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Determination of uncertainties in energy and exergy analysis of a power plant

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ABSTRACT

In this study, energy and exergy efficiency uncertainties of a large scale lignite fired power plant cycle and various measurement parameter sensitivities were investigated for five different design power outputs (100%, 85%, 80%, 60% and 40%) and with real data of the plant. For that purpose a black box method was employed considering coal flow with Lower Heating Value (LHV) as a single input and electricity produced as a single output of the plant. The uncertainty of energy and exergy efficiency of the plant was evaluated with this method by applying sensitivity analysis depending on the effect of measurement parameters such as LHV, coal mass flow rate, cell generator output voltage/current. In addition, an extreme case analysis was investigated to determine the maximum range of the uncertainties. Results of the black box method showed that uncertainties varied between 1.82–1.98% for energy efficiency and 1.32–1.43% for exergy efficiency of the plant at an operating power level of 40–100% of full power. It was concluded that LHV determination was the most important uncertainty source of energy and exergy efficiency of the plant. The uncertainties of the extreme case analysis were determined between 2.30% and 2.36% for energy efficiency while 1.66% and 1.70% for exergy efficiency for 40–100% power output respectively. Proposed method was shown to be an approach for understanding major uncertainties as well as effects of some measurement parameters in a large scale thermal power plant.

1. Introduction

Every measurement of a physical quantity involves uncertainty which must be expressed in the result of an analysis. Reporting a measurement and/or an indicator originating from this measurement without range of uncertainty can result in misleading and incomplete conclusions. Both energy and exergy efficiency is one of the major key performance indicators of a power plant [1] and therefore, associated uncertainties must be known for a correct interpretation of the condition of the plant. Unlike conventional energy analysis and exergy analysis based on second law of thermodynamics enables to locate major sources of irreversibilities and inefficiencies in a power plant. When conducting such analysis proper determination of uncertainties must be known for a complete picture of the plant. Since efficiency of a plant is calculated by means of various measurement devices during operation sensitivity of those uncertainties due to measurements is a major concern as well.

Uncertainties in a large scale modern power plant can be analyzed in a very large spectrum. Several national and international standards envisage uncertainties in determining efficiency of a power plant and they include the following uncertainties but not limited to thermodynamic parameters and coefficients, volumetric and flow measurements, LHV (Lower Heating Value) assignment, combustion parameters such as air/fuel ratio, input and loss calculations, unburned combustibles in the slag and flue dust, electrical device measurements and so forth. Some of these uncertainties are so small that they are neglected [9]. However, in these standards most of the uncertainty concern is given to boilers due to their complex structure and importance within the cycle.

There are not so many papers about the first and second law efficiency uncertainties of a power plant and its components. Most of the studies lack of uncertainty figures in energy and exergy efficiency of the power plants examined. Ameri et al. have performed a study on energy, exergy and exergoeconomics analysis for a steam power plant including load effect on exergy efficiency [2]. Regulagadda et al. have analyzed relatively a small coal fired power plant with measured boiler and turbine losses [3]. Koroneos et al. have concentrated on alternative designs for a number of power

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Nomenclature

c	mass fraction of carbon
$\dot{E}$	energy (W)
$\dot{Ex}$	exergy (W)
ex	specific exergy (J/kg)
h	enthalpy (J/kg)
h	mass fraction of hydrogen
$\dot{m}$	mass flow rate (kg/s)
n	mass fraction of nitrogen
o	mass fraction of oxygen
P	pressure (bar)
s	absolute entropy (J/kg K)
s	mass fraction of sulfur
T	temperature (K)
$\dot{W}$	work rate (W)
w	uncertainty (% pfs or absolute)
w	mass fraction of water
Greek Symbols	
η	energy efficiency
φ	ratio of chemical exergy to LHV
ζ	exergy efficiency
Subscripts	
fg	vaporization
s	sulfur
Superscripts	
CH	chemical
0	reference state value

plants running with heavy fuel, natural gas and diesel fuel [4]. Oktay has investigated exergy efficiency of coal-fired power plants with a case study of a fluidized bed power plant while suggesting some performance improvement and rehabilitation techniques for conventional plants [5]. Bejan et al. on the other hand characterizes a deep insight to exergy concept through detailed analysis extending to thermoeconomics and optimization [6]. Moran, gives a broad picture on exergy analysis by concentrating on fuel chemical exergy and application of exergy analysis to thermoceconomics [7]. Nevertheless almost none of the researchers refer uncertainties involved in the calculations.

