POSTER SESSION

ARCTIC AND OFFSHORE RESEARCH INFORMATION SYSTEM DEMONSTRATION

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The development of the Arctic and Offshore Research Information system (AORIS) is part of the programmatic activity of the Arctic and Offshore Research Program at METC. The purpose of this part of the Arctic R&D program is to advance the Arctic environment and technology knowledge base related to offshore oil and gas development. Through the development of AORIS, a centralized, computerized, energy-related knowledge base, important bibliographic and scientific information is made available to the engineering, scientific, policy making, and planning community. The use of AORIS will serve to decrease the technical and economic uncertainties associated with fossil fuels production in the Alaskan Arctic.

POSTER DISPLAY:

The unique Arctic environment poses significant technological and economic barriers to developing Alaskan oil and gas resources. That is, the technical uncertainties associated with the development of offshore oil and gas resources in the Alaskan Arctic create a variety of engineering problems regarding structures, pipelines, and shipping in the offshore regions. These include ice forces on structures, ice accretion, the stability of sea floor soils under structures, and potential ice gouge and subsidence problems associated with subsea pipelines. Each phase of Arctic operations presents severe technical challenges that require clear identification of available scientific, engineering, and management information.

The solution to the engineering problems identified above requires a wide range of Arctic information and data from a variety of sources. A large number of data bases or data centers currently exist that contain Arctic information and data. These data bases cover a broad range of Arctic information, including history and culture, wildlife preservation, as well as engineering information. The U.S. DOE role in developing the AORIS is to provide a single source of easily accessible bibliographic and technical information which focuses on the specific needs of the offshore oil and gas community. Figure 1 shows the AORIS bibliographic component contains information from a variety of publicly available Arctic information sources.

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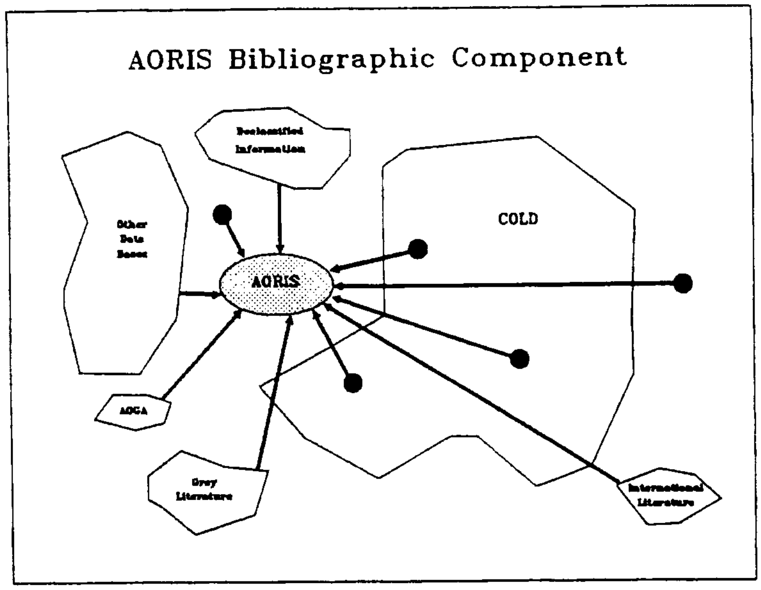

Figure 1. The AORIS provides a single source to a variety of Arctic information.

In general, AORIS is geographically dependent and, where possible, it is site specific. The major topics are sea ice, geotechnology, oceanography, meteorology, and Arctic engineering, as they relate to offshore oil and gas activities: exploration, production, storage, and transportation. Figure 2 shows the AORIS concept and access to the system. The large amount of publicly available, Arctic information is reviewed and evaluated according to the data needs of the user community. In the future, AORIS will be operable on a PC using compact disc - read only memory (CD-ROM) media. The development of a PC-AORIS is the next stage of system development.

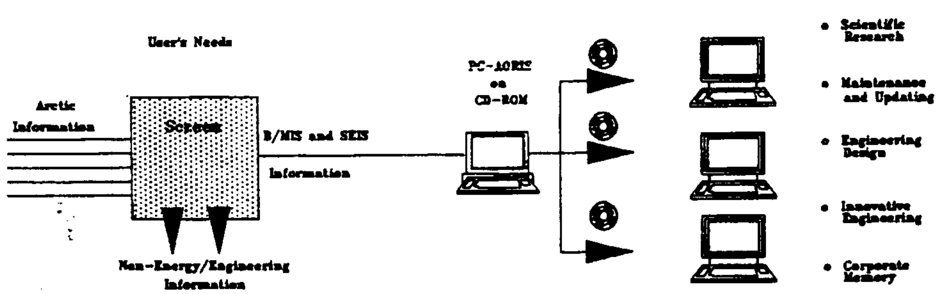

Figure 2. The AORIS Concept

Figure 3 illustrates the structure of the three principal components of AORIS, designed to meet the variety of data needs of the Arctic energy community. These components are:

- **Directory** - assists those seeking energy-related information by serving as a "road map" to publicly available data bases of interest, and providing information on how to access them. The directory contains descriptions of 85 major sources of Arctic-related data and library centers and provides information such as, summary of the contents, where the information resides, who to contact, and much more.

- **Bibliographic Component** - contains nearly 9,000 references and informational abstracts on energy-related research and engineering activities in the Arctic. The following information is available for each reference: title, author(s), language(s), source (where published), publication data, keywords, and an abstract. It provides much of the needed information on topics such as sea ice, ice gouging, sea floor soils, subsea permafrost, seismic activity, offshore structures, and subice hydrocarbon development technology.

- **Data Component** - contains nearly 1,100 tabular and graphic data sets extracted from the bibliographic citations on sea ice characteristics. The sea ice data section concentrates on identifying data on the morphology, mechanical and physical properties of sea ice, and ice-structure interaction.

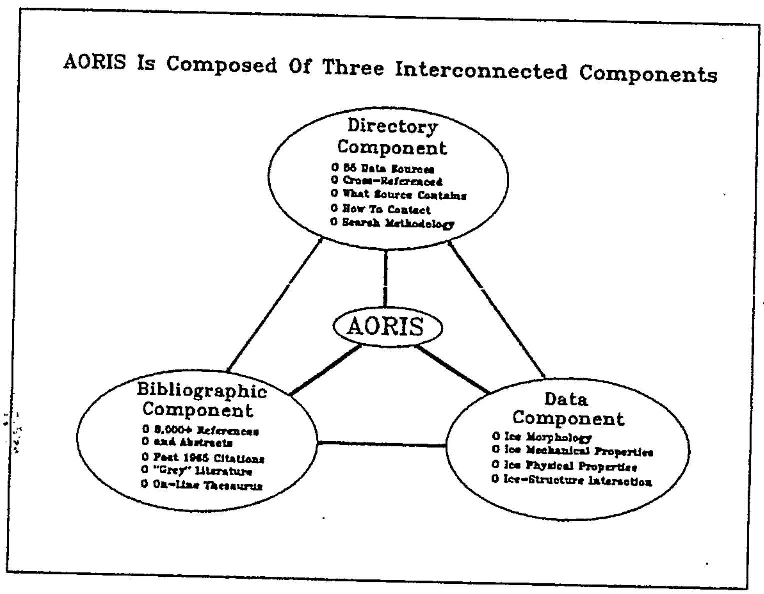

Figure 3. The AORIS is composed of three interconnected components

The three components are linked so the user may easily move from one component to the other. The tabular and graphical data available in the Data Component are labeled with the BIBLIO ID number corresponding to the unique reference code used to identify the reference from which the data is extracted. Thus, a user viewing data of interest may immediately switch to the Bibliographic Component to view the reference corresponding to that particular data set.

SLIDE PRESENTATION:

A series of slides will be presented to show actual oil and gas development activities conducted in the Arctic. This presentation will also show examples of engineering studies and data contained in AORIS. The following is a brief description of the major issues depicted by the slides:

- Caisson drilling structure surrounded by pack ice -- illustrates innovative offshore structure designs required to withstand forces exerted by moving ice. The ice fails and rides-up on the structure. The force exerted on the structure is a function of the ice failure mode and ice strength. The majority of data in the Data Component of AORIS addresses the problems associated with ice-structure interaction.

- Data gathering expeditions to measure real ice features -- it is important to obtain field data measurements to correlate with laboratory studies and simulation models. Small scale ice testing and long term ice investigations, such as conducted by the U.S. Manhattan, are important means of characterizing Arctic sea ice. The AORIS contains many references to field data pertaining to ice morphology, ice physical properties, and ice mechanical properties.

- Model testing of ice-structure interaction -- offshore structure designs must be tested to confirm the relationships of structure shape and size to ice failure mode developed through laboratory experiments and theoretical models. The effects of vertical versus sloping structures on ice failure is simulated to scale in a large test basin. AORIS contains both large and small scale ice model data.

AORIS DEMONSTRATION:

The AORIS will be demonstrated by conducting several information and data searches. The three data base components (directory, bibliographic, and data) will be searched to show the data contained in each component, data structure, and how the data is presented to the user. An important aspect of the demonstration is to show the user-friendly environment created by the use of command menus, online help facility, and keyword thesaurus. A demonstration of the data component will include a sample Arctic engineering problem to show the value of having tabular and graphic data available to the user online.

INTERACTIONS OF MASSIVE ICE FEATURES WITH OFFSHORE OIL PRODUCTION PLATFORMS IN THE ARCTIC

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ABSTRACT

The objective of this study is to provide the scientific knowledge and information required to predict forces on arctic offshore structures during interactions with massive multiyear sea ice floes and ice islands (tabular icebergs). To date the research has included the identification of ice island components and thickness distribution, ice island drift trajectory variations, development and evaluation of scenarios and models for the interaction of massive ice features with offshore structures, and identification of possible measures to mitigate the hazard. An ice island can have three main components (shelf ice and two types of multiyear ice) and a non-uniform thickness varying from 5-6 m to 40-50 m. If the multiyear ice components remain attached to the shelf ice component and they strike a structure, the lateral forces probably will be less than if the shelf ice component directly hits a structure. The ice island hazard is further complicated by the highly variable small-scale drift trajectories. Reversals and loops increase the probability of an interaction event once an ice island is in the vicinity of a structure, and it would be incorrect to assume that once an ice island has drifted past a structure that the hazard has passed. Some hazard detection and mitigation methods include satellite remote sensing using synthetic aperture radar, aerial reconnaissance and ground survey, deployment of satellite positioning buoys and automatic weather stations, construction of underwater gravel berms and artificial multiyear spray sea ice barriers.

1. INTRODUCTION

Research and engineering progress on first-year sea ice, generally less than 2 m thick, has advanced considerably since studies on offshore oil-related problems were initiated 20 years ago. The results of the first-year ice studies cannot, however, be applied to multiyear ice ($\geq$ 3 m thick) and ice islands ($\geq$10 m thick). Unfortunately, there have been few studies of these larger ice masses, particularly in the context of interactions with offshore production structures. Consequently, there is a need for new data and observations of the large-scale physical and dynamic characteristics of multiyear ice and ice islands. The objective of this study is to provide the scientific knowledge and information required to predict forces on arctic offshore structures during interactions with massive multiyear sea ice floes and ice islands. Preliminary work on this topic has included identification of ice island components and thickness distributions, ice island drift trajectory variations, development and evaluation of scenarios and models for the interaction of massive ice features with offshore structures, and identification of possible measures to mitigate the hazard.

2. IDENTIFICATION OF ICE ISLAND COMPONENTS USING SYNTHETIC APERTURE RADAR (SAR)

When ice islands break off an ice shelf they have one or two components; shelf ice only or shelf ice plus multiyear landfast sea ice (MLSI). The shelf ice will generally be of the order of 40-50 m thick and the MLSI 5-10 m thick. As ice islands drift away from the ice shelves, pack ice often becomes attached until there is an almost complete fringe of consolidated multiyear pack ice (MYPI) around the original ice island. This has happened to Hobson's Choice Ice Island (Figure 1), which broke off the Ward Hunt Ice Shelf in 1982-83. Originally the ice island had an area of 26 km^2 and a mass of 7.0 x 10^{11} kg (Jeffries et al., 1988), but with the addition of the MYPI its area has increased to almost 34 km^2 and the mass to 7.4 x 10^{11} kg (Jeffries and Sackinger, in press). The MYPI is believed to be a composite of multiyear floe fragments and annual ice rubble which has undergoe several summers of melting, brine drainage and consolidation to form a special category of multiyear ice which perhaps is as much as 10 m thick. A two or three component ice island has an unusual cross-sectional profile, with a non-uniform thickness (Figure 1b). The MLSI and the MYPI are considered to be integral parts of the ice island and they may remain attached to the shelf ice component. However, it is quite possible that the multiyear ice components will break off the shelf ice when it is drifting in open water in the southern Beaufort Sea (cf. Jeffries et al., 1988, p. 83); hence, only shelf ice might remain and large peak lateral forces are possible should an ice/structure interaction event occur.

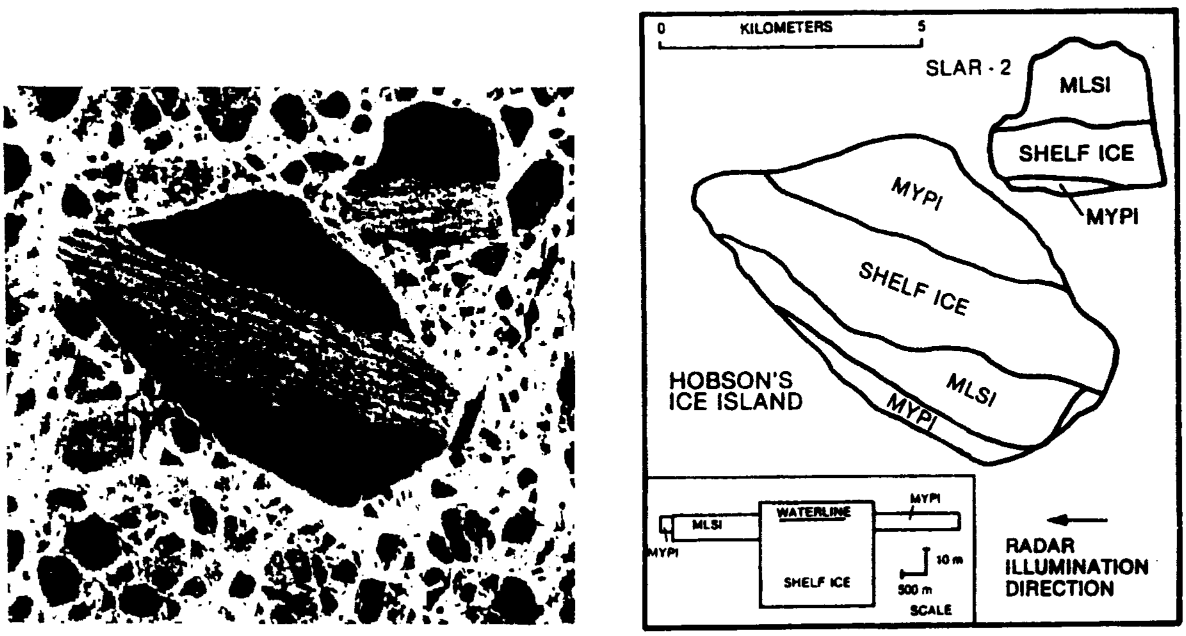

Figure 1. A (left): Airborne synthetic aperture radar image of Hobson's Choice Ice Island and a second ice island, the two largest ice islands known today in the Arctic Ocean. The distance along the bottom edge of the image is 11.25 km. B (right): Plan view of the shelf ice, multiyear landfast sea ice (MLSI) and multiyear pack ice (MYPI) components of the ice islands. The insert is an idealized cross-sectional profile of Hobson's Choice.

3. ICE ISLAND DRIFT TRAJECTORY VARIATIONS

The large-scale drift trajectories of ice islands in the Arctic Ocean are well-established, e.g., the clockwise motion of the Beaufort Gyre which takes ice islands through the southern Beaufort Sea where offshore production structures will be located. However, it is more important to know and understand the smaller-scale motions of the order of 10^1 to 10^3 metres which occur on hourly and daily time scales.

Two types of small-scale motion have been identified. Type 1: ice motion reversals where an ice island will drift in sequentially opposite directions covering a one-way distance of 3-5 km (Sackinger and Yan, 1987; Lu, 1988). Type 2: loops or clockwise motions of 12 hours duration (Hunkins, 1967). These motions have been observed in conditions ranging from open water to compact ice conditions (10/10 concentration).

The small-scale motion of ice islands is extremely variable. The reversals and loops increase the probability of an ice island-structure interaction event once an ice island is located within 3-5 km of a structure. It cannot be assumed the hazard has decreased once an ice island has moved past a structure.

4. ICE ISLAND-STRUCTURE INTERACTION SCENARIOS

Lu (1988) has found that with the long axis oriented parallel to the wind direction, with a consequent minimum water form drag, the ratio of ice island speed to wind speed (Vi/Va) is 0.014 for Hobson's Choice Ice Island, an example of a large ice island. Thus, a maximum expected velocity value for Hobson's Choice in a 55 kt. (28.3 m s^{-1}) wind is 0.4 m s^{-1}. Because of the large Coriolis Force (40 MN) acting on the ice island under these conditions,the movement of the ice island will tend to collect and consolidate pack ice on its right side and there will be open water on the left side (Fig. 2). Thus, it is possible that a region of compressed pack ice will first interact with a structure. This would be similar to conditions when pack ice forms rubble on the upstream side of a structure, without an ice island present. Any rubble between the structure and the ice island would act as a buffer, cushioning and deflecting the ice island to some extent if the geometric path of interaction was eccentric, as would be the most general case (Fig. 2).

If the eccentric alignment was with the structure on the open-water side of the ice island, then one might expect either the MLSI or MYPI edge to strike the structure. Further field measurements are necessary to determine the thickness, strength and crack size and spacing distributions in the MLSI and particularly in the newly-discovered MYPI, in order to quantify forces to be expected in such an interaction.

A possible MYPI-structure interaction scenario is shown in Fig. 3. The blocks of MYPI resulting from fracture against the structure may be grounded in front of the structure. This rubble also might act as a buffer and cushion the impact and deflect the ice island. The water depth in this scenario is > 40 m. In water depths < 35 m the shelf ice component would be expected to ground on the sea-floor, thus absorbing the ice island energy.

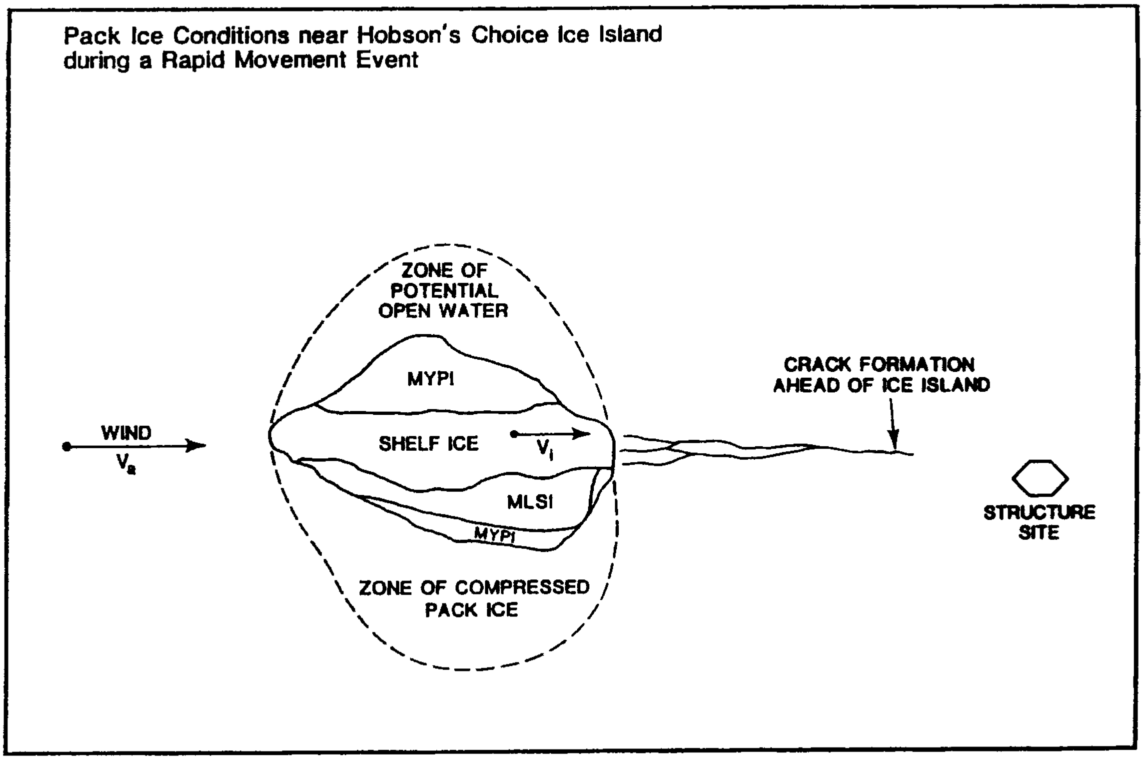

Figure 2. Pack ice conditions near Hobson's Choice Ice Island during a rapid movement event near an offshore structure.

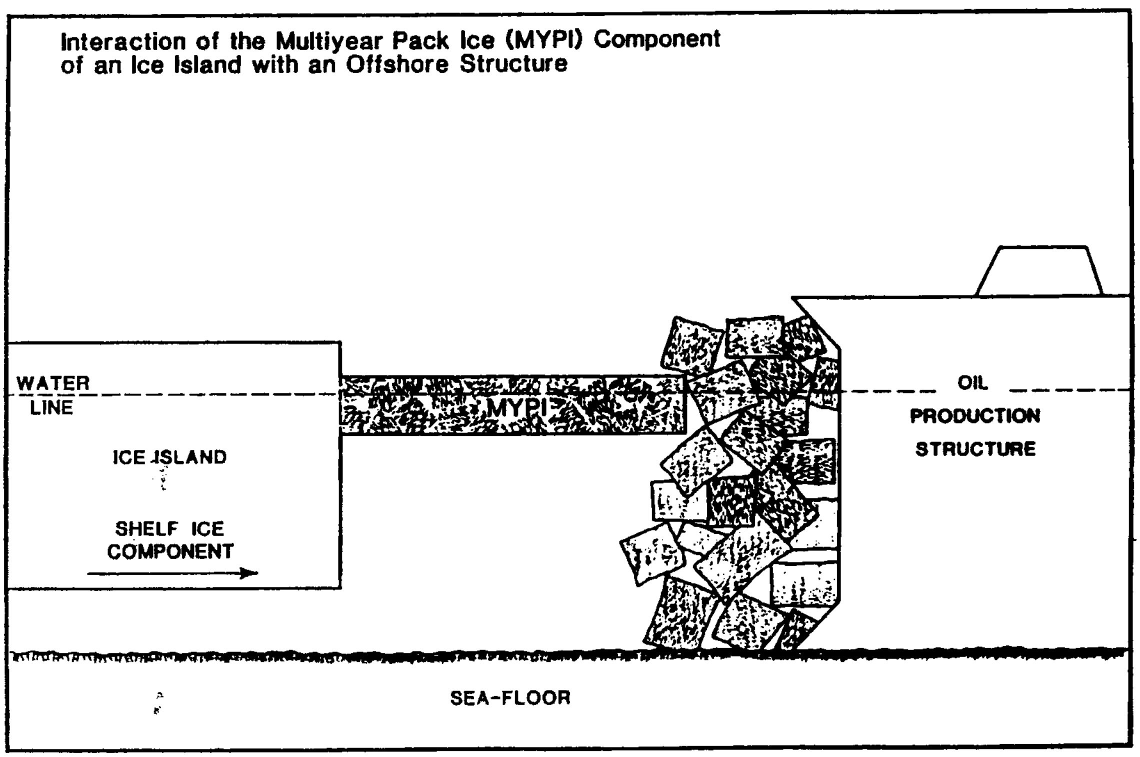

Figure 3. Possible interaction of the multiyear pack ice (MYPI) component of Hobson's Choice Ice Island with an offshore structure.

