



An integrated multi attribute decision model for energy efficiency processes in petrochemical industry applying fuzzy set theory



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ABSTRACT

Energy efficient technologies offered by the market increases productivity. However, decision making for these technologies is usually obstructed in the firms and comes up with organizational barriers. Compressor selection in petrochemical industry requires assessment of several criteria such as 'reliability, energy consumption, initial investment, capacity, pressure, and maintenance cost.' Therefore, air compressor selection is a multi-attribute decision making (MADM) problem. The aim of this study is to select the most eligible compressor(s) so as to avoid the high energy consumption due to the capacity and maintenance costs. It is also aimed to avoid failures due to the reliability problems and high pressure.

MADM usually takes place in a vague and imprecise environment. Soft computing techniques such as fuzzy sets and system can be used for decision making where vague and imprecise knowledge is available. In this study, an integrated fuzzy analytical hierarchy process (FAHP) and fuzzy technique for order performance by similarity to ideal solution (TOPSIS) methodologies are employed for the compressor selection. Fuzzy AHP was used to determine the weights of criteria and fuzzy TOPSIS was employed to order the scenarios according to their superiority. The total effect of all criteria was determined for all alternative scenarios to make an optimal decision. Moreover, the types of compressor, carbon emission, waste heat recovery and their capacities were analyzed and compared by statistical approaches. Six different scenarios were compared, scenario III was determined to be the best which has the highest closeness coefficient. In this scenario, the turbo compressors of active system reduces the total energy consumption due to low specific energy consumption (SEC) characteristics. Although the screw compressors have high maintenance costs, the heat recovery potential makes scenario III still preferable than the other 5 scenarios.

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1. Introduction

Compressed air is one of the most important industrial inputs after fuel, electricity and water. There are numerous industries using compressed air for the variety of applications which is mainly used in instrumentation systems, industrial processes, and hand tools. The electric energy consumption of compressed air systems fall in the ranking of third order in energy costs in the production facilities [1]. In European Union, compressed air constitutes almost 10% of industrial electricity consumption [2]. The compressed air consumption is the most expensive form of energy usage in an industrial plants [3]. Although, compression of air and its usage are inefficient and costly, it is substantially preferred in the applications of petrochemical processes. This is

usually because of its reliability against the risks of explosion. As Saudi Arabia is a very hot country, the usage of compressed air is important and is more reliable. The consumption of energy, especially electricity, is expected to increase significantly over the coming decades and will require huge amount of investment in technologies used to reduce gas emissions. Besides the environmental benefits and improving energy efficiency, the optimization of the industrial systems offers a way for companies to realize productivity and operational benefits [4]. Compressors and dryers are the main energy consumers in the systems. Dindorf [5] stated that when a compressor is installed efficiently, the energy can be saved in all applications. Sapmaz et al. [6] explained that about 90% of the power used to run the compressors could be recovered as a valuable heat energy. On the other hand, quantification approaches were applied to determine the energy losses associated with compressed-air systems, and the costs to the manufacturers using the payback period [7]. Similarly, Saidur et al. [8] identified energy saving opportunities and cost of current applications of electrical

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motors. Furthermore, Jianfeng et al. [9] examined the performance of water-cooled twin screw air compressors used for the Proton Exchange Membrane (PEM) for the conservation of mass and energy. In order to improve energy efficiency in industrial systems, there are different strategies [10]. For instance, replacing low efficiency with high efficiency technologies, or one of several strategies, implies energy saving. Although there are substantial gains in energy saving and profitable investments, many companies still do not take actions to apply energy efficiency policies and systems. This is usually due to technical, economical and behavioral complexity of organization's structure. This complexity strongly influences the energy related decision making policies in industrial systems. Because, in industrial production systems, energy is the key element for transforming and processing the materials into final products. This leads making it possible to distinguish the use of energy efficiency systems between the various industrial processes and companies [4]. Therefore, decision making in energy systems is not a simple rational view, two reasons were mainly highlighted by Stern and Aronson [11] in this context: first of all, an organization is a collection of actors with potentially conflicting objectives. Secondly, organizations do not act on the basis of complete and precise information. For instance, engineers in charge of the compressor selection have to assess the advantages and disadvantages of many scenario to make an appropriate decision, because there are several designs which can provide the same services. However, due to incomplete, vague and imprecise information, many criteria have to be taken into consideration [12,13]. In this study, a MADM model is proposed to select the best portfolio of actions for replacing technologies and to support the machinery engineers for selecting the best combination of compressors employed for specific purposes. Although many techniques can be used to select the compressors, it is a highly complex and non-linear process, because several quantitative and qualitative attributes and sub-attributes have to be considered. The main attributes considered are 'pressure, capacity of compressor, initial investment, and energy consumption, reliability, and maintenance costs.' On the other hand, the evaluation and selection of energy resource alternatives is also a MADM problem, some of these alternatives may be even conflicting, and must be taken into consideration at the same time. Table 1 shows the criteria and sub criteria employed in this study to determine the best alternative. The data corresponding to all criteria were collected and used for the development of an integrated fuzzy AHP and fuzzy TOPSIS method for enhancing the compressor(s) selection in Kingdom of Saudi Arabia. The objectives of the proposed study can be summarized as follows: searching out energy saving potentials in air compressor systems, determining if the energy loss is due to non-optimized operations of the air compressor systems, encouraging the petrochemical companies for energy efficiency investment in air

