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Multi-Agent Control System of a Kraft Recovery Boiler

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Abstract

In this paper the authors have undertaken an attempt to implement the Multi-agent technology on controlling a recovery boiler, aiming to manage and integrate production, quality and security to the process. The operation of the recovery boiler has two well defined objectives, each one with its operational constraints: (1) steam production, an important asset in the pulp and paper process, and, (2) reduction of inorganic reagents to recover sulfate and sodium carbonates, the necessary chemicals in the Kraft pulp production. Each one of these functions, is an independent system inside the recovery boiler, however they have their performances connected to each other by common variables present in the process. This is exactly the definition of an agent system, in other words, a definition of a Multi-Agent System (MAS), for which there is not an optimization, but the search for the best possible outcome. Agents' engineering aspects are addressed by adopting the domain independent software standard, formulated by FIPA. Jade core Java classes are used as a FIPA specification implementation. A dynamic model of a Kraft Recovery Boiler was built on a Matlab-Simulink platform.

Keywords: Process Control, Recovery Boiler, Kraft Process, Multi-agent System, FIPA.

1. Introduction

Engineers have been introducing better support for procedures of monitoring complex conditions through the application of intelligent decentralized systems, implementing a variety of artificial intelligent techniques. Nowadays it is vastly known that these problems that are consequence of the functional complexity of monitoring conditioning can be solved trough architectures, built by many intelligent distributed modules, which interact dynamically, known as intelligent agents.

This methodology was implemented in a Kraft Recovery Boiler dynamic model. Due to the complex tasks involved in controlling the Recovery Boiler it appears to be a process which may profit from a Multi-Agent Control System. The basic strategy for recovery boiler control is steady and stable operation. Process variations cause unstable recovery boiler operation. Unstable process parameters can limit the boiler operator's flexibility for control. When there are fluctuations in process parameters, boiler operators must make accommodations for the worst case. On the other hand, stabilizing furnace operation makes it possible to tightly control process variables and perform nearer to the optimum levels at all times. Incremental performance improvements can be realized by implementing an agent-based intelligent control system. The main reason is that the agents can always objectively take a decision on the basis of a large number of pieces of information. This is not easy for an operator who will have difficulties in being up to date with all relevant information in a critical situation.

2. Presentation of Basis Concepts.

2.1 Software Agents

An agent system is a set of distributed entities, each one with some capabilities that could potentially modify the its surrounded environment, and committed to a social goal, that is, a target objective for the whole agent community. Sycara (1998) defines the characteristic of a distributed problem based on Multi-Agents as: each agent has incomplete information or capability to solve the problem, and thus has a limited viewpoint; there is no system global control; data are decentralized and computation is asynchronous. Thus, a distributed problem – and specially a control problem – that is suitable to be solved by a Multi-Agent approach must be some or all of the characteristics above.

2.2 FIPA

Foundation for Intelligent Physical Agents (FIPA) is the most promising standardization effort in the software agent world. The FIPA agent reference model was chosen to provide the normative framework within which agents can be deployed and operate. FIPA specification establishes the logical reference model for the creation, registration, location, communication, migration and retirement of agents.

2.3 JADE Agent platform.

JADE is a software framework to aid the development of agent applications in compliance with the FIPA 2000 specifications for interoperable intelligent agent systems, (Bellifemine *et al*., 2001).. The JADE system can be described from two different points of view. On the one hand, JADE is a runtime system for FIPA compliant multi-agent systems, supporting application agents whenever they need to exploit some feature covered by the FIPA standard specification (message passing, agent life-cycle management, etc.). On the other hand, JADE is a Java framework for developing FIPA-compliant agent applications, making FIPA standard assets available to the programmer through object oriented abstractions. The JADE communication architecture tries to offer flexible and efficient messaging, transparently choosing the best transport available and leveraging state-of-the-art distributed object technology embedded within the Java runtime environment.

3. Kraft Recovery Boiler

The Kraft process is used in production of paper pulp and involves the use of caustic sodium hydroxide and sodium sulfide to extract the lignin from wood chips in large pressure vessels called digesters. The spent, extracted pulping liquor, called black liquor, is concentrated by evaporation and burned in the recovery boiler to recover the inorganic chemicals for reuse in the pulping process.

The objectives of the recovery boiler are:

- Production of Smelt (sodium sulphide and sodium carbonate): The efficiency of the smelt generation is measured by the reduction ratio, which is the fraction of the total sulphur in the smelt which is present as sodium sulphide.

- Production of steam: The combustion of the organic solids releases large quantities of heat which can be recovered in the steam generating part of the recovery furnace. High steam production efficiency requires complete combustion and clean heat transfer surfaces.