The least likely, yet possibly the most serious interaction scenario, is a centric impact of the end of the shelf ice component directly upon the structure. Crushing of the shelf ice would occur, in a manner described by Cammaert et al. (1983), Gershunov (1986) and Tunik (1988). Using the methods presented by Tunik (1988) it can be shown that the maximum lateral force on a 100 m diameter cylindrical structure with vertical walls is 3500 MN, and that this occurs just before the ice island is brought to rest. This maximum force is likely to exceed the shear strength of the sea-floor material beneath the structure, and structure sliding is probable. Clearly, this scenario is to be avoided, if possible. It should be noted that in all scenarios it is assumed that the local ice crushing pressures do not exceed the structure panel strength.

One method for preventing, or at least limiting, shelf-ice/structure contact is to introduce an artificial barrier on the sea-floor some distance from the structure, composed either of gravel (G) or multiyear spray sea ice (MSSI) (Fig. 4). The soft, low-strength artificial MSSI also could be constructed on the leading edge of the ice island itself, thereby ensuring that the useful, energy-absorbing MSSI buffer always will be in the proper place for any possible, future interactions.

Many other methods, including ice island fragmentation remain to be devised to reduce peak load during ice island-structure interactions. The advantages of MYPI and MSSI for cushioning the impacts and/or inducing flexural failure and fragmentation should be quantified in a variety of such cases.

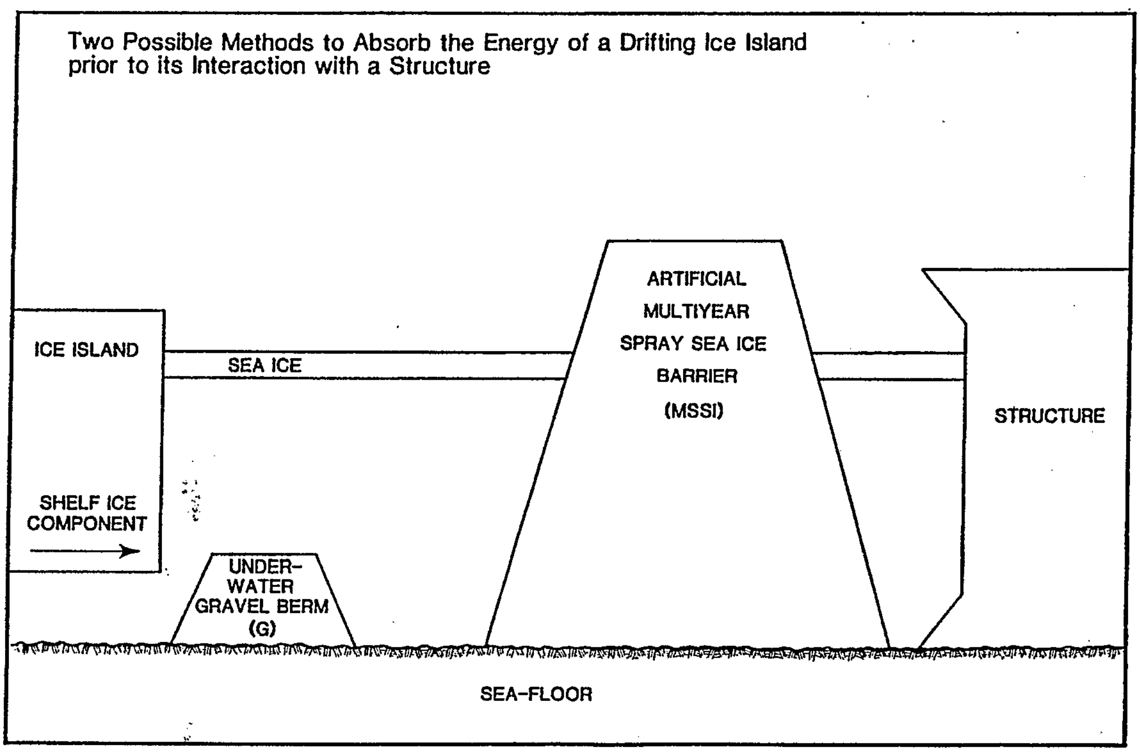

Figure 4. Possible use of a submerged gravel berm and a barrier of artificial multiyear spray sea ice for absorbing the energy of a drifting ice island prior to its interaction with an offshore structure.

5. SUMMARY

The mitigation of the ice island hazard to offshore structures is complicated by their multi-component structure and non-uniform thickness distribution, and extremely variable small-scale motions. Some active measures to mitigate the hazard include remote sensing detection of ice islands and their components, satellite positioning buoy deployment and automatic weather station operation to determine ice island drift trajectories. Passive measures include submerged gravel berms and/or multiyear spray sea ice barriers. Further work will include investigations of failure zones in multiyear floes and ice islands, and failure zones at the MLSI-MYPI-ice island accretion boundaries.

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THE SYNTHESIS, CHARACTERIZATION AND CATALYTIC REACTIONS OF METAL SILICATE CATALYSTS FOR THE PARTIAL OXIDATION OF METHANE

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It is clear that new catalyst materials are needed in order to facilitate reactions that directly convert methane to liquid fuels and higher value chemicals in economically viable processes. Our efforts are focused on the synthesis and reactions of new catalyst materials that would serve as the basis for these processes. The catalysts described here typically consist of an inorganic oxide matrix such as SiO_2 in which early transition metal and lanthanide ions are incorporated into the oxide coordination environment of the matrix. These catalysts are prepared by the controlled co-hydrolysis and condensation of silicon alkoxides with appropriate metal alkoxides. The resulting gels are then dried to provide a variety of materials ranging from high-density glasses, through solid xerogels, to low-density, high-surface area metal-silica aerogels. Silica-based materials containing Ti,Y, Zr, Nb, La, Sm, Ta and W have been prepared as either single- or multiple-metal catalysts. Characterization studies including elemental analysis, surface area and structural investigations by EXAFS (Extended X-ray Absorption Fine Structure) have been used to elucidate both bulk properties of the catalysts as well as determine details of the metal ion coordination environment. Reactor studies testing the catalysts for methane partial oxidation reactions have been performed and the results correlated to both the characterization data and to chemical kinetic modelling of the thermal reactions of methane and oxygen.

Objectives

(i) synthesize metal silicate catalysts for use in partial oxidation or oxidative coupling of methane
(ii) test materials in reactor
(iii) correlate reactor results with characterization
(iv) correlate catalyst reactor studies with thermal reactions of methane and oxygen

Background

(i) unique materials enable placement of metal directly into oxide coordination environment of the matrix
(ii) wide range of material densities available
(iii) direct comparison of catalyst results with thermal reactions essential to determine limits of oxidative coupling

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A wide variety of catalyst materials have been studied for efficacy in oxidative coupling or partial oxidation of methane. These are generally prepared via impregnation or physical mixing followed by a calcining step. The exact distribution and structure of the metal species within its support structure are rarely well known. Catalyst materials in this study were prepared by a controlled co-hydrolysis and condensation of silicon alkoxides with metal alkoxides, a procedure which places the metal directly in the silica matrix.

Direct Hydrolysis

- **Applicable when the rates of hydrolysis for the metal alkoxide and silicon alkoxide are comparable**
- **A simple co-hydrolysis reaction is possible**

example:

$$Si(OR)_4 + M(OR)_x \xrightarrow[CH_3OH]{H_2O} M\text{-}SiO_2 + (4 + x)\ ROH$$

M = V (x=3, for VO(OR)x); Ti & Zr (x=4); Nb & Ta (x=5)

Figure 1

Following gelation and a period of oven treatment, the gels were dried using a critical point drying apparatus (Polaron) with liquid carbon dioxide. By this procedure, metal silicate catalysts containing Ti, Y, Zr, Nb, La, Sm, Ta or W were prepared. Here we focus on catalysts containing lanthanum and/or niobium. Catalysts containing from 0 to 14 wt% lanthanum; 0 to18 wt% niobium; and varying ratios of niobium to lanthanum were prepared. The BET surface areas and metal content in the silica matrix were measured. Although the surface areas may differ at the outset, during the reaction, they all reach surface areas of 200 to 300 m^2/g

La/Si

Metal Content (wt%)	Surface Area (m^2/g)
0.09	842
2.3	716
3.9	764
3.9	250 (after reaction)
3.9	202 (after long times)
8.6	430
8.6	232 (after reaction)
8.6	460 (xerogel)
14	922

Nb/Si

Metal Content (wt%)	Surface Area (m^2/g)
0.3	676
2.7	699
5.7	724
10.4	724
17.5	690

Nb/La/Si

wt% Nb	wt% La	Surface Area (m^2/g)
5.7	0	724
4.3	1.2	776
2.4	3.7	820
1.3	6.6	771
0	8.6	430

Si

Surface Area (m^2/g)
1353
364 (after reaction)
421 (xerogel)

Figure 2

The catalysts were tested at 800 C in a quartz, flow-through reactor for a methane to oxygen ratio of 3:1 with an inlet flow rate of 50 cc/min. The major products of the reactions are CO, CO_2, C_2H_6 and C_2H_4 as determined by both gas chromatography and mass spectroscopy analysis and account for at least 98% of converted methane. The effect of even small amounts of lanthanum in the silica matrix is to increase the selectivity to C_2's from about 22 to 32%, with a small drop in the conversion of methane. The effect of niobium is unclear, although it appears to depress C_2+ selectivity. In the mixed catalysts, small amounts of lanthanum significantly increase the selectivity to C_2+ over pure niobium in the matrix.

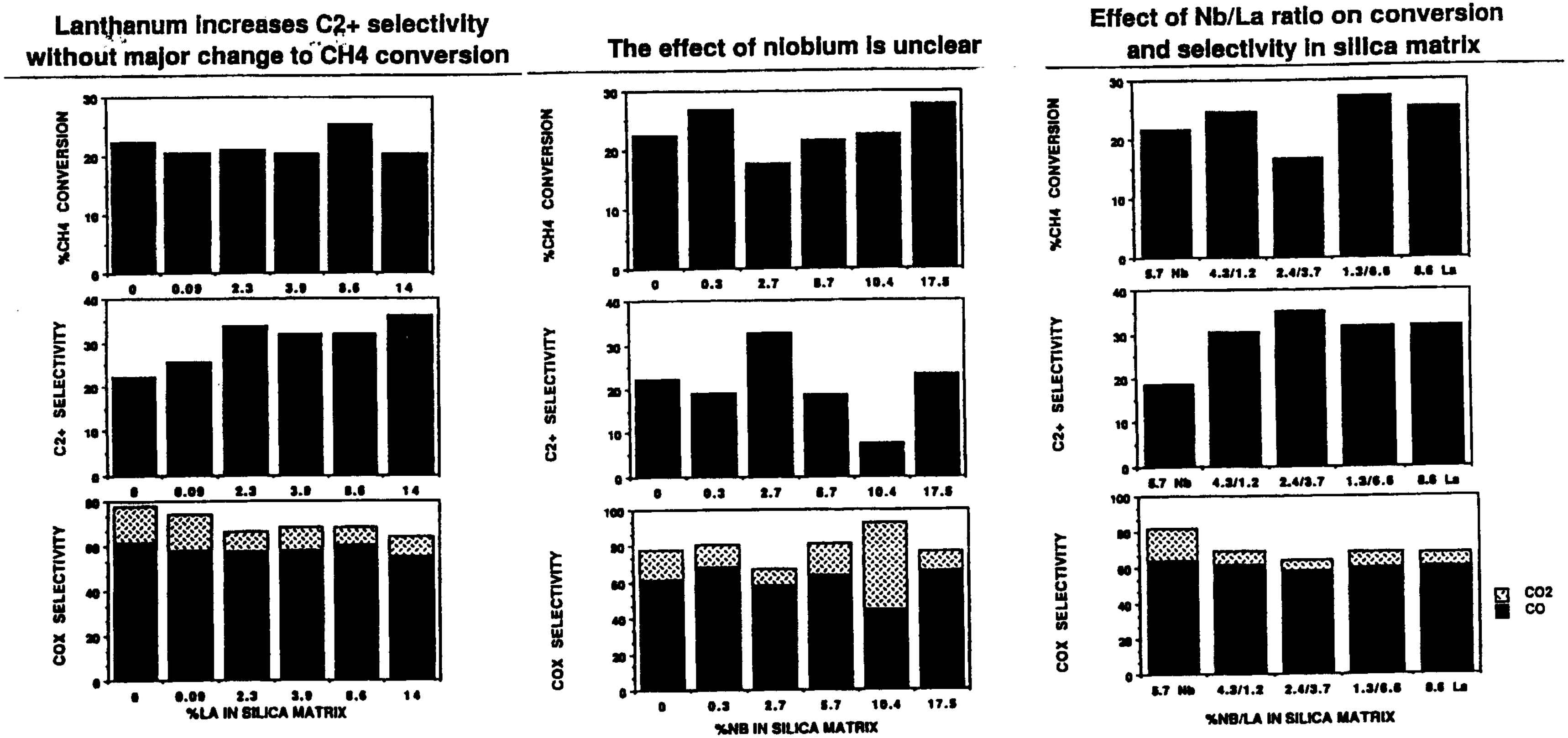
Lanthanum increases C2+ selectivity without major change to CH4 conversion
The effect of niobium is unclear
Effect of Nb/La ratio on conversion and selectivity in silica matrix
%CH4 CONVERSION
C2+ SELECTIVITY
COX SELECTIVITY
%LA IN SILICA MATRIX
%NB IN SILICA MATRIX
%NB/LA IN SILICA MATRIX
CO2
CO

Figure 3

It must be noted that the combined methane conversion/C_2+ selectivity for the lanthanum materials is no more than would be expected for thermal reactions alone. In fact, the silica matrix with no metal loading actually appears to depress both the overall conversion and the selectivity to C_2+'s.

When the silica matrix and the lanthanum/silica matrix materials are doped with about 3 wt%Li, we see an increase in selectivity to C2+'s and a decrease in methane conversion; however, the increase in C2+ production is significantly more than would be expected from thermal reactions alone. This result matches our expectations from studies of thermal reactions and catalytic materials in our work and in others. That is, C2+ yields above those expected from thermal reactions were generally obtained when the catalyst materials contained alkali metals and/or alkali earths.

Addition of Li increases C2+ selectivity and decreases methane conversion

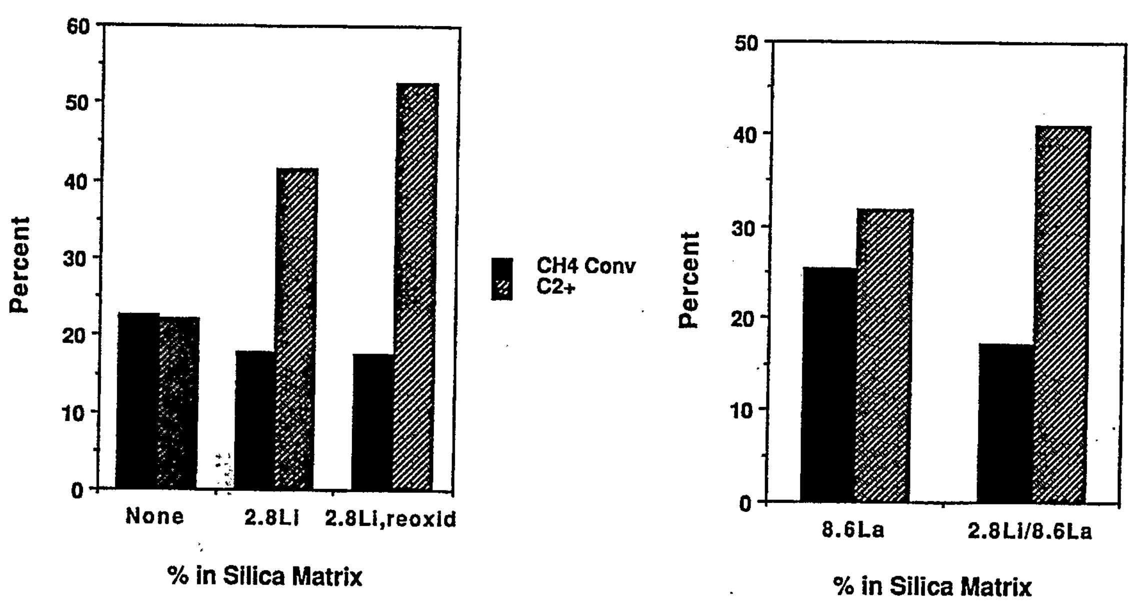

Figure 4

APPLICATION OF REMOTE GEOLOGIC ANALYSIS TO EXPLORATION OF GAS IN NATURALLY FRACTURED RESERVOIRS IN WEST VIRGINIA

Thomas H. Mroz
Morgantown Energy Technology Center

ABSTRACT

A computerized method of identifying linear features from digital topographic data was applied to a study area in southwest West Virginia by Pacific Northwest Laboratories (PNL). The program is a coplanar structural analysis module in the digital Remote Geological Analysis System developed through PNL. An analysis of the digital topographic data, independent of geology, was performed by PNL on sixteen 7.5 minute topographic quadrangles in Lincoln and Logan Counties, West Virginia. Concurrently, the METC Extraction Science and Engineering Branch staff developed geologic and production maps for the area. The output from the coplanar analysis by PNL was then compared to the geological production maps to determine correlation between lineaments mapped at the surface and projected in the subsurface and the higher gas production trends probably associated with more highly fractured shale reservoirs.

The results show a strong correlation in the orientation of the prominent surface lineament trends to deep basement faults, cross strike discontinuities and surface structural geology. These features influence the magnitude of production from the fractured reservoirs and can be used in locating and mapping enhanced fracture porosity in the Appalachian Basin in West Virginia.

PREDICTIVE MODELING OF HORIZONTAL WELLS IN DEVONIAN SHALE

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Abbie Layne
Morgantown Energy Technology Center

ABSTRACT

This poster session highlights two study areas of horizontal well predictive modeling; simulation of gas production from horizontal wells, and stimulation of horizontal wells. The objective of these efforts is to further understand the mechanisms of increasing gas production from tight gas reservoirs using horizontal well technology. The exploitation of these unconventional gas reservoirs will add significant knowledge to the UGR fossil energy program concerning the increase of recoverable gas reserves. Future efforts will be directed not only to tight gas basins in the east, but also to western tight gas basins.

The simulation study includes a comparative evaluation of predicted gas production from horizontal, high-angle, and vertical wells in the tight, fractured Devonian shales of West Virginia. The optimal drilling method was determined by economic and production comparisons of simulation results from studies of a single unstimulated and stimulated horizontal well, a single high-angle well, and up to four vertical wells. Infill drilling was compared to new lease wells, and the effect of faulting on predicted gas production was studied. The study showed that new-lease horizontal drilling is the optimal method in West Virginia, and high-angle drilling results in a slight improvement over vertical drilling. Horizontal drilling showed as much as a 41 percent improvement over 4 vertical wells and a 5-fold increase over 1 vertical well in production performance for new-lease wells. A ROR of 40% and payout time of 1.6 years was predicted for a single 2,000 ft. horizontal well and success ratios of at least 80% for a successful venture are required for a gas price of $2.00/Mcf.

The stimulation study includes an analysis of hydraulic fracture design and geometry predictions for a horizontal well drilled into the Devonian shales in Wayne County, West Virginia. Hydraulic fracturing is necessary to sustain production from horizontal wells in low-permeability, naturally fractured formations. Current hydraulic fracture theories have been adapted to predict the pressure, flow rate, and induced fracture geometry for each natural fracture intersected by stimulation fluid in the horizontal wellbore. Additionally, a closed form solution was developed to predict the pressure and flow rate distribution along the lateral extent of the wellbore. Predicted results were compared with in-situ fracture diagnostics from gas and foam stimulation treatments. Radioactive-tracer with spectral gamma-ray logging confirmed that both fluid pressure and stress perpendicular to the fracture affect the injection flow rate distribution along the wellbore. Both of these factors were

used as governing mechanisms for fracture geometry predictions in the simulation model. Predictions based on these models and tracer logs confirm that the single crack theory for fracture propagation is not applicable for stimulations that are initiated along an isolated part of a horizontal borehole.

HORIZONTAL WELL PRODUCTION TYPE CURVES

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Morgantown Energy Technology Center

ABSTRACT

Production performance curves have been developed for horizontal wells producing from low permeability gas reservoirs. These predictive curves were generated in support of a more general, systems model which is being used to evaluate natural gas potential from tight sand resources. In the systems model, horizontal completion strategies serve as one surrogate for advanced recovery technology.

The performance type curves are general solutions to porous media fluid flow problems and are presented in terms of dimensionless cumulative production and dimensionless time. Families of the curves are grouped based upon the horizontal wellbore radius and borehole length. The curves can be quickly accessed and natural gas production from horizontal wells initially estimated. Use of the production results in their general form also circumvent the need for time consuming and expensive computer modeling.

A 3-dimensional finite-difference reservoir model was used to generate the type curves. Simulation results indicate that production from a horizontal well may exceed that of a typical hydraulically fractured well for a given set of formation properties. Situations conducive to horizontal completions are relatively thin reservoirs and ones with higher vertical permeability. Naturally fractured formations are especially favorable for horizontal well strategies since anisotropic permeability is likely. In this case, the horizontal borehole would be directed perpendicular to the predominant natural fracture azimuth thus taking advantage of the preferred flow direction.

In the systems simulator, reservoir properties are used to access the curves and in turn, predict gas production schedules. These production forecasts are subsequently used in cost and financial models to assess well economics. As a final step in the systems analysis, sensitivity to well length, reservoir permeability, etc. are reviewed and gas reserve additions from low permeability formations quantified. This type of analysis will allow the coupling of a given recovery concept to regional geology so that an optimum exploitation scheme can be identified for resource development.

PRODUCTION SYSTEMS ANALYSIS OF LOW PERMEABILITY NATURAL GAS FORMATIONS

Scott M. Klara
Morgantown Energy Technology Center

ABSTRACT

The Morgantown Energy Technology Center (METC) is investigating potential supplies of natural gas from low permeability sources through the Unconventional Gas Recovery (UGR) Program. The overall program objectives are to develop estimates of recoverable gas and to outline "least cost" strategies for development of the resource. Supporting these objectives is an ongoing systems effort which ties production technologies to local and regional geology using an integrated gas resource model. Results of the systems analysis will be estimates of economically recoverable gas as a function of geology, extraction technology, and financial reward.

The "tight gas" systems analysis includes a comprehensive geological description of the formations under study. Using the reservoir characterizations, improved recovery technologies are being evaluated. The capability to forecast gas production from horizontal completions in low permeability reservoirs has been added to the systems model. This option will allow additional flexibility in assessing recovery strategies.

In general, past studies have provided resource and reserve estimates for basins as a "whole". The systems analysis at METC will couple regional geology with optimal production techniques in order to guide industry towards development of the resource. A portion of the analysis will also appraise regions which have traditionally been evaluated through analogies. The Appalachian Basin is one such area where the Clinton Sandstone is being appraised in terms of recoverable gas. Another basin that has exhibited considerable potential for the recovery of natural gas is the Greater Green River Basin (located in southwestern Wyoming). Recoverable gas estimates range from 3 trillion cubic feet (TCF) to 73 TCF for the low permeability formations underlying this area. Given the large potential, the Greater Green River Basin has been identified as a "priority basin" and is currently being assessed.

