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THE MOST MERCIFUL

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فهرس المحتويات

الموضوع **صفحة**

Survey of soil microorganisms distributed along Farasan Al-Kabir Island, Southwestern Coast of Saudi Arabia

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Abstract

The small coral island group of Farasan Archipelago had been declared as a terrestrial and marine reserve by 1996; those lie along the southern Red Sea and southwestern coast of Saudi Arabia. Two survey studies were conducted to outline the distribution of two main soil microorganisms, fungi and bacteria inhabiting the soil of Farasan Al Kabir Island which is the biggest island in the Farasan Archipelago. A total of 200 soil samples were collected from seven different sites chosen for the survey study, along 4 months from October 2019 to January 2020. Data showed that there is a high abundance of fungal genera more than bacterial genera in all the studied areas. For fungal isolation, each soil sample was mixed in the test tube containing 0.5% NaCl. The supernatant was centrifuged for 30 minutes at 2000 Rpm and 0.2 ml of the suspension was added to Czapek's Dox Agar media. For the isolation of bacteria, the serial dilution techniques on NA (Nutrient Agar was performed). The frequency (F) % of the isolated fungi and bacteria were calculated and recorded. A total of 27 fungal isolates belonged to the genera *Rhizoctonia* sp., *Fusarium* sp, and *Saccharomyces* sp., *Alternaria* sp., *Aspergillus* sp., *Botrytis* sp., *Helminthosporium* sp., *Mucor* sp., *Penicillium* sp., *Rhizopus* sp., *Sclerotinia* sp. and *Verticillium* were the most common fungi with frequency of 31-77.0%, followed by *Chaetomium*, *Cladosporium*, *Diplodia*, *Gibberella*, *Macrophomina*, *Paecilomyces* sp. Which were quite common with frequency of 20.6-27.6%. Meanwhile, *Acremonium* sp., *Actinomucor* sp., *Ascochyta* sp., *Candida* sp., *Cryptococcus* spp., *Curvularia* sp., *Dactylospora* sp., *Mycelia* sp., *Saagaromyces* sp. and *Stemphylium* sp. were less common with frequency of 6.5-17.2%. Also, eighteen bacterial isolates were found to belong to the genera *Corynebacterium* sp., *Ralstonia* sp., *Staphylococcus* sp. and *Bacillus* sp. were the most common in collected soil samples with frequency of 42.9-67.9%, followed by *Citrobacter* sp., *Paracoccus* sp., *Streptomyces* sp., *Azotobacter* sp., *Frankia* sp., *Klebsiella* sp., *Rhodococcus* sp., *Spirillum* sp., *Streptococcus* sp. which showed 12.5-37.9% Frequency. Meanwhile, *Clostridium* sp., *Micrococcus* sp., *Sarcina* sp., *Pseudomonas* sp. and *Xanthomonas* sp. showed the least Frequency (%) ranged between 5.9-11.5.

Keywords: Farsan Island, Fungi, Bacteria, soil microorganisms, Arabian Peninsula, Survey study

1. Introduction

The worlds northern most tropical sea (Red-sea), situated in area between Asia and Africa. KSA (Kingdom of Saudi Arabia) occupies 80% of kilometers of the Red Sea's eastern coastline; which includes more than 1100 islands (SGS, 2017). The red sea part of Southern islands in KSA occupies a unique geographical & ecological position (Hall et al., 2010, Myers et al., 2000; Mallon, 2011).

The Farasan Archipelago; is found forty kilometers offshore of the south western KSA coast in those areas near Jazan, between 16°20' to 17°20' latitude and 41°24' to 42°26' longitudinal (Figure. 1).

A fertile marine environment is an important character of an Archipelago as stated by (Kingdon, 1990, and Hausmann et al., 2019)

A majority of the Farasan Archipelago islands has been announced as a protected (save) area in period from 1989 by the KSA government (Cunningham and Wronski, 2011).

Soil microorganisms are diverse of Prokaryotic and Eukaryotic lineages, which play an important role in the decomposition of soil residues and consequently influence nutrients levels in soil (Bonkowski, 2004; Ruggiero et al., 2015).

Bacteria and fungi are considered as an important component among those microorganisms of the soil fauna which are typically constituting soil biomass depending on the depth of the soil and nutrition condition. Geographically; they are widely distributed, and observed in a wide range of habitats principally in soil (Gaddeyya et al., 2012; Magnuson and Lasure, 2002). The dominant group of Kingdom Myceteae is fungi which are considered as the main reservoir of fungi as stated by (Benson, 2002, Ali-Shtayeh and Jamous, 2000, Rane and Gandhe, 2006). Based on how they obtain their energy, mutualisms, decomposers and plant pathogens, the soil of fungi is grouped into three functional groups (Brady and Weil, 2002, Tugel et al., 2000). Also, soils have more than a million bacterial species (Gans et al., 2005).

Few groups of Bactria are considered as soil-borne, possibly because non-spore-forming bacteria can't survive well in soil for long periods (Genin and Boucher, 2004; Nester et al., 2005).

Despite several studies have been conducted to study the biodiversity of flora and fauna of the Farasan Archipelago, (Alfarhan et al., 2002, Atiqur Rahman et al., 2002, Tomas et al., 2010, Al-Mutairi et al., 2012, Al Mutairi and Al-Shami, 2014), no study has been conducted to document the soil microbial community at Farasan Archipelago islands. Only a survey study was conducted by El-Serehy et al. (2020) on the aquatic world of microbe of the Farasan Archipelago. This study focused only on the distribution of eukaryotes (nano-flagellates and ciliates) and Prokaryotes (bacteria) in water samples collected from the Farasan Archipelago. So, additional survey studies are needed of soil microorganism's diversity in different islands of the Farasan Archipelago. Therefore, the present survey study aimed to isolate and identify different fungal and bacterial genera which are representing in the collected soil samples from a larger island, Farasan Al Kabir of the Farasan Archipelago and demonstrates the frequency (F) of these microorganisms in soil samples.

2. Materials and Methods

2.1. Study Area:

The entire Farasan Archipelago (Figure. 1) includes of more than 120 different coral reef islands of different sizes (> 0.2–381 km^2). Archipelago width reaches 120 km in the southeast to a northwest direction (Cooper and Zazzaro, 2014). The Archipelago's largest islands is Farasan Al-Kabir and has permanent human residents, its elevation reaches up to 30m with some hills rising to 70m (Almalki et al., 2017). Farasan Al-Kabir is located in 16°42'N, 42°06'E, with a length of 66 km and a width of 6–8 km. It's 381 km^2 in area and has the longest perimeter (216 km) (Figure. 1). The islands are made-up of elevated plateaus (Cooper and Zazzaro, 2014).

Island soil characteristics feature mare dunes, coral rock outcrops, and marine flats (Hall et al., 2010). Subtropical climate and arid; with a high annual average temperature (30.3°C), a low rainfall, and 64.2% average relative humidity is most important character the Archipelago, (AL-Qthanin, 2019).

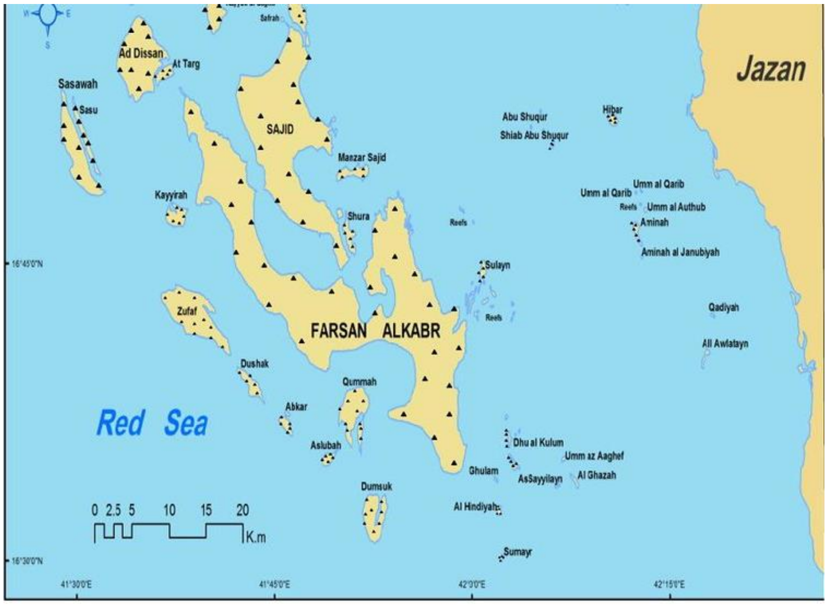

Fig. 1: Farasan archipelago islands in the KSA Red-Sea, (Source: Ministry of Defense, KSA).

2.2.Survey studies:

Two survey studies were carried out from October 2019 to January 2020 to determine the occurrence of fungal and bacterial genera in different locations in Farasan Al-Kabir Island. A total of 200 composite soil samples of 1 kg soil collected from seven locations at depth of 15-20 cm in Farasan Al Kabir Island; Al-Qassar, Messila, Muharraq, and Seer villages, Ottoman castle, Al Ghadeer Beach, and Farasan Islands Reserve (Table 1). During the sampling, necessary precision was considered to provide samples from different locations and places not directly exposed to sunlight. All samples were kept in polyethylene bags, labeled and transferred to the microbiology laboratory, stored at low temperature (4°C) for fungal and bacterial isolation and identification.

Table 1: Soil Samples collected from different locations in Farasan Al-Kabir Island

Location	No. of collected samples
Al Ghadeer Beach	26
Al-Qassar village	26
Farasan island reserve	30
Messila village	34
Muharraq village	29
Ottoman castle location	24
Seer village	31
Total No. of soil samples	**200**

2.3.Fungal isolation and identification:

Soil samples were mixed thoroughly at room temperature. Big particles were broken by hand to reach a reasonable uniform size.

The test tube contains 24 ml of 0.5% sterile NS (normal saline) where the sample of three grams of soil was transferred and mixed for three to five minutes and then the suspension was left in the laboratory at 25 ± 2 ºC for one hour for soil precipitations. The supernatant (5 ml) transferred to another serial tube and underwent centrifugation for 30 minutes at 2000rpm. One ml of sterile normal saline (NS) was added to the sediment and shaken for ten to twenty-second; after getting rid of the supernatant (Waksman, 1922).

Two ml of penicillin antibiotic and streptomycin solutions (2µg/l) were added to prevent bacterial growth and then vortexed for ten to twenty-second. The tube was incubated overnight in the lab at 27 ±2°C (Nazir et al., 2007). Again the solution was shaken and immediately, 0.2ml suspension was carefully added to Czapek's Dox Agar medium (CDA) and incubated at 27±2 ºC for fungal observation.

Successive transplanting technique of colony edge used to purify developed fungal colonies. The culture plates were incubated at 27±2 ºC for four to seven days. The morphological and microscopical characteristics used to identify the purified fungus, as described by Raper and Fennell (1965), Domsch et al. (1980), and Onion et al. (1981). The obtained fungal culture was saved on CDA plates and kept in the refrigerator at 5 °C.

2.4.Bacterial identification and isolation:

For the isolation of bacteria, the serial dilution techniques on NA (Nutrient Agar medium) were used. In order to prepare the sample suspension; one gram of each soil sample was added to a 20 ml buffer phosphate solution containing 0.05% M/V tween 80 (Sigma –Aldrich, USA) 10 ml distilled water, and vortexed well for 15min.

Serial dilutions of 6 up to 10 were prepared. Aliquots, 0.5 ml of the original sample and its serial dilutions were spread with a glass spreader, in triplicate, onto the surface of NA media and incubated at 37±2°C for bacterial observation (Dhingra and Sinclair, 1985).

Bergey’s Manual of Systematic Bacteriology; used for Morphological characterization of isolated bacterial cultural identifications according to (Krieg and Holt, 1984).

Cellular morphology was checked using gram-stating methods where the spore staining technique was used for identification of spore staining technique. The pure culture was grown on a nutrient agar medium for identifying and differentiating bacteria. The plates were incubated at 37±2 ºC in the incubator and readings were taken twenty-four hours after inoculation. The bacterial genera were identified according to (Harold, 2002; Zaved et al., 2008).

The frequency (F) % of the bacteria and fungi isolates were calculated and recorded according to the following equation F % = Number of positive samples/number of collected samples ×100.

3. Results

Data presented in Table (2) indicated that a total of 27 fungal genera were isolated from 200 soil samples collected from 7 locations; Farasan Nature reserve, Ottoman castle, Al-Ghadeer Beach, and four villages; Al-Qassar, Messila, Muharraq, and Seer located in Farasan Al-Kabir Island.

The following fungal isolates; *Fusarium* sp, *Rhizoctonia* sp, and *Saccharomyces* sp, were the most prevalent fungal genera with 55.9- 77.0% frequency (F), followed by; *Alternaria* sp., *Aspergillus* sp., *Botrytis* sp., *Helminthosporium* sp., *Mucor* sp., *Penicillium* sp., *Rhizopus* sp., *Sclerotinia* sp. and *Verticillium* sp. which showed F ranged between 31-54.2%. *Chaetomium* sp., *Cladosporium* sp., *Diplodia* sp., *Gibberella* sp., *Macrophomina* sp., *Paecilomyces* sp. were quite common with 20.6-27.6% (F). Meanwhile, *Acremonium* sp, *Actinomucor* sp, *Ascochyta* sp, *Candida* sp, *Cryptococcus* spp., *Curvularia* sp, *Dactylospora* sp, *Mycelia* sp, and *Stemphylium* sp. were less common with 6.5-17.2% Frequency.

Table 2. Frequency (F) % of isolated fungal genera from seven locations in Farasan Al-Kabir Island

Fungal isolate	Farasan Al-Kabir Island (Locations)						
	Al-Qassar village (26)*	Al-Ghadeer Beach (26)	Muharraq village (29)	Farasan nature reserve (30)	Messila village (34)	Ottoman castle (24)	Seer village (31)
***Acremonium* sp.**	**11.5****	**--**	**--**	**--**	**--**	**--**	**6.5**
***Actinomucor* sp.**	**--**	**--**	**--**	**13.3**	**--**	**12.5**	**9.7**
***Alternaria* spp.**	**34.6**	**--**	**--**	**--**	**32.4**	**37.5**	**--**
***Ascochyta* sp.**	**--**	**--**	**6.9**	**6.7**	**--**	**--**	**--**
***Aspergillus* sp.**	**48.3**	**--**	**--**	**--**	**38.2**	**33.3**	**--**
***Botrytis* spp.**	**32.6**	**--**	**31.0**	**--**	**35.3**	**--**	
***Candida* sp.**	**11.5**	**--**	**17.2**	**--**	**11.8**	**--**	**12.9**
***Chaetomium* sp.**	**--**	**--**	**27.6**	**26.7**	**--**	**25.0**	**22.6**
***Cladosporium* sp.**	**--**	**--**	**22.6**	**--**	**26.5**	**--**	**--**
***Cryptococcus* sp.**	**--**	**7.7**	**--**	**--**	**--**	**--**	**16.1**
***Curvularia* spp.**	**--**		**--**	**16.7**	**--**	**--**	**9.7**
***Dactylospora* sp.**	**--**	**11.5**	**--**	**--**	**--**	**--**	**--**
***Diplodia* sp.**	**--**	**--**	**27.6**	**--**	**23.5**	**--**	**--**
***Fusarium* sp.**	**77.0**	**--**	**65.5**	**--**	**55.9**	**58.3**	**--**
***Gibberella* sp.**	**23.1**	**--**	**--**	**--**	**20.6**	**--**	**--**
***Helminthosporium* sp.**	**48.5**	**--**		**--**	**32.4**	**--**	**38.7**
***Macrophomina* sp.**	**--**	**--**	**24.1**	**--**	**--**	**--**	**25.8**
***Mucor* sp.**	**--**	**--**	**--**	**37.6**	**--**	**54.2**	**--**
Mycelia sp.	**--**	**--**	**--**		**8.8**	**--**	**--**
***Paecilomyces* sp.**	**--**	**--**	**24.1**	**26.7**		**--**	**--**
***Penicillium* sp.**	**42.3**	**--**	**--**	**50.9**	**38.2**	**--**	**--**
***Rhizoctonia* sp.**	**66.3**	**--**	**65.5**		**--**	**--**	**58.1**
***Rhizopus* sp.**	**49,8**	**--**	**44.8**	**40.0**	**--**	**--**	**45.2**
***Saccharomyces* sp.**	**--**	**--**	**58.6**	**56.7**	**--**	**--**	**58.1**
***Sclerotinia* sp.**	**53.8**	**--**	**44.8**	**--**	**--**	**45.8**	**41.9**
***Stemphylium* sp.**	**--**	**--**	**--**	**--**	**8.8**	**--**	**--**
***Verticillium* sp.**	**50.0**	**--**	**--**	**--**	**47.1**	**--**	**48.4**

*** = Number of collected samples. ** = Frequency (F) %.**

The results presented in Table (3) indicated that 18 bacterial genera were isolated from 200 soil samples collected from 7 locations; Farasan Nature reserve, Ottoman castle, Al-Ghadeer beach, and four villages; Al-Qassar, Messila, Muharraq, and Seer located in Farasan Al-Kabir Island.

Bacterial genera, *Corynebacterium* sp, *Ralstonia* sp. and *Staphylococcus* sp, were the most prevalent in collected soil samples with frequency (F) 61.5-67.9%, followed by *Bacillus* sp. which showed F ranged from 42.9-53.8%. Also, *Citrobacter* sp., *Paracoccus* sp., *Streptomyces* sp. showed 30.0-37.9% F, followed by *Azotobacter* sp., *Frankia* sp., *Klebsiella* sp., *Rhodococcus* sp., *Spirillum* sp., *Streptococcus* sp. and *Sarcina* sp. which showed F ranged from 12.5-23.5%. *Meanwhile*, *Clostridium* sp., *Micrococcus* sp., *Pseudomonas* sp. and *Xanthomonas* sp. showed the least F% ranged between 5.9-11.5%.

Table 3. Frequency (F) % of bacterial genera isolated from seven locations in Farasan Al-Kabir Island

Bacterial isolate	**Farasan Al-Kabir Island (Locations)**						
	Al-Qassar village (26)*	**Al-Ghadeer Beach (26)**	**Farasan nature reserve (30)**	**Messila village (34)**	**Muharraq village (29)**	**Ottoman castle (24)**	**Seer village (28)**
***Azotobacter* sp.**	**14.3****	**--**	**--**	**--**	**20.7**	**--**	**--**
***Bacillus* sp.**	**53.8**	**--**	**--**	**50.0**	**--**	**50.0**	**42.9**
***Citrobacter* sp.**	**--**	**--**	**33.3**	**--**	**37.9**	**--**	**--**
***Clostridium* sp.**	**--**	**--**	**--**	**8,8**	**--**	**8.3**	**--**
***Corynebacterium* sp.**	**61.5**	**--**	**--**	**64.7**	**--**	**--**	**67.9**
***Frankia* sp.**	**--**	**--**	**16.7**	**--**	**--**	**12.5**	
***Klebsiella* sp.**	**--**	**--**	**--**	**20.6**	**--**	**--**	**17.9**
***Micrococcus* sp.**		**7.7**					
***Paracoccus* sp.**	**34.6**	**--**	**33.3**		**34.5**	**--**	**--**
***Pseudomonas* sp.**	**--**	**11.5**	**--**	**5.9**		**--**	**--**
***Ralstonia* sp.**	**--**	**--**	**--**		**65.6**	**--**	**64.3**
***Rhodococcus* sp.**	**23.1**	**--**	**--**	**17.6**	**--**	**16.7**	**--**
***Sarcina* sp.**		**15.4**					
Spirillum sp.	**17.2**	**--**	**--**	**20.6**	**--**	**--**	**14.3**
***Staphylococcus* sp.**	**--**	**--**	**63.3**	**--**	**62.0**	**--**	**--**
***Streptococcus* sp.**	**--**	**--**	**--**	**23.5**	**--**	**--**	**21.4**
***Streptomyces* sp.**	**--**	**--**	**30.0**	**35.3**	**34.5**	**37.5**	**--**
***Xanthomonas* sp.**	**11.5**	**--**	**--**	**8.8**	**--**	**8.3**	**10.7**

Legend as in Table (2)

4. Discussion

Farasan Archipelago natural ecosystem showed great biodiversity in soil microorganisms. Rhizosphere bacterial and fungal communities' distribution in seven locations in Farasan Al-Kabir Island southern KSA were studied in two survey studies.

The variability in population densities of soil microorganisms can be attributed to ecological factors, soil properties, physicochemical conditions, and vegetation which are among the most important factors that influence the distribution of soil microorganisms (Lomolino, 2001; Bryant *et al*., 2008, AlOtaibi, 2009; Dimitriu and Grayston, 2010, Fierer et al., 2011, Blaško et al., 2014 and Alghamdi et al., 2014).

Present work indicated the bacterial and fungal richness and diversity in the soil samples collected from Farasan Al-Kabir Island. First survey study data indicated that four locations, Al-Qassar, Messila, Muharraq, and Seer villages contain a higher fungal richness (13 fungal genera) than the other sites. While, two locations, Ottoman castle and Farasan Nature reserve contain seven and nine fungal genera, respectively.

From the Al-Ghadeer Beach location, only two fungal genera were isolated. The most prevalent fungal genera were *Fusarium* sp., *Rhizoctonia* sp. and *Saccharomyces* sp. with 55.9-77.0% (F). Second survey study data indicated that Messila village contains a higher bacterial richness (10 bacterial genera) than the other sites. While, soil samples collected from Al-Qassar and Seer villages contain seven bacterial genera, followed by six bacterial genera were isolated from Ottoman castle and Muharraq village and five from Farasan Nature reserve. From Al-Ghadeer beach soil samples only three bacterial genera were isolated. Bacterial genera *Corynebacterium* sp., *Ralstonia* sp., and *Staphylococcus* sp. are mostly associated with a prevalent frequency of 61.5-67.9%. Our findings are in agreement with those of other researchers (White *et al.*, 1991; Sahoo and Dhal, 2009; Toma and Abdulla, 2012).

Many researchers' hypotheses indicated that; the bacterial abundance are increases in the aquatic ecosystem of the Farasan Archipelago, according to trophic state (White et al., 1991, Sahoo and Dhal, 2009). In our present research soil samples were collected during the winter months so that, there was a reduction in the number of bacterial genera (Halim, 1984; Toma and Abdulla, 2012).

Toma and Abdulla (2012) reported that the highest frequency of isolated fungi was found during the winter season, while the lowest isolated fungi was found during the summer season. Also, data reported by Hashem (1991) indicated that twenty-nine fungal species belonging to eleven genera from soil samples of eight different places in Saudi Arabia. The most frequent genera isolated were *Aspergillus* sp., *Penicillium* sp. and *Mucor*. Also, Arif and Hashem (1998) collected soil samples from five localities in Jizan city, Saudi Arabia, to analyze fungal flora. Seventeen species belonging to 8 genera of fungi were mainly *Aspergillus* sp., *Fusarium* and *Penicillium* sp., *Alternaria* sp., *Cladosporium* sp., *Curvularia* sp. *Mucor* sp. and *Nigrospora* sp.

The present study was conducted during the winter months so that, there was a reduction in the number of bacterial genera. Many researchers' hypotheses have indicated that bacterial abundance increases in the aquatic ecosystem of the Farasan Archipelago, according to trophic state (Halim, 1984; White et al., 1991; Sahoo and Dhal, 2009; Toma and Abdulla, 2012).

5. Conclusion:

The present study considered the first investigation for the soil microorganisms distributed in the soil of Farasan Al-Kabir Island. Results showed the highest richness and diversity of soil microorganisms within the soil samples collected from Farasan Al-Kabir Island.

Due to the lack of previous studies in this field, the current research has a great value in understanding the presence of soil microorganisms in the Farsan Archipelago especially Farasan Al-Kabir Island. Further studies are needed to find out the distribution of different soil microorganisms in the other Islands.

6. Acknowledgements:

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مسح الأحياء الدقيقة في التربة الموزعة على طول جزيرة فرسان الكبير الساحل الجنوبي الغربي للمملكة العربية السعودية

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الملخص

تم إعلان مجموعة الجزر المرجانية الصغيرة في أرخبيل فرسان كمحمية أرضية وبحرية في عام ١٩٩٦م ؛ وهي تقع على طول جنوب البحر الأحمر والساحل الجنوبي الغربي للمملكة العربية السعودية. تم إجراء دراستين مسحيتين لتحديد توزيع نوعين من الكائنات الحية الدقيقة الرئيسية في التربة ،وهما الفطريات والبكتيريا التي تعيش في تربة جزيرة فرسان الكبير، والتي تعد أكبر جزيرة في أرخبيل فرسان. تم جمع عدد ٢٠٠ عينة تربة من سبعة مواقع مختلفة من الجزيرة ، على مدى ٤ أشهر من أكتوبر ٢٠١٩ إلى يناير ٢٠٢٠م. أظهرت البيانات أن هناك تواجد من الأجناس الفطرية أكثر من الأجناس البكتيرية في جميع مناطق الدراسة. بالنسبة للعزل الفطري ، تم خلط كل عينة تربة في أنبوب اختبار يحتوي على ٠,٥٪ كلوريد الصوديوم. تم الطرد المركزي للعينات لمدة ٣٠ دقيقة عند ٢٠٠٠ دورة وتم استخدام بيئة Czapek's Dox Agar. . وبالنسبة لعزل البكتيريا ، تم استخدام تقنية التخفيف التسلسلي وبيئة الاجار المغذي . اظهرت النتائج انه تم عزل ٢٧ عزلة من العزلات الفطرية والتي تنتمي إلى الأجناس Rhizoctonia sp. ، Fusarium sp، و Saccharomyces sp. ، Alternaria sp.، Aspergillus sp.، Botrytis sp.، Helminthosporium sp.، Mucor sp.، Penicillium sp.، Rhizopus sp.، Sclerotinia sp.و Verticillium بنسبة تكرار ٣١-٧٧,٠٪ ، تليها Chaetomium ، Cladosporium، Dublinia، Gibberella، Macrophomina، Paecilomyces (sp).والتي كانت بنسبة تتراوح من ٢٠,٦ إلى ٢٧,٦٪. اما العزلات Acremonium (sp.)، Actinomucor (sp.)، Ascochyta (sp.)، Candida (sp.)، Cryptococcus (spp.)، Curvularia (sp.)، Dactylospora (sp.)، Mycelia (sp.)، كانت Saagaromyces (sp.) و Stemphylium (sp.) فكانت أقل شيوعًا بنسبة ٦,٥-١٧,٢٪. كما تم عزل ثمانية عشر عزلة بكتيرية تنتمي إلى الأجناس Ralstonia (sp.)، Staphylococcus sp.و Bacillus sp. كانت الأكثر تواجداً في عينات التربة بنسبة ٤٢,٩-٦٧,٩٪ ، تليها Citrobacter sp.، Paracoccus sp.، Streptomyces sp.، Azotobacter sp.، Frankia sp.، Klebsiella sp.، Rhodococcus sp.، Spirillum sp. Streptococcus sp. التي أظهرت تواجد بنسة ١٢,٥-٣٧,٩٪. تليها Clostridium sp., Micrococcus sp., Sarcina sp., Pseudomonas sp. and Xanthomonas sp و التي أظهرت أقل نسبة تواجد تراوحت بين ٥,٩-١١,٥٪.

مفتـاح الكلمـات : جزيـرة فرسـان ، الفطريـات ، البكتيريـا ، الكائنـات الحيـة الدقيقـة فـي التربـة ، شـبه الجزيرة العربية ، دراسة مسحية .

Mechanical behavior of an epoxy reinforced with graphitic carbon nitride

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Abstract

Modern research has shown significant interest in graphitic Carbon Nitride($g\text{-}C_3N_4$)sheets because they exhibit impressive electronic and mechanical properties. These sheets also have an excellent photocatalytic property. Present studies showed the synthesize of $g\text{-}C_3N_4$ nanoparticles for the enhancement of mechanical features of epoxy composites. Four distinct weight fractions of $g\text{-}C_3N_4$ (0%, 0.5%, 1%, and 1.5 %) were used in reinforced epoxy resin. The influence of the percentage increase of nanoparticles on epoxy composites was investigated. All of these results will be compared to the neat material of epoxy resin. Because of the weak adhesion resulting from nanoparticles, the highest tensile strength was noted in a neat epoxy. There is increasing hardness when adding the $g\text{-}C_3N_4$ nanoparticles, due to the enhancement of filler-epoxy.

