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The potential of Saudi Arabian natural zeolites in energy recovery technologies

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ABSTRACT

Energy consumption in KSA (kingdom of Saudi Arabia) is growing rapidly due to economic development with raised levels of population, urbanization and living standards. Fossil fuels are currently solely used to meet the energy requirements. The KSA government have planned to double its energy generating capacity (upto 120 GW (gigawatts)) by 2032. About half of the electricity capacity of this targeted energy will come from renewable resources such as nuclear, wind, solar, WTE (waste-to-energy) etc. Natural zeolites are found abundantly in KSA at Jabal Shamah occurrence near Jeddah city, whose characteristics have never been investigated in energy related applications. This research aims to study the physical and chemical characteristics of natural zeolite in KSA and to review its potential utilization in selected WTE technologies and solar energy. The standard zeolite group of alumina–silicate minerals were found with the presence of other elements such as Na, Mg and K etc. A highly crystalline structure and thermal stability of natural zeolites together with unique ion exchange, adsorption properties, high surface area and porosity make them suitable in energy applications such as WTE and solar energy as an additive or catalyst. A simple solid–gas absorption system for storing solar energy in natural zeolites will be a cheap alternative method for KSA. In AD (anaerobic digestion), the dual characteristics of natural zeolite like Mordenite will increase the CH_4 production of OFMSW (organic fraction of municipal solid waste). Further investigations are recommended to study the technical, economical, and environmental feasibility of natural zeolite utilization in WTE technologies in KSA.

1. Introduction

1.1. Energy requirements of KSA

In 2013, the energy consumption in the KSA (Kingdom of Saudi Arabia) has increased up to 9 quadrillion Btu (British thermal units), due to a rapidly growing population, urbanization, and economic development. This placed the country to the world's 12 largest primary energy consumer [1]. Fossil fuels are currently solely used to meet the energy requirements. About 60% of the energy demand is fulfilled from petroleum and the remaining comes from natural gas. The government has planned to increase its electricity generating capacity of 55 gigawatts (GW) to 120 GW in 2032 to meet the ever-increasing electricity demand. For this, government has launched a special program; KACARE (King Abdullah City of Atomic and Renewable Energy) to establish the renewable-energy sources through science, research and industries [2]. The ambition is to generate about half of the electricity capacity from renewable sources such as solar, wind, nuclear and WTE (waste-to-energy) facilities by the year 2032 [1,3].

1.2. MSW (municipal solid waste) in KSA

In 2013, the total waste generation was 15.3 million tons with an average rate of 1.4 kg per capita per day [4,5]. This waste rate is projected to double (30 million tons) in 2033 with the current population growth rate (3.4%) [6]. The MSW (municipal solid waste) is consist of food waste (50.6%), plastic (17.4%), paper (12%),

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List of acronyms and abbreviations

AD	anaerobic digestion
CH_4	methane
EDS	energy dispersive spectrometer
FFA	free fatty acid
FAME	fatty acid methyl ester
GW	gigawatts
GHG	greenhouse gases
KACARE	King Abdullah City of Atomic and Renewable Energy
KSA	Kingdom of Saudi Arabia
MSW	municipal solid waste
NZ	natural zeolite
OFMSW	organic fraction of municipal solid waste
PVA	poly vinyl alcohol
RDF	refused derived fuel
SWM	solid waste management
SEM	scanning electron microscopy
WTE	waste-to-energy

cardboard (6.6%), glass (2.9%), wood (2%), textile (1.9%), metals (1.9%), aluminium (0.8%), leather (0.1%) and others (3.7%) [4,5]. Animal waste including rumen, blood, stomach, intestine and fats is another main source of waste generated from slaughter houses [7]. The municipalities regulate the SWM (solid waste management) activities in the KSA [4]. All the household and commercial places waste is collected and disposed at the landfills or dumpsites without value-added product or energy recovery [5]. The requirement for landfill is extremely high, about 28 million m^3 per year. The recycling of metals and card boards is the only waste recycling practice, which covers 10–15% of the total collected waste by informal sector [8].

