Towards Better Understanding of Circulating Fluidized Bed Boilers: A Data Mining Approach

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Abstract. Fuel feeding and inhomogeneity of fuel typically cause process fluctuations in the circulating fluidized bed (CFB) process. If control systems fail to compensate the fluctuations, the whole plant will suffer from fluctuations that are reinforced by the closed-loop controls. This phenomenon causes reducing efficiency and the lifetime of process components. Therefore, domain experts are interested in developing tools and techniques for getting better understanding of underlying processes and their mutual dependence in CFB boilers. In this paper we consider an application of data mining (DM) technology to the analysis of time series data from a pilot CFB reactor.

Keywords: CFB reactor, process monitoring and control, time-series mining.

1 Introduction

Self-sufficiency of energy is one of the most significant issues in EU policy. Enlargement of EU makes the challenge of ensuring the stable and reliable energy production even bigger, as the energy consumption in Eastern Europe will be increasing rapidly, ensuring their economic growth so as to reach the level of Central and Western Europe. This will lead to thermal exploitation of low quality fuels, which remains the main local energy source in European Union and especially in Eastern Europe. Cheap and stabile fuel guarantee lowest price for power production.

Continuous and growing increase of fluctuations in electricity consumption brings new challenges for the control systems of boilers. Conventional power generation will face high demands to ensure the security of energy supply because of increasing share of renewable energy sources like wind and solar power in power production. This can lead to frequent load changes which call for novel control concepts in order to minimize emissions and to sustain high efficiency during load changes.

From combustion point of view the main challenges for the existing boilers are caused by a wider fuel selection (increasing share of low quality fuels), increasing share of bio fuels, and co-combustion. In steady operation, combustion is affected by the disturbances in the feed-rate of the fuel and by the incomplete mixing of the fuel in the bed, which may cause changes in the burning rate, oxygen level and increase CO emissions. This is especially important, when considering the new biomass based fuels, which have increasingly been used to replace coal. These new biofuels are often rather inhomogeneous, which can cause instabilities in the feeding. These fuels are usually also very reactive. Biomass fuels have much higher reactivity compared to coals and the knowledge of the factors affecting the combustion dynamics is important for optimum control. The knowledge of the dynamics of combustion is also important for optimizing load changes [2].

The development of a set of combined software tools intended for carrying out signal processing tasks with various types of signals has been undertaken at the University of Jyväskylä in cooperation with VTT Processes[1]. This paper presents the vision of further collaboration aimed to facilitate intelligent analysis of time series data from circulating fluidized bed (CFB) sensors measurements, which would lead to better understanding of underlying processes in the CFB reactor.

2 Addressing Business Needs with the Data Mining Approach

Currently there are three main topics in CFB combustion technology development; once through steam cycle, scale up (600 – 800 MWe), and oxyfuel combustion.

The supercritical CFB combustion utilizes more cleanly, efficiently, and sustainable way coal, biofuels, and multifuels, but need advanced automation and control systems because of their physical peculiarities (relatively small steam volume and absence of a steam drum). Also the fact that fuel, air, and water mass flows are directly proportional to the power output of the boiler sets tight demands for the control system especially in CFB operation where huge amount of solid material exist in the furnace.

When the CFB boilers are becoming larger, not only the mechanical designs but also the understanding of the process and the process conditions affecting heat transfer, flow dynamics, carbon burnout, hydraulic flows etc. have been important factors. Regarding the furnace performance, the larger size increases the horizontal dimensions in the CFB furnace causing concerns on ineffective mixing of combustion air, fuel, and sorbent. Consequently, new approaches and tools are needed in developing and optimizing the CFB technology considering emissions, combustion process, and furnace scale-up [3].

Fluidization phenomenon is the heart of CFB combustion and for that reason pressure fluctuations in fluidized beds have been widely studied during last decades. Other measurements have not been studied so widely. Underlying the challenging objectives laid down for the CFB boiler development it is important to extract as much as possible information on prevailing process conditions to apply optimization of boiler performance. Instead of individual measurements combination of information from different measurements and their interactions will provide a possibility to deepen the understanding of the process.

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[1] Further information about the project, its progress and deliverables will be made available from http://www.cs.jyu.fi/~mpechen/CFB_DM/index.html.

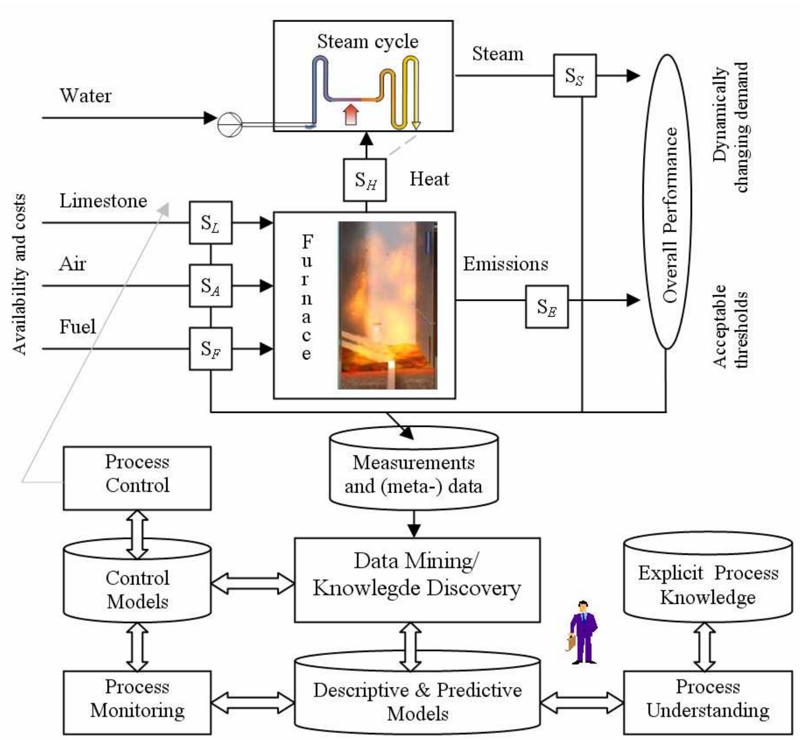

Fig. 1. A simplified view of a CFB boiler operation with the data mining approach

A very simplified view on how a CFB boiler operates is presented in the upper part of Fig. 1. Fuel (mixture of fuels), air, and limestone are the controlled inputs to the furnace. Fuel is utilized to heat production; air is added for enhancing the combustion process and limestone is aimed at reducing the sulfur dioxides (SO_2). The produced heat converts water into steam that can be utilized for different purposes. The measurements from sensors S_F, S_A, S_L, S_H, S_S and S_E that correspond to different input and output parameters are collected in database repository together with other meta-data describing process conditions for both offline and online analysis. Conducting experiments with pilot CFB reactor and collecting their results into database creates the necessary prerequisites for utilization of the vast amount of DM techniques aimed to identifying valid, novel, potentially useful, and ultimately understandable patterns in data that can be further utilized to facilitate process monitoring, process understanding, and process control.

The estimation of boiler's efficiency is not straightforward. The major estimates that can be taken into account include ratio of produced volumes of steam to the volumes of the consumed fuels, correspondence of volumes of emissions to environmental laws, amortization/damage of parts of boiler's equipment, reaction to fluctuations in power demand, costs and availability of fuels, and others. Correspondingly to these factors, a number of efficiency optimization problems can be defined.

However, developing a common understanding of what basic, enabling, and strategic needs are and how they can be addressed with the DM technology is essentially important. From the DM perspective, having input and output measurements for processes, first of all we are interested; (1) to find patterns of their relation to each other including estimation of process delays, level of gain, and dynamics, (2) to build predictive models of emissions and steam volumes, (3) to build predictive models of char load, having few measurements of it under different conditions during the experiments (in a commercial plant there is no way to measure char inventory on-line as it can be done with oxygen concentration and other output parameters). Currently, we are concentrated on estimation of the responses of the burning rate and fuel inventory to changes in fuel feeding. Different changes in the fuel feed, such as an impulse, step change, linear increase, and cyclic variation have been experimented with pilot CFB reactor. In [1] we focused on one particular task of estimating similarities in data streams from the pilot CFB reactor, estimating appropriateness of the most popular time-warping techniques to the particular domain.

3 Concluding Remarks and Future Work

We recognized basic, enabling, and strategic needs, defined what the current needs are and focused on them, yet continuing to define the most important direction of our further joint research efforts. Those include development of techniques and software tools, which would help to monitor, control, and better understand the individual processes (utilizing domain knowledge about physical dependence between processes and meta-information about changing conditions when searching for patterns, and extracting features at individual and structural levels). Further step is learning to predict char load from few supervised examples that likely lead to adoption of active learning paradigm to time series context. Progressing in these directions we, finally, will be able to address the strategic needs related to construction of intelligent CFB boiler, which would be able to optimize the overall efficiency of combustion processes.

Thus, a DM approach being applied for time series data being accumulated from CFB boilers can make critical advances addressing a varied set of the stated problems.

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