Keywords : Nano-composites; mechanical properties; graphitic Carbon Nitride ($g\text{-}C_3N_4$)

1 INTRODUCTION

The unique properties of epoxy resins like adhesion strength, stability, and insulating properties have made them widely used in many applications [1-7]. The addition of nanoceramics, nanowires, nanotubes, and graphitic materials can enhance the mechanical properties of resins [8-13]. Despite the possibility of crack pinning and plastic void formation, increased toughness is an added benefit [14]. There have been reports on a higher surface-to-volume ratio in the physical network structure with a strong layer of film and differences in nano-sizes in the open literature. [15,16].

Several studies revealed that 2D/two-dimensional graphitic monolayers of carbon possess tremendous advantages because of their superior mechanical, physical properties extensive industrial applications [17]. More research is focused on graphitic Carbon Nitride (g-CN) sheets due to their impressive mechanical, electronic, and photocatalytic properties [18-21]. According to the current understanding, heptazine (triazine-based CN sheets) with the chemical formula $g\text{-}t\text{-}s\text{-}C_3N_4$ is the most stable graphitic CN allotrope at ambient conditions [22]. This is because of its intrinsic uniformly dispersed cavities, which are successful at trapping nanostructures. Additional advantages of the substrate include its inert nature and wide surface area, which mean it can serve as a good substrate. There is a wide range of research interests related to the physical properties of heptazine sheets, with a particular focus on the adsorption/embedding of nanostructures [23-26]. Recently more attention was focused on strain response, mechanical, electronic interactions, and other properties of sheets.

It was also featured that for the device fabrication and thin-film development and g-C_3N_4 the strain behavior analysis is important. The studies were also extended on reinforcing fillers, improved polymer composites, mechanical properties, and thermal behaviors [27, 28].

By introducing the g-C_3N_4 as reinforcement into epoxy materials, a dual-phase combination by the viable interaction amidst $NH_2$and NH groups in g-C_3N_4 and epoxide groups would be possible. Also, the etching temperature plays a major role which affecting the content of active groups and enhancing the interaction between g-C_3N_4 and epoxy materials. This paper compares the varied percentage of g-C_3N_4 as a filler reinforced epoxy resin in various mechanical characteristics.

2 EXPERIMENTAL WORK

2.1 Materials

Nanoparticles have been added to reinforce commercial resin (LR 1110) with hardener (RAZEENCURE® 942) to produce a composite material. Nano-particles of g-C3N4 are added at various percentages to epoxy, before mixing it with hardener. The percentage of hardener to the epoxy material is twelve to one hundred.

The reagents used in this work are Urea AR and. Nitric acid (98%–99%) with analytical grade. Using deionized water, all the solutions were prepared with the help of the PURE GROUP 30 water purification system.

2.2 Fabrication of g-C_3N_4)

The facile single pot method was used to prepare g-C_3N_4 with a discrete heating (thermal polymerization) of the urea (AR, 10grams) in a crucible under ambient conditions; the ramping rate was 20°C/minute. It was then heated to 550°C using a muffle furnace for about four hours. The resulting material was then air-cooled(natural) at room temperature.

To remove the ammonia and residual alkaline species which were absorbed on the surface of the sample, a pale-whitish-yellow powder was washed with distilled water and 0.1mol/L nitric acid.

Then substance was dried for about 24hours at 80°C. Later this pale-whitish-yellow powder was utilized as a sheet-like structure of g-C_3N_4 [29-31]. Fig. 1 represents the fabrication steps of graphitic-carbon nitride using thermal polymerization used in the present investigation.

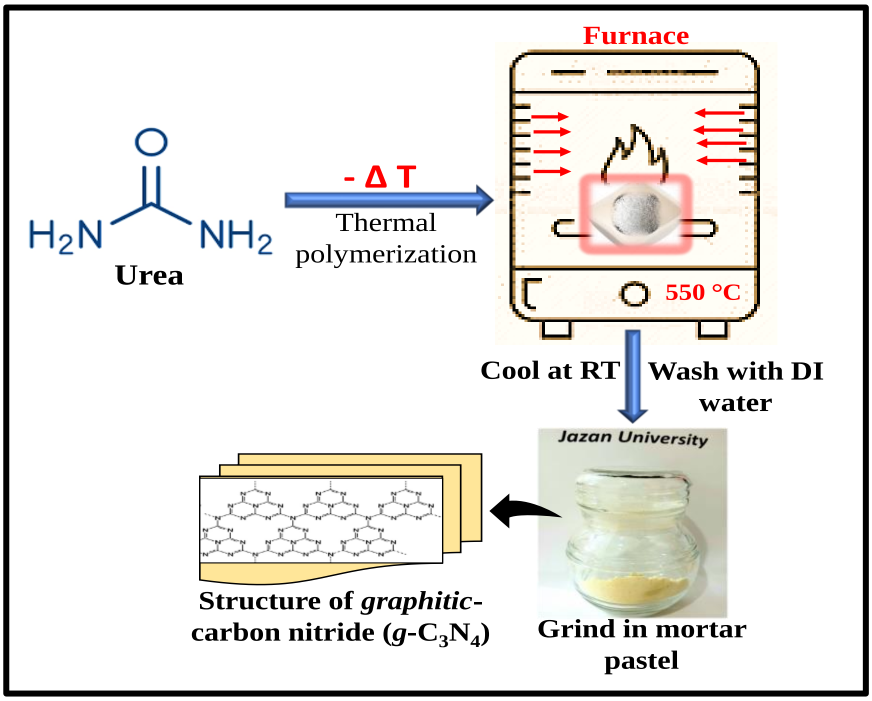

Fig. 1. Fabrication steps of graphitic-carbon nitride using thermal polymerization

Characterization of graphitic-carbon nitride (g-C_3N_4)

The fabricated graphitic carbon nitride sheets were analyzed by the XRD technique. Fig. 2 displays the X-ray diffraction patterns of the as-prepared g-C_3N_4 nanoparticle. Two peaks appear around 13.1° and 27.5°, which were attributed to the (100) and (002) planes of g-C_3N_4 (JCPDS 87-1526). The tri-s-triazine unit structure and interplanar spacing is the reason for the two peaks observed in Fig. 2 [32]. Hence g-C_3N_4 was synthesized successfully.

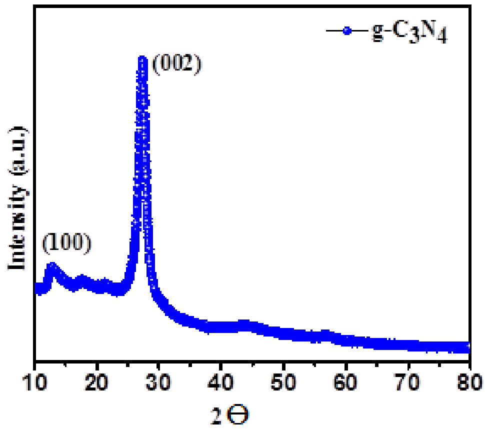

Fig. 2. XRD patterns of the graphitic carbon nitride (g-C_3N_4)

2.3 Preparation of Composite Samples

To experiment, composite samples were prepared using Sonicator equipment with having a maximum frequency of 40kHz for mixing nanoparticles with resins. Figure 3 shows the photographic view of the sonicator apparatus used in the present work.

To ensure nanoparticles were evenly dispersed in the resin, the mixture was placed in the sonicator and warmed to around 40°C for two hours. In addition, 12% hardener was added to the mixture as well. To avoid bubbles from forming, a stirrer was used to mix the mixture uniformly and the mixture was then discharged into the mold made of foam. As a result, the geometry of the mold, as well as the weight percentage of the additives, was changed which is required for proper testing.

Fig. 3 Photographic view of Sonicator apparatus

2.4 Sample and Tests Characterization

Experimental results of five specimens were obtained for each test by performing hardness and indirect tensile tests at room temperature.

2.4.1 The hardness test

The test specimen is stabilized in place, and the indenter suitable for conducting the Rockwell-B hardness (HRB) test is used with an applied load of 100kg. The diameter of the spherical indenter used in this test is equal to 5mm. The average number of specimens conducted from each composite type is five specimens.

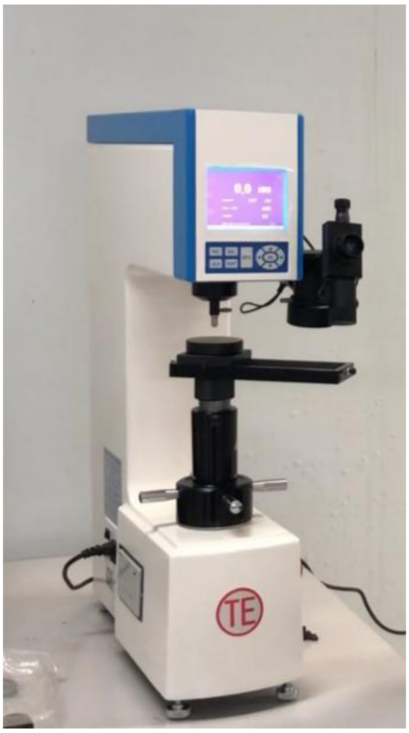

Fig. 4. Hardness Test Machine

2.4.2 Diametral Tensile Test

Diametral tensile strength (DTS) is also called an indirect tensile test. DTS of composite materials is measured in many applications by the indirect tensile test [33]. A diameter of 16 mm was used for a cylindrical-shaped specimen to conduct this test. To investigate the effects of increasing the percentage of wt. % Nano-particles g-C_3N_4 on the DTS, the samples were reinforced with fluctuating percentages of weight (0%, 0.5%, 1%, and 1.5 %) as an independent parameter. A Universal Testing Machine Instron-8801 was used to conduct DTS, corresponding to a strain rate of 0.75 mm/min. To calculate the result of the test (DTS) the following equation was used [34,35]:

$$\sigma_{DS} = \frac{2F}{\pi d t}$$

(Eq. 1)

Where; F is the fracture load, d be the specimen diameter, and t -the thickness of the specimen.

3. RESULTS AND DISCUSSION

3.1 Results of the Hardness Test

As seen in Fig. 5, the hardness increases with an increase of the nanoparticles. In other words, by adding 0.5% of nanoparticles to the neat epoxy, the hardness increased by about 37%. At the same time, with the increase in the content of g-C_3N_4 nanoparticles (0.5 to 1 %), the hardness increased by about 27%. In addition, the change in the content of g-C_3N_4 nanoparticles from 1 % to 1.5% increased by about 22%, increasing the hardness. The present experimental result is compared with others and good agreement is achieved [36-38]. The increasing hardness of these composite materials may result from the enhancement of filler-epoxy by adding nano-particles of g-C_3N_4 [39].

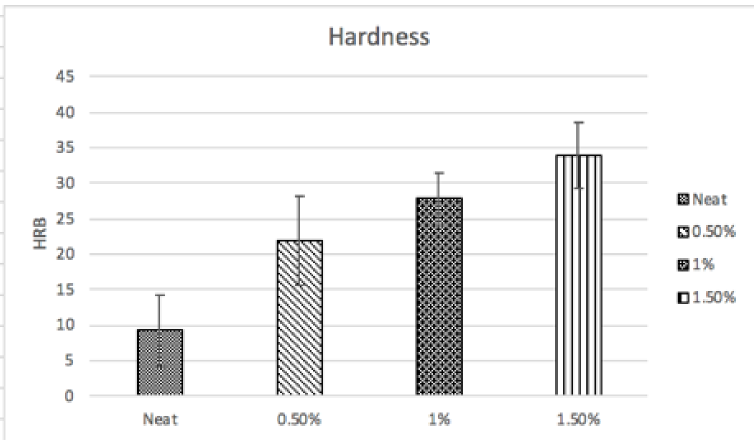

Fig. 5. Average hardness Test of various g-C_3N_4 nano additives concentrations

3.2 Diametral/Indirect tensile test results

Figure 6 shows the experimental results of the effect of nanoparticles on epoxy resins measured by indirect tensile test. It is observed that the neat epoxy has the maximum average DTS value of 40.04 MPa. It is worthwhile to note that an increase of 0.5% g-C_3N_4 nanoparticles shows the reduction of DTS value to 14.35 MPa. It is also noticed that further increase of weight percentage of g-C_3N_4 nanoparticles in epoxy resin by 1% and 1.5%, the average value of the DTS found to be decreased to 11.77 MPa and 10.17 MPa, respectively. From the experimental results, it is clearly understood that higher the additives in the composite, resulting from lower DTS value. This result showed a good agreement with others [40, 41]. The decrease in the tensile strength is mainly due to the poor adhesion between the epoxy and g-C_3N_4 nanoparticles.

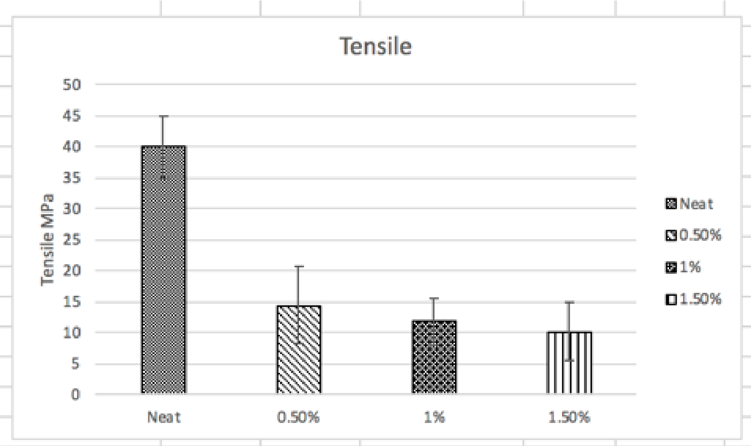

Fig. -6 Average Diametral Tensile Strength (DTS) of various concentrations of g-C_3N_4 nano additives.

4. CONCLUSIONS

The present study provides a new approach for studying the mechanical behavior of graphitic-carbon nitride nanoparticles. According to the experimental results, the following conclusions can be drawn:

- Optimum composite hardness was achieved for the maximum addition of 1.5% g-C_3N_4 nanoparticles to the epoxy resins.
- The highest tensile strength for epoxy material in this work was conducted for a neat epoxy because weak adhesion resulted from nanoparticles.
- The hardness of the epoxy is increased by adding g-C_3N_4 nanoparticles due to a higher concentration of filler-epoxy with the addition of Nano-particles g-C_3N_4.
- A decreasing trend of tensile strength of the epoxy has been observed by the addition of g-C_3N_4 nanoparticles.

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السلوك الميكانيكي للايبوكسي المقوى بنيتريد الكربون الجرافيت

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الملخص

أظهرت الأبحاث الحديثة اهتمامًا كبيرًا بألواح نيتريد الكربون الجرافيت (g-C3N4) لأنها تتميز بخصائص إلكترونية وميكانيكية رائعة. تحتوي هذه الألواح أيضًا على خاصية تحفيز ضوئي ممتازة. هذا البحث يوضح توليف الجسيمات المتناهية الصغر من g-C3N4 لتعزيز السمات الميكانيكية لمركبات الايبوكسي. تم استخدام أربع كميات مختلفة من (g-C3N4) (0%, 0.5%, 1%, and 1.5 %) في راتنجات الايبوكسي. تم التحقق من تأثير النسبة المئوية للزيادة في الجسيمات المتناهية الصغر على مركبات الايبوكسي. تمت مقارنة كل هذه المركبات الجديدة بعد إضافة النسب المختلفة من (g-C3N4) بالإيبوكسي النقي. بسبب الالتصاق الضعيف الناتج عن الجسيمات المتناهية الصغر ، لوحظت أعلى قوة شد في الإيبوكسي النقي. كما لوحظ وجود صلابة متزايدة عند إضافة جزيئات g-C3N4 المتناهية الصغر ، بسبب تعزيز حشو الايبوكسي.

الكلمات المفتاحية: المركبات المتنهية الصغر، الخواص الميكانيكية، نيتريد الكربون الجرافيتي

Theoretical Study of Burned Methanol Hydrocarbon Fuel Used in Steel Manufacturing With Emphasis on Emissions Production Rates

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Abstract

This paper discusses an alternative proposed fuel to be used in steel production plant with emphasis on emissions production rates, at certain pressures and temperatures. All calculations were performed by the Model called "PROPERTIS". Four types of emissions were tracked and estimated at different initial conditions (ϕ, P, T), CO_2, NO, CO and OH. The Lewis Number, *Le*, was also calculated for each mixture. Obtained results show that mixture strength, (ϕ), is an important parameter which influences the amount of emissions produced form combustible mixture of Methanol (CH40). Results also show that CO_2 emissions have always the highest values. Regardless of the initial conditions.

Lewis number, *Le*, for this fuel, was noted to be the highest values associated with lean mixtures, where the rich ones have the lowest values. This is due to faster thermal diffusion compared to mass diffusion in lean mixtures.

Key Words: Combustion - Methanol - Emissions - COx - NOx - OH - Lewis Number (*Le*)

1 Introduction

Steel production considered to be one of the most essential needs in industry sectors worldwide. However, due to the heavy amount of emissions emitted from production processes, it became serious threat to environments and society. Iron making industry consumes much energy and then generates significant amount of waste gas. The waste gas emitted during combustion contaminates the environment, to the extent affecting the global climate and threatening the future habitability of the earth [1]. In order to improve quality production of steel, with less emissions, more effective controlling methods must be used to monitor carbon oxides in the furnace flue gas. One common way to accomplish that is using (BF/ BOF) method, Blast Furnace/Basic Oxygen Furnace [2]. This way was noted to be less coast, more efficient and high production rates. Electric-Arc-Furnace (EAF) is another way available for steel production, in which steel scrap is re-melted and desired quality of steel grades is produced. Although this method considers a fast-growing manufacturing process, it generates high degree of harmful gases and hazardous metal dust [3]. In 2010, according to the International Energy Agency, the steel producer industry accounted for approximately 6.7% of total world CO_2 emissions.[4]. In 2012, iron and steel production and metallurgical coke production in the USA accounted emissions of around 54 million metric tons of CO_2. This number represents the third highest source of emissions in the USA [5]. In EU, during the period 2005 to 2008, it is estimated that between 4 and 7% of the CO_2 emissions has originated from the steel industries, which has generated 252.5 million tons of CO_2 emissions on this period [6].So, conducting an intensive researches and studies became a mandatory issue. In fact, carbon dioxide extends widely in our atmosphere due to the increase in burning fossil fuels and become a serious danger for environments and societies [7], [8].

Another efforts were conducted in 2017, by scientist named Alexander [9], who has analyzed some possible means for eliminating CO_2 emission from the steel industries. These ways were by integrated renewable power into the steel manufacturing process, with techniques such as blast furnace gas recirculation, furnaces that utilize carbon capture, a higher share of electrical arc furnaces and the use of direct reduced iron with hydrogen as reduction agent. It is demonstrated that these processes were applied in Germany in 2008 for reducing from 27 to 9% of CO_2 [10]. In 2020, Zeeshan [11], has analyzed experimentally that the average gases emissions are much lower in the blowing phase comparing with the melting phase of Electrical Arc Furnace (EAF) steel production. Based on his experiment work, the average concentration of CO_2 in the melting phases exceeded the alert threshold by 105%.

In 2020, Lauri [12], indicated that sintering/pelletizing, coke making, and rolling mills consider the best available technologies that can be installed in the existing integrated steel and EAF plants for assisting to improve energy efficiency and mitigate CO_2 emission. In Sweden in 2020, Alla explored that carbon capture and storage (CCS) in combination with biomass substitution in the blast furnace and a replacement primary steel production plant with Electrical Arc Furnace (EAF) with biomass yields CO_2 emission reductions of 83% compared to CO_2 emissions with current steel process configurations.

Since fossil fuel still considered to be the main, widely used fuel in such furnaces, and in industry as well. The current paper will focus on studying an alternative proposed hydrocarbon fuel, methanol, to be used in steel production plant with emphasis on emissions production rates, at certain pressures and temperatures, hoping for more reduction rates of emissions. All calculations were performed by the computational Model called "PROPERTIS, PM". Four types of emissions were tracked and estimated at different initial conditions.

2 Method of Prediction Emissions From Burned Methanol, (CH_{40}) Fuel

In this work, an effective Model was used "PROPERTIS" to evaluate emissions from combustions processes of Methanol Fuel (CH40) and the Lewis number. It requires specified input parameters ie initial temperature and pressure, equivalence ratio, and type of thermodynamic process which is in this work " adiabatic temperature and composition at constant volume", to calculate the adiabatic temperature and equilibrium composition of a flame under certain pressures and temperatures. Shown below in Fig. 1 is a sample output file produced by the "PM" model. The file displays all initial conditions for each combustion process, equilibrium pressure and temperature, and products compositions (species) in molar fraction. Shown in Table1, all combustion initial conditions used by Computational Model " PROPERTIES" for the three air-fuel mixtures types, lean, stoic and rich, with different equivalence ratios (0.8, 1.0, 1.3)

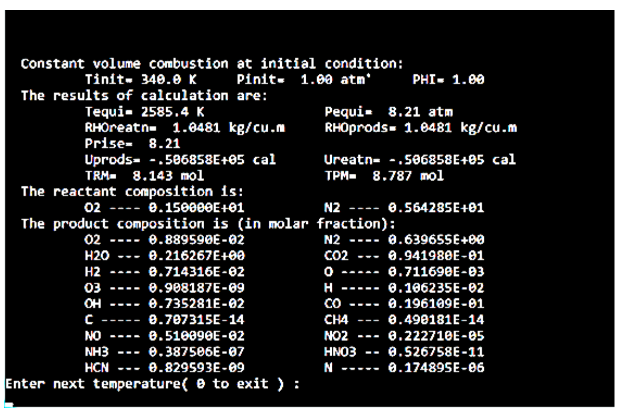

Fig. 1 Sample output calculations obtained from "Properties" software

Fuel Type	Mixture Type, (Ø)	P_i (bar)	T_i (K)
Methanol (CH40)	Lean, 0.8 Stoic, 1.0 Rich, 1.3	1	298
		1.5	298
		2	340
		2.5	400
		3	500

Table 1: Input parameters and initial conditions used for computational model, "PM".

3 Results and discussion

Three different air-fuel mixtures have been used for methanol fuel (CH_{40}), to evaluate the amount of emissions produced in mole fraction for each combustion process. First chosen mixture was lean, (ϕ= 0.8). Second one was stoichiometry, (ϕ= 1.0), and the third mixture was rich, (ϕ= 1.3). Emissions species to be calculated were Nitrogen Oxide (NO), Carbon monoxide (CO), Carbon dioxide (CO_2) and OH emissions. The Figures 2- 5 below, show emissions concentrations at various equivalence ratios, with initial conditions(Ti, Pi), 298K & 1bar.

Results showed that the "CO_2" emission is the highest concentration for all mixtures, with gradual decrease as the mixture shifts to rich regimes for all conditions. All graphs show similar trends for all species at different temperatures, ranging from 298K to 500K. On the other hand, "CO" emission tends to increase for all mixtures as ϕ and T increase. The other emission species, (CO_2, NO and OH) tend to decrease . It's also noted that they all decrease as ϕ shifts from lean to rich mixtures, except CO, it increases for all mixtures.

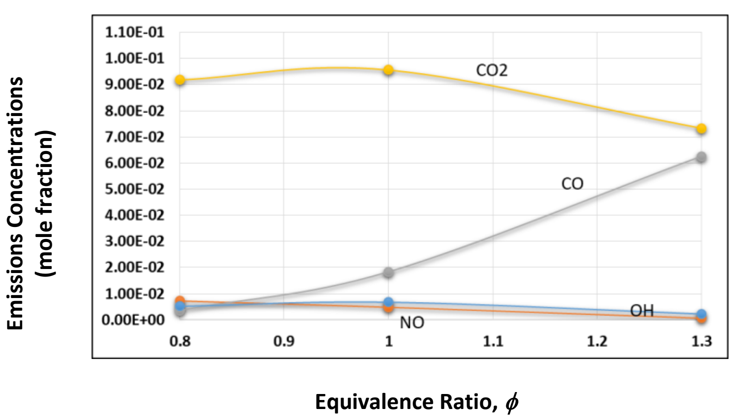

Fig. 2 Effects of Equivalence Ration on Emissions

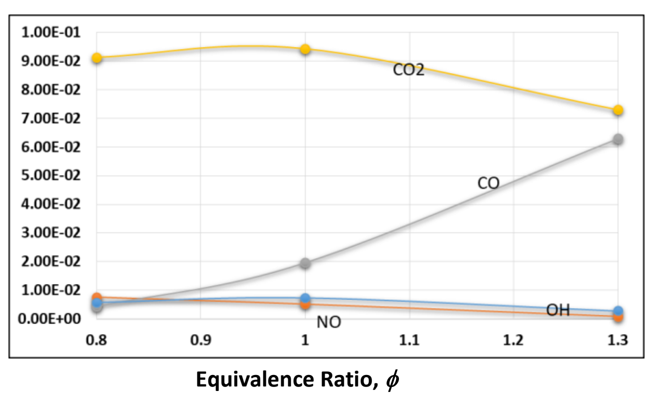

Fig.3 Effects of Equivalence Ration on Emissions

Production Rates at Initial Pressure and Temperature,Pi , Ti, (1 bar , 298 K).

Production Rates at Initial Pressure and Temperature,Pi , Ti , (1 bar , 340 K).

It is quite clear from previous figures, that the same behaviors in values of concentrations for all mixtures and species of methanol fuel, was noted. Which proves that variations of temperatures at the same pressure have nearly, no effects on emissions concentrations. Even at higher temperatures as shown in figures 3 and 4, show same trends and behavior.

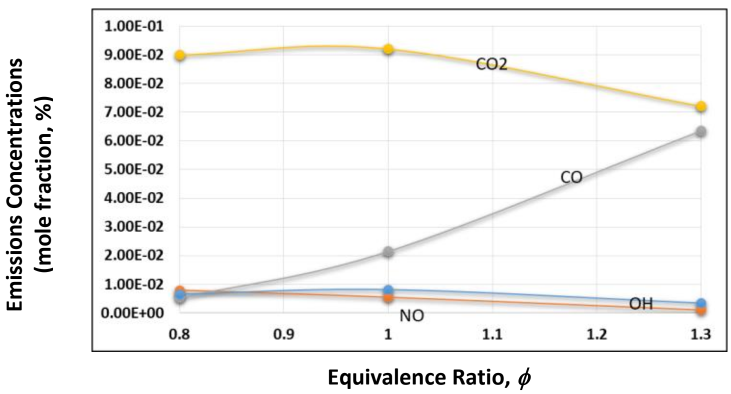

Fig.4 Effects of Equivalence Ration on Emissions Production Rates at Initial Pressure and Temperature,Pi , Ti, (1 bar , 400 K).

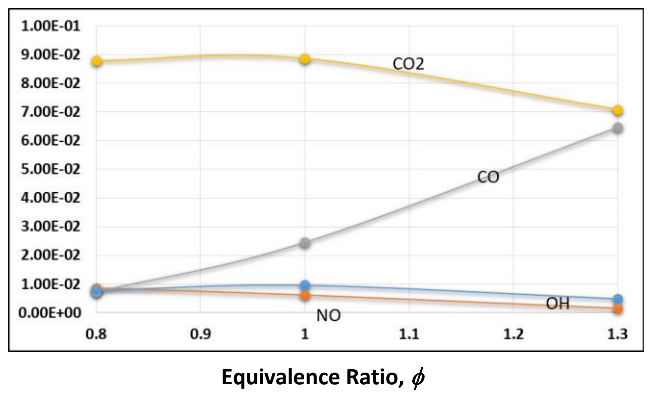

Fig.5 Effects of Equivalence Ration on Emissions Production Rates at Initial Pressure and Temperature,Pi , Ti, (1 bar , 500 K).

The Figures 6 - 9 below , show effects of Equivalence Ration, Pressures and Temperatures changes on the production rate for each emission species . it is noted that the maximum concentrations for CO_2 and OH, emissions is at ϕ =1 , where the maximum value for CO is at rich condition (ϕ=1.3). On the other hand NO emissions have the highest value at lean condition

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(ϕ=0.8). Also, shown on the mentioned graphs below, effects of Ps and Ts variations on emissions production rates for all mixtures. It's quite clear that increasing pressures and temperatures increase emission concentrations for all species except CO_2, it decrease with increasing P & T. This is due to the chemical chain reactions rates and activation energy effects

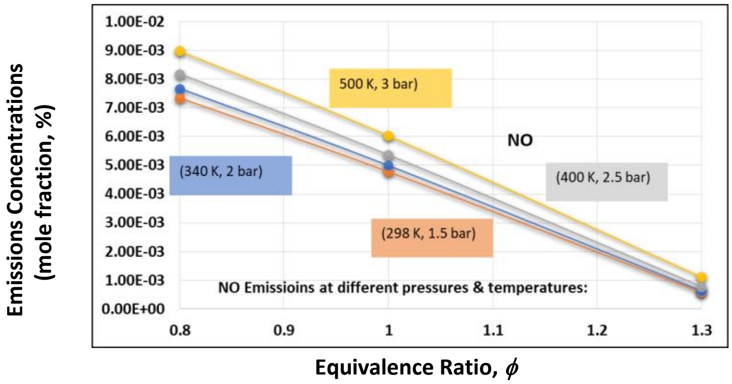


Fig.6 Effects of Equivalence Ration, Pressures and Temperatures changes on NO Emission Production at different pressures and temperatures.