- Prevention of the emission of particulate and gaseous matter: Particulate emissions are made up of a fine dust of salt cake and sodium carbonate carried by the flue gases. The gaseous emissions are carbon monoxide, sulphur dioxide, hydrogen sulphide and various other foul smelling sulphur components. The composition of the flue gas can be controlled to some extent by manipulating some of the furnace input variables.

- Safety: If free water or too dilute liquor comes into contact with molten smelt, violent explosions can occur. To minimize the possibility of such explosions, close monitoring of the spray liquor density is required.

4. Controling a Recovery Boiler Using a Multiagent System

4.1 Control strategy

Optimum chemical recovery, low emission levels, and maximum steam production per ton is accomplished by maintaining a satisfactory char bed on the furnace wall and on the floor, a good air flow and maintaining a steady tapping of smelt to the dissolving tank. To reach these conditions we choose to manipulate two important variables:

- <u>Temperature of the black liquor</u>: To keep a satisfactory char bed the usual method is by varying the temperature of the black liquor going to the spray nozzles. The drop size distribution is extremely sensitive to the liquor temperature as a few degrees will change a coarse spray to a fine mist. At the same time as an increase in the liquor temperature immediately increases the rate of combustion in the secondary zone, less water will reach the char bed surface, and less heat is required for evaporation, the char bed will start to heat up, and more combustible material will be released. The net result is more combustion. As the air flow is kept constant, the oxygen deficiency in the primary zone is higher and the reduction is better. The liquor temperature is accurately controlled and responds very quickly to set point changes as the steam is injected directly into the liquor.

- <u>Liquor Flow</u>: Manipulating the liquor flow we have a control over the steam production because the flow of combustible solids is directly affected. Increasing the liquor flow first cools the char bed and causes the char bed level to increase slightly. As the primary flow is increased by the air control system, the rate of combustion is increased, and the net disturbance in the char bed is slight.

5. Simulation Model

The implemented simulation model is composed for three components: The recovery boiler dynamic simulation, the agent's platform and the communication middleware.

5.1 Kraft Recovery Boiler Dynamic Simulation

A Simulink implementation of a mathematical model of a Kraft Recovery Boiler. The recovery boiler implemented in this project is an adaptation of the Babcock and Wilcox recovery unit model done by Karnienny et al. (1979). Since this model there has been very intensive research on nearly every aspect of recovery boiler operation which made it obvious that an update was needed. Most of these studies were found at the reference textbook on recovery boiler by Adams et al. (1997). The mathematical model is composed by mass and energy balances (145 equations and two closed loops to control air furnace inlets and boiler pressure).

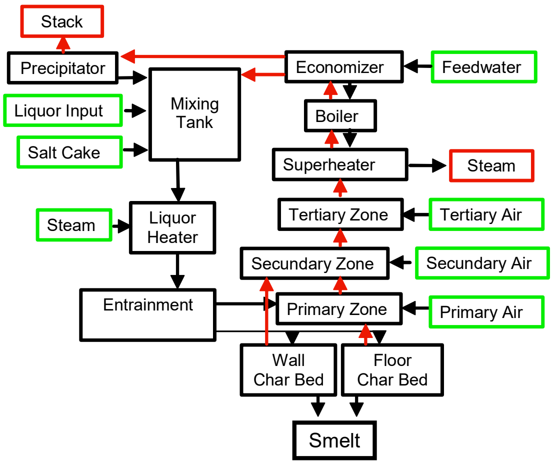

Fig. 1. Material and energy balance diagram

5.2 MAS Platform.

An implementation of the MAS platform in JAVA Agent Development Framework (JADE). The agent platform has two containers with two types of agents, TCP Agents that provides the communication bridge between the control agent and the recovery boiler simulation (TCP4000 and TCP4001) and Control Agents that represents the action control (Reduction agent and Vapor agent). The interaction between agents happens when a fault situation occurs, when the efficiency of the smelt is less than 90% and when the Production of steam is less than 2700 ton/day. When a fault condition occur a TCP Agent receive the fault from the simulation and send a FIPA Request message to the Control Agent reporting the status. When the Control Agent receive REQUEST message, it stars the negotiation process with the other Control Agent. Based on the requirements of the process, we needed and auction or negotiation protocol. FIPA standardizes some of these interaction protocols and we decided to use the Contract Net Interaction Protocol. The contract-Net Protocol was proposed and described in FIPA (2006).

5.3 Communication Middleware.

We needed a communication middleware that allows the MAS to send/receive data to/from the Kraft Recovery Boiler model in Simulink. The MAS reads information of the status of the recovery boiler to determine the required control actions which are applied to the case. In our Simulation Model, the Client is the implementation in Simulink and the Server is the Multi-Agent System.