1.3. WTE (waste-to-energy) technologies in KSA

There are several WTE technologies in use worldwide: incineration, pyrolysis or gasification, plasma arc gasification, RDF (refused derived fuel), AD (anaerobic digestion), and transesterification to generate energy and value-added products in the form of electricity, transportation fuels, heat, fertilizers and chemicals [4,9,10]. Each of these technologies and their setup depends on the type of waste, capital and operational cost, technological complexity, labour skill requirements, geographical locations and the conversion efficiency of the technology [11,12]. The possibilities of WTE have never been investigated in KSA until very recently. Ouda et al. [4,5] showed the high environmental values of the two MSW management scenarios such as mass burn and mass burn with recycling over landfilling option with regards to energy demand, GHG (greenhouses gas) emission reductions, and landfill area saving.

1.4. The role of natural zeolites in energy applications

Zeolites are micro-porous crystalline materials made up of mainly silicon, aluminium and oxygen atoms. There unique micro-porous framework structure gives them the capability to be used in a wide range of applications [13]. There are around 50 different types of naturally occurring and 150 synthetic zeolites identified all over the world [14,15]. The zeolite applications include, but not limited to; petroleum industry, environmental sector, water purification, oil spill clean-up and radioactive substance adsorption etc (Table 1). The use of natural zeolites in energy applications such as solar energy, pyrolysis, AD and transesterification have gained a significant interest due to their qualities of gas adsorption, moisture absorption and heat storage [14]. Rancon and Laurent [16] highlighted the availability of natural zeolites in KSA in the areas of Jabal and Harrat Shamah, near to Jeddah city. Different types of natural zeolites such as mordenite, heulandite/clinoptilolite, analcime, stilbite, thomsonite, natrolite, chabazite and wairakite were found in these areas [17].

1.5. Focus of the paper

There is no WTE facility exist in KSA to convert waste into energy and value-added products. Similarly, the natural zeolites available abundantly in KSA are not characterized for their potential role in energy-related applications as a process catalyst and additive. Therefore, this research aims to study the physical and chemical characteristics of natural zeolite in KSA and review its potential utilization in selected WTE technologies and solar energy.

2. Materials and methods

2.1. Study area

Harrat Ash-Shamah is an area located in the North West of KSA. It is extended from North West KSA to Jordon and Syria. The word Harrat is meant to the lava fields in Arabian Peninsula [18]. These fields are made of fluid blastic lava. Small shield volcanoes, tuff ring, composite volcanoes and cinder cones are scattered across these fields. Minerals of olivine, pyroxene, plagioclase and zeolites are found in these fields [19]. Volcanic activity in the area started 10–14 million year ago, however the recent activity was about few hundred years ago. Lava field was established from these volcanic activities comprised of five episodes, which appeared during the different time periods. In the interval time between the volcanic eruption, wind had blown Arabian desert sands onto lava and hence layering of sediment and lava was found [18,20].

The young volcanic Harrat fields is 600 km long on north southern chain (Makkah-Medina-Nafud volcanic line), having no direct link related to Red Sea Rift. The total area is broadly divided into two distinct areas i.e. between Makkah and Medina (20,000 km^2) and between Medina and Great Nafud (20,560 km^2). The area between Makkah and Medina have scoria cones (644 in number), shied volcanoes (36) and domes (24), while between Medina and Great Nafud there are also scoria cones (327 in number), basaltic shield volcanoes (46), domes (20), tuff cones (5), basaltic stratovolcano (1) and major lava flow (39). The areas lies in between Medina and Great Nafud are harrats Khaybar, Ithnayn and Kura. These are the biggest and longest basalt flow with most extensive lava-tubes in southern part of KSA [18–20].

Volcanic eruption and Red sea rifting are directly linked with the occurrence of zeolite in KSA mainly in the areas called Jabal Shamah and Harrat Shamah. Harrat tuffil was formed during the Plio-Pleistocene volcanic activity. It is mainly composed of thin blast flow. It has similar lithostratigraphic as the Jabal Shamah, however rhyolitic rocks are covered with recent basalt flow. Zeolite deposit found in this area has association with the pyroclastic green tuff of the field [21]. Exposure of Jabal Shamah is due to the early Miocene volcanic eruption and related to beginning of Red sea split in the Arabian-Nubian Shield. The whole area contains the deposits of hydrothermal and silicified pyroclastic pumiceous breccia and rhyolite lava [18,20,21].

2.2. Sample collection

The areas in KSA with respect to zeolite occurrence are Jabal and Harrat Shamah. Harrat Shamah is located on coordinate E39°40′18″