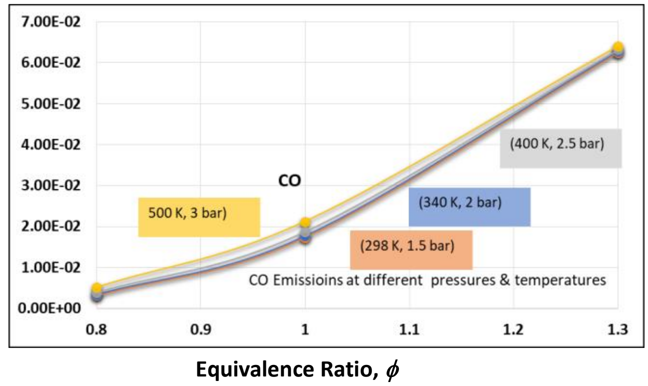


Fig.7 Effects of Equivalence Ration, Pressures and Temperatures changes on CO Emission Production at different pressures and temperatures.

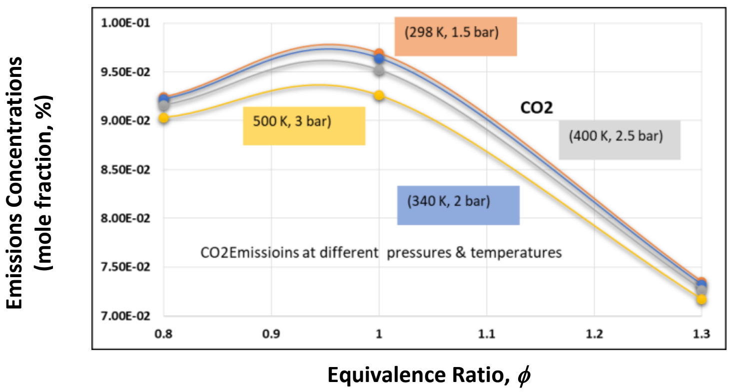


Fig.8 Effects of Equivalence Ration, Pressures and Temperatures changes on CO_2 Emission Production at different pressures and temperatures .

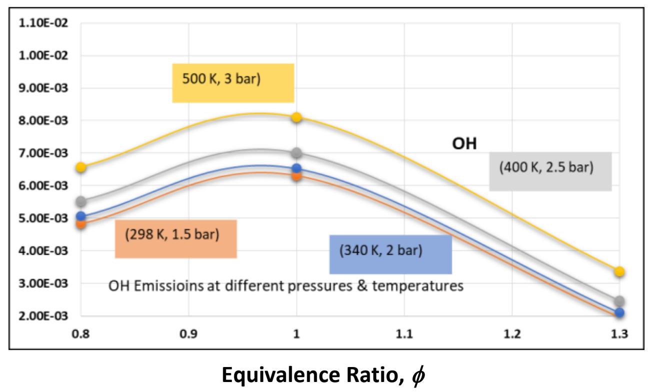


Fig.9 Effects of Equivalence Ration, Pressures and Temperatures changes on OH Emission Production at different pressures and temperatures.

Shown in figure 10, Lewis Number, which is a dimensionless number, named after Warren K. Lewis (1882–1975). It is defined as the ratio of thermal diffusivity and mass diffusivity. It is used to characterize fluid flows where there is simultaneous heat and mass transfer. The Lewis number is therefore a measure of the relative thermal and concentration boundary layer thicknesses [13]. It can be calculated using the following equation (1) :

$$Le = \frac{\alpha}{D} = \frac{K}{\rho C_p D} \qquad (1)$$

Where,

α: the thermal diffusivity, D: mass diffusivity,

K: thermal diffusivity, C_p: the specific heat constant

for different methanol-air mixtures (lean, stoic and rich). From the mention figure, it is so clear that the highest values associated with lean case, where the rich mixtures have the lowest values. This is due to faster thermal diffusion compared to species diffusion in lean mixtures. Consequently, this may result in reduced turbulent flame propagation. The figures 11 – 13, show the effects of pressures and temperatures changes on Lewis Number. Results, clearly, indicate that for stoic and rich mixtures no effects on values of Le, whereas, for lean mixture, the values decreases as P & T increases.

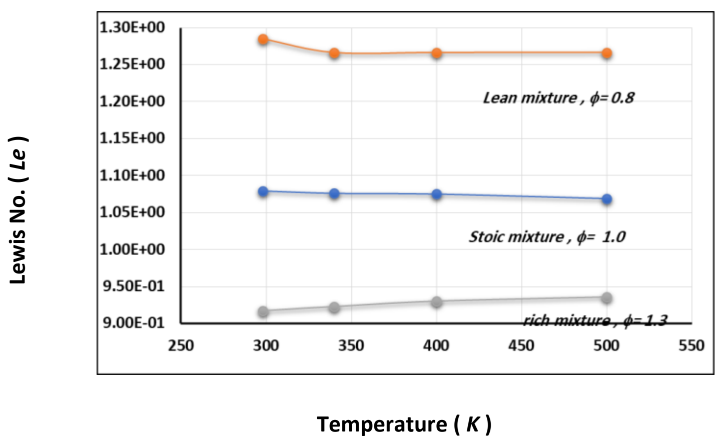


Fig.10 Variation of Lewis number with temperature for different methanol-air mixtures (lean , stoic and rich) at initial conditions: Pi = 1 bar and Ti = 298 K.

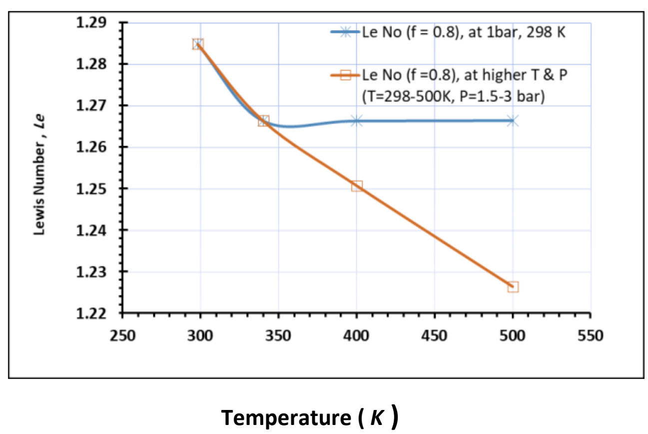
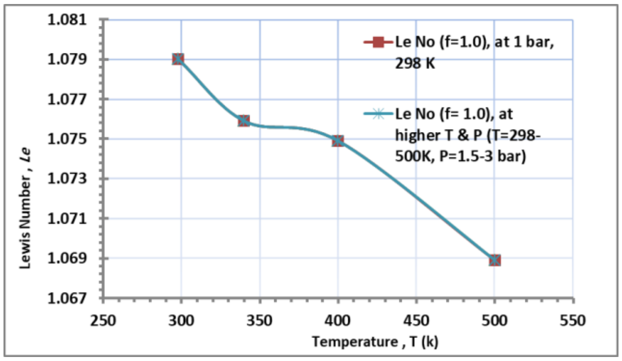
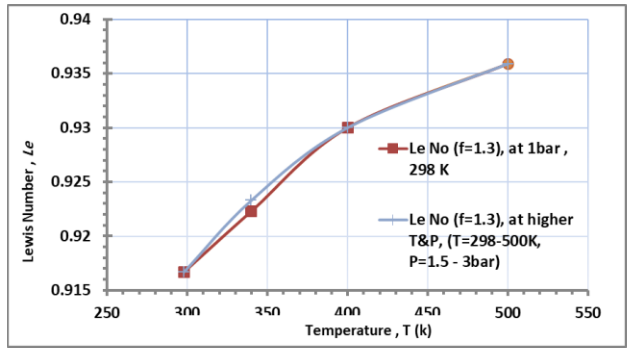


Fig.11 Variation of Lewis number with temperature for lean, (ϕ =0.8), methanol-air mixture at higher P and T ranging from 1.5 -3 bar & 298 – 500 K. compared to initial results at 1 bar and 298 K.

Lewis No. (*Le*)



Temperature (K)



Temperature (K)

Fig.12 Variation of Lewis number with temperature for stoic, (ϕ =1.0,), methanol-air mixture at higher P and T ranging from 1.5 -3 bar & 298 – 500 K. compared to initial results at 1 bar and 298 K.

Fig.13 Variation of Lewis number with temperature for rich, (ϕ =1.3,), methanol-air mixture at higher P and T ranging from 1.5 -3 bar & 298 – 500 K. compared to initial results at 1 bar and 298 K.

It is an interesting fact to mention here that fuels with high Lewis numbers have an applications in spark ignition engines, gas turbine, etc., [12]. Therefore examining flames characteristics for such fuels is an essential issue, to ensure high thermal efficiency in such applications.

4. Conclusions

The investigation in this study shows that emissions produced from burned proposed hydrocarbon fuel (methanol CH_{40}), used in steel manufacturing, are strongly effected by equivalence ratio (mixture strength). The specie "CO_2"emissions have always the highest values regardless of the initial conditions. The pressure increase has positive effects on emissions concentrations with exception for CO_2, it decreases as P&T increases. Finally, Lewis Number for this fuel, was noted to be the highest value with lean mixtures, where the rich ones have the lowest. This is due to faster thermal diffusion compared to mass diffusion in lean mixtures. Emissions of this fuel seem to be fairly low compared to some other hydrocarbons fuels due the chemical structure of methanol and low number of carbon atoms, (single C atom).

Recommendation

Experimental work for this study is recommended to verify obtained results and check for accuracy .

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دراسة نظرية لوقود الميثانول الهيدروكربوني المستخدم في تصنيع حديد الصلب مع التركيز على معدلات إنتاج الانبعاثات الكربونية

علي سعيد الشهراني
هادي علي مدخلي
كلية الهندسة – جامعة جازان

الملخص

تناقش هذه الورقة الوقود البديل المقترح لاستخدامه في مصانع إنتاج الحديد الصلب (الميثانول) بالتركيز على معدلات إنتاج الانبعاثات الكربونية (نواتج الاحتراق)، عند ضغوط ودرجات حرارة معينة. تم إجراء جميع الحسابات بواسطة النموذج الرياضي "PROPERTIS Model (PM)". وتم تتبع أربعة أنواع من الانبعاثات وتقديرها في ضغوط ودرجات حرارة ابتدائية مختلفة :(، CO2، NO، CO و OH). تم أيضًا حساب اللويس نمبر ، - Le Lewis Number ، لكل مزيج من الوقود. أظهرت النتائج التي تم الحصول عليها من هذه الدراسة أن قوة تركيز الوقود في المزيج المحترق (□) ، عامل مهم جدا ويؤثر على كمية الانبعاثات الناتجة من الخليط القابل للاحتراق من الميثانول (CH40). تظهر النتائج أيضًا أن انبعاثات ثاني أكسيد الكربون دائمًا أعلى في القيم . بغض النظر عن اختلاف الضغط ودرجة الحرارة .

كما أظهرت الدراسة أن اللويس نمبر ، Le ، لهذا الوقود ، هو أعلى في القيم المرتبطة بالمزيج الفقير بالوقود lean mixtures ، بينما تكون القيم أقل للمزيج الغني بالوقود – rich mixtures. ويرجع ذلك إلى الانتشار الحراري هو الأسرع مقارنة لانتشار الكتلة لوقود الميثانول .

Efficient liquefaction of lignin in methanol using ZrO_2 electrospun nanofibrous catalyst

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Abstract

Lignin is a major constituent of agricultural solid biomass that can be used as a natural sustainable source for value-addition of chemicals and fuels. However, efficient conversion routes of lignin are still challenging to accomplish due to the complicated nature of lignin. The catalytic decomposition of lignin was achieved in this work using methanol as a solvent at different reaction temperatures in the range 180-300 ºC and at different reaction times from 2 to 8 hours, using 0.3g lignin and 10 mL methanol. The results show that the conversion of lignin increased with an increase in the amount of ZrO_2 nanofiberous catalyst up to 50 mg. Further increase in the catalyst content had an adverse effect on the lignin conversion. Most of the lignin conversion (45 to 65%) occurred within the initial 2 hours of the decomposition reaction at all reaction temperatures. After these initial 2 hours, the lignin decomposition rate was very slow, and the decomposition of the lignin was around 10-15% during the next 8 hours. The major compounds detected in the reaction products were vanillin, homovanillic acid, vanillic acid methyl ester, apocynin, methyl dehydroabietate, and dehydroabietic acid.

Keywords:
lignin catalytic cracking; methanol; electrospinning; ZrO_2 nanofiberous catalyst; polyvinylpyrrolidone

1 Introduction

1.1 Scientific background of the lignin research

Agricultural solid biomass is a natural plentiful, renewable, and clean resource. It contains a considerable calorific value, which can substitute a portion of the expected depletion of petroleum and fossil feedstock for sustainable production of value-added chemicals and fuels. Among the numerous constituents present in the biomass, lignin is the most stable and considered a refractory material [1-4]. Lignins are complex naturally occurring organic polymers consists of both aliphatic and aromatic constituents, which are amorphous, and hydrophobic in nature [**5**]. The lignin forms the basic structural materials in the support tissues of most of the plants and abundant in cell walls of some specific cells. Lignins are very important in the formation of cell walls, especially in wood and bark, because they lend stiffness and do not undergo deterioration easily. The lignin has many biological functions which include transportation of water, and provide mechanical support and resistance to the cells and the plants. Lignin is completely insoluble in most solvents and very difficult to decompose into simpler units. The structure properties and morphology of the fibers depends upon the lignin content. Lignin is resistant to degradation by most microorganisms linkages in the presence of an active catalyst in methanol medium. Under this condition, catalytic materials can catalyze methanol in the following two reactions to produce more hydrogen.

reforming reaction

$CH_3OH \longrightarrow 2H_2 + CO$ (**reaction 1**)

water-gas shift

$H_2O + CO \longrightarrow 2H_2 + CO_2$ (**reaction 2**)

The presence of the catalyst and the H_2 produced from the aforementioned reactions, converts lignin to a low molecular weight compound by a sequence of hydrogenation reactions (**Fig. 1**).

and, indeed, its primary role in the wood cell wall is to protect the carbohydrates from microbial attack [6].

1.2 Decomposition of Lignin

The hydrolysis process of its phenolic ether linkages as well as reducing overall oxygen content without producing chars is difficult [7]. However, an efficient conversion route is still difficult to accomplish without char production due to the complicated nature of the lignin. A simple effective approach was used to overcome the problem of lignin depolymerization using the dihydro benzo furan model [8] and more complex model using organic solvent to solubilize lignin [9] via hydrolysis of phenolic ether

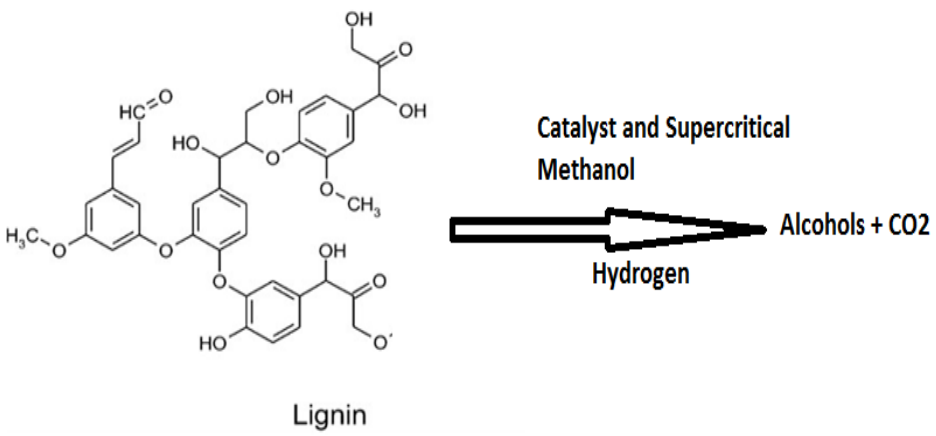

Fig. 1 Scheme showing conversion of lignin to low molecular weight compound by hydrogenation reactions.

and the structure of the catalysts have a great effect on the catalyst activity and selectivity.

Fig. 2 shows that during the decomposition of lignin, both C-C and C-O bonds are broken. The breaking of these bonds produced a variety of products which depends upon the reaction conditions, type of catalyst, and amount and characteristics of the solvent used.

During the reaction, highly active reducing agents (H_2 and CO) and electrons were created on the surface of the catalyst due to the methanol decomposition. Thus, robust catalysts are requiring in the methanol condition to convert lignin to low molecular weight chemical compounds. Accordingly, Various complex catalysts have been demonstrated in the literature (e.g. copper-supported Al_2O_3/MgO catalyst) [8]. It is a well-known fact that the synthesis method

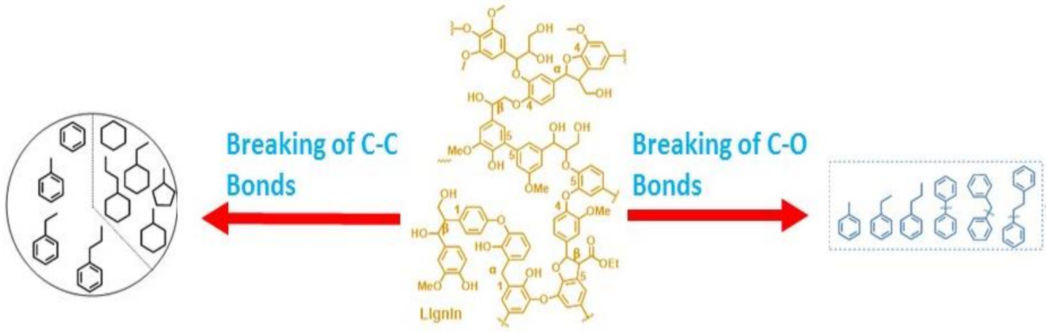

Fig. 2 Lignin decomposition reaction scheme as illustrated by the reaction products identified.

2. Experimental

2.1 Chemicals and Materials

Zirconium (IV) isopropoxide (Zr(Iso), $Zr(OCH_2CH_2CH_3)_4$, polyvinylpyrrolidone (PVP), having average molecular weight ~ 1300000 $g.mol^{-1}$, ethanol (99.5, assay), methanol (99.5, assay), acetic acid (99.5, assay) and lignin were purchased from Sigma Aldrich, USA and were utilized without further treatment.

2.2 ZrO_2 nanofibers preparation

To prepare ZrO_2 nanofibers, 2g PVP was mixed with a mixture of acetic acid and ethanol (1:1) with stirring for 1 h at 25ºC followed by dropwise addition of Zr(Iso) **(**1g**).** The mixture was continuously stirred until a clear yellow solution was obtained. Finally, the prepared solution was subjected to an electrospinning process as described in our previous reports [10-18] and briefly it is described below. The solutions underwent electrospinning at an applied voltage of 12 kV and 15 cm tip-to-collector distance. The collected nanofiber mats were dried under vacuum at 60°C for 24 h and then were calcined at 700°C for 2 h in a muffle furnace (**Fig. 3**).

Nasser et al 2018 [10] have prepared different composition from TiO_2/ZrO_2 (ZrO_2: 0, 25, 50, 75, 100wt%). They study the effect of catalyst composition in the lignin decomposition at subcritical methanol condition (180°C) for 2h reaction time. The catalyst TiO_2/ZrO_2 containing 75wt% ZrO_2 showed the best catalytic activity towards lignin degradation as compared to other formulations and showed 57 wt% decomposition of the lignin at 180°C and in 2h reaction time. Moreover, the same catalyst decomposed 60 wt% of sawdust to simple alcohol at 300°C reaction temperature.

In this study, ZrO_2 nanofibers were used as a catalyst for lignin depolymerization in methanol. The prepared catalyst was fabricated by an electrospinning technique. The results demonstrated that the synthesized catalyst has a good ability to depolymerize the lignin into low molecular weight compounds at different temperatures (180, 200, 220, 240 and 300°C). The amount of catalyst and reaction time was optimized to obtain the maximum conversion.

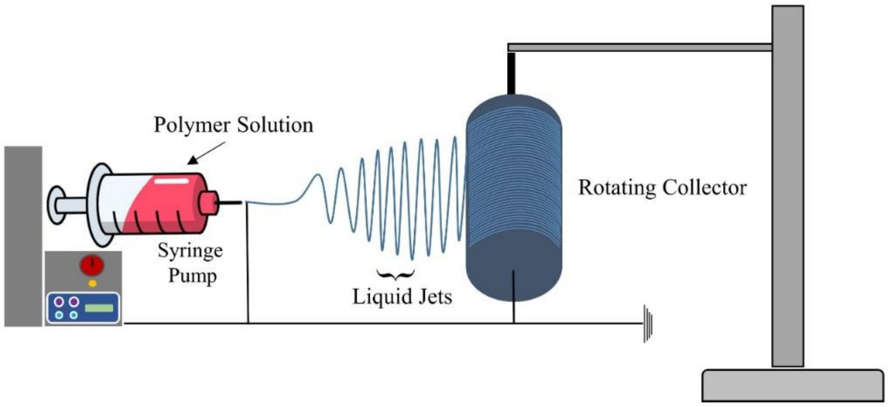

Fig. 3 Electrospinning process demonstration.

steel autoclave vessel and the vessel was tightly closed. The autoclave vessel was placed in a muffle furnace and heated at different temperatures (180, 200, 220, 240 and 300 $^{\circ}$C) at a heating rate of 3 $^{\circ}$C/min. After a definite reaction time, the autoclave vessel was removed from the furnace and cooled quickly in an ice bath. Then, the reaction product was filtered and the solid material obtained was washed several times using water and methanol. Finally, the solid was weighed and compared to the original total mass used. The liquid product was kept in a sealed bottle for further analysis. The experimental steps are summarized in

2.3 Alcohol based thermocatalytic treatment process for lignin decomposition

The catalytic experiments were started by testing the chemical stability of the catalyst before performing any lignin reaction. The reaction conditions were as follows: 50mg catalyst, 10 mL methanol, 245 $^{\circ}$C reaction temperature, and 10 h reaction time. After the reaction, the weight of the catalyst was checked for any loss of the catalyst. There was no observable change was found. Thus, it was concluded that the prepared nanofibrous catalyst is quite stable under all reaction conditions examined. Similarly, the decomposition of lignin without catalysts was also evaluated. The lignin reaction experiments were started by making a slurry of lignin and methanol in the absence of catalyst using 0.3g lignin, and 10 mL methanol. The reaction was performed at 245 $^{\circ}$C for 10 h and no change in the weight of the lignin was observed. This was a clear indication that the lignin decomposition reaction did not occur at a temperature lower than 245 $^{\circ}$C without using a catalyst.

A known amount of the prepared catalyst and 0.3 grams of lignin were added to 10 mL methanol, and the mixture was sonicated for few minutes. Then, the resultant mixture was transferred to a Teflon-lined stainless

Fig. 4.

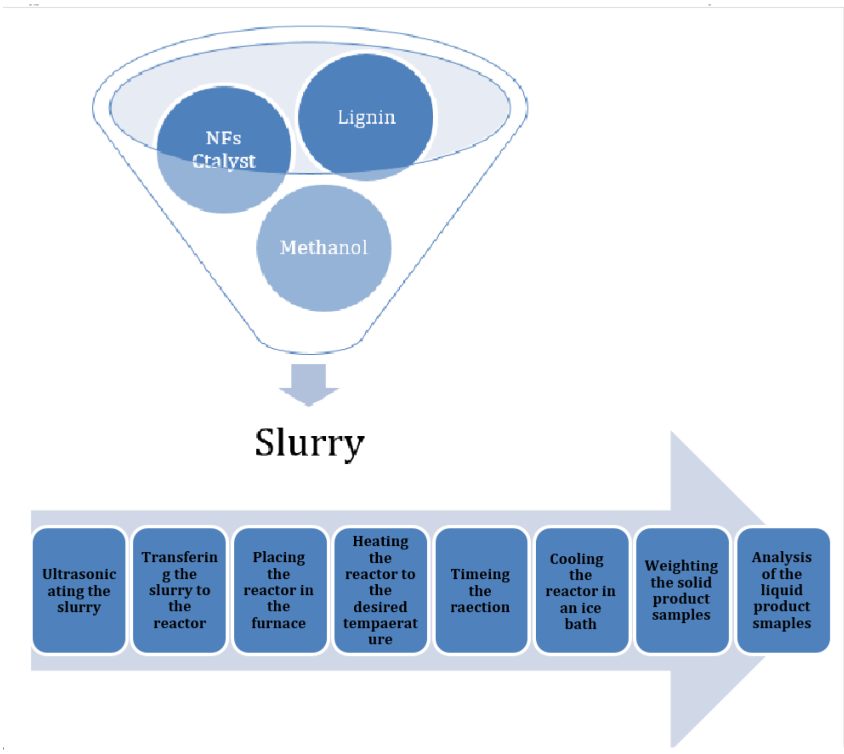

Fig. 4 Flowchart showing the experimental steps adopted during lignin decomposition in methanol.

Ver.11). The relative amount of each component was calculated based on area percent.

2.5 *Characterization of the catalyst*

The surface morphology was characterized using a JEOL JSM-5900 scanning electron microscope (JEOL Ltd., Japan). The phase and crystallinity of the catalyst were characterized using X-ray diffractometer (Rigaku Co., Japan) with Cu Kα (λ=1.54056 Å) radiation over a range of 2θ angles from 20^{o} to 80^{o}.

3 Results and Discussion

Electrospinning is a technique to produce organic and inorganic nanofibers [19]. The process consists of applying a high voltage on polymeric sol-gels to create a stretching force. Concisely, the electrospun sol-gels pumped in a syringe is connected to an open electric

2.4 Reaction products analysis by GC-MS technique

The gas chromatography-mass spectrometry (GC-MS) analysis was done using a GC-MS system (model QP2010 Ultra, Shimadzu Corporation, Kyoto, Japan). The reaction products were chromatographed on a capillary column coated (Rtx-5MS, Restek Corporation, U.S) using helium gas as a carrier. The sample volume injected was 1.0 µL. The injection port temperature was 290 °C. The GC oven temperature programming was as follows: 5 min. at 30 °C, heated at 4 °C/min. to 300 °C and held for 4.5 min. The MS ion source temperature was 230 °C and the Interface at 280 °C. Total ion chromatogram (TIC) was generated for m/z range 30-700. The GC peaks were identified by comparing their mass spectra to the database of the National Institute of Standards and Technology (NIST, quality nanofibers due to their high gelation tendency. Accordingly, zirconium isopropoxide is the most widely used precursors to fabricate ZrO2 nanofibers [20–22]. Furthermore, PVP has also indicated excellent participation in the fabrication of different metal oxides. Electrospinning of a sol-gel consist of PVP/Zr(Iso) appears beads-free, smooth, and good nanofibrous morphology after drying as shown in SEM image (**Fig. 5**). The powder obtained after the calcination of the as-fabricated electrospun nanofibers mats consist of PVP/Zr(Iso) and showed good nanofibers morphology. The width of the nanofibers appeared to be between 100-500 nm. It is worth mention that, the calcination process in the presence of air did not affect the nanofibrous structure.

circuit. The negative electrode is introduced in the sol-gel at the same time as the positive one is fixed to a rotating metallic cylinder to collect the product. The high applied voltage allows the nanofibers to stretch and collect on the rotating metallic cylinder. The characteristics of the solution ids very critical and a key parameter in electrospinning process. To synthesize nanofibers containing metal oxide, the polymer and the metallic precursors should be mixed together easily and provide a homogeneous solution selected carefully. Generally, high molecular weight polymers and relatively high solution viscosity are preferred. In case of metal oxide precursor, high propensity of polycondensation is the foremost desirable feature. Metal alkoxides have been proved to be the best candidates for producing high

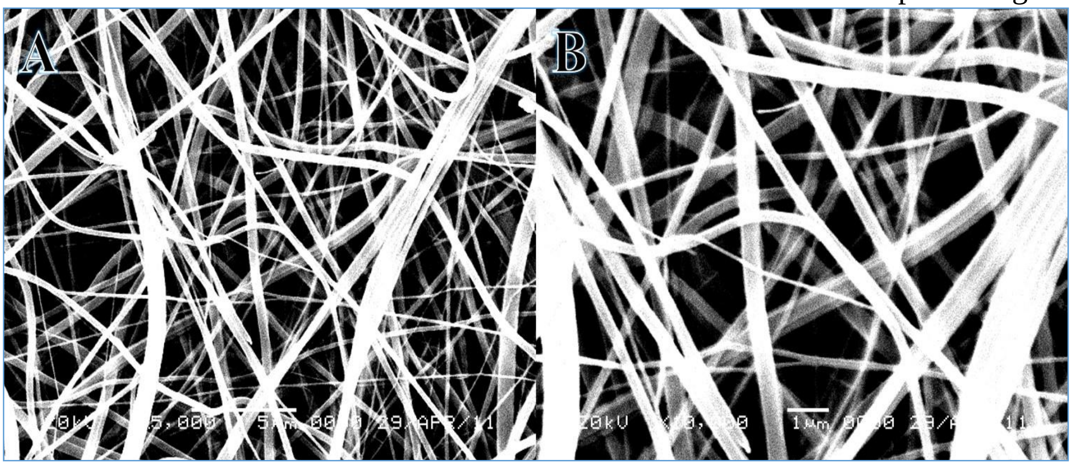

Fig. 5 (A) Low and (B) high magnifications SEM images of electrospun nanofiber mats obtained after calcination of PVP/Zr(Iso) at 650 °C for 2h.

fabricated nanofibers obtained from the calcination of electrospun nanofibers mats consist of PVP/Zr(Iso). XRD analysis is the most dependable equipment to investigate the chemical composition of the crystalline materials. Thus, the ceramic materials can be readily specified by XRD. The cubic ZrO_2 peaks appeared at 2ϴ values 30.5°, 35.2°, 50.6°, and 60.3° which is agreement with (1 1 1), (2 0 0), (2 2 0), and (3 1 1)crystal planes, while the

XRD analysis is the most dependable equipment to investigate the chemical composition of the crystalline materials. Thus, these ceramic materials can be readily specified by XRD. **Fig. 6** shows the XRD pattern for the fabricated ZrO_2 nanofibers, exhibiting two phases of zirconia (cubic ZrO_2 (Fm3m (225)) (JCPDS card no. 27-0997) and baddeleyite ZrO_2 [Sp. Gr. P21/a(14)] (JCPDS card no. 37-1484)) were detected in the baddeleyite ZrO_2 peaks presence at 2ϴ values of 24.04°, 28.16°, 31.46°, 34.21°, and 50.19° which is corresponding to the (1 1 0), (-1 1 1), (1 1 1), (2 0 0), and (0 0 2) crystal planes [23].

One of the most critical issue in the lignin thermal degradation using liquid media is char formation which is an unattractive material that decreases the caloric efficiency of the conversion process. In the absence of suitable catalytic materials, the dehydration process is considered the most preferable during lignin conversion under methanol conditions which leads to char production [24].

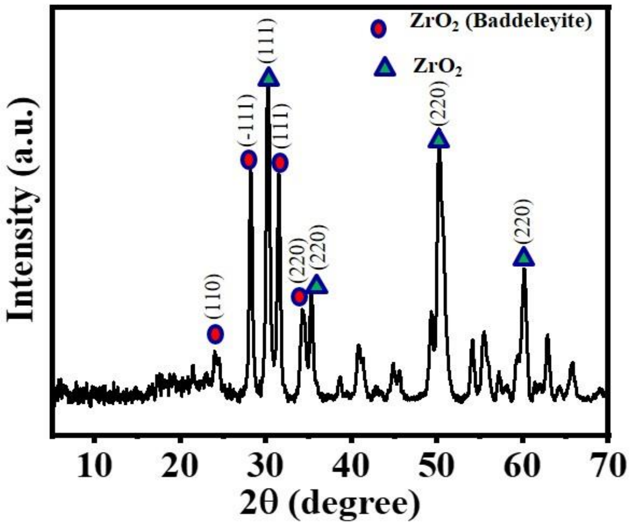

Fig. 6 XRD result of the catalyst powder (ZrO_2 NFS) obtained after calcination of electrospun NF mats consist of PVP/Zr(Iso) at 650 ^{o}C for 2h.

Fig. 7 shows the effect of ZrO_2 nanofiberous catalyst content on the conversion of lignin in the methanol at 200 ^{o}C and 2 h. As shown in **Fig. 7**, the increase in the catalyst content leads to an increase in the lignin conversion; however, a further increase in the catalyst content increased the residual solid materials. The optimum conversion of lignin achieved was 45% using 50 mg of catalyst. From these data, it is evident that further increase in the amount of catalyst enhanced the char formation rather than the desired reactions. The proper catalyst amount can improve methanol-reforming (**equation 1**) and water gas shift (**equation 2**) reactions. However, in this process, the water gas shift reaction is undesirable which consumes the produced water that enhances the char formation. Consequently, the increase in the catalyst amount improved the char formation rather than lignin decomposition.

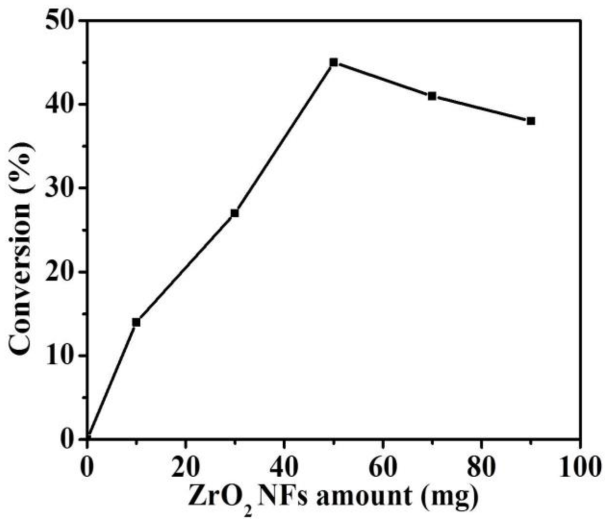

Fig. 7 Influence of the ZrO_2 NFs catalyst amount on the lignin depolymerization using methanol at 200°C and 2h.

temperature and reaction time as shown in **Fig. 8A**. The figure indicates the effect of reaction time on lignin conversion using 50mg ZrO_2 nanofiberous catalyst at different temperature and reaction time. However, the increase in the holding time to more than 10 hours leads to a decrease in the lignin conversion may be potentially due to polymerization of the produced reactive intermediates to char. The reaction rate was increased with increase in the temperature and subsequently the time needed to increase the conversion was decreased. From the Arrhenius plot of ln K *vs.*1/T (**Fig. 8B**), the activation energy (E_a) was determined to be 15.22 kJ.mol^{-1}.

The supercritical conditions have been found quite appropriate to make the lignin constituents soluble that further support the decomposition and depolymerization of the active lignin [25]. It has been determined that the lignin depolymerization starts with the aromatic ring hydrogenation and then the hydrogenolysis of different functional groups such as aryl and ether occur [8-9]. The hydrogenations of the different intermediates formed during the depolymerization need to be at faster rate than the formation of chars through polymerizations of reactive intermediates [26]. The above mentioned proposition can be utilized to describe the increase of lignin conversion with increase in

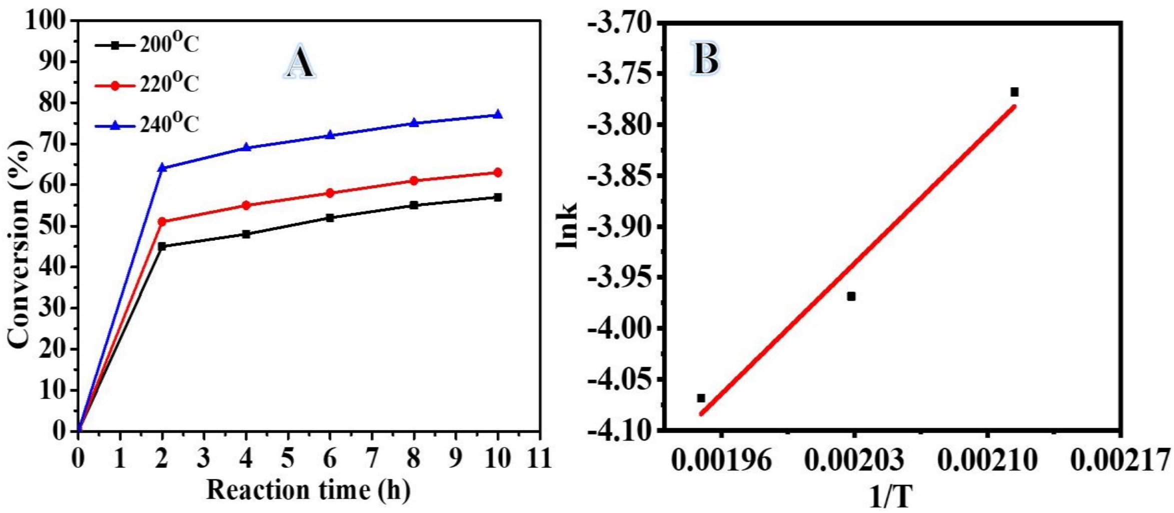

Fig. 8 Influence of the ZrO_2 NFS on the lignin depolymerization using methanol at different reaction temperatures and times (A) and logarithmic value of conversion constant vs. (1/T) (B).

methyl dehydroabietate together were about 40% in each product. These type of compounds have been reported in earlier studies [27]. Other compounds with appreciable concentration were methyl 2-hydroxypropanoate, 3,4-dimethoxyacetophenone, 7-oxodehydroabietic acid, methyl ester, methyl isopimarate, methyl glycolate, 4-ethylguaiacol, 3,4-dimethoxyphenylacetone and methyl isodextropimarate. Other compounds present were in low variable concentrations. The concentrations of different compounds do not seem to show a clear relationship with the lignin to catalyst weight ratio used during the reaction. These results are plotted in **Fig. 9** to show relative concentrations of different compounds produced.

3.2 Lignin Decomposition Reactions

3.2.1 Effect of lignin to catalyst ratio (1.0, 2.0, 2.7, 6.0 and 8.0) at 240 °C reaction temperature

Table 1 shows the compounds identified and quantified (wt%) by GC–MS from lignin decomposition using ZrO_2 NFs catalyst at 240 °C. The similarity index (SI) of the peaks with the GC-MS database was more than 85. Other peaks showing low SI were not included in the results. The amount of methanol used was 10 ml and the reaction time was 10h. The data shows that 22 major compounds were identified and quantified in the reaction products. There were other compounds identified with smaller amount (less than 1%) that were removed and are not reported here. The o-guaiacol and

Table 1 Compounds identified and quantified by GC–MS from lignin decomposition using ZrO_2 nanofiberous catalyst at 240 °C (amount of methanol used 10 ml, reaction time 10h, lignin to catalyst weight ratio (1.0, 2.0, 2.7, 6.0 and 8.0).

			Sample name	lignin to catalyst weight ratio(1-8)				
				N7	**N3**	**N2**	**N5**	**N4**
No.	**RT**	**Compounds identified and Quantified**	**CAS #**	**1.0**	**2.0**	**2.7**	**6.0**	**8.0**
1.	5.528	Methyl glycolate	96-35-5	4.05	1.68	7.66	1.38	1.48
2.	6.553	Methyl 2-hydroxypropanoate	2155-30-8	4.34	4.58	7.07	3.73	4.34
3.	18.876	Dimethyl succinate	106-65-0	2.97	1.25	6.35	1.16	1.11
4.	20.235	Dimethyl 2-methylsuccinate	1604-11-1	1.77	1.42	3.18	1.24	1.32
5.	20.501	p-Guaiacol	150-76-5	1.84	1.46	1.52	1.59	1.44
6.	21.071	o-Guaiacol	90-05-1	18.76	18.37	19.85	20.04	21.50
7.	24.989	4-Methylguaiacol	93-51-6	0.50	1.69	1.61	1.84	2.50
8.	28.081	4-Ethylguaiacol	2785-89-9	0.38	2.71	2.57	2.66	3.67
9.	36.844	3,4-Dimethoxyphenylacetone	776-99-8	1.20	1.98	2.20	2.93	2.36
10.	37.254	3,4-Dimethoxyacetophenone	1131-62-0	2.28	2.76	1.21	2.83	3.28
11.	37.695	4-Butyl-1,2-dimethoxybenzene	59056-76-7	2.86	1.35	1.16	2.20	1.64
12.	38.043	Methyl veratrate	2150-38-1	3.30	2.14	2.70	1.96	2.09
13.	39.628	2-Ethoxy-6-(methoxymethyl) phenol	0-00-0	4.37	3.31	2.91	3.19	3.46
14.	46.169	Methyl cis-6-octadecenoate	2777-58-4	2.74	3.69	2.01	2.04	3.86
15.	50.728	Methyl linoleate	112-63-0	1.10	1.17	1.10	1.15	1.60
16.	54.102	Methyl isodextropimarate	1686-54-0	4.88	3.95	3.53	3.70	4.32
17.	55.365	Methyl isopimarate	1686-62-0	3.16	2.58	2.04	2.41	2.92
18.	56.125	Methyl 6-dehydrodehydroabietate	18492-76-7	4.57	3.52	4.15	3.70	3.77
19.	56.294	Methyl dehydroabietate	1235-74-1	23.72	19.01	19.78	17.33	20.47
20.	57.167	Methyl abietate	127-25-3	3.26	3.20	2.07	2.77	3.60
21.	60.879	7-Oxodehydroabietic acid, methyl ester	110936-78-2	5.03	3.33	3.71	3.31	3.28
22.	61.625	Methyl 12-methoxyabieta-8,11,13,15-tetraen-20-oate	57397-32-7	1.40	1.10	1.05	1.19	1.53

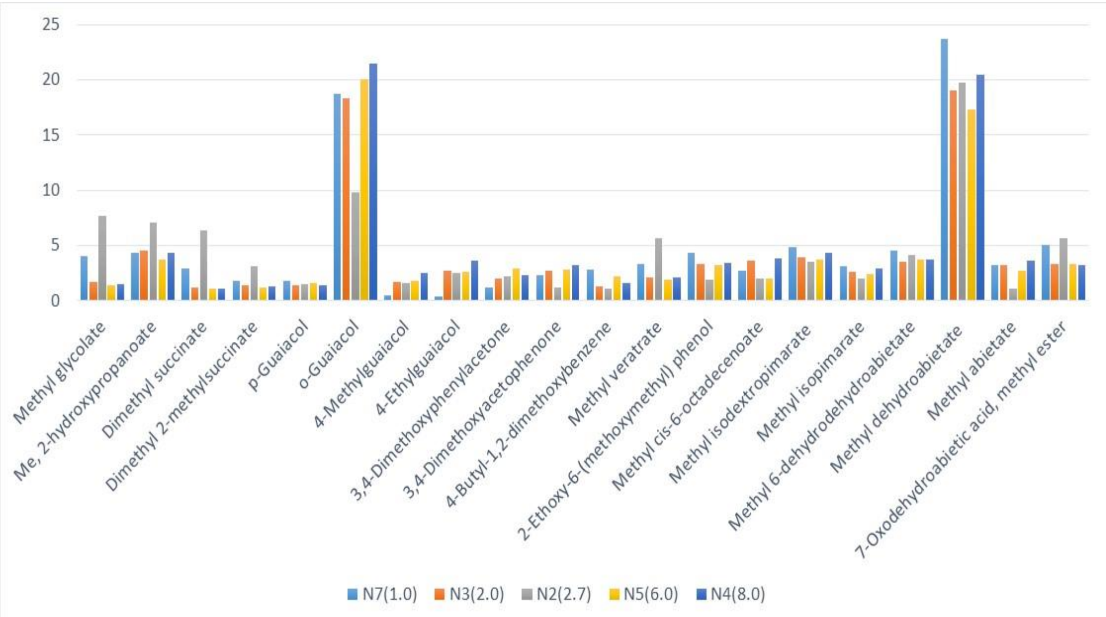

Fig. 9 Compounds identified and quantified by GC–MS from lignin decomposition using ZrO_2 NFs catalyst. Reaction conditions: reaction temperature 240 °C, amount of methanol 10 ml, reaction time 10h, lignin to catalyst weight ratio (1.0, 2.0, 2.7, 6.0 and 8.0).

lower reaction temperature while at a higher temperature, high molecular weight compounds were produced. Some compounds were produced at a lower temperature but gradually disappeared at higher temperatures. Some of the major compounds identified and quantified include homovanillic acid, dimethyl succinate, butanedioic acid, methyl-dimethyl ester, o-guaiacol, vanillin, apocynin, methyl vanillate, homovanillic acid methyl ester, homovanillic acid, and methyl dehydroabietate. Among these, vanillin and methyl vanillate were with quite high concentration reaching more than 30% of the reaction products.

3.2.2 Effect of reaction temperature (180, 200, and 220 ºC) for 8 h reaction time

Fig. 10 shows the compounds identified and quantified (wt%) by GC–MS from lignin decomposition using ZrO_2 N nanofiberous catalyst at a variable temperature of 180, 200, and 220 ºC during 8 h reaction time. The similarity index (SI) of the peaks with the GC-MS database was more than 85. The data shows that more than 20 major compounds were identified and quantified in the reaction products. The lignin to catalyst weight ratio was 4. The data show that low molecular weight compounds were produced at

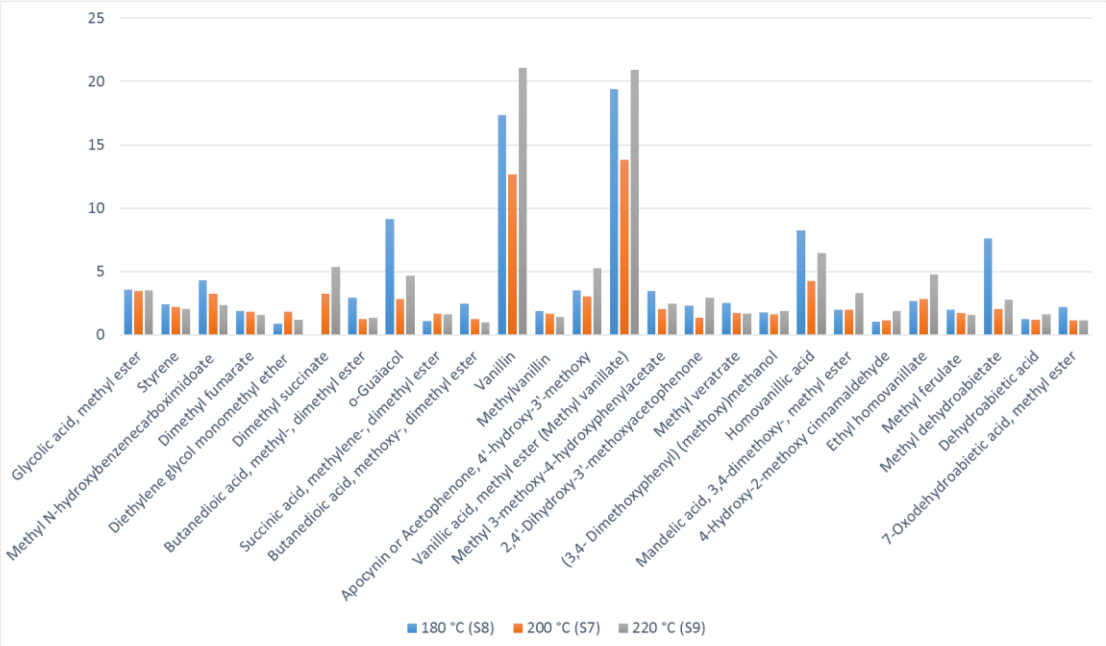

Fig. 10 Compounds identified and quantified (wt%) by GC–MS from lignin decomposition using ZrO_2 catalyst. Reaction conditions: the amount of methanol 10 ml, reaction time 8h, lignin to catalyst weight ratio 4, reaction temperatures 180, 200, and 220 °C.

the peaks with the GC-MS database was more than 90%. The data shows that more than 20 major compounds were identified and quantified in the reaction products. Some compounds were produced at a lower temperature (200 °C and 240 °C) but gradually disappeared at higher temperatures and new compounds appeared at higher temperatures (300 °C). The concentration of lower molecular

3.2.3 Effect of reaction temperature (200, 240 and 300°C) for 4h reaction time

Fig. 11 shows the compounds identified and quantified (wt%) by GC–MS from lignin decomposition using ZrO_2 NFs catalyst at a variable temperature of 200, 240 and 300 ºC using 10 ml methanol and a reaction time of 4h. The similarity index (SI) of methyl phenol, 5-methylguaiacol, vanillin, p-propylguaiacol, methyl vanillate, methyl veratrate, homoveratrole, methyl dehydroabietate, and apocynin. Among these, vanillin, methyl dehydroabietate, and methyl vanillate were present in high concentration reaching more than 35-40% of the reaction products at different temperatures.

weight compounds was higher at 300 °C compared to other temperatures while the higher molecular weight compounds were more at lower decomposition temperature. This observation confirmed that at higher decomposition temperature, the bigger molecules experienced cracking. Some of the major compounds quantified include o-guaiacol, 4-methoxy-3-

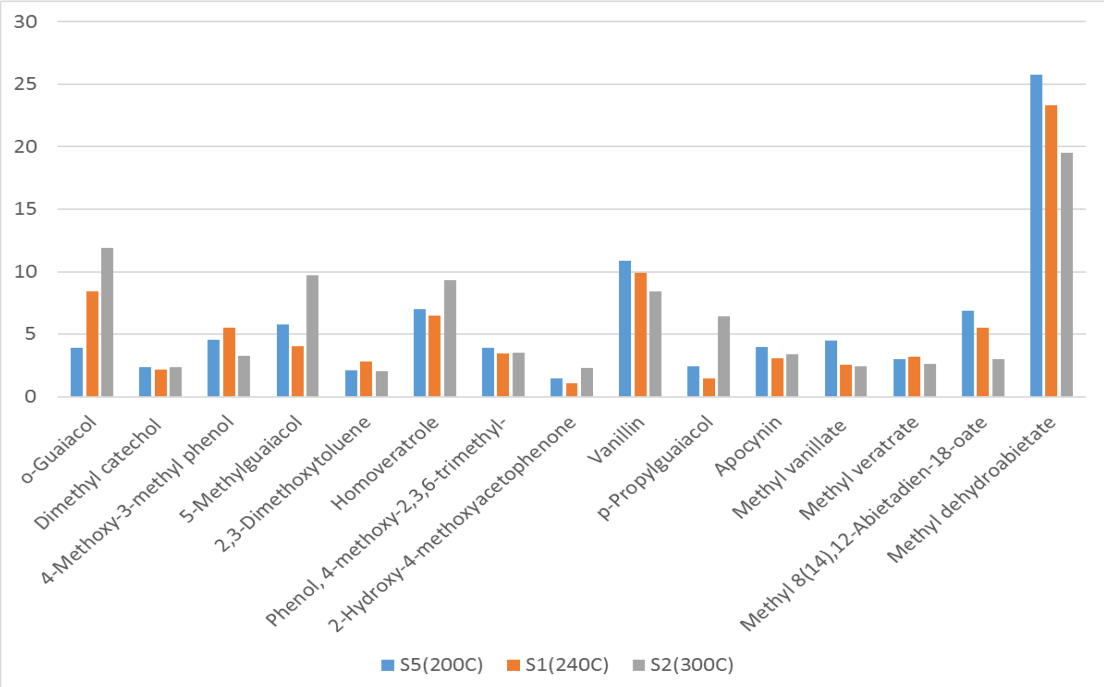

Fig. 11 Compounds identified and quantified (wt%) by GC–MS from lignin decomposition using ZrO_2 NFs catalyst. Reaction conditions: the amount of methanol 10 ml, reaction time 4h, lignin to catalyst weight ratio 4, reaction temperatures 200, 240, and 300 °C.

quantified in the reaction products. The data show that low molecular weight compounds were produced in large amounts since the reaction temperature was low. At higher reaction time, more compounds were produced. Some of the major compounds include, o-guaiacol, vanillin, apocynin, homovanillic acid, butandioic acid, methyl ester and methyl vanillate. Among these, homovanillic acid, vanillin, and methyl vanillate were present in high concentration reaching more than 30% of the reaction products.

3.2.4 Effect of reaction run time (2, 4, 6 and 8 h) at 200 °C reaction temperature

The compounds identified and quantified (wt%) by GC–MS from lignin decomposition using ZrO_2 NFs catalyst at a variable reaction time of 2, 4, 6 and 8 hours using 10 ml methanol and the reaction temperature was 200 °C are shown in **Fig. 12**. The similarity index (SI) of the peaks with the GC-MS database was more than 85. The data shows that several major compounds were identified and

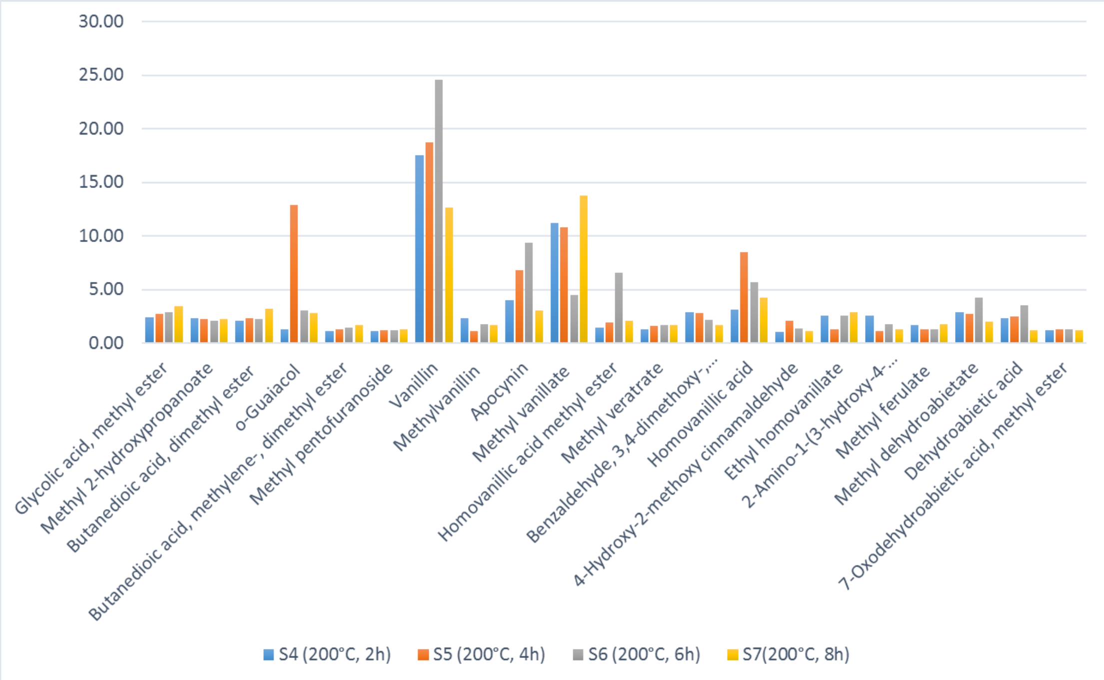

Fig. 12 Compounds identified and quantified by GC–MS from lignin decomposition products obtained at a variable reaction time of 2, 4, 6, and 8 hours using ZrO_2 NFs catalyst. Reaction conditions: reaction temperature 200 °C, amount of methanol 10 ml, lignin to catalyst weight ratio 4.

vanillic acid methyl ester, apocynin, methyl dehydroabietate, and dehydroabietic acid. These compounds were present in major concentration as well.

Fig. 13 shows the structure of some of the compounds which were quantified in the lignin decomposition products at different reaction conditions. These include vanillin, homovanillic acid,

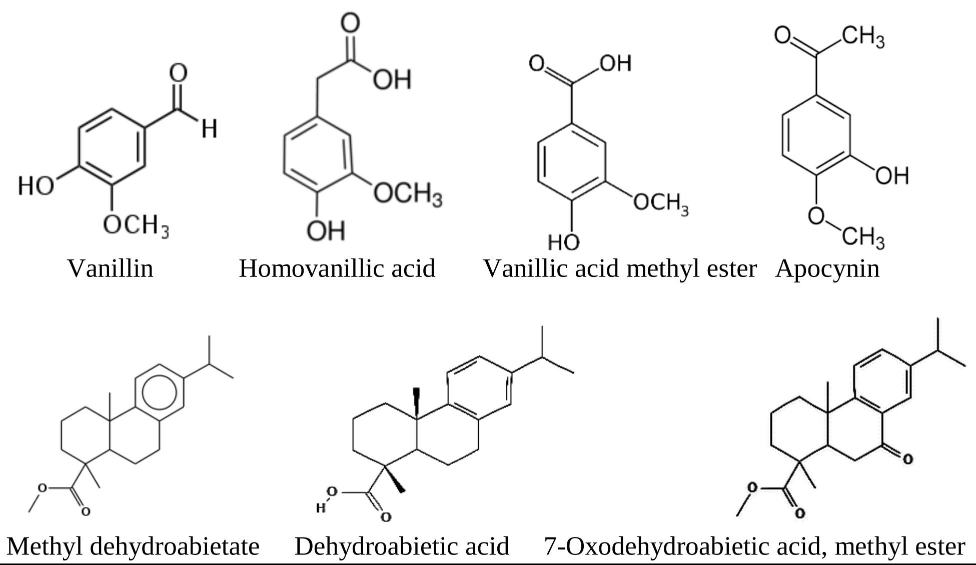

Fig. 13 Structure of some of the major compounds quantified in the lignin decomposition products

The catalytic decomposition of lignin in methanol solvent was successfully achieved using methanol at different

4 Conclusions

reaction temperatures (180-300 ºC), different lignin to catalyst weight ratio (1.0, 2.0, 2.7, 6.0 and 8.0) and different reaction times (2-8 h). The results show that the conversion of lignin increased with an increasing amount of ZrO_2 NFs catalyst up to 50 mg. Further increase in the catalyst amount had an adverse effect on the lignin conversion. During the initial 2 hours, the lignin decomposition was very high (45-65%) and then it decreased. This shows that maximum decomposition was during the first two hours. During the next 8 hours of the reaction, the decomposition of the lignin was about 10-15%. The major compounds found in different reaction products were vanillin, homovanillic acid, vanillic acid methyl ester, apocynin, methyl dehydroabietate, and dehydroabietic acid. Other compounds present were in minor concentration. Overall vanillin and its substituted compounds were present in appreciable amount. This lignin could provide a significant source for vanillin and substituted vanillin for commercial purposes. The amount of specific desired compounds can also be enhanced through optimizing the lignin conversion conditions.