OXIDATIVE COUPLING OF METHANE: PHENOMENOLOGICAL MODELING AS A GUIDE TO EXPERIMENTATION

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ABSTRACT

A phenomenological model program was conducted in parallel with the Morgantown Energy Technology Center experimental program for the oxidative coupling of methane. The purpose of the modeling was twofold: (1) to elucidate possible mechanistic aspects of the oxidative coupling reaction on metal-oxide surfaces, and (2) to guide experimental results by predicting the probable outcome of experimentation under as yet untried conditions. The model was fitted to actual data under various conditions of temperature and methane/oxygen ratios. The success of the model is exemplified by the excellent prediction of a non-monotonic yield curve given only two end-point data sets as initial conditions. The optimum conditions for the modeled catalyst were determined as a function of temperature and methane/oxygen ratio.

STRESS-STRAIN BEHAVIOR OF GEOLOGICAL MATERIALS CONTAINING GAS HYDRATES

CONTRACT NUMBER: DE-FG21-MC24051

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PERIOD OF PERFORMANCE: 09/14/87 - 06/30/89

ABSTRACT

Gas hydrates as an energy reserve is very attractive in view of the large amount of gas that can be produced. Vast amounts of natural deposits of hydrates have been identified and a number of conceptual models have been developed for the recovery of this resource. In the development of extraction technology of gas hydrates, it is necessary to have an understanding of the geomechanical behavior of reservoir materials. It is believed that large quantities of natural deposits of these hydrates are formed in unconsolidated media. This paper deals with an investigation on the mechanical behavior of a fine grained sand containing a gas hydrate and a sand-ice mixture, which represents a depleted (or dissociated) reservoir. The ultimate goal is to use this information in investigating ground movements and subsidence resulting from reservoir compaction.

The stress strain-strength behavior and fracture properties of a sand hydrate mixture and a sand-ice mixture was investigated. A sample preparation procedure was developed for obtaining the desired porosity and the hydrate or ice content. A novel experimental setup was developed at METC for performing uniaxial tests under controlled conditions. Dissociation tests indicated that the hydrate samples prepared with the developed procedure were fairly homogeneous. The observed influence of porosity, hydrate (or ice) content, and strain-rate on the stress-strain-behavior is presented.

NATURAL GAS RESEARCH

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ABSTRACT

The natural gas research program is focused on geologically complex resources that have low permeability and production mechanisms which are not understood. The thrust of research focuses on maximizing supply from marginally productive (existing fields) and geologically complex resources (eastern/western). It also is developing the knowledge base to develop new supplies for the future from speculative resources (gas hydrates, deep and subducted sediments, overthrusted regions, covered sediments). The program goal is to increase confidence in future gas supplies. The objective is to establish guidelines for a strategy of resource development based on least costs for the produced gas.

In the eastern resources, emphasis is on the research to define the extent of fractured reservoirs (where, how they vary) and in technology tests to verify well stimulation concepts that could prolong the life of marginal productive wells producing multiple strata. This includes establishing a test site for multiple completion research at a location where shales, sands, and coalbeds exist. A technology development program is underway to increase performance and cut costs for drilling horizontal wells.

In the western resources, emphasis is on the documentation of what was learned at the multiwell site, and extrapolation of the results to other similar basins. New thrusts to advance the state of knowledge include a two-step approach to drill and evaluate a slant hole as an effective recovery concept for both the lenticular sands and coalbeds that coexist in as the tight strata of the Piceance Basin. Supporting research on drilling and formation diagnostics would provide the necessary confidence for acceptance by industry.

In the speculative resources, one initiative is to acquire in-situ data in cooperation with industry in an area where hydrates are known to exist. The hydrate formation at the site would be cored and simulated in an attempt to recover the gas. A second thrust looks at the detection of hydrate deposits offshore using seismic surveys. A third activity is on the verification that deep source rocks exist under shallower reservoirs, and that a pathway can exist for the migration of deep source gas to the shallower sedimentary reservoir. New activities are being considered to increase knowledge of overthrust regions and covered sediments along the Atlantic coast to determine their attractiveness as exploration targets in the future.

Complementing these activities is an investigation to increase the ultimate natural gas recovery from water driven gas fields that are primarily depleted or approaching depletion. In addition, research is emphasizing the conversion of natural gas to liquids, so that the production from wells in disadvantaged locations can become a new way of doing business.

In summary, research needs now should be based on a strategy for gas development that combines sands, shales, and coalbeds, as appropriate, to reduce the risks of achieving a noneconomic well. The application of recovery concepts

like lateral well drilling would serve to increase the profitability. This includes marginally productive sands as likely targets for research as well wherein the secondary recovery recovery of gas becomes likely. Then, program emphasis would be broadened to include all eastern formations and western formations, and more speculative resources, such as hydrates and deep formations, as the likely sources for future gas supplies. Coupled with this, a research is needed with the principal goal to enhance the value of all gas produced by economically converting this gas to a liquid fuel and/or to a chemical intermediate.

ROCKY MOUNTAIN 1 - STRUCTURE AND RESULTS OF A COOPERATIVE INDUSTRY/GOVERNMENT PROJECT IN UNDERGROUND COAL GASIFICATION

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ABSTRACT

During 1987 and 1988, an industrial consortium comprised of Gas Research Institute (GRI), Amoco Production Company (Amoco), Electric Power Research Institute (EPRI), and Union Pacific Resources Company (UPRC), co-sponsored with the U.S. Department of Energy (DOE) a major test of underground coal gasification (UCG). Stearns-Roger (S-R) Division of United Engineers and Constructors, Inc. (UE&C) was selected by the consortium as the project manager. Lawrence Livermore National Laboratory provided instrumentation and data acquisition support, Western Research Institute provided geohydrology and environmental monitoring support. Energy International, Inc. acted as the operations manager during the operations phase of the test. GRI provided the primary management of the test. In this role, GRI chaired and was supported by a Sponsor's Management Committee and a Technical Advisory Subcommittee.

The test was fielded in a 30-foot thick, non-swelling, subbituminous coal seam located near Hanna, Wyoming. Two parallel, 300-foot long underground coal gasification (UCG) modules in the 350-foot deep Hanna #1 coal seam were operated simultaneously. The first module was a demonstration of the Controlled Retracting Injection Point (CRIP) technique which utilized two horizontal boreholes drilled at the bottom and parallel to the coal seam. One borehole, which served as the injection well, was lined with a thin-wall stainless steel tube. The other borehole, which was drilled at a 30° angle to intersect the injection borehole, served as the production well. The second module was a demonstration of the Extended Linked Well (ELW) concept which consisted of two vertical injection wells connected, or linked, by a horizontal borehole that served as the production well.

The horizontal boreholes were emplaced using directional drilling with medium-radius drilling technology. A build angle of about 22° per 100 feet of hole drilled was used to form the curved portion of the wells. Each well was cased with 7-5/8 inch BTC P110 casing which, it was found, permitted up to 8 linear inches of thermal expansion from the hot product gases with little or no gas loss. The three directionally drilled wells were only the second, third, and fourth such wells known to be drilled in the United States at that time. Although the end points of the process wells were placed nearly within the 5 foot target zone, actual mechanical linking was not achieved and a process known as reverse combustion was used to make the final physical connection.

The test began late in November 1987 and continued until shutdown in February 1988, 102 days later. Including linking, the ELW module operated for 61 days during which 4,000 tons of coal was consumed. Approximately 132 million standard cubic feet (MM scf) of steam and oxygen were injected at steam to oxygen ratios ranging from 1:1 to 3:1 to produce 333 MM scf of product gas having an average steam- and tar-free heat of combustion of 261 British thermal unit (Btu) per scf. The product gas was comprised primarily of

hydrogen (H_2), methane (CH_4), carbon monoxide (CO), and carbon dioxide (CO_2) at mole fractions of 0.31, 0.10, 0.09, and 0.43 respectively. Shutdown of the module became necessary when oxygen began bypassing the reaction zone and was detected in the product gas stream.

Including linking, the CRIP module operated for 97 days during which about 10,000 tons of coal were consumed from four gasification chambers, three of which were established using the CRIP technique. To execute the CRIP process, a movable gas burner (igniter) is inserted into and positioned at the far end of the injection borehole. The gas flame burns through the steel tubing and ignites the coal at the base of the seam. As the coal is gasified, a cavity forms which eventually reaches the overlying roof rock resulting in a degradation of gas quality from heat loss to the inert material. At this point, the igniter is retracted to a new location within fresh coal at the bottom of the coal seam, and a new reaction zone is established. Approximately 270 MM scf of steam amd oxygen were injected to produce 650 MM scf of product gas having an average steam- and tar-free heating value of 287 Btu/scf. The product gas was comprised primarily of H_2, CH_4, CO, and CO_2 at mole fractions of 0.38, 0.09, 0.12, and 0.37 respectively. Module shutdown was voluntary.

