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An intelligent system for monitoring and diagnosis of the CO_2 capture process

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ABSTRACT

Amine-based carbon dioxide capture has been widely considered as a feasible ideal technology for reducing large-scale CO_2 emissions and mitigating global warming. The operation of amine-based CO_2 capture is a complicated task, which involves monitoring over 100 process parameters and careful manipulation of numerous valves and pumps. The current research in the field of CO_2 capture has emphasized the need for improving CO_2 capture efficiency and enhancing plant performance. In the present study, artificial intelligence techniques were applied for developing a knowledge-based expert system that aims at effectively monitoring and controlling the CO_2 capture process and thereby enhancing CO_2 capture efficiency. In developing the system, the inferential modeling technique (IMT) was applied to analyze the domain knowledge and problem-solving techniques, and a knowledge base was developed on DeltaV Simulate.

The expert system helps to enhance CO_2 capture system performance and efficiency by reducing the time required for diagnosis and problem solving if abnormal conditions occur. The expert system can be used as a decision-support tool that helps inexperienced operators control the plant; it can be used also for training novice operators.

1. Introduction

The emission of large amounts of carbon dioxide (CO_2) has caused increasing public concern regarding environmental pollution and global warming. To mitigate this serious environmental problem, the CO_2 capture technology has become widely accepted as useful technology for reducing CO_2 emissions from industrial sources. The goal of CO_2 capture is to capture and remove CO_2 from industrial gas streams before it is released into the atmosphere.

The amine-based CO_2 capture process has become a common method for CO_2 removal because it is energy efficient (Sholeh, Svendsen, Karl, & Olav, 2007). In the amine-based CO_2 capture process, an amine solvent is used to absorb CO_2 from the flue gas, and CO_2 is subsequently extracted from the amine solvent, which can then be regenerated and reused. Operation of an amine-based CO_2 capture system is a complicated task because it involves monitoring and manipulation of 16 components and a number of valves/pumps. The 16 components are associated with over a 100 parameters, including temperatures, flow rates, pressures, and levels of reaction instruments. The monitoring and control of critical parameters is an important task in operation of the CO_2 capture process because it directly impacts plant performance and capture efficiency of CO_2. Since the monitoring and control task is complex, it is desirable to build a knowledge-based system that can automatically monitor, control, and diagnose the CO_2 capture process. In this paper, we present research conducted with the objective of building a knowledge-based expert system that can monitor, control, and diagnose the CO_2 capture processes at the International Test Centre for CO_2 Capture (ITC) located at the University of Regina in Saskatchewan, Canada.

The system is called the Knowledge-Based System for Carbon Dioxide Capture (KBSCDC). The knowledge base consists of domain knowledge about: (1) the plant components and their attributes, and (2) the important process parameters and their desired operating ranges. The knowledge base also consists of the remedial actions that would address these abnormal situations. The KBSCDC system can help the operator monitor the operating conditions of the CO_2 capture pilot plant by continuously comparing the measured values from sensors with normal or desired values. Plant components that have abnormal parameter values indicate that abnormal operating conditions have occurred. Deviations from the normal ranges would set off an alarm to advise the operator that a problem has occurred. The KBSCDC can conduct real-time monitoring and diagnosis, as well as suggest remedies for any abnormality detected, thereby improving the performance efficiency of the plant.

An initial prototype of the system was developed on G2 (trademark of Gensym Corporation, USA), which is an object-oriented expert system development tool. However, the prototype can only monitor reaction instruments and diagnose their abnormalities. The system did not include the process control strategies applied

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to the control devices. Details of the prototype system have been presented in Zhou, Chan, and Tontiwachiwuthikul (2009). This paper presents an improved version of the knowledge-based expert system that was implemented with DeltaV Simulate (trademark of Emerson Corp., USA). DeltaV Simulate provides control utilities which enables the configuration of control strategies in small modular components. These modules link algorithm, conditions, and provide control over the field devices such as pumps and valves. Modules can communicate directly with each other, and can be coordinated by other modules to perform higher-level control strategies. The modules deploy different algorithms such as sequential function chart (SFC) and function block diagram (FBD). SFC is made up of a series of steps, transitions, and actions and it is used for representing the sequence of controlling strategies which contain multiple states. FBD is made up of interconnected function blocks, which process the incoming signals and send the signal to the control devices. Each function block contains standard process control algorithm and parameters that customize the algorithm to perform a particular function in the process control. Therefore, the new version of KBSCDC has the following additional functions compared to the earlier G2 version: (1) modules for different control devices are configured based on their characteristics, and (2) the control strategies applied to the control devices are simulated.