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الملخص

اللجنين هو أحد المكونات الرئيسية للكتلة الحيوية الزراعية الصلبة التي يمكن استخدامها كمصدر طبيعي ومستدام لإنتاج مواد كيميائية ووقود حيوي. ومع ذلك، لا يزال إيجاد طرق تحويل فعالة للجنين صعبة التحقيق بسبب الطبيعة الكيميائية المعقدة للجنين. في هذا العمل تم تحقيق التحلل التحفيزي للجنين باستخدام الميثانول كمذيب عند درجات حرارة تفاعل مختلفة في نطاق من ١٨٠-٣٠٠ درجة مئوية وفي أزمنة تفاعل مختلفة من ٢ إلى ٨ ساعات، باستخدام ٠,٣ جرام من اللجنين و١٠ ملى من الميثانول. أظهرت النتائج أن تحويل اللجنين يزداد بزيادة كمية ثاني أكسيد الزركونيوم المحفز المصنع من الياف النانوي حتى ٥٠ ملليجرام. كان للزيادة الإضافية في كمية المحفز تأثير سلبي على تحويل اللجنين. أظهرت النتائج نسبة تحول من ٤٥% الى ٦٥% خلال الساعتين الأوليين من التفاعل عند جميع درجات الحرارة المستخدمة للأجراء التفاعل. نسبة تحليل قليلة تترواح مابين ١٠% الى ١٥% تم الحصول عليه خلال الساعات الثماني التالية. المركبات الرئيسية التي تم الحصول عليه من التفاعل هي الفانيلين ، حمض الهوموفانيليك ، حمض الفانيليك ميثيل إستر ، أبوسينين ، ميثيل ديهيدروأبيتيت ، وحمض ديهيدروأبيتيك.

الكلمات المفتاحية: التكسير التحفيزي للجنين، الميثانول، الغزل الكهربائي، ثاني أكسيد الزركونيوم المحفز المصنع من الياف النانوي، بولي فينيل بيروليدون.

A High-Power Density Multilevel Inverter Applied in Chemical Energy Storage Systems for Electric Vehicles

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ABSTRACT

In electric vehicles (EV) and large-scale chemical energy storage systems, many battery cells or modules are typically connected to improve motor driving output voltage. The diversity in battery characteristics makes voltage output and state-of-charge (SOC) inequality for various battery modules. A new cascaded multilevel converter topology utilizing a Level Elevating Cell (LEC) is presented in this paper. The LEC block involves two half-bridge converters per basic cell per phase that can approximately triple the output voltage steps, including chemical energy management and control of EVs. In the suggested structure, every module is involved or bypassed by a DC/DC converter. All battery modules can be cascaded through half-bridge converters to provide dc voltage staircase steps. Next, an H-bridge inverter is employed to convert the dc steps voltage to an ac waveform. The inverter outputs are cascaded voltage steps with fewer low order harmonics and less voltage stress, increasing the achievement and control of the drive circuits. By controlling each cell separately, the batteries' energy capacity can be increased according to the state of charge of each module. Hence, the unbalance of voltage output can also be eliminated. Using MATLAB, results are performed to support the achievement of the introduced hybrid converter.

Key Words: Charging systems, Battery energy storage systems, Hybrid Topology, Staircase Modulation.

INTRODUCTION

In driving electric vehicles (EV), the battery energy storage system performs a vital part. Redox flow or lithium chemical technologies are the most popular batteries in the worldwide power sector because of their convenient chemical energy power, density, and cost. Considering these battery cells' voltages are relatively low, many chemical cells or modules must be combined in series to match the motor drive's output specification (Wang, Alaas, and Chen, 2020). The capacity and internal resistance characteristics vary between these cascaded chemical cells or modules because of cell manufacturing differences, cell characteristics, and degradation with time. In a conventional arrangement, chemical modules are coupled in a series connection and hence discharged or charge by the equal charged/discharged value. However, the value of voltage waveform and battery state-of-charge (SOC) vary because of the chemical modules' electrochemical characteristic variations. If a chemical module/cell touches the cut-off value, the charge and discharge power must be discontinued.

Furthermore, when any module is fatally weakened, the whole battery system is shut down. Consequently, the energy of battery modules must be controlled to overcome those variations. Therefore, a terminal voltage or state of charge balancing system is usually required in real design applications to prevent the weaker modules from getting into the over-charging/discharging process (Alaas et al., 2017). Usually, two methods of balancing solutions. The primary solution utilizes the excess chemical energy on parallel resistance to even all chemical modules' voltage values. If one chemical module comes at its cut-off value in the charging mode, another battery cell will discharge its energy using resistances in parallel. Hence, the chemical energy uses rate is lacking. The different balancing circuit involves inductances, transformers, and DC/DC circuits, which can transfer energy between chemical energy modules. The modules with higher power can transfer their energy to others to achieve voltage and SOC balancing and improve the energy utilization ratio. The problem is the need for many inductances or isolated multi-winding in such structures, and the system's control is complex for a large-scale battery energy storage system (Alaas and Wang 2015, S. Yarlagadda, et al. 2011, Cheng, and Yeung 2012, Chol-Ho et al. 2013, Sang-Hyun et al. 2012). Excellent investigations have been performed to analyze system control and enhance stability by multi-stage balancing (Cheng and Yeung 2012, Chol-Ho et al. 2013, Sang-Hyun et al. 2012). Also, some techniques were used, such as zero voltage and zero current switchings, to reduce the equalization circuit's loss (Cheng and Yeung 2012).

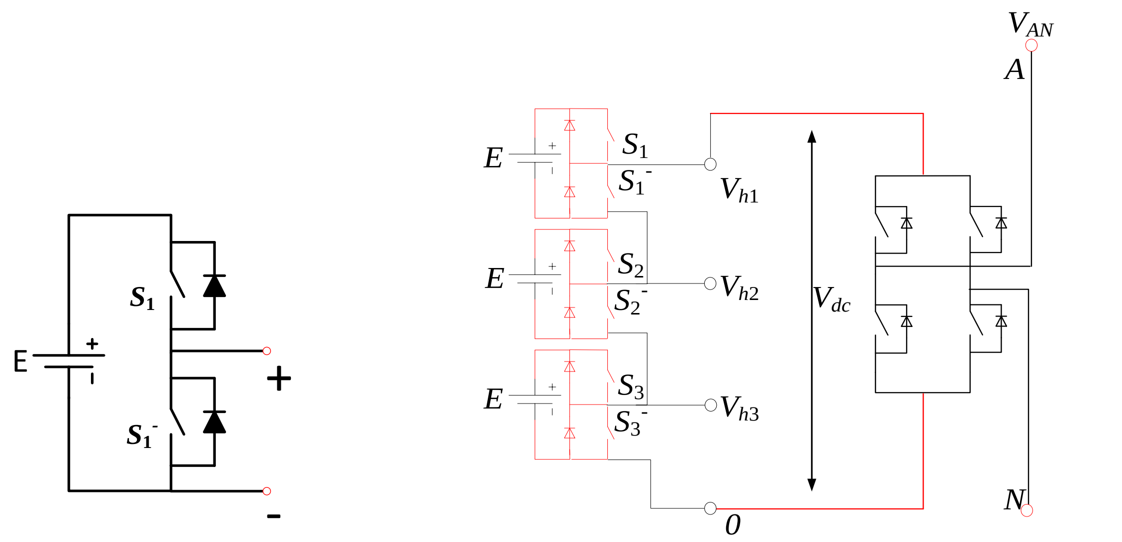
Cascaded multilevel inverters are generally applied in high-power applications (Rahman et al. 2020, Bahia et al. 2019, Singh and Kant 2019, Theliander et al. 2020, Gao and Lu 2019, Pal et al. 2021, Yao et al. 2021, Marquez et al. 2021, Ruiz-Caballero et al. 2010, Gui-Jia 2005). If the battery modules replace their dc supplies, the battery modules can be cascaded through half-bridge converters with inverters instead of directly connecting them. In the conventional cascaded converter (Pragallapati and Ranade 2020, Chen et al. 2014), the conventional multilevel H-bridge inverter is applied for the battery modules' voltage waveform uniform. Each H-bridge block manages a chemical energy module; hence, separate charging and discharging power control can realize the voltage balance. The output waveform of the inverter is step values that improve output power quality and is suitable for motor drive applications. The filter requirements can be significantly reduced when utilized for large-scale storage systems like integration to the power grid. The cascaded topology structure has a more reliable fault-tolerant capability by its modular configuration. Output requirements determine the number of cascaded cells to generate a higher output value utilizing those low-voltage chemical energy modules, particularly used in the sizeable scale grid application. The chemical energy module's energy or SOC stability control can be recognized by adjusting each H-bridge's modulation to the voltage waveform uniform approach in conventional multilevel inverters (Qiang and Wenhua 2009). The multilevel inverter topologies are more suitable for balancing battery modules than the conventional SOC balance circuit. Unique additional combination structure converter topologies are introduced in (Ruiz-Caballero et al. 2010, Gui-Jia 2005), where fewer devices achieve the same output voltage levels. Some supercapacitors are used to increase the system power density (Aharon and Kuperman 2011, Cao and Emadi 2012). In the cascaded multilevel converter structure, the number of elements is proportional to the output waveform levels. An increased number of system components complicates the control and increases insulation specifications, hence challenging its reliability. The H-bridge inverter can change the dc-link's output waveform's polarity to generate an ac voltage waveform. The H-bridge converter's switching semiconductor devices must manage higher values of power levels work at the frequency of fundamental value. Moreover, the semiconductor devices in the half-bridge converter also switch at the fundamental frequency but with lower power and voltage. The switching devices in the LEC block operate faster to Elevating the output voltage waveform levels. The new structure can be used in a wide range of power applications shus as Electric Vehicle (EV) drives, BESS systems, active filters, motor drives, DC power source utilization, back-to-back link systems, power factor compensators, and also with renewable energy resources.

The proposed circuit structure has a smaller number of component requirements than the H-bridge inverter to realize the battery modules' charge and discharge power control. The target ac value is at the terminal of the H-bridge to control the motor of the EV or connect to the utility grids. Such extra chemical energy module chargers are not needed. Also, motor control converters are not required for this situation. The inverter's ac outputs are multi-step values, while the voltage steps are proportional to cascaded chemical energy modules. So, the output voltage waveform is nearly sine waveform in the EV or power grid applications with the proposed LEC block. Hence, the total harmonic distortion and voltage stress can be significantly decreased. Simulation evaluations are intended to support the achievement of the suggested combination cascaded multilevel inverter in this article.

PROPOSED INVERTER

A. THE HYBRID MULTLEVEL INVERTER

The introduced Hybrid Cascaded Multilevel Inverter (HCMI) with Level Elevating Cell structure is formed by joining H-bridge inverter topologies and half-bridge circuits. Fig. 1(a) presents a DC/DC converter which has been linked to a single energy storage cell to manage that module's output power. Therefore, the energy of various battery energy storage cells is controlled separately through DC/DC circuits. The H-bridge inverter produces positive and negative polarity of the dc-link output waveforms cascaded three dc-dc converter blocks. These converter blocks are connected in a string and hence joined to an DC/AC inverter to create a hybrid structure of multilevel topology. For illustration, a seven-level cell converter circuit is demonstrated in Fig. 1 (b), where only a three-dc energy storage subsystem is joined to one H-bridge inverter. Although, a new switching methodology of control is used for the HCMI converter. It is demonstrated further in detail in the B Section.



(a) (b)

Fig. 1. Circuit building structure of a primary cell inverter: (a) Half-bridge module connects to one power supply module; (b) a 7-level hybrid inverter.

For example, in Fig. 1(b) show the value of the half-bridge circuit voltage waveforms are labeled as V_{h1}, V_{h2}, and V_{h3}, respectively. Therefore, the overall dc-link output waveform of the seven-step inverter arrangement is defined as the following:

$$V_{dc}= V_{h1}+V_{h2}+V_{h3}. \qquad (1)$$

The voltage V_{dc} waveform of the dc-link has four different voltage levels of 3E, $2E$, E, and 0. Since the H-bridge converter structure operates symmetrically, there are extra three waveform levels of $-3E$, -2E, $-$E that could be achieved. On the whole, there are seven waveform levels of $\pm 3E$, $\pm$2E, $\pm$E, and 0. In Table I, the switching positions of the seven-step hybrid block of the introduced inverter are listed. As shown in Table I, some output steps are generated by additional switching arrangement. For illustration, the output step 2E is formed by three unlike redundancies. The number of waveform levels in an HCMI inverter is described by$m = 2h + 1$ (2)

For symmetrical introduced hierarchical cascaded multilevel converter, the output signal waveform steps m is an odd number, and h is the number of half-bridges for main power supplies in one phase. It is like to that of a traditional cascaded H-bridge converter circuit. The waveform steps can be odd or even numbers in other common dc power supply multilevel structures, like diode-clamped or capacitor-clamped inverters.

Table I
Switching states of the Seven-level basic cell converter in Fig. 1.

DC-bus Voltage	ON, OFF positions			DC/DC output waveforms		
	S_1	S_2	S_3	V_{h1}	V_{h2}	V_{h3}
3E	1	1	1	E	E	E
2E	1	1	0	E	E	0
	1	0	1	E	0	E
	0	1	1	0	E	E
E	0	0	1	0	0	E
	0	1	0	0	E	0
	1	0	0	E	0	0
0	0	0	0	0	0	0

B. CONTROL METHOD

The staircase method is obtained to control the proposed structure circuit due to its switching arrangement building construction (Bin 2006, Alaas 2021). This control methodology technique's principle is demonstrated in Fig. 2, where V_{h1}, V_{h2}, and V_{h3} are the half-bridge cells' voltage waveform in the seven-step converter presented in Fig. 1(b). A seven-step voltage waveform shapes the proposed converter phase voltage signal without adding the LEC circuit.

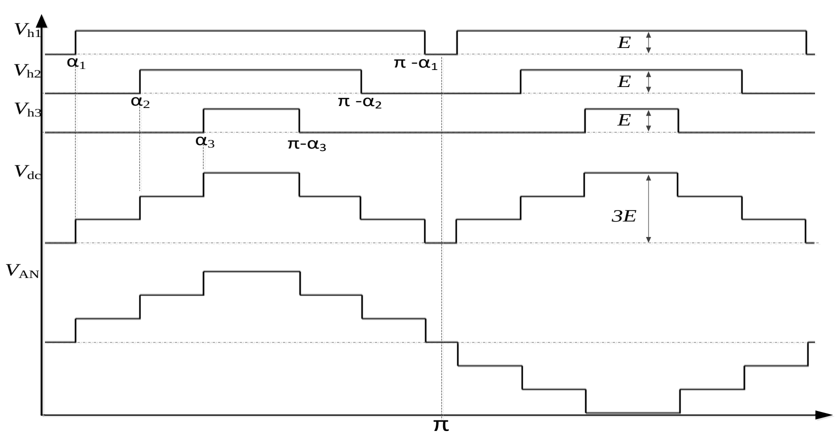


Fig. 2. Staircase scheme technique for basic cell converter without LEC circuit.

For the seven-step phase waveform, the voltage signal is described by its Fourier series below:

$$V_{AN} = \frac{4E}{\pi} \sum_{k=1,3,5,\ldots..}^{\infty} \frac{1}{n} \{\cos k\alpha_1 + \cos k\alpha_2 + \cos k\alpha_3\} \sin kwt \quad (3)$$

$$\text{For } 0 \leq \alpha_1 < \alpha_2 < \alpha_3 \leq \frac{\pi}{2}$$

where α_1, α_2 and α_3 are the switching angles of cascaded half-bridge converters, and k is the harmonic order. The peak voltage of the fundamental value $\hat{V}_{h,max}$ for a half-bridge converter module can be defined by the $\frac{4E}{\pi}$ value, which happens when the regulating angle α_1 of V_{h1} waveform, for instance, reductions to zero value. The three independent angles have been working to decrease or remove two low order harmonics for V_{AN} waveform, additionally deliver a flexible modulation index, determined by

$$m_a = \frac{\hat{V}_{AN}}{h \times \hat{V}_{h,max}} = \frac{\hat{V}_{AN}}{h \times \frac{4E}{\pi}} \qquad (4)$$

Where the peak point of the fundamental converter output waveform V_{AN} is $\hat{V}_{AN}$, and h is the total number of half-bridge cell blocks in one phase. The following equations have been shown for the seven-step converter for fifth and seventh harmonic order to be eliminated:

$$\cos\alpha_1 + \cos\alpha_2 + \cos\alpha_3 = 3m_a$$

$$\cos 5\alpha_1 + \cos 5\alpha_2 + \cos 5\alpha_3 = 0 \quad (5)$$

$$\cos 7\alpha_1 + \cos 7\alpha_2 + \cos 7\alpha_3 = 0$$

As a consequence, the three controlled angles could have the following values:

$$\alpha_3 = 57.106^\circ, \alpha_2 = 28.717^\circ,$$
$$\alpha_1 = 11.504^\circ \quad \text{for} \quad m_a = 0.85 \quad (6)$$

The staircase scheme is flexible to achieve where all the switching angles can be calculated off-line and stored in a look-up table for digital management. This modulation corresponds to the carrier-based pulse width scheme; the staircase technique has lower stress for switching because all the switching devices work at the fundamental frequency.

Section A states that dc source modules are managed separately by half-bridge blocks, where a basic cell inverter circuit can produce $2h + 1$ steps of output waveform without the LEC block (i.e., the seven-step signal given in Fig. 2). As presented in Fig. 3, the half-bridge converter module's output waveforms are identified as V_{h1}, V_{h2}, V_{h3}, and V_{LEC}, respectively. So, the total dc-link waveform of the converter with the new structure building is defined by

$$V_{dc} = V_{h1} + V_{h2} + V_{h3} + V_{LEC} \qquad (7)$$

C. THE HYBRID CASCSADED MULTLEVEL INVERTER WITH LEC

Among similar energy storage technologies, the single-phase building of the suggested basic module converter with a Level Elevating Cell (LEC) is presented in Fig. 3. The inverter is recognized by combining two additional half-bridge blocks connected to dc power supplies ($\frac{E}{2}$) and ($-\frac{E}{4}$) voltage (V_{LEC}) to produce $\frac{E}{2}$, $\frac{E}{4}$ or 0 voltage steps and hence increase the voltage level of the output waveform to nearly triple output steps.

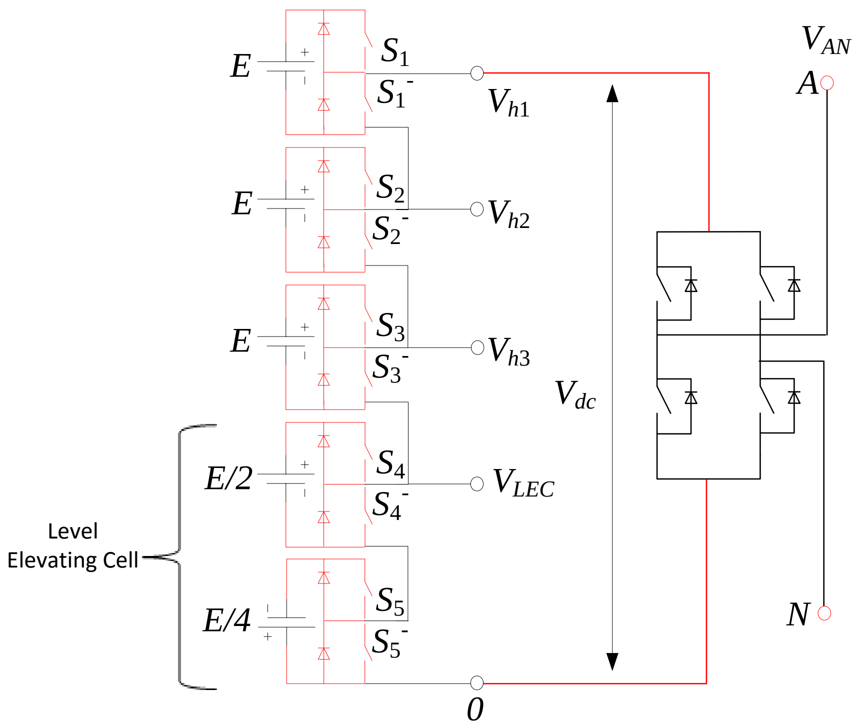


Fig. 3. Circuit of a basic cell converter with LEC block.

Table II

Switching states of the twenty-five-level basic module converter with LEC block for Fig. 3.

DC-bus Voltage	ON, OFF positions position					DC/DC output waveforms with LEC			
	S_1	S_2	S_3	S_4	S_5	V_{h1}	V_{h2}	V_{h3}	V_{LEC}
3E	1	1	1	0	0	E	E	E	0
$2E+\frac{3}{4}E$	1	1	1	0	1	E	E	E	$-\frac{E}{4}$
$2E+\frac{E}{2}$	1	1	0	1	0	E	E	0	$\frac{E}{2}$
	1	0	1	1	0	E	0	E	$\frac{E}{2}$
	0	1	1	1	0	0	E	E	$\frac{E}{2}$
$2E+\frac{E}{4}$	1	1	0	1	1	E	E	0	$\frac{E}{4}$
	1	0	1	1	1	E	0	E	$\frac{E}{4}$
	0	1	1	1	1	0	E	E	$\frac{E}{4}$
2E	1	1	0	0	0	E	E	0	0
	1	0	1	0	0	E	0	E	0
	0	1	1	0	0	0	E	E	0

$E+\frac{3}{4}E$	1	1	0	0	1	E	E	0	$-\frac{E}{4}$
	1	0	1	0	1	E	0	E	$-\frac{E}{4}$
	0	1	1	0	1	0	E	E	$-\frac{E}{4}$
$E+\frac{E}{2}$	0	0	1	1	0	0	0	E	$\frac{E}{2}$
	0	1	0	1	0	0	E	0	$\frac{E}{2}$
	1	0	0	1	0	E	0	0	$\frac{E}{2}$
$E+\frac{E}{4}$	0	0	1	1	1	0	0	E	$\frac{E}{4}$
	0	1	0	1	1	0	E	0	$\frac{E}{4}$
	1	0	0	1	1	E	0	0	$\frac{E}{4}$
E	0	0	1	0	0	0	0	E	0
	0	1	0	0	0	0	E	0	0
	1	0	0	0	0	E	0	0	0
$\frac{3}{4}E$	0	0	1	0	1	0	0	E	$-\frac{E}{4}$
	0	1	0	0	1	0	E	0	$-\frac{E}{4}$
	1	0	0	0	1	E	0	0	$-\frac{E}{4}$
$\frac{E}{2}$	0	0	0	1	0	0	0	0	$\frac{E}{2}$
$\frac{E}{4}$	0	0	0	1	1	0	0	0	$\frac{E}{4}$
0	0	0	0	0	0	0	0	0	0

If the LEC block gets into operation, the output signal waveform becomes $6h$ extra signal steps in the H-bridge phase output waveform V_{AN}. The new dc-link waveform V_{dc} signal has thirteen waveform levels of 3E, $2E+\frac{3}{4}E$, $2E+\frac{1}{2}E$, $2E+\frac{1}{4}E$, 2E , $E+\frac{3}{4}E$, $E+\frac{1}{2}E$, $E+\frac{1}{4}E$, E, $\frac{3}{4}E$, $\frac{1}{2}E$, $\frac{1}{4}E$ and 0. Since the H-bridge converter circuit operates symmetrically, there are additional twelve waveform steps of $-3E$, $-(2E+\frac{3}{4}E)$, $-(2E+\frac{1}{2}E)$, $-(2E+\frac{1}{4}E)$, $-2E$, $-(E+\frac{3}{4}E)$, $-(E+\frac{1}{2}E)$, $-(E+\frac{1}{4}E)$, $-E$, $-\frac{3}{4}E$, $-\frac{1}{2}E$, $-\frac{1}{4}E$ may be achieved. On the whole, there are twenty-five waveform levels of $\pm 3E$, $\pm(2E+\frac{3}{4}E)$, $\pm(2E+\frac{1}{2}E)$, $\pm(2E+\frac{1}{4}E)$, $\pm 2E$,

$\pm(\mathrm{E}+\frac{3}{4}\mathrm{E})$, $\pm(\mathrm{E}+\frac{1}{2}\mathrm{E})$, $\pm(\mathrm{E}+\frac{1}{4}\mathrm{E})$, $\pm\mathrm{E}$, $\pm\frac{3}{4}\mathrm{E}$, $\pm\frac{1}{2}\mathrm{E}$, $\pm\frac{1}{4}\mathrm{E}$ and 0. In Table II, the switching positions of the twenty-five-step basic module with the LEC cell of the proposed inverter are summarized. Also, it can be remarked that some waveform steps could be achieved by more than one switching position. For the symmetrical introduced hybrid cascaded multilevel inverter with LEC cell, the output signal waveform steps m is an odd number, and h is the number of main dc-dc energy storage power supplies in one phase (i.e., V_{h1}, V_{h2}, and V_{h3}). The number of waveform levels in the basic module with LEC block can be described by

$$m = 8h + 1 \qquad (8)$$

Hence, if the LEC is joined to a 2h + 1 level of the basic module converter, the inverter circuit will successfully operate similar to the traditional Cascaded H-bridge Multilevel Inverter but with $8h+1$ levels. Note that the LEC block will periodically apply a positive or a negative voltage waveform when it is needed to produce $\pm(2\mathrm{E}+\frac{3}{4}\mathrm{E})$, $\pm(2\mathrm{E}+\frac{1}{2}\mathrm{E})$, $\pm(2\mathrm{E}+\frac{1}{4}\mathrm{E})$, $\pm(\mathrm{E}+\frac{3}{4}\mathrm{E})$, $\pm(\mathrm{E}+\frac{1}{2}\mathrm{E})$, $\pm(\mathrm{E}+\frac{1}{4}\mathrm{E})$, $\pm\frac{3}{4}\mathrm{E}$, $\pm\frac{1}{2}\mathrm{E}$, $\pm\frac{1}{4}\mathrm{E}$ waveform steps, as presented in Fig. 4.