6. Simulation Results

In order to test the operation of the MAS and to evaluate its performance, some scenarios were simulated and evaluated. Next, we still present, the result of one of the scenarios. We include the description of the message exchange of agents.

6.1 Negotiation Process

From t=0 to t=1000 there was no monitored action from the MAS. At t=1000 the status of the process was %Reduction = 88.0137 Steam=2536.03 Ton/d. Precisely at the moment that the agent "Reduction" gets into the system, it is detected a reduction below 90%, and it is sent a message of REQUEST to the agent "TCP4000"

The agent "TCP4000" sends this message encapsulated in another message REQUEST to the control agent "Reduction".The agent "Reduction" builds a message CFP to initiate a negotiation with the agent "Vapor". After negotiating the agents get to the conclusion that the best strategy is to lower the liquor temperature to "101.21"

This value is sent together with other two variables that did not suffer changes. The content of the message has the following variables: Air Temperature= 134.44 C, Liquor Input = 1750 Ton/d, Liquor Temperature = 101.21 C. The message sends these values to the simulation platform, where each one of them is written on the manipulated variables of the recovery boiler simulation. The immediate answer is the increase on the efficiency reduction to a percentage slightly over 90.

At t=1100 the agent "Vapor" enters the system and receive a message indicating that the vapor production is below the fault limit (2700 ton/d). The agent "Vapor" starts a communication using the "FIPA-Contract-Net-Interaction-Protocol", sending a CFP message.

The agent sends a proposal for the increase of the input liquor, which is accepted and forwarded to the simulation platform. Liquor Input = 1841.81 ton/d. With the increase of the liquor input, the efficiency reduction drops. The agent reduction receives a message which is processed to control the fault situation. Again the best control strategy was to decrease the liquor temperature to 100.07 C. The agent "Reduction" reacted quickly, taking the efficiency reduction to a value close to the safety limit.

Because the vapor production has a slower dynamic than the reduction, the response to the control was slower than the efficiency response. At t=1400 the vapor production leave the fault zone and enters the safety zone. Fig 2 shows the action of the manipulated variables and the response of the controlled variables.

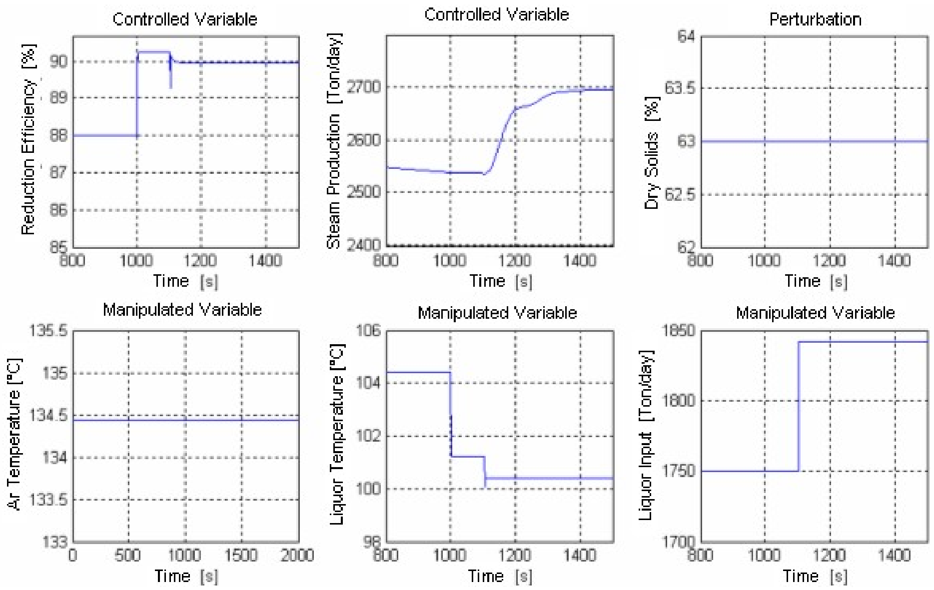

Fig 2. Response of the simulation system.

7. Conclusions

This paper presents the partial results of our work in applying multi-agents agents to develop an intelligent control system to a Kraft Recovery Boiler and the MAS implementation in the JADE platform, probably the fist application in a chemical process industry. The simulation system is implemented using Matlab and Simulink to simulate the Recovery Boiler and the JADE platform to develop and simulate the MAS. Through simulation, we evaluated the performance of the MAS controlling the recovery boiler. Our Simulation results show the feasibility of implementing a control system of a recovery boiler using a FIPA compliant MAS.

The MAS provide autonomous capabilities to the Recovery Boiler system and it allows agents to make negotiations without full knowledge of the system using the Contract Net Protocol.

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