Since contamination of the groundwater system is one of the major questions remaining to be answered in the development of this technology, a comprehensive environmental program was established to address this issue. An extensive baseline was determined prior to coal seam ignition from an array of 22 groundwater monitoring wells placed across as wall as surrounding the gasification zone. During the gasification operations, reactor pressures were restricted to about 80% of the local hydrostatic head to inhibit gas losses within the coal seam or to the adjacent strata. In addition, when the modules were shut down, the cavities were permitted to vent under controlled conditions to prevent pressure build-up. Finally, the cavities were cooled rapidly using steam injection to enhance removal of a large fraction of the volatile organics produced from the hot cavity residue.

These procedures proved to be very effective in containing the contaminants within the gasification cavities. After the cavities filled with water from the surrounding groundwater system, only boron and phenols (two of the indicator species selected to monitor the contaminant levels) were found to exceed baseline values. The phenols, which were only 900 micrograms per liter immediately after the gasification operations, were nearly 100 times less than levels observed in prior tests. To remove the organics, about 2.1 million gallons of cavity water were pumped to the surface during August 1988, treated in activated carbon adsorption units, and spray evaporated over a remote section of the site. Upon refilling in late 1988 it was found that, with the exception of boron, cavity water quality was within baseline values.

The Wyoming Department of Environmental Quality is currently reviewing the short term trends in the quality of the site groundwater with major emphasis on the cavity waters and the quality of three nearby water monitoring wells. These wells are exhibiting slightly elevated boron and total organic carbon. The results of this evaluation will determine if a second pump out and treatment of the cavity groundwater will be required. The groundwater system will be monitored through 1992 to ascertain any long-term adverse environmental effects and, at that time, with WDEQ approval, the surface of the site will be reclaimed and the site will be abandoned.

EFFECT OF SODIUM PROMOTERS ON THE OXIDATIVE COUPLING REACTION OF METHANE OVER METAL OXIDE AND MIXED METAL OXIDE CATALYSTS

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ABSTRACT

Calcium oxide, gadolinium oxide and gadolinium manganate promoted with sodium pyrophosphate were found to be active and selective catalysts for partial oxidation of methane to higher hydrocarbons. C_2 - yields ranging from 18 to 21 percent were obtained over these catalysts at 1,101K. For both $Na_4P_2O_7/CaO$ and $Na_4P_2O_7/GdMnO_3$ there was no appreciable change in either C_2 - yield or total conversion of CH_4 during the testing period of 26 hours at 1,101K, while there was a small decrease in the C_2 yield over $Na_4P_2O_7/Gd_2O_3$ after 20 hours of reaction. Analysis of the elemental composition obtained by Auger electron spectroscopy of the catalysts indicated that a larger portion of sodium was retained after the reaction at 1,101K on the catalysts containing $Na_4P_2O_7$ compared to those containing Na_2CO_3. The stability at 1,101K of the catalysts containing $Na_4P_2O_7$ was also greater than those containing Na_2CO_3. Phosphorous on the surface of $Na_4P_2O_7/CaO$ was found to stabilize the sodium on the surface without being consumed during the reaction. X-ray photoelectron spectroscopic (XPS) data indicated that both sodium and phosphorous were in different chemical states on both $Na_4P_2O_7/CaO$ and $Na_4P_2O_7/GdMnO_3$ compared to those on pure $Na_4P_2O_7$, while on $Na_4P_2O_7/Gd_2O_3$ they were found to be similar to those of pure $Na_4P_2O_7$.

NATURAL GAS RECOVERY/UTILIZATION SBIR PROGRAM

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ABSTRACT

The U.S. Department of Energy (DOE) annually invites small business firms to submit proposals for the Small Business Innovation Research (SBIR) program. The DOE SBIR program is designed to stimulate technological innovation in the private sector, strengthen the role of small business in meeting Federal research and R&D needs, increase the commercial application of DOE-supported research results, and improve the return on investment from Federally funded research for economic and social benefits to the Nation. The SBIR program is phased: Phase I concentrates on research that will contribute to proving scientific or technical feasibility of an approach or concept (for 6 1/2 months and up to $50,000), Phase II awards are to firms with approaches that appear sufficiently promising as a result of the Phase I effort (for up to 24 months and up to $500,000), and Phase III is where small businesses pursue commercial applications of the research with Federal capital. In the 1989 DOE SBIR solicitation, the natural gas topic was No. 24. Advanced Technology for the Recovery and Utilization of Natural Gas. The subtopics were (1) Advanced Geoscience and Geotechnology for Application to Low-Permeability Formations, (2) Advanced Geoscience and Geotechnology for Recovery of Additional Gas from Existing Reservoirs, (3) Advanced Instrumentation and Interpretation Techniques for Locating and Characterizing Gas Reservoirs, and (4) Advanced Concepts for Natural Gas Conversion to Liquid Fuels and/or Natural Gas Utilization. The solicitation is usually mailed about mid-November, and the proposals are due about mid-February. Questions about the DOE SBIR program may be addressed to Mrs. Gerry Washington, Program Spokesperson, c/o SBIR Program Manager, U.S. Department of Energy, Washington, DC, 20545, telephone (301) 353-5867.

GEOLOGY AND EXPLORATORY ACTIVITY IN THE EASTERN OVERTHRUST BELT

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ABSTRACT

The "eastern overthrust belt" is a term that has been applied in recent years by industry explorationists and others to variously define parts of the Appalachian thrust and fold belt (valley and ridge) and adjacent areas. Regardless of precisely how it is defined or the particular terms applied to it, the area has gone through several cycles of oil and gas exploration. The most recent exploration phase was spurred by reports of large flows of natural gas from the 1977 Amoco Centre Co., PA discovery and the 1978 Columbia Gas discovery in Mineral County, WV and analogies with the geology and recent discoveries in the "western overthrust belt". Data and interpretations from the most recent phase of industry exploration, coupled with attendant governmental and academic studies, have greatly increased our fundamental knowledge of the geology of the Appalachian orogenic belt, and according to some interpretations, have at least doubled the potentially productive area. Although that recent interest has waned in response to failure of some high risk exploratory drilling, e.g., Columbia's remote wildcats in Vermont and New York, and overall industry conditions, it now appears to be an opportune time for industry to consolidate, synthesize, and evaluate all of the data available, acquire leases where justified, and begin to prepare for the next phase of "eastern overthrust belt" exploration.

DEEP SOURCE GAS RESEARCH

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ABSTRACT

Deep Source Gas research is focused on the hypothesis that natural gas is generated in sediments carried to great depths at convergent plate boundaries in the earth's crust. These deeply emplaced sediments may source gas to shallower, drillable traps through deep fracture systems. Many areas of North America are believed to have experienced plate tectonic convergence. The western Cordilleran geologic province in particular appears to have thrust fault structures (associated with subduction and obduction) that enabled deep emplacement of hydrocarbon-generating sediments during more recent geologic ages (during the last 180 million years). The specific area of interest in this province encompasses approximately 1.5 million mi^2 (3.9 million km^2) of the western U.S. (including Alaska) and Canada; other portions of this same province extend southward into Mexico and Central and South America.

The ongoing research consists of basic studies of hydrocarbon generation, stability, and preservation at depths in excess of 30,000 ft (9150 m) in addition to a comprehensive evaluation of the geologic structures, stratigraphy, and geochemistry of the above region.

Results to date include geologic and geophysical evidence of deeply emplaced sedimentary rock units at depths exceeding 30,000 ft (9150 m) in western Washington and south-central Alaska, a new methodology for verifying deep methane stability via fluid inclusion studies, and a preliminary gas resource estimate of 3000 Tcf. If only a fraction of the gas thought to exist is found to be recoverable, it could have a profound influence upon the international energy industry.