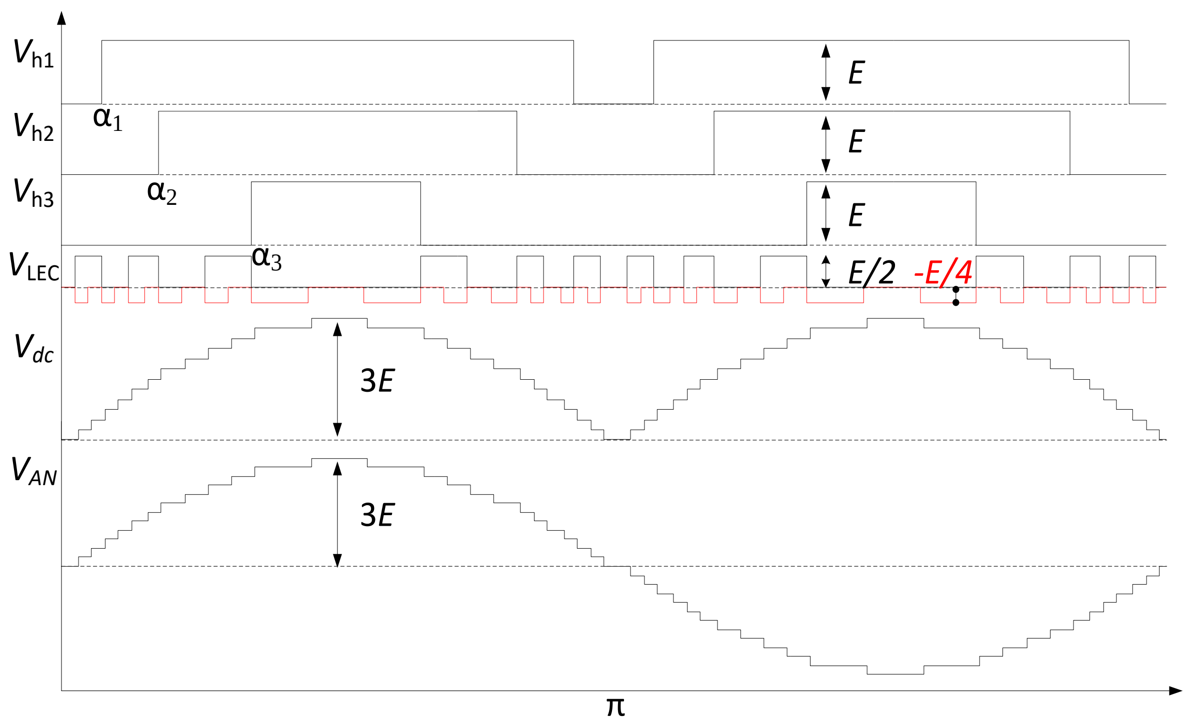


Fig. 4. Staircase scheme technique for basic module converter with LEC circuit.

If implementing a particular staircase scheme technique (discussed in the simulation section), Fig. 5 shows a three-phase hybrid multilevel converter with a LEC block circuit explained in this paper. Two basic cells with the level elevating network (Fig. 3) joined in every single-phase leg extended at the H-bridge level to meet higher power and voltage levels. Each energy storage module can be added or bypassed in generating the output waveform in this suggested hybrid cascaded converter. This switching arrangement is made by controlling the half-bridge circuit's semiconductor devices for each battery energy storage module.

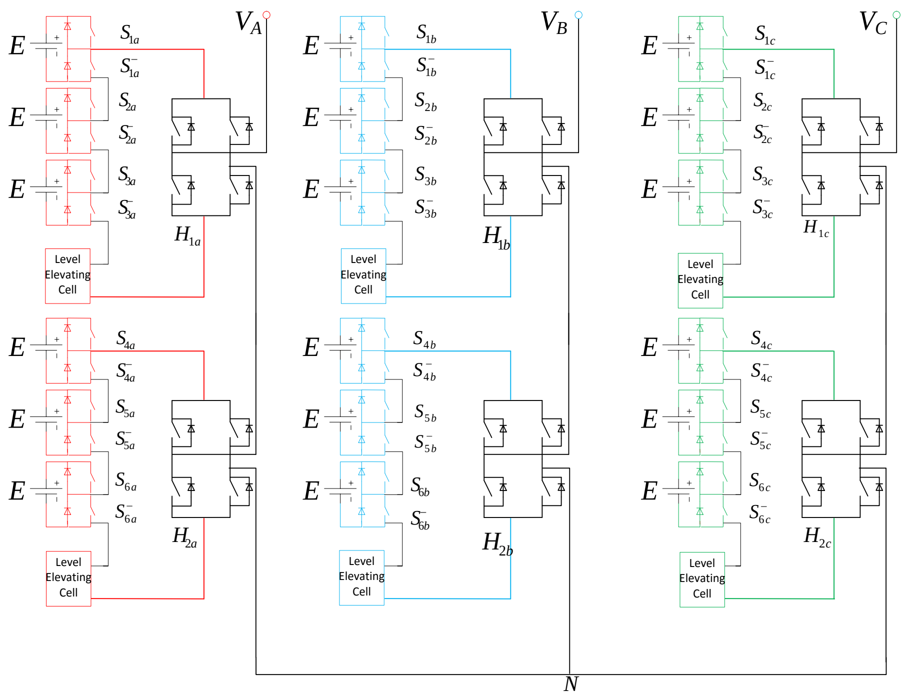


Fig. 5. Circuit of a three-phase introduced converter with LEC cells.

In the cascaded multilevel converter structure, the number of elements is proportional to the output waveform levels. An increased number of system components complicates the control and increases insulation specifications, hence challenging its reliability. The H-bridge inverter can change the dc-link's output waveform's polarity to generate an ac voltage waveform. The H-bridge converter's switching semiconductor devices must manage higher values of power levels work at the frequency of fundamental value. Moreover, the semiconductor devices in the half-bridge converter also switch at the fundamental frequency but with lower power and voltage. The switching devices in the LEC block operate faster to Elevating the output voltage waveform levels. Increased number of system components increases the size of inverter, weight, and cost, imposes a higher requirement of insulation, and also complicates the control. Moreover, these drawback factors will challenge the system reliability. Table III presents the number of components required to implement a three-phase twenty-five-level inverter with different topologies, including the proposed inverter. The proposed inverter achieves a 70.8% reduction in the number of system components required and uses only 42 switches compared with 144 switches used in a traditional cascaded H-bridge (CHB) converter and modular multilevel converter (MMC).

Table III
Comparison of total component count for a three-phase twenty-five -level converter.

	CHB [16]	MMC [22]	Sub-MI [23]	Proposed Inverter
Transformers	0	0	6	0
Switches	144	144	108	42
Diodes	144	144	108	42
Total #	288	288	222	84
% of reduction	0%	0%	22.9%	70.8%

D. BATTERY SYSTEM CHARGING METHOD

The power of an individual battery module can be regulated by controlling upper semiconductor devices for the half-bridge or dc-dc circuit joined to a pack. The charging and discharging process is managed by controlling the modulation-index $m_{k,i}$ (energy storage cell k in phase i, i=a, b, c) of the upper switch from every dc-dc circuit. The instant energy or power for charging and discharging of the chemical energy module is provided by

$$P_{pack,k}(t) = S_{upper,k,i}(t) \times E_{k,i} \times I_{dc} \quad (٩)$$

where $S_{upper,k,i}$ is the k^{th} chemical energy cell upper semiconductor device conditions in phase i, i=A, B, C: where (1) is ON state, or (0) is OFF state; $E_{k,i}$, and I_{dc} are output dc voltage of the single chemical energy module and the chemical energy current for the all chain, respectively.

For the proposed inverter structure, the reference value signal for the circuit of dc-link is the value of absolute voltage of the output reference waveform in ac side. Hence, not all the chemical energy modules are required to feed the load simultaneously. The H-bridge is employed to change the direction of the dc-link waveform. Battery charging or discharging energy is defined by the duration of each chemical energy module attached to the system used for state of charge or chemical energy balancing. The cell with a higher charge can be discharged further or charged less in use for the battery storage cells with the same rated terminal voltage. A balanced SOC is maintained continuously via the proposed inverter without an external balancing circuit. As a result, the reliability of individual battery modules is improved; hence, the utilization of the whole battery energy storage system is increased.

One battery module in each phase of the main dc power supplies

(i.e., V_{h1}, V_{h2}, and V_{h3} in Fig. 3) is allowed to operate in a switching position in the staircase modulation. The upper switching devices of other converters keep their position state without change, and hence the switching loss decreased father more. When the individual battery cell is practiced to maintain supplying power to the grid (discharging mode), the energy storage cell for the highest SOC is managed to form the bottom step of the staircase voltage waveform (more connection period than other battery cells). In contrast, the battery with the lowest SOC will create the upper staircase (less connection period than other battery modules). During charging mode, the battery module with less SOC is controlled to form the bottom step of the staircase signal, and the battery for higher SOC can be placed to create the top step of the staircase output waveform. When the Electrical Vehicle is in braking mode, the chemical energy modules are in charged mode for the regeneration process of an electric vehicle.

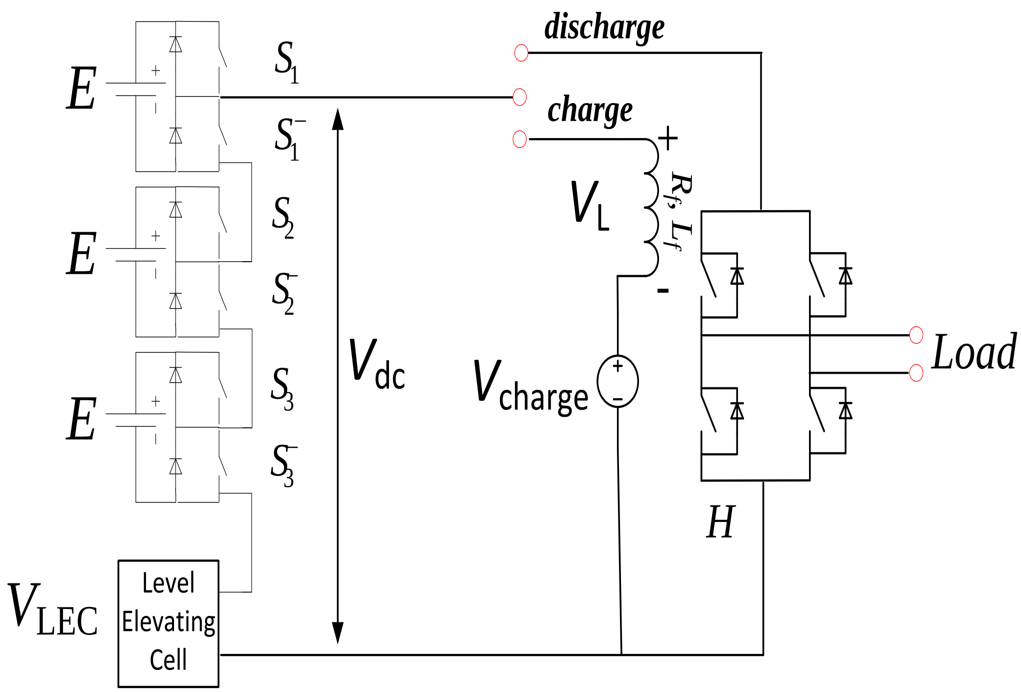
The chemical energy module SOC is challenging to be measured in the battery energy storage systems in a real application, and the voltage value uniform is typically applied. Typically, the cut-off value throughout charge/discharge modes keeps the same. Therefore, the overcharge and over-discharge of the battery system is reduced. The SOC of chemical energy modules changes very slowly through regular use. Hence, battery module positions updated by fundamental value of frequency are sufficiently for the terminal output waveform and state of charge uniform.

A dc power supply for the proposed inverter is required to charge the chemical energy modules. The presented structure is controlling the charging current and voltage. The charging/discharging system is shown in Fig. 6 (a). Moreover, an inductance filter is joined in series with the dc power supply to achieve the current control. A capacitor and the H-bridge can also obtain the dc voltage power supply, as illustrated in Fig. 6 (b). The H-bridge inverter is operated as rectifier equipment, and a dc waveform is generated.

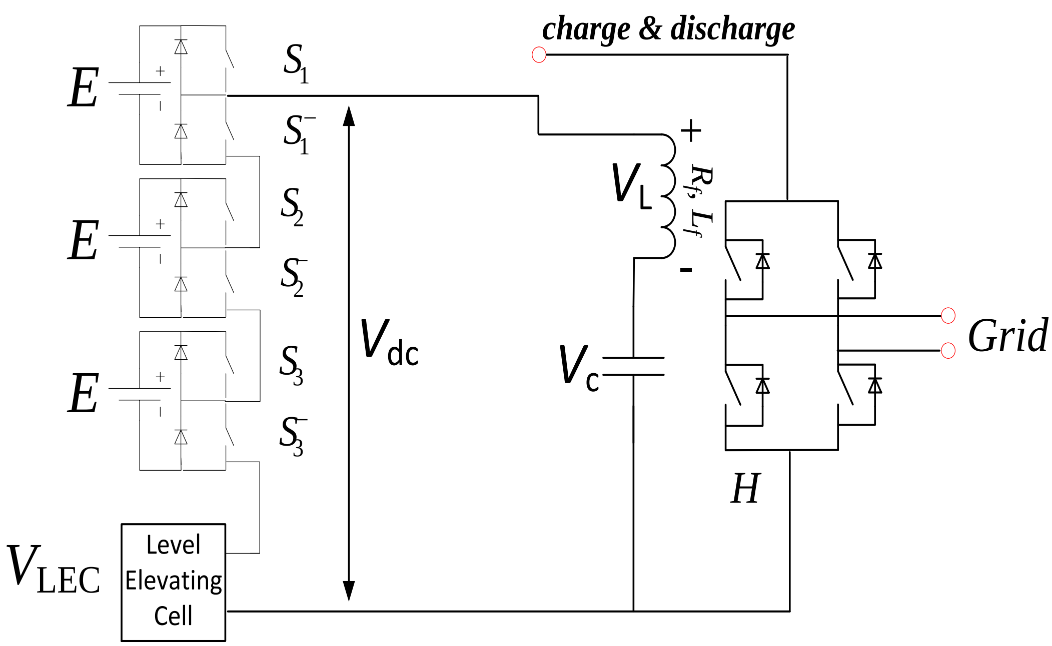
For the charging process of the chemical energy modules, the current must be regulated, and the current can be expressed as follow:

$$V_{charge} + R_f i + L_f \frac{di}{dt} = V_{dc} \quad (10)$$

V_{dc} is the dc-bus waveform, V_{charge} is the voltage of the dc power supply, L_f and R_f are the impedance elements of the inductive filter that can be connected to the battery system and the dc power supply. By this presented charging procedure, the dc power supply value should be the maximum achievable voltage of the dc-link waveform.



(a)

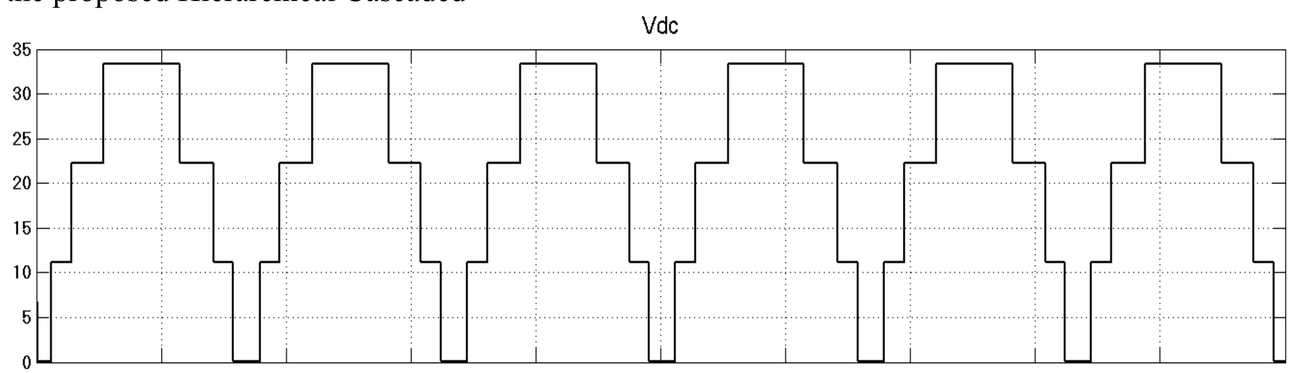


(b)

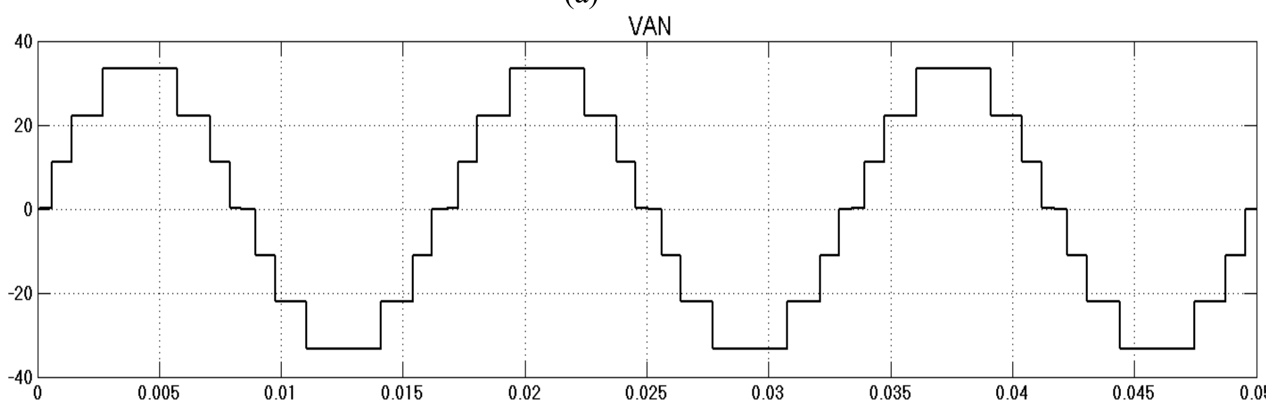
Fig. 6. Charging/discharging of battery energy storage system: (a) Connected to dc source; (b) Connected to grid or ac source.

SIMULATION ANALYSIS

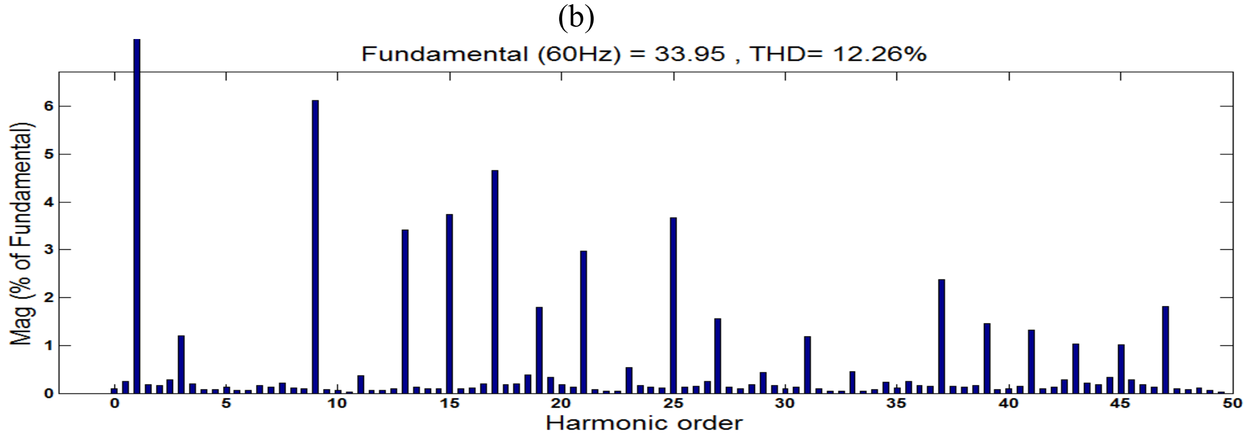
Simulation results have been carried out to confirm the presented cascaded converter with LEC circuit. The dc-link and phase output voltage signal waveforms of the seven-level primary cell (Fig. 1. without the LEC block) of the proposed Hierarchical Cascaded Multilevel Inverter based on (4) and (6) are presented in Fig. 7 (a and b) respectively, where the output waveform spectrum is given in Fig. 7 (c). The output phase waveform V_{AN} has 12.26% THD and does not have the fifth or seventh harmonic order.



(a)



(b)



(c)

Fig. 7. Basic cell of proposed inverter without LEC block: (a) dc-bus waveform, (b) single-phase waveform V_{AN}, (c) the Harmonic spectrum for the waveform of V_{AN} signal.

The dc-link waveform and output phase voltage of the twenty-five-level basic cell with LEC block inverter is demonstrated in Fig. 8(a and b). For the twenty-five-level phase voltage V_{AN}, the signal is represented in terms of its Fourier series as in (3) for $0 \leq \alpha_1 < \alpha_2 < \alpha_3 < \alpha_4 < \alpha_5 < \alpha_6 < \alpha_7 < \alpha_8 < \alpha_9 < \alpha_{10} < \alpha_{11} < \alpha_{12} \leq \frac{\pi}{2}$ where α_1, α_2, α_3, α_4, α_5, α_6, α_7, α_8, α_9, α_{10}, α_{11} and α_{12} are the independent switching angles. The twelve independent angles have been employed to reduce two harmonics in V_{AN} waveform and further give a flexible modulation index, determined by (4). The next equations have been expressed for the proposed twenty-five -step converter with fifth and seventh harmonic elimination by applying (5):

$$\cos\alpha_1 + \cos\alpha_2 + \cos\alpha_3 + \cos\alpha_4 + \cos\alpha_5 + \cos\alpha_6 + \cos\alpha_7 + \cos\alpha_8 + \cos\alpha_9 + \cos\alpha_{10} + \cos\alpha_{11} + \cos\alpha_{12} = 3m_a$$

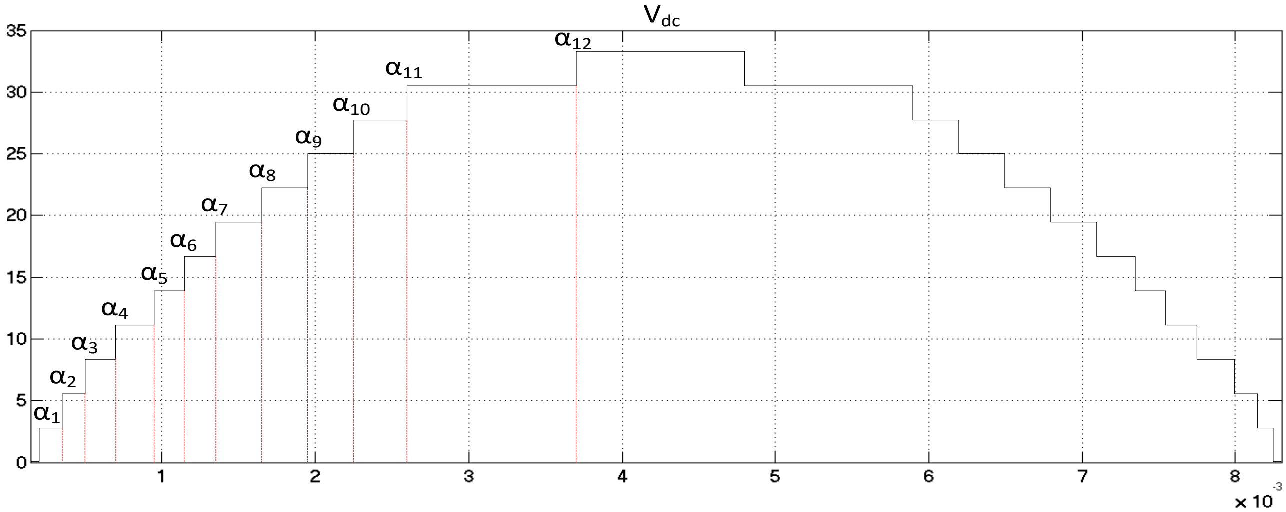
$$\cos 5\alpha_1 + \cos 5\alpha_2 + \cos 5\alpha_3 + \cos 5\alpha_4 + \cos 5\alpha_5 + \cos 5\alpha_6 + \cos 5\alpha_7 + \cos 5\alpha_8 + \cos 5\alpha_9 + \cos 5\alpha_{10} + \cos 5\alpha_{11} + \cos 5\alpha_{12} = 0$$

$$\cos 7\alpha_1 + \cos 7\alpha_2 + \cos 7\alpha_3 + \cos 7\alpha_4 + \cos 7\alpha_5 + \cos 7\alpha_6 + \cos 7\alpha_7 + \cos 7\alpha_8 + \cos 7\alpha_9 + \cos 7\alpha_{10} + \cos 7\alpha_{11} + \cos 7\alpha_{12} = 0$$

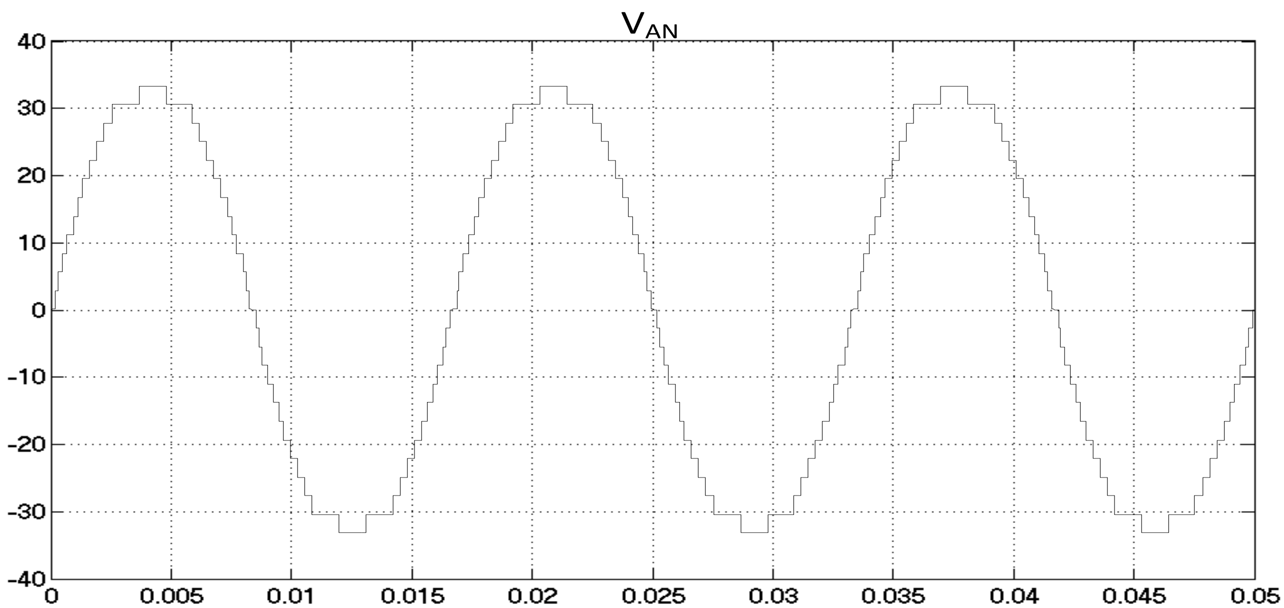
As a result

$\alpha_1 = 3^\circ$, $\alpha_2 = 6^\circ$, $\alpha_3 = 9^\circ$, $\alpha_4 = 13.725^\circ$, $\alpha_5 = 18.45^\circ$, $\alpha_6 = 23.76^\circ$, $\alpha_7 = 28.08^\circ$, $\alpha_8 = 34.56^\circ$, $\alpha_9 = 41.04^\circ$, $\alpha_{10} = 47.52^\circ$, $\alpha_{11} = 54^\circ$, $\alpha_{12} = 77.76^\circ$ for $m_a = 0.85$

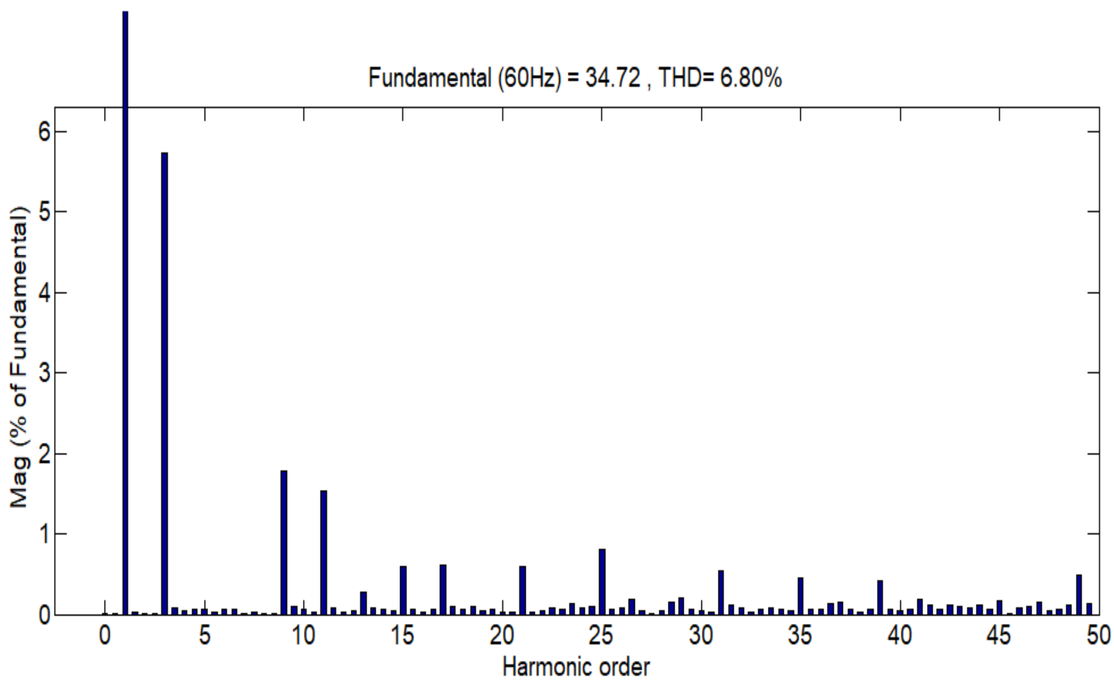
By applying the above angle values the fifth and seventh harmonic orders are eliminated and hence the most next important two harmonic are the third and ninth harmonic orders which can be eliminated in three phase system. The staircase schem method is manageable to realize where all the angles of semiconductor devises can be computed off-line and later saved in a look-up table for digital regulation. The voltage waveform with adding LEC block to the main basic cell inverter has THD of 6.80%, as given in Fig.8 (c). It is watched that, by adding the level Elevating cell to the basic cell inverter, the output voltage level increased from 7 to 25 steps, and hence, the total harmonic distortions of the phase voltage can be reduced from 12.26% to 6.80%, which results in a total THD reduction of 55.45%.



