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Bayesian network-based early-warning for leakage in recovery boilers

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Abstract

Early-warning for leakage in a recovery boiler can help the process operator to detect faults and take action when a dangerous situation is developing. By analysing the mass-balances on both the steam and combustion side of the boiler in a Bayesian network, the probability of leakage can be determined and used as an early-warning. The method is tested with real plant data combined with leakage simulations. The results show that it is possible to detect considerably smaller leakages using this method than using the type of simple steam-side mass-balance method that is in use today. Bayesian network is an efficient tool to combine information from measurement signals and calculations giving an early-warning system that is robust to signal faults.

Keywords: Early-warning; Bayesian networks; Recovery boiler

1. Introduction

Operating and diagnosing complex industrial processes are usually difficult tasks. Faults that cause only minor disturbances in the production can be frequent. It is mainly the operator who detects, isolate and take action when a disturbance or fault appears. It can be very hard to distinguish between normal process operation with its minor disturbances and a developing fault.

Early-warning systems can help the process operator to detect faults at an early stage and thus prevent further fault development. Early-warning systems have been developed for safety critical events, e.g. fire on ships [1], disconnections in electrical systems [2] and landslides [3]. Common for early-warning systems are that they are designed to make a person aware of that a critical situation is or might be developing.

Industrial processes normally have alarms on signal levels to pay attention to large deviations from a normal value. The alarm trigging levels are set to protect the process equipment, maintain product quality, etc. A diagnostic system can give the process operator more information than just an alarm that a signal is deviating. Fault diagnosis is commonly divided in the two steps: detection; and isolation [4]. Fault detection is to determine that there is a fault and isolation is to determine where the fault is located. An early-warning system is a diagnosis system aimed to help the process operator to detect and isolate faults as early as possible.

Leakage detection in recovery boilers is important to avoid severe damages on equipment. The walls of the furnace are containing evaporating water with high pressure. Fireside corrosion and thermal stress can cause leakages, implying that water or steam comes in contact with the smelt. Water in the smelt can cause an explosion with total destruction of the boiler as result. There are a number of commercial systems for detection of leakage flows in both conventional boilers and recovery boilers [5,6]. These systems are detecting the leakage flow or cracking with acoustic sensors.

In this work, a new method to detect boiler leakage flows by a mass-balance in a Bayesian network is evaluated by study of a typical recovery boiler. Data from real

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process operation are combined with a process model to simulate leakage flows. Bayesian networks [7,8] have been used for diagnostics in many different areas, e.g. medicine, electronics and mechanics [9]. An advantage over other diagnostic methods is the handling of uncertainty. An alternative would be to use, e.g. fuzzy logic [10]. This methodology will be investigated in future research on the current application.

2. Chemical recovery

Black-liquor is a residue from the cooking-plant in sulphate pulp mills. It consists of both organic and inorganic materials and has a dry solids content of 14–18%. The organic material contains energy and the inorganic material gives valuable process chemicals. Before it can be combusted, the dry solid content has to be increased in an evaporation plant. Content of dry solids is 65–80% after the evaporation plant.

2.1. Black-liquor combustion

The recovery boiler burns the organic material in the concentrated black-liquor and produces high-pressure steam [11]. It also recycles and regenerates chemicals through reduction, mainly from potassium-sulphate to potassium-sulphide. The recovery boiler is an important component in the process because it both regenerates the cooking chemicals and produces steam to processes.

Concentrated black-liquor is fed in a furnace where volatile organic material is combusted. The remaining material falls down to the bottom and forms a smelt. Reducing conditions in the lower part of the boiler reduces the sulphates to sulphide with some of the energy generated in the combustion. The smelt is also containing a number of other components, mainly sodium carbonate, which are not active in the process. Smelt spouts bleeds the smelt out of the furnace to be solved in weak-liquor.

2.2. Steam generation

Water is fed from a feed-water deaerator through the economiser. The economiser is located as the last component in the flue-gas path and utilises the reminding heat in the flue-gas to preheat the feed-water before it enters the steam drum. Furnace walls and a convection section in the flue-gas path are cooled by evaporating water. From the steam drum, the furnace walls and the convection section are connected in a natural circulation system, see Fig. 1.

Steam is separated in the upper part of the steam drum and lead to the super-heaters. Super-heaters are located first in the flue-gas path, close to the furnace. To protect the super-heater closest to the furnace from radiation, water or steam cooled screen-tubes can be located in front of the super-heater. Steam cooling to control the outgoing steam temperature of each super-heater section is done with injection of water or by a surface-cooler. Injection

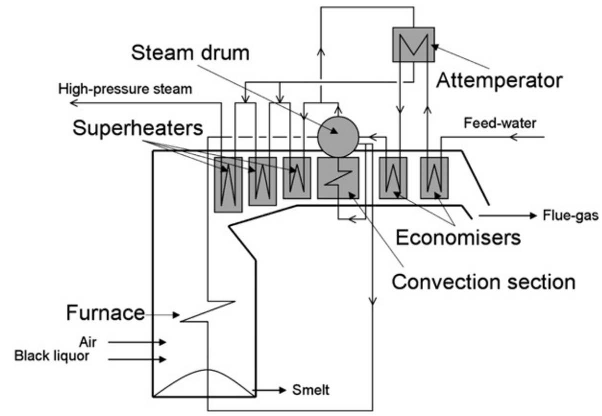

Fig. 1. Recovery boiler.

water can be feed-water or, to prevent salts and other contaminations in the steam, water produced by condensing steam from the drum through cooling with feed-water [11].

2.3. Leakage

Corrosion, erosion and thermal stress can cause holes and cracks resulting in a flow of water or steam into the combustion side of the boiler. The leak can be located in either the water or steam tubes, but a leak in the furnace wall-tube is the most severe due to the risk of water to come in contact with the smelt. A leak in the economiser results mainly in a water flow, with some flashing steam, while a leak in the super-heaters results in a pure steam-flow.

A smaller leak from a corrosion hole can cause erosion on tubes close to the leaking tube. The erosion can then lead to a larger tube rupture with an extensive leakage flow as result. The magnitude of a leakage can be varying. Leakages have in other models been simulated with flows from 0.2 kg/s [12,13].

3. Early-warning

Leakage detection by analysing the mass-balance on the steam-side of the boiler is only possible when a large leakage flow is present. This is due to relatively low-measurement precision on feed-water and steam-flow in comparison to a leakage flow. A leakage can also be detected on the combustion side by indirect calculations of mass-flows, but the precision is lower with this method compared to the method exploiting the mass-balance on the steam-side. By combining the two balances, indications on a leakage can be considered from both the steam-side and the combustion side. This is exploited here to generate an early-warning to the process operator.

3.1. Bayesian networks

In this paper, we use a Bayesian network for diagnostics. A Bayesian network is defined from [7]: