DEVELOPMENT OF AN INTEGRATED DECISION SUPPORT SYSTEM FOR MANAGEMENT OF CO_2 GEOLOGIC STORAGE IN THE WEYBURN FIELD

Prepared by
G. H. Huang, X. S. Qin, Y. F. Huang,
L. He, Y. Zou, X. H. Nie and X. D. Zhang

Energy and Environment Program
Faculty of Engineering
University of Regina
Regina, SK S4S 0A2

Prepared for
Mr. Michael Monea

Executive Director PTRC

December 2004

RESEARCH PERSONNEL

PROJECT LEADER:

G. H. Huang and X. S. Qin

EXECUTIVE SUMMARY

By G. H. Huang

CHARPTER ONE – Background

By X. S. Qin and G. H. Huang

CHARPTER TWO – Research Framework

By X. S. Qin and G. H. Huang

CHARPTER THREE – Data Management System

By X. S. Qin and G. H. Huang

CHARPTER FOUR – Integrated Inexact Modeling System

By L. He, X. D. Zhang and G. H. Huang

CHARPTER FIVE – Real Time Dynamic Modeling and Process Control

By Y. F. Huang and G. H. Huang

CHARPTER SIX – Integrated Risk Assessment

By Y. Zou, X. D. Zhang and G. H. Huang

CHARPTER SEVEN – Post-Modeling Analysis

By X. H. Nie and G. H. Huang

CHARPTER EIGHT – Integrated Decision Support System

By X. S. Qin, X. H. Nie and G. H. Huang

CHARPTER NINE – Summary

By G. H. Huang

OUTLINE

EXCUTIVE SUMMARY

Geologic carbon storage is a means of storing carbon dioxide (CO_2) away from the atmosphere by injecting it at depths greater than 1 km into porous sedimentary formations using technologies derived from the oil and gas industry. The injected CO_2 acts as a solvent to overcome forces that trap oil in pore spaces and helps sweep the immobile oil left behind after the effectiveness of primary or secondary recovery methods decrease, resulting in increased oil production. Thus, geologic storage of CO_2 in depleted oil reservoirs is considered to be a safe and effective approach for both facilitating GHG sequestration and enhancing oil recovery. However, to achieve comprehensive understanding on mechanisms of CO_2 distribution and containment within reservoir, investigation of CO_2 movement and leakage through abandoned wells and natural fractures, and assessment of economic realities, a great number of research efforts are desired.

The IEA GHG Weyburn CO_2 Monitoring and Storage Project (Phase I), launched by the Petroleum Technology Research Centre (PTRC) located in Regina, Saskatchewan, in close collaboration with EnCana Resources of Calgary, was such an effort. A significant range of core competencies was built over the three-and-a-half year life (started from July 2000) of the project (Phase I). Although extensive investigation was conducted about the concept of geological storage of CO_2, insight of CO_2 leakage mechanisms, health risk assessment, real-time process control, system optimization, post-modeling analysis, and integrated decision support as well as associated uncertainty analysis is still unavailable. To facilitate the development of a Design and Operating Manual aimed at site assessment, project design, and field implementation of commercial CO_2 geological storage projects, many questions still remain to be answered in project Phase 2, such as:

- How will uncertainties affect CO_2 storage capacity and distribution predictions?
- How will uncertainties affect CO_2 risk assessment?
- What are the potential sources of uncertainties?

- How to develop effective real-time process-control approach for optimizing CO_2 injection and oil production?
- What are the potential impacts of an environmental or an energy policy?
- How the public concerns and participation will affect management of CO_2 EOR operations?
- What kind of risk need to be considered in dealing with CO_2 storage management?
- How significant is the risk that could happen?
- What action should we take to deal with potential CO_2 leakage, by each alone or by joint action?

Answers to the above questions will help decision-makers to get deep insight into the mechanisms of CO_2 geological storage in the Weyburn Field. However, these answers can only be obtained in a general management framework by integrating a variety of functions such as geophysical, reservoir, and geochemical simulations, process optimization, economic activity investigation, heath/environmental risk assessment and posting-modeling analysis. The integrated management framework is desired to demonstrate the benefits and shortfalls of various policies and decisions as well as the associated uncertainties.

Therefore, this proposal developed an integrated Decision Support System (DSS) containing functions of database management, hybrid numerical modeling, inexact process optimization, long-term risk assessment and decision support analysis for the CO_2 EOR management in Weyburn Field. In detail, it consists of the following tasks:

- Development of a data management system

Fortunately, the dataset being generated by Phase 1 of Weyburn CO_2 project is unsurpassed anywhere in the world. Further development and analysis of this unique dataset in Phase 2 will continue to create a valuable resource that is available for existing and future CO_2 Storage Projects. Consequently, an efficient data management system for this project was developed in order to facilitate obtaining all relevant information on the field being studied. These data included geophysical and geological data, engineering data and monitoring data of CO_2 movement.

- Development of a hybrid numerical modeling system under uncertainty

The hybrid modeling system module will be used to quantify the potential CO_2 migrations away from the site into geosphere and biosphere over a short or long period of time, as well as accounting for uncertainties inherent in the modeling processes. Such system could help get insight of the mechanisms of CO_2 injection, distribution, movement, and fate under uncertainties. It also expected to be used as a basis for assessing the short- (technological safety) and long-term risks (health/environmental impacts). In addition, this inexact modeling system would also facilitate management of CO_2 storage in the oil reservoir, with oil production being effectively maximized. This module consisted of a number of components such as inexact reservoir simulation, well leakage modeling, and air dispersion analysis.

- Optimization of CO_2 EOR process under uncertainty

This part mainly consisted of four components. Firstly, the interrelations between the system respondents (e.g. CO_2 concentrations or pressures, oil production rates, and CO_2 emission rates) and the storage practices (e.g. CO_2 injection rates and pressures) were examined through the reservoir model under uncertainty. Dynamic effects of varied control variables on those system respondents was then analyzed. In the next step, stepwise cluster analysis was used to establish the system respondents to operating-condition variations. Then a bridge between the complex reservoir model and the operating decision was established for further determining the desired operating conditions. With the established relationship obtained through the stepwise cluster analysis, a nonlinear optimization model was formulated to identify the optimal operating conditions that correspond to specific site situations (e.g. CO_2 concentration and pressures in the reservoir). After the optimal operation conditions under each scenario were determined, a neural network controller was developed through the obtained knowledge base related to optimal operating conditions.

- Development of hybrid fuzzy-stochastic risk assessment

A hybrid fuzzy-stochastic risk assessment (FSRA) approach was developed in this module to identify and evaluate the risks associated with geological storage of CO_2 within the oil reservoirs and to assess their ability to securely store CO_2. Such an approach would quantify both probabilistic and possibilistic uncertainties associated with regional conditions, environmental quality guidelines, health impact criteria, and geological conditions. This module consisted of five components, i.e. data gathering and processing, risk identification, reservoir modeling, scenario design and integrated risk assessment.

- Post-modeling analysis and decision support system (DSS) development

In this task, two components were included. They were public survey and fuzzy multicriteria decision analysis. The former one was to be conducted for the sectors which include industrial sectors, as well as other economic development conditions. The survey results would be analyzed to identify significant CO_2 impacts and impact factors, as well as to validate research inputs/outputs for the next component. The second component (FMCDSS) was developed to generate and select out the feasible optimal decision alternative according to multiple criteria, incorporating many environmental, social and economic objectives which are of concern to a number of potential decision-makers. These potential decision makers might include those responsible for federal and provincial government policies CO_2 quality management in the Weyburn field; a number of MCDA methods would be integrated in the developed FMCDSS.

An operational decision support system (DSS) for integrating data investigation, hybrid reservoir modeling, CO_2 storage management, risk assessment, energy and environmental policy, and post-modeling analysis. Such a typical decision support system includes three basic components: user interface, inference engine, and knowledge base. User interface is the means by which the user may communicate with the knowledge base. It allows the user to input the data required by the decision support system and shows the answers and suggestions for the user. Inference engine may drive knowledge base through reasoning processes, which use an interpreter to decide how to apply the rules to infer new facts and conclusions and a scheduler to determine the order in which the rules should be applied. Knowledge base is actually a number of databases which contain relevant information on facts, definitions, heuristics and computational procedures applicable to problem domain.

The developed DSS will provide project managers with a collection of measures for analyzing and visualizing operations and development of different applicable technologies. It will provide valuable information to project operators about what might be required for new projects or project expansions and how to go about gathering and using the data they will need. This could effectively facilitate the establishment of a "Best Practices Manual for Development and Operation of CO_2 Geological Storage Projects", which is the specific objective for Phase 2 of Weyburn project.

This report consists of nine chapters. Chapter 1 is an introduction of the project. Chapter 2 is an overview of the research framework. Six major components of this framework is described in detail in the chapters 3 to 8, respectively. Chapter 3 presents development of a data management system. The methodology of integrated inexact modeling system for is proposed in Chapter 4. Chapter 5 illustrates formulation of optimization models for the real-time process control for CO_2 EOR process management. Chapter 6 is to assess environmental and health risks of the potential CO_2 leakage in the Weyburn Field through a hybrid fuzzy-stochastic approach. Post-modeling analysis (PMA) are incorporated in Chapter 7 to unify optimization model with a rule-based system and to enable the multi-objective consideration. Chapter 8 presents decision supporting system incorporating a variety of modules for data management and knowledge acquisition. Chapter 10 is devoted to the summary of this project, which is followed by cited references.