(a)



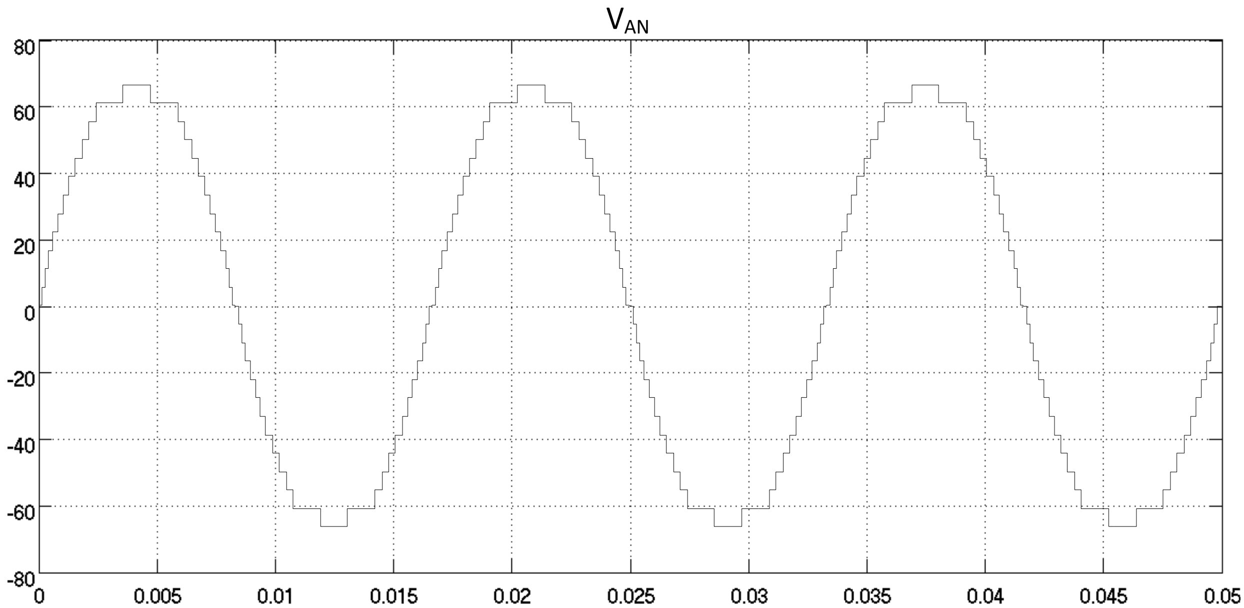
(b)



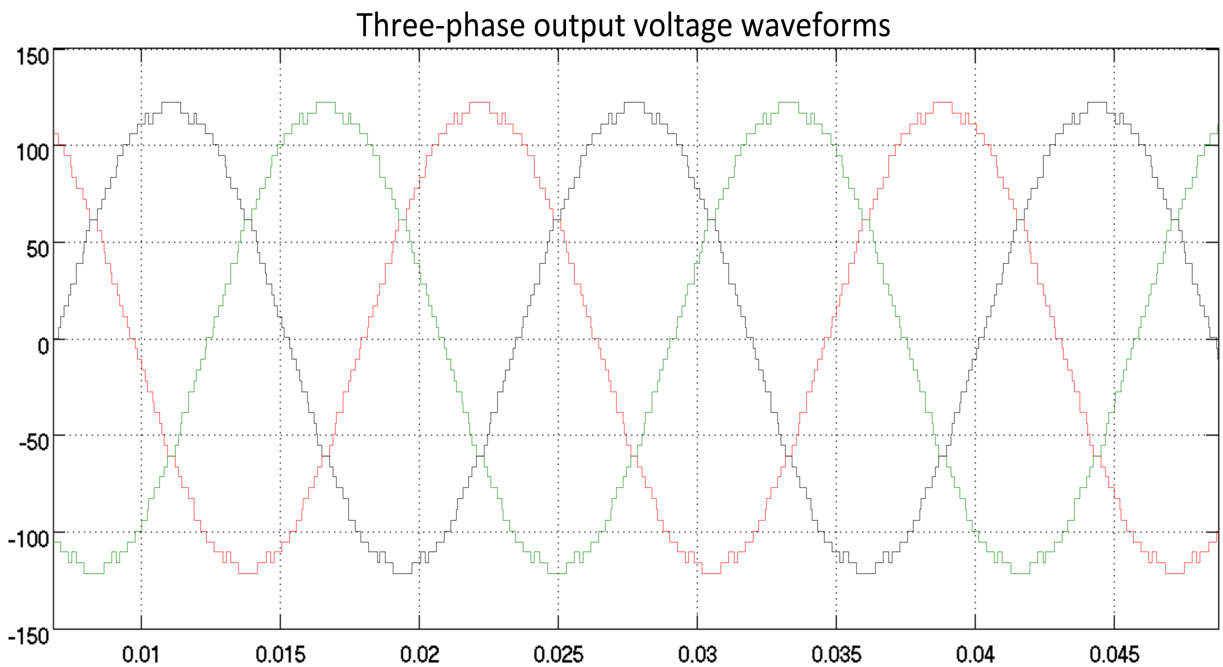
(c)

Fig. 8. Basic cell of proposed inverter with LEC block: (a) dc-link voltage waveform, (b) single phase voltage waveform V_{AN}, (c) the Harmonic spectrum for the waveform of V_{AN} signal.

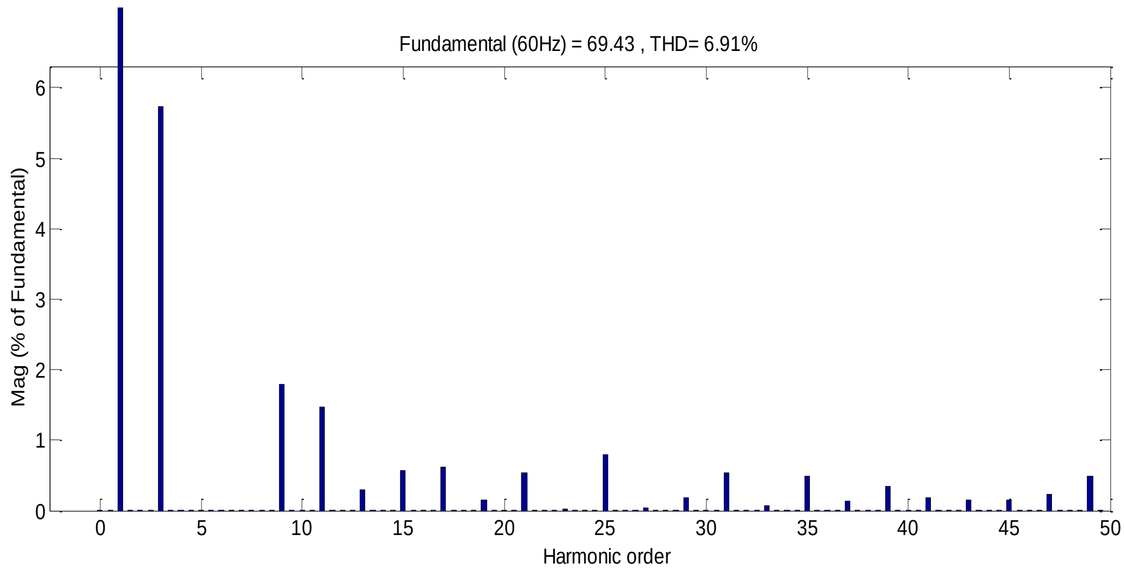
For a three-phase system with a 25-level inverter structure (Fig. 5), a system consisting of 30 dc source modules (6 main dc sources with 2 LEC cells in each phase) is analyzed to test the effectiveness of the suggested inverter. The main power supply module is a 12 V unit, where the LEC module has a 6 V and -3 V dc sources. The switching frequency of the inverter is 60Hz (for the main half-bridge and H-bridge blocks). The 25-level phase voltage V_{AN} waveform and the three-phase output voltage waveform are given away in Fig. 9 (a) and (b) respectively. The output spectrum of the phase waveform which not include the fifth and seventh harmonics is presented in Fig. 9 (c), and the Line-Line voltage spectrum is presented in Fig. 9 (d). The converter line-to-line waveform V_{AB} does not include any triple harmonic orders such as 3^{rd}, 9^{th}, and 15^{th} on top of eliminating the fifth and the seventh harmonic orders in phase voltage, ending in a more decrease in total harmonic distortion and hence nearly sinusoidal waveforms.


V_{AN}
80
60
40
20
0
-20
-40
-60
-80
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045
0.05

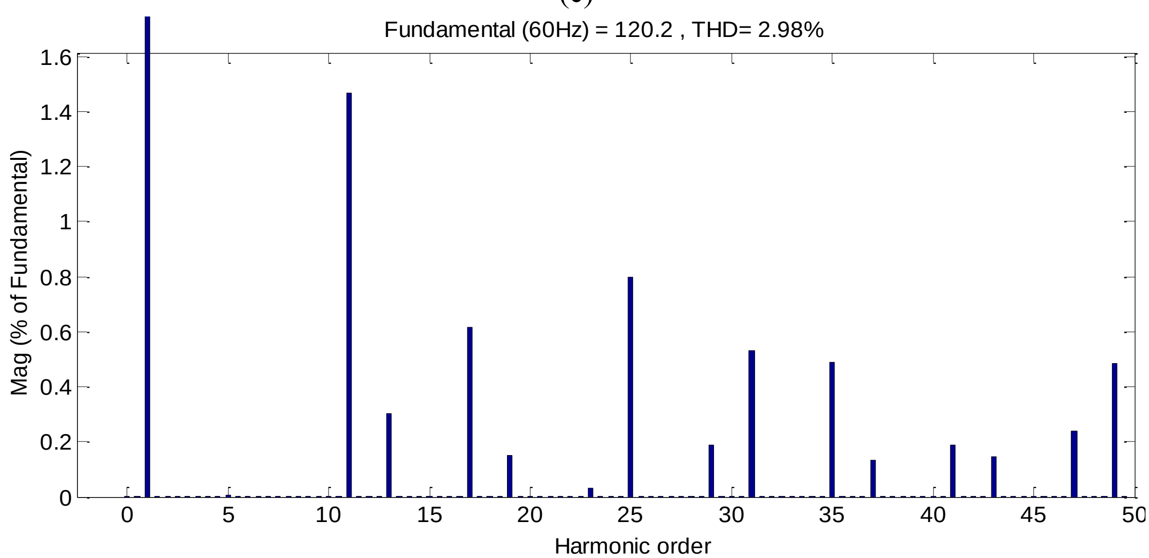
(a)


Three-phase output voltage waveforms
150
100
50
0
-50
-100
-150
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045

(b)



(c)



(d)

Fig. 9. The proposed Inverter with LEC block: (a) 25-step phase V_{AN} signal, (b) Three phase waveforms, (c) the Harmonic spectrum for the 25-level phase voltage V_{AN} waveform, (d) the Harmonic spectrum for the Line-Line output voltage V_{AB} waveform.

CONCLUSIONS

In driving electric vehicles (EV), the battery energy storage system performs a vital part. Redox flow or lithium chemical technologies are the most popular batteries in the worldwide power sector because of their convenient chemical energy power, density, and cost.

This paper introduces a new circuit of a hybrid inverter with a level elevating circuit. This structure has the following features: (1) It can handle heterogeneous battery energy storage technologies, i.e., new or used batteries, or even energy storage with different chemistry materials due to the individualized battery energy control management. (2) The new proposed converter uses a Level Elevating Cell (LEC) where the LEC cell consists of two half-bridge converters per basic cell that can be used to approximately triple the output voltage levels. Power quality has significantly enhanced, so the performance of motor control in EVs is improved. (3) It is a hybrid circuit topology of both dc/dc converters (half-bridges) and dc/ac inverter (H-bridge converter blocks) connected at couple cascaded multilevel, i.e., the DC/DC half-bridge level and DC/AC H-bridge cascaded level. This circuit topology structure provides the proposed multilevel inverter for high power and high voltage utilization with a modular arrangement for reliability enhancement and cost reduction. (4) The proposed structure realizes the charging mode and discharging mode of chemical energy storage modules where the SOC or output waveform uniform management is recognized simultaneously. (5) A staircase scheme method can be utilized with the multilevel suggested inverter to decrease switching losses. (6) The weaken battery cell is bypassed without bringing the system down. As a result, the fault-tolerant characteristic is improved that leads to improving the whole system reliability significantly. Simulation studies have verified the proposed converter's effectiveness and increased the voltage level at the output.

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عاكس متعدد المستويات لأنظمة تخزين طاقة بطاريات عالية الكثافة المستخدمة في المركبات الكهربائية

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الملخص

في أنظمة تخزين طاقة المركبات الكهربائية (EV)، يتم توصيل العديد من خلايا أو وحدات البطارية عادةً لتحسين جهد الخرج للتحكم في المحرك. سيؤدي التنوع في الخصائص الكهروكيميائية إلى عدم توازن حالة الشحن (SOC) والجهد الطرفي بين وحدات البطاريات المختلفة. تم اقتراح هيكل محول متعدد المستويات متتالي جديد يستخدم خلية رفع المستوى (LEC) في هذا البحث. تتكون دائرة LEC من محولين نصف جسر لكل خلية أساسية لكل مرحلة والتي يمكن أن تضاعف ثلاث مرات تقريبًا خطوات جهد الخرج، بما في ذلك إدارة طاقة البطارية والتحكم في المحركات للمركبات الكهربائية. يمكن مشاركة كل وحدة / خلية في الدائرة أو تجاوزها بواسطة محول DC / DC (محول نصف جسر) في الهيكل المقترح. جميع وحدات البطارية متتالية من خلال محولات نصف جسر لإنتاج جهد تيار مستمر ناتج على شكل جهد متعدد المستويات. بعد ذلك، يتم استخدام عاكس جسر H لتحويل اتجاه جهد ناقل التيار المستمر إلى جهد تيار متردد. مخرجات العاكس عبارة عن جهد متعدد المستويات مع عدد أقل من التوافقيات وانخفاض dv / dt، مما يزيد من أداء المحركات. يمكن تحسين نسبة استخدام طاقة البطاريات عن طريق التحكم الفردي وفقًا لمعيار SOC لكل خلية أو وحدة وبالتالي يمكن أيضًا تجنب عدم توازن الجهد الطرفي و SOC. تم إجراء دراسات المحاكاة للتحقق من أداء العاكس المقترح.

الكلمات المفتاحية: أنظمة الشحن، أنظمة تخزين طاقة البطاريات، الهيكل الهجين، تقنية الاستيركيس

The Practices and Obstacles of Lean Implementation in Saudi Arabian Healthcare System: A Scoping Review

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ABSTRACT

Background and Objective: The principles of lean implementation were designed to reduce the cycle time of delivery services. In this context, our scoping review was conducted to evaluate various practices and obstacles for lean implementation in the healthcare system in Saudi Arabia.

Design/Methodology: In the present scoping review, all study design articles depicting the practices and barriers of the lean implementation technique in the healthcare industry of Saudi Arabia were identified and included in the review.

Results: Based on their eligibility, a total of 27 articles were included. The six sigma define, measure, analyze, improve, and control (DMAIC) approach was used in most studies. Additionally, most studies were conducted in the emergency department to reduce overcrowding. Identifying and reducing waste was the most common positive outcome in most studies, and staff-related barriers specifically, the barrier related to the lack of trained personnel were predominantly reported.

Conclusion: The knowledge gained from this scoping review can help with the development of models/roadmaps for a healthcare system enhancement in both Saudi Arabia and other countries.

Keywords: Healthcare system, lean implementation, Saudi Arabia, barriers

INTRODUCTION

The demand for better healthcare services is constantly increasing, which places tremendous pressure on hospitals to deliver quality care with limited monetary support and resources [1]. Additionally, hospitals must strike a balance between the costs and improvement of healthcare services [2]. In short, the healthcare system should be reachable, reasonable, well-organized, and cost-effective. Due to this, healthcare organizations suffer from several problems that can impact the quality of services provided by the organization.

These issues can be eliminated using an organizational redesign approach. This approach, which is known as lean implementation, focuses on improving the process of healthcare services by maximizing value, minimizing waste, and continuously improving processes to achieve a greater satisfaction of the customers (patients) in lesser time [3,4]. The lean principles are thought to derive from the Toyota Production System (TPS) [5]. TPS was first described in the late 1970s [6] and has gained popularity under the name "lean production" through the book *The Machine That Changed the World*, which was written by Womack and Jones [7]. Womack and Jones were the first to suggest the implementation of lean principles and the development of this field [8]. Lean production seeks to improve the structure of an organization's current processes and resources and the quality of healthcare [9]. The lean management principles are an alternative strategy to improve quality care without investments.

In a healthcare setting, such as the hospital, it has become increasingly important to implement these lean principles in the existing body of research [10]. Since then, there has been an increase in the research related to lean principles in healthcare [11-13].

Developed nations, such as the United Kingdom (UK), United States of America (USA), and Australia, have successfully implemented lean management principles in several healthcare organizations [14]. In the UK, the lean principles are implemented systematically through the UK's National Health Service (NHS) [13]. An extensive literature review conducted in healthcare settings in Gulf Cooperation Council (GCC) countries, with the Kingdom of Saudi Arabia (KSA), showed that there is a lack of frameworks for the lean supply chain (LSC) [11]. The KSA is ranked as the largest and fifth-largest country among the Middle Eastern and Asian countries, respectively, with a population of approximately 35,568,557 [15]. To manage the health of such a huge population, several efforts were directed by the Saudi government to improve the healthcare system. According to one study, 298 public and 137 private hospitals offer healthcare services in KSA. Currently, the KSA government delivers healthcare services free of charge to all citizens via the Ministry of Health (MOH), as endorsed in Article Number 31 of the Saudi Arabia constitution [16]. The MOH regulates healthcare and is working towards the goal of "health for all" [17]. According to Alkhamis, the healthcare system of KSA has secured 26th position amongst 190 international healthcare systems, for which, the government has exerted huge efforts toward improving the healthcare sector [18]. However, despite these achievements, the Saudi health sector is struggling with several issues related to increased demand for better health services, shortage of healthcare personnel, lack of proper flow of patients, interruption of the workflow, etc. that require the formation and implementation of new rules and plans by the Saudi MOH [17].

While the lean principles were employed in many western healthcare organizations for a long period of time, the implementation of the principles in KSA remains in the early stages, as the lean management principles are unfamiliar in KSA [19]. Hence, this scoping review has been conducted to evaluate various practices and obstacles for lean application in the healthcare system in KSA.

METHODOLOGY

The present scoping review is constructed on the basis of the approach suggested by Arksey and O'Malley (2005) [20], which involves the following five steps: recognizing the research question; defining the bibliographic portfolio (BP); analyzing the data as well as the bibliometrics; and conducting analysis through creating theoretical lenses.

(a) Recognizing the research question

As per Arksey and O'Malley (2005), identifying the research question is the foremost part of the scoping review [20]. Following the strategies and rules for scoping reviews, this paper developed the following comprehensive research question for our literature search: "What are the main practices and obstacles faced during lean implementation in the healthcare system in Saudi Arabia?". A sequential methodology was used to answer this question.

(b) Defining BP and consolidating research axes

Based on the description of BP, several steps were taken based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework which includes several steps of identification, screening, eligibility, and inclusion.

Identifying the literature

The papers that were published in the English language up to October 2021 in peer-reviewed journals, related to the use of lean management practices (used at least one lean practice activity), and conducted in a healthcare setting were included. In the first step, four research axes (healthcare, lean production, barriers, obstacles) were defined. Scientific articles were recognized from the following databases: PubMed, MEDLINE, Scopus, The Cochrane Database of Systematic Reviews, and Emerald Journals.

The following keywords were used to recover posts in the titles, abstracts, and/or keywords from PubMed ("lean practices" OR "lean implementation" OR "lean production" OR "lean healthcare" OR "lean") AND ("healthcare" OR "health system" OR "health service" OR "health organizations" OR "hospital" OR "healthcare") OR "emergency department" AND ("Saudi Arabia" OR "KSA" OR "Kingdom of Saudi Arabia").

Screening

Based on the inclusion and exclusion criteria, the filtering procedure was managed in two phases. In phase I, the titles of all the studies were screened first, followed by the abstracts. Articles were deemed eligible based on the title, and the abstracts were read and assessed for their eligibility. Duplicates and irrelevant papers were excluded from the scoping review. The full-text articles of all relevant studies were obtained and evaluated.

After the first filtering process, the selected articles were screened for references to search for any new potentially eligible studies in phase II. The full-text articles were independently reviewed by two reviewers, and the relevant data was extracted. Additionally, the references of the selected articles were scanned for any relevant studies. The Zotero software was used to extract additional references. Furthermore, an extensive search was carried out using the reference lists of the previous systematic reviews [21-29].

Eligibility

All study designs that included qualitative or quantitative methodologies and described the practices and barriers of the lean implementation technique in the healthcare industry of Saudi Arabia were eligible. This paper included research, case, observational, and qualitative studies. Studies that were accomplished in any location and those that were published in any other language apart from English were excluded.

Inclusion

Based on their eligibility, 27 articles [19,30-55] were included in the scoping review (Tables 1 and 2, Appendix 1). The details regarding the data selection and extraction of the studies are shown in Figure 1 (Appendix 2).

(c) **Charting the data**

The data of the included studies were extracted and categorized based on the issues and themes. Microsoft Excel was used to record the details related to the journal name, author names, publication years, aim of the study, design of the study, study location or hospital name, lean tools used, area of lean implementation, main reasons to apply lean principles, outcomes of lean implementation, and barriers of this technique. The differences in abstraction were answered by discussion.

(d) **Bibliometric analysis**

To obtain the details of the authors and journals of the included studies, a quantitative or bibliometric analysis was conducted.

Based on the 27 papers involved in the BP, 78 authors were recognized. It is noteworthy that Almutairi [46,51,53], Salonitis [46,51,53], Abdelhadi [34,35,52], Shakoor [34,40,48], Al-Ashaab [46,51,53], and Al Owad [32,45,50] had the highest (n=3) number of publications in BP, followed by Hassanain [38,41], Jaber [40,48], Karim [32,45], and Al Kuwaiti [36,39], who have two publications each in BP. The rest of the authors had one publication in BP (Table 1, Appendix 1).

The articles were segregated based on their journals. BMJ Open Quality [54,55], Jordan Journal of Mechanical and Industrial Engineering [40,48], and International Journal of Lean Six Sigma [46,51] had two publications each in BP. The remaining 21 journals had one publication (Table 1, Appendix 1).

Regarding publications per year within the BP, most publications were published in the years 2017 [19,39-42] and 2018 [43-47] (n=5). As shown in Figure 2 (Appendix 2), lean implementation in hospitals is a relatively new concept for Saudi Arabia.

The most frequent research method that was used in the included articles was a "case study," which was used in 13 of the included studies [30,32,36,37,41,43,46,48,49,51,52,54,55] followed by a research study or survey (n=10) [19,31,34,35,39,40,42,44,47,53] (Figure 3, Appendix 2). Since healthcare organizations are complex and multidimensional, the case study approach is the most common. Considering the research methods that were used in lean healthcare papers, de Souza, in their systematic review, categorized the article under two headings, namely theoretical and case studies [11]. D'Andreamatteo et al. [27] applied similar criteria as de Souza [11] and divided the article into theoretical and empirical categories. Costa and Filho categorized the scientific papers as, action research, theoretical-conceptual, survey, ethnography, and case study [28].

(e) **Conducting an analysis and discussion through theoretical lenses**

In 1925, the healthcare system of KSA was formed by King Abdul Aziz Al-Saud's royal decree. Since then, many efforts were directed by the Saudi Government toward the citizens by improving efficiency within the health system. The health services in KSA are offered through the following two key sectors: publicly funded health system (80%) and private sector health suppliers (20%). The publicly funded health system (80%) includes MOH (60%) and other governmental agencies (20%) that provide healthcare via more than 3,000 primary care centers of KSA. The biggest health service provider of KSA is the MOH, which provides health services through many healthcare hospitals and medical centers that are distributed throughout the country with the objective of providing high-quality healthcare services to a quickly increasing population [56]. The other 20% of publicly sponsored healthcare was supported by several governmental agencies, such as the

Ministry of National Guard (MNG), Ministry of Defense (MoD), Royal Commission for Jubail and Yanbu, Ministry of the Interior (MoI), and Ministry of Education [57].

The hospital is a complex structure that comprises various departments and people with different specializations who work at different grades within the same organization. Due to the never-ending demands of society and the large quantities of resources that are consumed, hospitals are under constant pressure to improve their performance and services and reduce costs and waiting times [58]. To manage such a complex structure, hospitals spend enormous amounts of money. Poulin [59] and Schwarting et al. [60] concluded in their research that 50% percent of the hospital's total expenditures could be reduced using proper management practices. De Souza [11] emphasized that like any other organization, continuous improvement and operations management should be conducted in hospitals, and robust management techniques are required by the hospital managers to improve the processes

To eliminate the hospital system's problems, several management techniques were emerged [61]. One such technique is related to lean thinking. Lean is a management philosophy that is often perceived as a collection of tools and methods that are used to enhance the process of the organization. It mostly emphasizes on adding value to the client by reducing cost and waste, minimizing errors, and improving profitability within the organizational processes [62]. As per Womack and Jones (1997), lean thinking is constructed on the following five principles: identifying the value; mapping the value stream; creating continuous flow; promoting pull production; and constantly striving for perfection [63]. The principles of lean application can be applied to various organizations or areas, such as pharmaceutical industries, construction, banks, hospitals, and insurers [11].

Our scoping review aimed to evaluate the various practices and obstacles of lean application in healthcare settings of KSA. According to de Souza [11], although the origin of lean implementation in a healthcare setting is unknown, the first global publication related to this topic dates to 2002. KSA became one of the first countries in the Middle East to implement a data-driven lean approach to improve hospital performance and patient healthcare services.

The first step of lean implementation is recognizing the patient as the primary customer, which should be considered when designing a process or delivering healthcare. According to Sugimori et al., the main feature of the model created by Toyota is the emphasis on the employees and teamwork [6]. Improving the quality of the healthcare system for the patient at the right time should be the ultimate lean healthcare goal. Hence, the leading principle of lean implementation is to realize the value and needs of the patients that enable essential changes in a healthcare system [64].

The following two theoretical lenses were selected for the BP analysis: (a) practices of lean implementation; and (b) obstacles faced by the organization while applying the lean technique (Table 2, Appendix 1).

(a) Practices of lean implementation

Lean tools

According to Machado and Leitner, lean tools enable one to handle the situation or problem adequately and efficiently [65]. The tools, methods, and principles of lean implementation are divided into the following five classes: "production flow," "continuous improvement," "work organization and visual management," "diagnosing and problem-solving," and "complementary management approaches." A number of lean tools come under these five categories. To name a few, these are 5S which is mainly used to organize work area (Sort, Straighten, Shine, Standardize, and Sustain); continuous flow; Kaizen continuous improvement (strategy used to increase the communication between employees); Kanban continuous improvement (to regulate the flow of goods and eliminate waste); PDCA (Plan-Do-Check-Act); Poka-Yoke (to eliminate and prevent errors); Single-Minute Exchange of Die (SMED) (to reduce changeover time); Takt time (to calculate the pace of production in relation to the customer demand); Total Productive Maintenance (TPM) (to maximize operational time); Value Stream Mapping (VSM) (to map the flow of production); define, measure, analyze, improve, and control (DMAIC) approach, etc [26]. In the present scoping review, 15 lean tools were identified by the studies, and the most common was the six sigma DMAIC approach (continuous improvement), which was used by ten studies [19,30,31,33,36,37,39,43,45,50], followed by the lean six sigma (LSS) (complementary management approach) [19,32,41,42,43,44,47] and value stream mapping (VSM) (diagnosing and problem-solving) [32,34,46,47,49,50,53] (n=7 each) (Table 3, Appendix 1). In a systematic review by Lima et al., more scientific publications were allocated to the groups "diagnosing and problem-solving" and "work organization and visual management" [26]. Another systematic review by Borges and Tortorella showed that the most frequently cited practice was the VSM [21]. Costa and Filho discovered a reasonable number of several lean tools (n=24) and methods that were utilized in the healthcare system. They analyzed 107 articles and found that the most applied tools were the Ishikawa Diagrams, VSM, and DMAIC methods [28]. According to Anvari et al., one of the main obstacles encountered by managers is to choose an adequate lean tool, which is considered the most significant process in verifying the success or failure of the lean process [66]. The main reason for the failure of the lean process is the selection of the wrong lean tool [67].

