meters have to be saturated or the transducer must be placed at or below the water table.

The first transducer used was an Edo Western model 4034B - 6122 transducer. This transducer produces a $\pm 10^\circ$ beamwidth in water defined by the 3 dB threshold; it has a 24 kHz resonant frequency. Fig. A3.2a shows the directivity pattern and lists the specifications of this transducer. After the ground was well soaked and a puddle could be maintained at each site, the transducer was placed at various positions in the water (Fig. A3.1) and recordings were made. For the various positions at each site, at least six consistent reflections were seen as well as other localized signals (Fig. A3.3). It is not clear which reflected signals represent a subsurface interface and which could be reverberations between beds. What is needed is a known bed at a known distance. Then a velocity can be determined for the subsurface. Real signals or reflections were determined by varying the pulse width. Increasing the pulse width will cause a loss of resolution (two signals could become one) but a true reflection will just broaden but its first arrival will remain at the same time. The variations in amplitude of the records in Fig. A3.3 are due to differences in coupling, small differences in gain and transducer orientation (with respect to the horizontal).

The furthest consistent reflection recorded occurs at a two way travel time of approximately 13 ms (Fig. A3.3). Since the cavity is overlain by a shaley clay substrate, the acoustic velocity was assumed to lie in the range of 2000 to 2200 m/s (Clark, Handbook of Physical Constants). Therefore, maximum penetration, using this transducer, is in the range of 26 to ~ 29 meters two way, or 13 to ~ 15 meters one way.

A narrower beam transducer (i.e., a larger degree of directivity) was then employed to increase penetration. The Edo Western model 4034B-6169 transducer has a $\pm 5^\circ$ beamwidth in water (again at the 3 dB threshold) and also operates

WIDE BEAM TRANSDUCER

Model 4034B-6122

Resonant Frequency	24 kHz
Impedance @ 24kHz	60 ohms nominal (internal transformer)
Efficiency	75% minimum
Mechanical Q	≈ 2.0
Maximum Power Input	1,000 watt (10% duty cycle maximum)
Transmitting Sensitivity @ 24 kHz	+73 db nominal
Receiving Sensitivity @ 24 kHz	-75 db nominal
Construction	All ceramic, mass loaded piston array
Active Material	Lead titanate zirconate

MECHANICAL

Housing Material	Cadmium plated mild steel (Stainless steel option)
Acoustic Window	Neoprene boot
Weight in air	35 pounds (15.88 kg)
Cable	65 feet (19.81 meters) Type DSS-2
Maximum Installation Depth	200 feet (60.96 meters)

- a. Specifications and directivity
pattern of Model 4034B-6122
Edo Western Transducer

* ≡ 3 dB threshold

NARROW BEAM TRANSDUCER

Model 4034B-6169

Resonant Frequency	24 kHz
Impedance @ 24 kHz	60 ohms nominal (internal transformer)
Efficiency	75% minimum
Mechanical Q	≈ 2.0
Maximum Power Input	5000 watt (10% duty cycle maximum)
Transmitting Sensitivity @ 24 kHz	+79 db nominal
Receiving Sensitivity @ 24 kHz	-70 db nominal
Construction	All ceramic, mass-loaded piston array
Active Material	Lead titanate zirconate

MECHANICAL

Housing Material	Hard coated aluminum (stainless steel optional)
Acoustic Window	Neoprene (with stainless steel clamping ring)
Weight in air	105 pounds (47.63 kg)
Cable	75 feet (22.86 meters) Type DSS 2
(hull mount or faired unit)	100 feet (30.48 meters) 25 feet hair faired with 75 feet lead in cable DSS 2
(towed unit)	
Maximum Installation Depth	200 feet (60.96 meters)

- b. Specifications and directivity
pattern of Model 4034B-6169
Edo Western Transducer

Fig. A3.2

Fig. A3.3. All records were made using the Model 4034B-6122 transducer with a pulse width of 3 ms. The vertical scale is 100 volts/division; the horizontal scale is 2 ms/division.

Position A, gain = 645
Position B, gain = 645
Position C, gain = 645

Position D, gain = 696
Position E, gain = 730
Position F, gain = 728

at 24 kHz. Figure 2b shows the directivity pattern and lists the specifications of this transducer. This transducer was placed in the water of site 2 at locations A and B (Fig. A3.1). Several consistent reflections were seen at both locations as well as other localized signals (Fig. A3.4). Again, differences in reflection strength are due to variable coupling, small changes in gain, and horizontal orientation of the transducer. The farthest consistent signal was now seen at approximately 19 ms two way travel time. This corresponds to 38 to 42 meters of penetration two way, or 19 to 21 meters one way. Therefore, increasing the directivity (decreasing the beamwidth) causes an increase in penetration as it should.

A3.3 Summary and Recommendations

Very pertinent variables in tests such as those described above are the amount of coupling attained as well as the degree of attenuation present. As was described, signal quality improved when the ground was saturated with water. However, soaking the ground cannot remove all of the gas which may be present in the substrate. Therefore, a test should be conducted to determine the maximum degree of penetration obtainable by the two transducers when we are sure the soil is 100 percent water saturated. This could be accomplished by placing the transducers on or above a lake bottom in 5 - 10 meters of water where water saturation should be 100 percent. Also, the muddy-clay floor of a lake is similar in composition to that of the overlying shaley-clay substrate at the Rockdale site.

Greater penetration was also observed when a narrower beam transducer was utilized. However, another means of achieving greater penetration is by going to a lower frequency transducer. Some degree of signal resolution will be lost, but there is no real need for the degree of resolution obtainable by a 24 kHz transducer. The smallest layer resolvable using a 24 kHz transducer in a medium with a velocity of 2000 - 2200 m/s is of the order of 2 cm

Figure A3.4
All records were made using the Model 4034-6169 transducer
with a pulse width of 3.0 ms and horizontal and vertical
scales the same as in Figure A3.3.
Position A, gain = 707
Position B, gain = 676

($\sim 1/4$ wavelength). By using a 6.3 kHz transducer (which is available), resolution will be of the order of 9 cm. This is within resolution requirements; the 6.3 kHz transducer will have a noticeable effect on the amount of penetration. Again, the maximum penetration obtainable using a 6.3 kHz transducer and having 100 percent water saturation could be determined in the above manner. If these tests do not produce usable ranges of penetration, nonlinear techniques could be employed. It is evident that further work needs to be done in this area to determine the viability of sonar probing as a mapping tool for a gasification site.

A4.1 Potential Future Sites (Donn Mohrman and James Russell)

The current UCG test site located adjacent to the Sandow Mine near Rockdale is reaching its maximum limits for in situ experimentation within the existing permit area. The selection process for another site is currently under review. Potential sites must meet certain criteria to insure a thermo-energy balance. Two critical factors controlling the thermo-energy balance are water inflow and seam thickness, Kaiser (1978), p. 181. Figure A4.1 shows the critical relationship between seam thickness (2 meters) and water inflow to the heating value of the gas produced. It follows that the associated stratigraphy for an in situ gasification site should contain an impermeable roof and floor with a seam thickness greater than 2 meters.

Based on geologic and hydrologic criteria, the Jackson Group may be the best lignite to gasify in situ due to its low sand environment and highly impermeable roof and floor, Kaiser (1978), p. 185. There is some question, however, about the effects of the higher ash content of the Jackson lignite at the sites under consideration. Kaiser (1978), p. 182 notes that "there may even be an optimum ash value at about 40 percent" because the "higher ash value optimizes gasification, retains sulfur, and minimizes subsidence". On the other hand, much of the heat released in oxidizing the lignite is consumed in raising the temperature of the greater quantity of ash. This heat is then not available to foster the desirable char-steam reaction, Strickland (1981).

It would appear that the best areas to research for new UCG sites would be in south Brazos County or Grimes County utilizing the Jackson Group (Manning and Wellborn Formations), Kaiser (1978), p. 187.

Currently, TAMU is considering the Brazos Coal Ltd. property in south Brazos County. Brazos Coal Ltd., subsidiary of McFarlane Oil Co., has been

GREGG, HILL, AND OLNES, 1976

Fig. A4.1. Effect of Water Inflow on Gas Heating Value.
after Kaiser (1978), p. 181

extensively drilled by the Morrison-Knudsen Company, Inc. of San Antonio. McFarlane Oil is cooperating with TAMU to determine if any parcels exist within the reserve area that are potential UCG sites.

To date, three areas, A, B, and C have been identified that could possibly be used as a future location. They are outlined on the seam isopach map in Fig. A4.2 which also contains the drill hole location map.

Site B is owned in fee by Brazos Coal Ltd., while ownership of sites A and C is unknown at this time. The heating values of A and C are below 4000 BTU per pound on an as-received basis.

Table A4.1 is a summary of data from the three areas. Because of the close proximity of these sites to TAMU, 20 miles SE of College Station, this area would allow more frequent visits by interested parties due to the reduced travel time required.

Through conversations with McFarlane Oil, McFarlane (1981), we know that Brazos Coal Ltd. would probably permit a test facility on their property with no direct costs involved.

The depth to coal at all three sites is less than any previous tests run by TAMU thus operating pressures would probably be lower. The groundwater levels indicate that water intrusion may not be a problem at these sites. There may, however, be a question of how typical of the deeper lignite these near-surface seams are, particularly with respect to groundwater.

At this point in time no decision to move has been made. If a move is made, the sites above will probably be considered if they are acceptable to the process project.

Fig. A4.2. Seam Isopach Map of Potential Sites A, B, and C

Table A4.1
Characteristics of Potential Sites and As-Received Lignite Properties

Area	Hole #	Depth to Coal (ft)	Depth to Water (ft)	Coal Thickness (ft)	Approx. Area (Acres)	Roof Composition	Floor Composition	BTU Per lb	Ash (%)	Moisture (%)
A	G-16	61.5	64	7.3	48	clay	clay	3712	32.07	36.54
B	L-17	153	153	6.5	28	clay	clay	N.A.	N.A.	N.A.
C	E-22.5	33	114	7	40	clay	clay	3604	36.42	34.85

A4.2 References

Kaiser, W. R. (1978), "Geological Factors in the In-Situ Gasification of Texas Lignites", Proc. Gulf Coast Lignite Conference sponsored by NUS Corporation at Woodlands Inn, Houston.

McFarlane, J. (1978), Telephone conversation between John McFarlane, President, McFarlane Oil Co. and Donn Mohrman, Instructor, Texas A&M University on February 19, 1981.

Strickland, R. A. (1981), Personal communication between R. A. Strickland and J. E. Russell, February 20, 1981.