The paper discusses design and development of the improved version of the knowledge-based system, and demonstrates use of the system by using problems scenarios that occur due to abnormal conditions. The paper is organized as follows: Section 2 presents the background literature relevant to the area of CO_2 capture and the knowledge acquisition approach of the inferential modeling technique adopted in this research. Section 3 describes the process of development of the knowledge base. Section 4 presents design and implementation of the system on DeltaV Simulate based on the developed knowledge base. Application of the system is demonstrated using a case study in Section 5. Section 6 gives a conclusion and includes some discussion about future work.

2. Background literature

2.1. Studies of amine-based CO_2 capture

The study of amine-based CO_2 capture has been ongoing for the last decade. The general objective of the study is to improve effectiveness and efficiency of the CO_2 capture process. The research has been primarily conducted in the following two areas:

(1) Study of the behaviour of the conventional amine solvents and development of new or improved solvents with higher CO_2 absorption capacities, faster CO_2 reaction rates, higher degradation resistance, and lower heat consumption for regeneration. The studies of corrosion were conducted in CO_2 absorption systems using different types of aqueous amine solvents including methyldiethanolamine (MDEA), diethanolamine (DEA), 2-amino-2-methyl-1-propanol (AMP) and monoethanolamine (MEA), and it was found that the corrosiveness increased in the order of MDEA < DEA < AMP < MEA (Veawab, Tontiwachwuthikul, & Bhole, 1997; Veawab, Tontiwachwuthikul, & Chakma, 1999). It was suggested that 2-(2-aminoethyl-amino) ethanol (AEEA) is a potentially good absorbent for capturing CO_2 because of its high absorption rate and high absorption capacity (Sholeh et al., 2007). Chakma (1997) proposed that utilization of mixed solvents could reduce energy consumption and solve a number of operational problems. Idem et al. (2006) evaluated the benefits of using mixed MEA/MDEA solvent for CO_2 capture and found that a very large heat-duty reduction could be achieved by using a mixed MEA/MDEA solvent instead of a single MEA solvent.

(2) Selection of appropriate solvents for different applications to reduce the energy penalty. It was proposed that the crucial criteria of solvent selection include feed gas characteristics such as composition, pressure, temperature, and the treated gas specifications (Veawab, Aroonwilas, Chakma, & Tontiwachwuthikul, 2001). White, Strazisar, Granite, and Hoffman (2003) suggested that solvent selection is influenced by solvent characteristics such as CO_2 absorption capability and rates and operational issues of the process such as corrosion potential and solvent stability. These factors influence the equipment size, solvent consumption and heat consumption. Tontiwachwuthikul (1996) proposed that the best solvents can be formulated by blending different amines to take full advantage of the desirable properties of each solvent.

Some observations that can be derived from our survey of past research conducted in the field of CO_2 capture include the following:

(1) With respect to the objective of improving efficiency of the CO_2 capture process, previous research studies rarely focused on using automation for supporting the process of monitoring and control of the CO_2 capture system as a means for optimizing the plant performance and enhancing efficiency of the CO_2 capture process. Operation of a CO_2 capture system is a complicated task because it involves control of over 100 parameters. If these parameters are monitored and controlled effectively, the entire plant can work under desirable conditions and efficiency of the CO_2 capture process can be greatly enhanced.

(2) Application of artificial intelligence technologies has not been made to the CO_2 capture domain. Since operation of a CO_2 capture system is extremely complicated, the process operators have accumulated significant knowledge and problem-solving skills over time. This experience is exclusive and hard to develop, and it is desirable to capture and encode the human expertise into a knowledge-based system for documentation and training purposes.

Therefore, the objective of this study is to develop a knowledge-based system for monitoring and control of the CO_2 capture process. Such a research study would help fill the gap in research for the field of CO_2 capture process.

2.2. Inferential modeling technique

An important prerequisite for developing a knowledge-based system is to acquire expertise that can be encoded in the knowledge base. For acquiring knowledge on the CO_2 capture process, we adopted the inferential modeling technique, which is derived from the inferential model. An inferential model is a generic categorization of knowledge types. It functions as a "conceptual map" to aid the knowledge engineer to identify and classify elements of the elicited expertise (Chan, Tontiwachwuthikul, & Cercone, 1995). Based on this map, the inferential modeling technique or IMT supports "an iterative-refinement of knowledge elements in a problem-domain that provides top-down guidance on the knowledge types required for problem solving" (Chan, Peng, & Chen, 2002). The resulting inferential model consists of the following four levels of knowledge: