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Biomethanation plant assessment based on reliability impact on operational effectiveness

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ABSTRACT

The biomethanation process is a promising eco-friendly solution for the treatment of organic biomass that can further lead to efficient bioenergy production. Thus, the analysis of operational reliability and maintainability is important when considering the availability assessment of operative plant conditions, and accordingly, an analysis of plant operational effectiveness impact (P-OEI) is necessary to identify the opportunities for improvement in asset management. A fundamental aspect of an industrial plant is to determine what the effect of each element is on the system. To clarify the importance of the primary equipment and improve the decision making related to asset management, a novel methodology proposal has been developed and applied to real data of a biomethanation plant located in Spain. This new methodology develops an analysis based on a reliability block diagram configuration that structures the process analysis by levels, i.e., ascending for availability analysis from the element to the system and descending for the P-OEI analysis from the system to the smallest element.

The expected operational impact of EOI (i.e., the expected effect of an element constraint on the overall system) is also calculated. The P-OEI analysis conducted in this study reveals important results that can be used to evaluate the design and performance of an industrial plant.

1. Introduction

The current global scenario presents a grim picture of solid waste generation, especially in developing countries where the optimisation of waste management is necessary. Treating the waste at its source of generation is the best way to reduce the pollution load of a city [1], which means that consumer habits and commitment to the environment play a critically important role. The U.S. Environmental Protection Agency considers MSW to be a renewable energy resource [2].

Anaerobic digestion (AD), also known as biomethanation, is widely used for waste management [3,4]. Anaerobic digestion is a simple and effective biological process for the treatment of various organic wastes (MSW as well as other waste biomass, such as animal manure, crop residues, slaughterhouse and dairy production waste) and for the production of energy in the form of biogas [5]. Because oxygen is not required for the decomposition of waste, the anaerobic process is inherently the most energy efficient option for the safe disposal of organic waste with simultaneous biogas generation, which can then be used as fuel [6]. This technology requires, in all cases, the pre-treatment of the waste to ensure an adequate separation of metal, plastic, glass, paper, etc., and it has been successfully implemented in the treatment of agricultural wastes, food wastes and wastewater sludge [7]. One of the main advantages of anaerobic digestion based on the global need to reduce greenhouse gas emissions is associated with fossil fuel based energy production. A wide variety of process applications for biomethanation of wastewater, slurries, and solid waste have been developed [8]. It is generally accepted that post-treatment after anaerobic digestion is necessary to obtain a high-quality, finished product [9] as the biogas generated is not suitable for direct use. Rather, it requires a cleaning treatment prior to its use to remove components that can decrease the performance of processes or cause damage to the equipment involved in these processes. The main objective behind the cleaning of generated biogas is to reduce the concentrations of H2S, CO2 and CO, as these compounds are toxic, they reduce the quality of biogas as a fuel, and they damage metal equipment and engines in which they are used to generate

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Nomenclature and parameters

α	Scale Parameter of Weibull Distribution
A	Availability
AD	Anaerobic Digestion
β	Form Parameter of Weibull Distribution
CMMS	Computerised Maintenance Management System
EOI	Expected Operational Impact
Γ	Gamma Function
KPI	Key Performance Indicators
λ	Failure Rate
LCSA	Life Cycle Sustainability Assessment
MTTF	Mean Time to Failure
MTTR	Mean Time to Repair
MSW	Municipal Solid Waste
P-OEI	Plant Operational Effectiveness Impact
RAM	Reliability, Availability and Maintainability
RBD	Reliability Block Diagram
RES	Renewable Energy Sources

electric power. Moreover, methane production through biomethanation technology has been evaluated as one of the most energy-efficient and environmentally benign ways of producing vehicle biofuels, and as such, it can provide multiple benefits to the users. The use of biogas in vehicles, i.e., vehicles capable of running solely on biogas or on a coordinated mix of biogas/petrol is now a reality, especially in fleets of garbage trucks, buses and cars for internal use in industrial installations. The autonomy of these vehicles is generally lower compared to the autonomy of a petrol or diesel vehicle due to the lower heating value of biogas per litre of fuel. However, the estimated life of a biogas vehicle is usually between two and three years less than equivalent petrol vehicles, which also have reduced maintenance costs compared to biogas vehicles. From the perspective of the risk of inflammation, biogas vehicles are safer than gasoline vehicle because of their narrow range of flammability and because biogas is lighter than air, meaning that, in the case of leakage, biogas rises and dissipates into the atmosphere.

Recent life cycle assessment studies have demonstrated that biogas derived methane (biomethane) is one of the most energy efficient and environmentally sustainable vehicle fuels. At the same time, the nutrients contained in the remaining digestate can be used for crop production, and as well, these nutrients play a remarkable role in promoting sustainable biomass production systems [10]. Furthermore, pre-treatment, additives and reactor design according to feedstock can solve major limitations, such as low gas production from agricultural residues and large hydraulic retention time [11].

In recent times, biomethanation technology has become a more attractive source of renewable energy due to its reduced technological cost and process efficiency [10]. Moreover, household biogas digesters for rural communities have the important potential to focus on technical, economic and environmental aspects [12]. However, the application of reliable techniques to support decision making is a necessary fundamental task to achieve an accurate and efficient management of assets and resources in this type of industrial plant, even when a large number of devices with highly complex functional settings is present. A typical problem when generating and controlling action plans for improving the availability of equipment is the lack of mechanisms to support maintenance management.

The reliability theory from a life cycle perspective offers significant support for studying and generating proposals for the improvement of industrial plants [13]. Specifically, with respect to energy equipment and relevant processes, the opportunities regarding design are a relevant success factor [14], and reliability evaluation is crucial in the assessment of performance to the degree that it involves technical and cost parameters [15]. Some experiences and methodologies for power system reliability evaluation, specifically for renewable energy sources (RES), are presented in Ref. [16].

Additionally, the evaluation of assets may include the Life Cycle Sustainability Assessment (LCSA) methodology based on the ISO 14040 and 14044 environmental management principles [17].

To understand the healthiness of a productive process, it is necessary to develop an analysis of its KPI (key performance indicators). The performance measurement corresponds to the quantification process of an action, where the measurement is the process of quantification and the action leads to a performance [18].

The concepts of efficiency and effectiveness are precisely used in this context, where effectiveness refers to the extent to which the objectives or requirements defined for the process are met, and efficiency is a measure of the economy in which the resources of the company in meeting the established targets are used [19]. It is further recognised that there is a close relationship between management control through performance indicators, thus defining strategies and decision making [20,21].

Interpretation tools and methodologies to understand the performance of a single element and a total system are essential and are, as a result, continuously being requested. This deficiency is even more pronounced when the selected process for analysis must be disaggregated on many levels, where each level has been disaggregated according to several assets [22]. Therefore, a reliability, availability and maintainability analysis (RAM) must be complemented with a quantitative reliability impact analysis to interpret the real performance, to identify bottlenecks and to provide improvement opportunities. A useful and well-known indicator is the Birnaum importance measure (IM) [23], which ranks the components of the system with respect to the impact of their failure on the system's performance. Its application, however, is primarily related to epistemic uncertainties.

This article proposes an integral and quantitative innovative methodology to analyse the reliability, availability, maintainability and plant OEI [24], and it applies this methodology in a case study of a biomethanation plant. The P-OEI analysis is related specifically to production capacity and the effect of preventive and corrective maintenance intervention on system availability. This proposal designs a novel algorithm to compute an impact index based on the frequency of failures associated with the reliability and maintainability of the machinery and the expected impact according to different scenarios and configurations. This impact index, based on a probabilistic approach, defines the expected condition of the item in the system from a perspective of evaluation of its possible states (intrinsic behaviour) and related to the logical and functional configuration of the system. This approach enables an overall comparison of elements and the prioritisation of those elements, as well as a partial effectiveness evaluation.

2. Problem statement

In many industrial companies, there is no formal criteria to identify the impact of each asset and its behaviour or failure, and therefore, asset replacement decisions are made ad hoc and not as part of the business process. It is necessary to define a key performance indicator (KPI) oriented to establish a hierarchy and determine the effectiveness of the KPI's impact on the elements. For this