Bresolin et al. discuss Fourier transform method for sensitivity analysis in coal fired power plant [8]. They have conducted an uncertainty analysis for energy efficiency of 160 MW coal fired power plant through comparing Monte Carlo, Fourier transform and differential methods. As they indicated evaluating plant efficiency is strongly related to measurement of plant operation and therefore it is essential for plant management to understand and know which measurements are most critical and how accurate they need to be within the context of maintenance and modernization decisions. Ertesvåg, on the other hand, determines uncertainties in heat-pump Coefficient of Performance (COP) and exergy efficiencies based on standardized testing via International (International Organization for Standardization-ISO) and European (European Committee for Standardization-CEN) standards [9]. This paper is important for showing that second law efficiencies are accounted through well known standards such as ISO and CEN. The uncertainties in the COP and exergy efficiency allowed by these two standards ranged between 5% and 10%. DIN (Deutsches Institut für Normung) standards details uncertainties for flow, pressure and temperature measurements as well as the uncertainties for LHV measurements in acceptance testing of steam generators [10]. This standard neglects the uncertainties due to enthalpy and unburned combustibles in the slag and flue dust and as well as a number of parameters which have only a very minor effect on the energy efficiency calculations. Furthermore, it is bounded to energy efficiency uncertainties only. Mcdonald and Strachan review the sources of uncertainty in the predictions from thermal simulation programs [11]. They emphasize the necessity on understanding all of the factors that can cause uncertainty. Kotas, provides accuracy of expressions used in determining chemical exergy of industrial solid, liquid and gaseous fuels [12]. As he points out the accuracy of the expression for liquid fuels is estimated to be ±0.38% and within 1% for solid and gaseous fuels. Kessel, stands out the necessity of stating the quality of measurement in terms of measurement uncertainties in order to make the measurements comparable [13]. Lars et al. incorporate uncertainty analysis in modeling of integrated reforming combined cycle [14]. They conclude that gas turbine inlet temperature, compressor and turbine efficiencies have the largest impact on uncertainties of power output and efficiency predictions. Furthermore, their systematic approach to quantify uncertainties by using Deterministic Equivalent Modeling method (DEMM) resulted in deterministic (43.4%) and probabilistic efficiencies (42–45%) for the plant in question. Liszka and Ziebik, study coal fired oxy fuel power unit process and system analysis where main components of uncertainties are presented. When two options (1% and 5%) of input variables are applied for assumed relative uncertainties, they conclude that the uncertainty in energy efficiency becomes 0.4% and 1.98% respectively [15].

In general management of a power plant operator has a global understanding of efficiency of the plant [16]. For them there is a set of inputs such as operating and maintenance labor, materials, fuel provided to the plant on one hand and electricity or product such as steam generated on the other one. Energy and exergy efficiency are key performance indicators which are widely accepted for that purpose. First one is used an indicator to show how much energy is extracted from the input while the second one can determine magnitudes and location of irreversibilites which provides more effective insight of component efficiencies. There are several methods available for determining energy efficiency of thermal power plants employed in acceptance tests [10] which also include detailed uncertainty determination. However, such methods are not used during routine operation of the plant and they do not involve exergy efficiency calculations. Acceptance tests employed in commissioning of power plants require some specific conditions such as closure of some valves, and no make up water use, in fact, tests focus on efficiency of boiler and turbines as well as electricity generated in the generator rather than analyzing the whole cycle.

The main objective of this study is determining and demonstrating the differences in energy and exergy efficiency uncertainties of a lignite-fired power plant. As indicated earlier plant management has a global understanding of efficiency in the form of fuel supplied and electricity generated. In order to reflect this prospect, a black box method is employed which accounts single energy/exergy input (coal) into and single energy/exergy output (electricity) from the power plant. A sensitivity analysis is also performed to investigate the impact of LHV and flow of the fuel as well as electricity output measurements on the uncertainty of the efficiency. Uncertainties especially in exergy efficiencies are not yet considered in many papers for overall plant based analysis. It is therefore intended to compensate this gap in the literature.