compressor systems, developing cost-effective alternative scenarios, increasing the efficiency performance of alternative choices, and increasing the reliability and determining the pay-back period of alternative scenarios.

Hence, the literature on compressed air systems, energy efficiency and energy systems selection as well as multi-criteria methods was introduced in Section 2. Section 3 gives the fundamentals of fuzzy AHP methodology for compressor weight determination and sets out the data collection and evaluation by fuzzy approaches and continues with the details of fuzzy AHP application. Section 4 is devoted to the fuzzy TOPSIS methodology for multiple criteria decision making and describes selecting the best portfolio. In Section 5, the process of application and results of fuzzy TOPSIS method and the key elements for generating results are presented. Finally, Section 6 draws some conclusions and makes final remarks. The paper ends with the acknowledgement and a list of references.

2. Literature Review

The MADM methods have substantial applications in the energy fields, such as site selection, project evaluation, and equipment evaluation and selection which were widely presented by Wu and Geng [14]. The commonly used methods are briefed as; AHP is used to analyze the energy source policy [15], TOPSIS is employed to select the material of metallic bipolar plates for polymer electrolyte fuel cell [16], and ELECTRE is used to evaluate the energy planning [17]. Roghanian et al. [18] studied TOPSIS approach as a MADM technique to rank the alternatives according to their distances from the ideal and the negative ideal solution, and the advantages and disadvantages of these methods are summarized by Wu and Geng [14] and Choudhary and Shankar [19] in these studies. Kaya and Kahraman [20] used fuzzy TOPSIS method to determine the best energy technology among conventional, nuclear, solar, wind, hydraulic, biomass and combined heat-power systems for Turkey. Atmaca and Basar [21] utilized ANP method to prioritize the nuclear, wind, hydroelectric, natural gas, geothermal and coal-lignite power plants in which the criteria were ascertained by economical suitability, socio-economic, sustainability, technology and life quality issues in Turkey. Tao et al. [22] presented a hybrid model for the multiple criteria decision making problems consisting of three parts: DEA was used to provide the best combination on the performance parameters, AFS (axiomatic fuzzy set) theory and AHP were used to determine the weight of each attribute and TOPSIS was applied to provide the ranking order of that best combination based on the weights of attributes. Wu and Geng [14] evaluated attributes of solar-wind hybrid power station site (SWHPS) for selection from the perspective of project management according to the principle of AHP method.

As it is well known, knowledge of energy systems comes from the energy audit processes for improving energy efficiency, and the impact of operations. In this respect, Worrell et al. [23] identified the improvement and effectiveness of motor systems for energy savings and tackling production issues. Dat et al. [24] integrated fuzzy quality function deployment (QFD) to support the market segment selection and process evaluation by fuzzy TOPSIS method to obtain the final ranking of alternatives. In addition, Yilmaz and Dagdeviren [25] developed the class of models for energy end use to choose technologies. They combined the Fuzzy-PROMETHEE and Zero-One-Goal-Programming to select the equipment in case of vague linguistic terms existence in the evaluation process. Moreover, Liou et al. [26] used the fuzzy preference programming and the analytic network process (ANP) to form a model for the selection of partners for outsourcing providers. The

Table 1
The selection criteria and sub criteria employed to determine the compressors.

Main criteria set	Sub criteria set
Pressure	
Capacity	
Initial investment	- Oil free twin screw compressor - Oil free turbo compressor - Turbo compressor
Energy consumption	- Specific energy consumption - Stand by steam consumption - Waste heat recovery potential
Reliability	- Used or new stand by compressor usage - Start up time of stand by compressors - Leakage
Maintenance cost	- Oil change cost - Screw element change cost

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