Hospital areas

Amongst the 27 papers on lean implementation, we found ten key areas (operating room, emergency department, vaccination room, discharge process, pharmacy, pathology lab, performance improvement unit, nursing unit, inpatient unit, and others) where the lean approach was applied. Mainly of the researches in our scoping review (n=7) [32,45,35,40,48,49,54] were conducted in the emergency department (ED), followed by the pharmacy (n=3) [34,36,52] (Table 4, Appendix 1). EDs are categorized as the main front door of the hospitals, and they offer 24/7 emergency care. However, due to the increased flow of patients to the ED, the department faces several challenges. Hence, the efficient management of this vital department requires a proper strategy to identify the patients' needs and maintain the flow of patients, along with the limited use of resources, which is possible by applying the principles of lean management. Regarding the intervention and strategies that aim to solve the problem of overcrowding and flow metrics, the scoping review by Jeyaraman et al. (2021) found that the interventions that were led by public healthcare professionals directed a positive effect on the problem of overcrowding of the ED (68% found a positive impact on the utilization of ED resources) [68]. The systematic review by Souza et al. on the ED stated that the reduction of waiting times was the most significant benefit for EDs, which improves both the problem of overcrowding and patient satisfaction [69]. In contrast, a cross-sectional descriptive community-based study concluded that most patients were satisfied with the management of the ED of the hospitals of KSA [70]. In the systematic review by Lima et al. (2020), the general hospital, ED, specialties, operating room (OR), oncology, and pharmacy were the key areas of lean application [26]. Costa and Filho found that most of the studies were conducted in a hospital pharmacy (n=7), followed by pathology (n=4) and radiology (n=2) [28]. In the category of clinical procedures, maximum papers (n=18) were accomplished in the ED followed by OR (n=13). In the hospital category, 23 studies were included. D'Andreamatteo et al. indicated that most of the researches were performed in the surgery and emergency areas [27]. As some areas, such as radiology and nursing, are less referenced in the previous studies compared to the above-mentioned areas, they should be the target of the implementation of lean principles in future studies.

Main reasons and outcomes of lean implementation

The main reason for applying the lean principles, as found in our scoping review, was to improve the flow of patients or reduce overcrowding (n=6) [32,40,45,50,52,54], followed by improving the supply chain (n=3) [46,51,52] and waiting times [30,52,54] (Table 5, Appendix 1).

Regarding the outcomes of lean implementation, the main positive outcome in the studies was the identification and reduction of waste (n=7) [34,40,44,45,48,49,51] and increased efficiency of the hospital (n=7) [31,32,35,41,42,50,53] (Table 6, Appendix 1). Mazzocato et al. found that improved staff satisfaction and reduced costs were the main outcomes of lean implementation [29]. Isfahani et al. analyzed 48 studies and found enhancements in 69 out of 150 indicators [71]. Lima et al. found time enhancements, improved cycle and hospitalization times, organizational culture, and communication (n=18); reduced lead and patient waiting times, waiting lists (n=22), identification, errors, waste, costs (n=19), and stocks; reorganized physical space; increased efficiency (n=17); and a positive impact on the quality and safety indicators (n=7) [26]. Kollberg B et al found cost reduction as the positive outcome of lean implementation in the healthcare system of Sweden [72]. However, the success of the hospital is not always due to the positive outcomes of lean implementation, as many authors have reported mixed success. Barnabe et al. referred to the impact of the lean approach as a puzzle, as some organizations find success with it and some do not [73]. Kovacevic et al. stated that although numerous healthcare organizations applied the principles of lean implementation, several of them failed [74]. D'Andreamatteo et al. indicated that the key outcomes of lean implementation in a healthcare setting have a desirable effect on efficiency and cost-efficacy [27]. All studies in the present scoping review found positive results, whereas, studies conducted by Lindskog P et al [75] and Mahmoud Z et al [76] found several disadvantages related to deterioration of work condition and dehumanization of individuals due to lean implementation respectively. Hung and coworkers in a study showed a significant increase in stress, burnout, and emotional instability among physicians following lean implementation [77].

Barriers of lean implementation

Several obstacles interfere with the successful implementation of lean practices within an organization. Very few studies explicitly addressed the barriers of lean implementation in our scoping review (n=11). The systematic review by Borges and Tortorella found that only 26% of the included studies cited the barriers faced during lean implementation in the healthcare supply chain [21].

In our scoping review, the main barrier affecting the implementation of lean principles in a healthcare setting was the staff-related barriers, which included inexperienced staff or a lack of properly trained staff (n=6) [32,33,41,45,50,53], followed by miscommunication or disagreements between staff (n=4) [46,50,51,53], shortages of staff (n=4) [38,45,50,53], and lack of motivation (n=4) [32,33,45,53] (Table 7, Appendix 1). The patient-, resource-, and organization-related barriers were only mentioned in four [31,41,45,53], three [38,46,50], and two studies [33,49], respectively. A study conducted by Ruiz and Ortiz stated the barriers of lean implementation in the Columbia health care system which are related to lack of top management of the hospital, the structure of the organization, lack of resources and finances, lack of multidisciplinary collaboration, lack of educated and trained staff, and lack of information on this topic [78]. According to Poksinka, the first barrier of lean implementation is to persuade the concerned staff of the hospital that the lean approach can operate in a healthcare situation [25]. Lima et al. found that the most common barriers of lean implementation were the lack of training of teams (n=6), low participation between the stakeholders and operational team (n=6), and poor vision of the process (n=6) [26]. Poksinska [25] and Glasgow et al. [79] found that the lack of experts in the healthcare sector and training of the staff were the most common barriers to lean application. An Uruguayan study mentioned 17 barriers of lean implementation related to lack of commitment of top managers, resistance to change, lack of motivation, training, education, communication, resources, finances, managerial skills, healthcare regulations, limited time, etc [80]. Another study conducted in Kuala Lumpur enumerated a total of 28 barriers related to lean implementation in a health care setting which are related to lack of management roles and responsibility, leadership empowerment, people management, resource management, strategies and planning, information & knowledge, etc [81]. Not only in the healthcare setting, but also in the construction industry, same barriers were noted by Al Balkhy W et al where they mentioned the most serious barriers hindering the implementation of lean principles were related to the lack of adequate support from the top management, lack of training, awareness, and the absence of transparency [82]. Ideally, training should be given by people from the manufacturing sector; however, they talk and educate using manufacturing jargon, which makes it difficult for a healthcare person to understand and implement lean practices. Hence, more emphasis should be given to the training of healthcare professionals regarding the lean approach. In addition to the lack of training, miscommunication or disagreements between staff is another major barrier that was found in four studies [46,50,51,53]. The organizational structure of the hospital is a complicated system with various hierarchies and numerous interdependent elements. Among these, physicians are the dominant decision-makers and possess the highest rank in the hierarchy. Effective lean implementation requires teamwork and interdepartmental communication between all professionals, not just physicians. It is important for the physicians to understand that the aim of lean implementation is to enhance the whole system rather than only the specific department. According to Almutairi et al., a major barrier in lean implementation is that disagreements between physicians slow supply chain processes and increase delivery lead times [46]. Albliwi et al. [83] exposed several common elements as threats to lean implementation, including limited commitment, involvement of management, communication, stakeholders training, and resources. According to a scoping review by Mahmoud et al. (2021), lean principles help to improve teamwork, communication, and coordination between staff [84].

Although we have tried to summarize the studies related to the implementation of lean principles in healthcare settings, our scoping review has a few limitations. The first limitation is that we have only focused on the studies related to KSA. Second, the practices of lean implementation are focused on one department of the hospital, and slight consideration is paid to the broader supply-chain context. Furthermore, studies that focus on the barriers of lean implementation in KSA are even rarer, which can be mitigated by future studies that focus on Middle Eastern countries or are conducted in a broader context.

CONCLUSION

To conclude, the practice of lean implementation is a relatively new topic for KSA. The most common tool that was used in studies depicting the lean implementation in KSA was the six sigma DMAIC approach. Most of the studies were conducted in the ED, and the main reason for lean implementation was to reduce overcrowding. Identifying and reducing waste was the most common positive outcome in most of the studies, and staff-related barriers, such as the lack of properly trained staff, were reported in most studies. Further, the information gained from this scoping review can help decision-makers to make a roadmap for the lean principles to create excellence and sustainability in healthcare organizations for KSA and other countries.

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Appendix 1: Tables

Table 1: Details of the included studies (n=27)

S. No.	Author (year)	Journal	Study location	Aim of the study	Study design	Lean methodology	Study findings
1.	El Faiomy and Shaban (2012) [30]	Saudi Ministry of Health	El-senayea Primary Healthcare Centre	To improve waiting time in vaccination room	Case study	LSS methodology	The highest delay was due to the waiting time at the well-baby room, which was reduced significantly after applying the lean principles
2.	Reddy and Shammari (2013) [31]	Australian Journal of Basic and Applied Sciences	King Khalid Hospital	To evaluate the deficiency faced by the patients regarding the discharge facility	Research paper	Six sigma quality tool DMAIC	The hospital yield and the process sigma level increased to 99.46% and 4.05 respectively.
3.	Al Owad A et al (2013) [32]	Advanced Materials Research	EDs of hospitals	To identify the problem of patient flow in EDs of hospital	Case study	LSS methodology and VSM	The lean principles are important for the overall improvement of the hospitals of KSA.
4.	Walley P (2014) [33]	Oxford Brookes University	King Faisal Specialist Hospital and Research Center, Riyadh	Issues concerning the adaptation and implementation of improvement methods	Ethnographic study	LSS	A 75% reduction in the total waiting time was achieved for leave applications
5.	Abdelhadi and Shakoor (2014)	Leadership in Health Services	Large regional hospital (574 beds)	To minimize the lead times regarding the processing of	Research paper	Lean manufacturing concept	Since the number of prescriptions (992) was higher at the outpatient pharmacy processes as compared to the inpatient pharmacy (728), the outpatient pharmacy must be

	[34]		in the southern region of the KSA	medications in 2 pharmacies (external and internal)		(Takt time)	improved regarding lean strategies
6.	Abdelhadi A (2015) [35]	International Journal of Health Care Quality Assurance	EDs of hospitals	To assess the quality of a public hospital's service	Research paper	A lean manufacturing metric (Takt time)	The tool of lean implementation is significantly used in the healthcare industry
7.	Al Kuwaiti A (2016) [36]	International Journal for Quality Research	King Fahd Hospital of the University	To analyze the medication errors in the outpatient pharmacy of the hospital	Case study	DMAIC	A marked reduction of defects (PPM of prescription from 56,000 to 5,000) and improvement of their sigma rating (4.08 from 3.09)
8.	Almorsy L and Khalifa (2016) [37]	Stud Health Technol Inform	King Faisal Specialist Hospital and Research Center	To improve and reduce the waste of the hospital	Case study	Six sigma DMAIC approach	Using the lean techniques, the percentage of the utilization of the unnecessary quality control reduced from 13% to 4%
9.	Hassanain M et al (2016) [38]	Int J Health Plann Manage	12 hospitals of KSA	To improve the efficiency of the operating room in hospitals	A quasi-experimental design	SPI or Kaizen initiative	Statistically significant improvements were found with the on-time start for the first case and turnover times of the room
10.	Al Kuwaiti and Subbarayalu (2017)	Saudi J Med Med Sci	King Fahd Hospital of the University, Al-Khobar	To examine the impact of the six sigma DMAIC approach in reducing HAI	Prospective study	DMAIC	The rate of infection reduced significantly 3.92 to 2.73 ($P < 0.05$)

	[39]						
11.	Shakoor M et al (2017) [40]	Jordan Journal of Mechanical and Industrial Engineering	Government, teaching and general hospitals of southern KSA	To assess the use of the services in ED	Retrospective study (November 1, 2013 to October 31, 2014)	Lean manufacturing approach (Takt time)	The utilization of extra-equipped beds that were used in the ED can be given to other crowded rooms.
12.	Hassanain M (2017) [41]	Inquiry	PIU within MOH	To evaluate the setting up a PIU within the MOH	Case study	LSS methodology	PIU can be incorporated to improve the healthcare delivery system in KSA
13.	Albliwi SA et al (2017) [19]	International Journal of Quality & Reliability Management	Questionnaire distributed to 400 organizations via email	To systematically evaluate the condition of LSS implementation in Saudi Arabian organizations	Survey	LSS, DMAIC, PDCA, DFSS	The implementation of LSS in healthcare delivery systems of KSA is in the early stages
14.	Al Rashed and Kang (2017) [42]	IEEE International Conference on Industrial Engineering and Management	Hospital of KSA	To evaluate the lean management implications to improve the healthcare services	Research paper	Lean principles	The principles of lean implementation can be effectively applied to manufacturing and service industries of the healthcare system.
15.	Alkinaidri A et L	American Journal of	King Abdullah	To improve the healthcare referral	Case study	LSS and DMAIC	The response time of the referral system improved from 2.05 to 2.2

	(2018) [43]	Industrial and Business Management	Medical City in Makkah	system		methodology	
16.	Radwan MA (2018) [44]	J Nutr Food Sci	Royal Commission on Medical Center	To recognize the perceived advantages, critical success factors and anticipated obstacles of lean implementation	Research paper	LSS methodology	The implementation of LSS is in its development phase in healthcare system, especially in developing countries.
17.	Al Owad A et al (2018) [45]	Prod Plan Control	Aseer Central Hospital	To improve patient flow in EDs	Mixed method design (qualitative and quantitative)	Integrated lean methodology	The most likely waste of the hospital comes from the ED, physicians, patients, nurses, administration, data/information, and uncertainty/changes to the treatment work schedules
18.	Almutairi MA et al (2018) [46]	International Journal of Lean Six Sigma	King Saud Medical City, Riyadh	To evaluate the implementation of lean principles in a healthcare supply chain	Case study (model framework)	Supply chain leanness index	The implementation of lean principles enable decision-makers to take suitable actions in order to improve the process of the healthcare system.
19.	Alshahrani S et al (2018) [47]	International Journal of Logistics Management	498 public and private hospitals	To examine the role of lean practices between hospital-supplier integration	Survey	Lean principles (model)	Hospital-supplier integration has a positive impact on the hospital performance

20.	Shakoor M et al (2019) [48]	International Journal of Health Care Quality Assurance	Two vital rooms of the ED (rapid response trauma and rapid response medical)	To improve the efficiency and effectiveness of ED rooms	Case study	The lean manufacturing approach	The optimal allocation of resources enhances the efficiency and effectiveness of ED rooms. Based on the lean manufacturing concept, efficiency for ED rooms is recommended
21.	Baslyman M et al (2019) [49]	IEEE	Al-Rass Hospital, Saudi Arabia	Use of lean model (AbPI) to reduce the delay between delivering laboratory samples from the ER	Case study	Lean management with the AbPI	The identified waste was transportation between activities and waiting
22.	Al Owad. A (2020) [50]	Business Process Management Journal.	Questionnaire	To enhance the problems of patient flow and waiting time in hospital EDs	Mixed-method design (qualitative and quantitative)	Lean tools, such as process mapping	The main reasons for delays in emergency services were limited bed capacity and resources and a lack of trained staff
23.	Almutairi A et al (2020) [51]	International Journal of Lean Six Sigma	Three hospitals of KSA	To propose a new framework for implementing lean in HSCM practices	Case study	LSCM (framework)	Lean principles help in the identification and improvement of the non-added activities of the hospitals.
24.	Alodan A et al (2020)	MethodsX	Medical city, Riyadh	To improve the waiting times of the outpatient	Case study	TQM	The lean techniques can be used reduce the waiting time and increase patient satisfaction of the pharmacy setting.

	[52]			pharmacy			
25.	Almutairi AM et al (2021) [53]	Logistics	Review of studies	To propose solutions for removing the obstacles of lean implementation	Research paper	Lean impleme ntation (framew ork)	The obstacles faced during lean implementation can be overcome by adopting various practices in the hospitals.
26.	Elkholi A et al (2021) [54]	BMJ Open Quality	Alhada Armed Forces Hospital	To improve the patient flow of the ED	Case study	Spaghetti diagram	The waiting time of the ED significantly reduced from 27 min to 4.09 min after the successful application of the lean principles.
27.	Obaid LM et al (2021) [55]	BMJ Open Quality	Sultan Bin Abdulaziz Humanitar ian City	To improve the handover process in nursing services	Case study	VSM Plan, do, study, act (PDSA)	The duration of the handover process of the hospitals were significantly reduced to 50% after the usage of lean techniques.

Table 2: Details of lean practices and obstacles in the lean implementation of the included studies (n=27)

Authors (Year)	Problem identified		Lean Practices	Obstacles
El Faiomy and Shaban (2012) [30]	The main problem is waiting at the well-baby room	LSS and DMAIC	To reduce the waiting time of the vaccination room, the process of pre-vaccination should be redesigned to be in one room only.	-
Reddy and Shammari (2013) [31]	a) Poor flow of patient b) Miscommunication c) No standardization d) Low utilization of resources	Six sigma quality tool DMAIC	a) **People:** The relatives should be pre-informed about the discharge of the patient. b) **Environment:** All patients' documents were secured and placed in order c) **Process:** Improving the communication process with the patient d) **Materials:** Three wheelchairs and stretchers were reserved for the discharge patients	Without any prior information or informing the staff, the patient leaves the ward.
Al Owad, A et al (2013) [32]	a) Problem of overcrowding in EDs b) Bed capacity c) Shortage of physicians	LSS and VSM	a) To manage patient flow in ED, integrated bed management system should be developed b) Educational programs to increase the awareness of the patient c) Usage of triage system before the registration process of the patient	(a) The hospital staff were resistant to accept the lean practices. (b) Low experience of the ED staff
Walley P (2014) [33]	a) Employee satisfaction b) Perceptions of future challenges c) Current concerns	Kaizen or PDSA, DMAIC, and A3 reporting systems	a) Decision-devolvement project b) Waste elimination and process redesign	a. The site of the organization b. The slow pace of the organization c. Insufficient attention to patients d. Low motivation of the staff e. Limited understanding of lean principles f. Lack of confidence and inexperienced team leaders

Abdelhadi and Shakoor (2014) [34]	a) The long prescription waiting times b) Over-processing c) Waste related to motion d) Unnecessary walking distances for the pharmacist	VSM and Takt time as lean manufacturing tools	a) To reduce the waste related to motion, the floor plan should be redesigned b) Education and training of staff members **c)** Managing the dispensing process of the prescriptions	-
Abdelhadi A (2015) [35]	a) Uneven distribution of staff and resources in male and female wards	Takt time as a lean manufacturing tool	a) Education provided to the staff regarding the importance of lean principles b) Even distribution of staff in male and female wards	-
Al Kuwaiti A (2016) [36]	a) Long processing time b) Difficulty in understanding the handwriting c) Missing information (i.e. dosage)	Six sigma DMAIC VOC analysis SIPOC 5S methodology	a) Development of patient code numbers b) Physicians were provided with name tag indicating his or her name in a legible manner c) A barcode scanner for prescription labels d) Standardize and implement appropriate training programs	-
Almorsy and Khalifa (2016) [37]	a) Inappropriate use of glucose test strips in laboratory	DMAIC	a) Changes to policies and procedures b) Training of laboratory staff	-
Hassanain M (2016) [38]	a) Delay in surgery in OR b) Surgical list management c) OR schedule d) Pre-anesthesia	The surgical pathway improvement (SPI) or Kaizen	a) to reduce the delay in starting the first case of the day, visual dashboards were created b) The surgical list was computerized c) Improving the utilization of the OR d) Optimal time allocation to increase the productivity of OR	a) Low availability of trained staff b) Issues related to infrastructure c) In surgery, delays occurs due to late starting of the first case of the day

	clinic e) Day surgery cases	initiative	e) To reduce cancellations, an operating model was created f) To increase the surgical cases, governance structure along with policies was made	
Al Kuwaiti and Subbarayalu (2017) [39]	a) Higher number of patients with HAI	DMAIC SIPOC	a) Policy development related to infection control b) Programs for training staff c) Development of brochures related to hand hygiene d) Environmental assessment regarding the location of hand hygiene supports	-
Shakoor M et al (2017) [40]	a) Overcrowding in EDs b) Beds are not utilized most of the time	Takt time	a) Identification of waste (extra beds and resources) in the ED of four rooms e) Elimination of waste to improve the efficiency and quality and reduce costs	
Hassanain M (2017) [41]	a) Poor performance of the hospitals	LSS	a) The communication between the ED staff and primary health care centers of the surrounding area was increased. b) The need for critical clinical pathways was identified and created	a) Lack of trained staff b) The problem of attrition
Albliwi SA et al (2017) [19]	a) To critically assess the status of lean implementation	LSS, DMAIC, PDCA, DFSS	a) The status of lean six sigma practices in Saudi Arabian organizations was evaluated	a) Lack of involvement of other departments in the organization
Alkinaidri A et L (2018) [43]	Delays in the referral process due to the following: a) Lack of consultants b) Lack of personal contact c) Failure in internet	LSS (DMAIC approach) and SIPOC	a) For referral purpose, a specific number was provided to each department b) SMS will be sent to consultants after the incorporation of the referral into the system c) In urgent cases, direct calls will go to the consultant d) Developing a standing committee for	-

	connection d) Unable to view PDF e) Lack of internal communication		referrals e) E-referral mobile app f) In cases of failure of the above-mentioned actions, direct communication can be achieved with the medical director	
Al Owad A et al (2018) [45]	a) Overcrowding of patients in EDs b) Lack of understanding of the difference between urgent and non-urgent cases c) Inefficient layout design and bed capacity d) Non-availability of resources	Lean strategy of integrating the voices of the process, staff and patients	a) Improving the patient arrival process b) To reduce the waiting process, a serial number is provided c) Improving the registrations process of the patient for getting ID d) Reduce the waiting time of the patient for triage process e) During the triage, initial assessment should be done by a nurse f) Reduce the waiting time for medical treatment g) Reduce the time taken by laboratory/X-ray for diagnosis test results and reports h) Reduce the waiting time for getting the report of the examination i) Improving the discharge or bed admission process	a) The path track of the hospital is unclear to the patients b) The resistance of the hospital staff toward lean practices c) Low experience of the staff of ED d) Low availability of physicians
Almutairi MA et al (2018) [46]	a) To assess leanness in supply chain	Supply chain leanness index	a) Redesigning supply chain processes b) Redesigning the operating chamber c) Directly linking the department with the chief executive officer (CEO) d) Formation of the lean committee, including physicians, pharmacists, or medical equipment engineers	a) Communication issues within the healthcare sector b) Lack of supportive staff c) Non-agreement between physicians and other hospital staffs d) No hospital-supplier integration
Alshahrani S et al (2018) [47]	a) Problem in hospital–supplier	Lean principles	a) Increase in delivery speed b) The size of the hospital is significantly	

	integration		associated with the integration process of the hospital with the supplier	
Shakoor M et al (2019) [48]	a) Under-utilization of the ED rooms	Takt time	a) Redistribution of the beds b) To reduce the acceptable Takt time to below 1700 minutes/patient	-
Baslyman M et al (2019) [49]	a) Delay in delivering the report of the samples from laboratory to the ER	Use of RTTS	a) Identification and reduction of the waste that occurs due to transportation between various activities. b) Proposition of a new system of RTTS	a) Delay in notification process of the laboratory unit regarding arrival of new lab samples
Al Owad. A (2020) [50]	a) Overcrowding of patients in ED	Lean tools, such as process mapping	a) Introduction of lean practices to the staff of the ED b) Improving the observation process c) Tracking the patient from entering into the hospital till discharge process by making a sheet for recording the time spent by patients for each process.	a) Lack of communication between ED staff b) Lack of trained ED staff c) Lack of proper teamwork d) Low-availability of bed and resources e) Shortage of working staff of the ED
Almutairi A et al (2020) [51]	a) To improve the hospital supply chain management	Lean supply chain manageme nt (LSCM) framework	a) Adopting the lean practices of VSM b) Exchange of information between various departments c) Training HSC employees d) Coordination with other healthcare providers	a) The breakdown of effective communication b) Lack of communication
Alodan A et al (2020) [52]	a) Improvement of waiting time of the patient b) Increase satisfaction of the	TQM	a) Using automated prescriptions b) Categorization of patients c) Redesigning the pharmacy d) Construction of a mini pharmacy for each floor	-

	patient c) Improving the workflow			
Almutairi AM et al (2021) [43]	a) Obstacles that healthcare organizations might face when implementing the lean methodology	Lean supply chain management (LSCM) framework	a) A committee related to "standards and sourcing" should be created b) Use of radio-frequency-identification (RFID) system c) Implementation of lean practices such as VSM and 5S d) Improving the culture of the institution to reduce resistance e) A reward system should be created in order to motivate people f) Increasing communication and sharing of information g) Training of employees	a) Lack of trained staff b) Hospital staff is resistant to change c) Low communication and sharing of information d) Identification of the supply chain of the hospital e) Non-belief of the hospital staff in lean practices f) Lack of understanding regarding the practices related to lean implementation g) Unpredictable demand of the patient
Elkholi A et al (2021) [54]	a) Long waiting times in the ED b) To improve patient flow	Spaghetti diagram	a) Changes in triage design of ED b) Redesigning the waiting room and registration area	-
Obaid LM et al (2021) [55]	a) No standardization regarding the team leader handover process and their roles	PDSA cycles VSM	a) Creation of new forms b) Standardizing the roles of team leaders c) Eliminating the interruptions during the handover process	-

DMAIC: define, measure, analyze, improve and control; LSS: lean six sigma; ED: emergency department; ER: emergency room; VSM: value stream mapping; OR: operating room; PDCA: plan, do, check, act; DFSS: design for six sigma; RTTS: real-time tracking sample; SIPOC: suppliers, inputs, process, outputs, customer

Table 3: Tools to implement lean principles in a healthcare setting

VOC: voice of customers; VOP: voice of process; SIPOC: suppliers, inputs, process, outputs, customer; LHSC: lean hospital supply chain; SPI: surgical pathway improvement; PDCA: plan, do, check, act; PDSA: plan do study act; TQM: total quality management.

	Lean Practices	**Studies**
Complementary management approaches	Lean six sigma	Al Owad A et al [32]; Hassanain M [41]; Alrashed IA et al [42]; Albliwi SA et al [19]; Alkinaidri A et L [43]; Radwan MA [44]; Alshahrani S et al [47]
Continuous improvement	Six sigma DMAIC approach	El Faiomy and Shaban [30]; Reddy and Shammari [31]; Walley P [33]; Al Kuwaiti A [36]; Albliwi SA et al [19]; Alkinaidri A et L [43]; Almorsy and Khalifa [37]; Al Owad A et al [45]; Al Owad A [50]; Al Kuwaiti and Subbarayalu [39]
	VOC VOC and VOP	Reddy and Shammari [31]; Al Kuwaiti A [36] Al Owad A [45]; Al Owad A [50]
	Kaizen or SPI	Walley P [33]; Hassanain M [38]; Albliwi SA et al [19]
	PDCA	Walley P [33]; Albliwi SA et al [19]; Alkinaidri A et L [43]; Al Owad A [45]
	PDSA	Obaid LM et al [55]
Production flow	Takt time	Abdelhadi and Shakoor [34]; Abdelhadi A [35]; Shakoor M et al [40,48]
	LHSC	Almutairi MA et al [46,51,53]; Al Kuwaiti and Subbarayalu [39]
Diagnosing and problem-solving	SIPOC analysis	El Faiomy and Shaban [30]; Reddy and Shammari [31]; Al Kuwaiti A [36]; Alkinaidri A et L [43]
	Value chain analysis or VSM	Adelhadi and Shakoor [34]; Al Owad A et al [32]; Almutairi MA et al [46,53]; Baslyman M et al [49]; Alshahrani S et al [47]; Al Owad A [50]
	A3 planning reporting system	Walley P [33]
	TQM	Alodan A et al [52]
	Spaghetti diagram	Elkholi A et al [54]
Work organization and visual management:	Mistake-proofing (Poka-yoke)	Al Kuwaiti A [36]
	5S	Al Kuwaiti A [36]

Table 4: The hospital areas requiring implementation of the lean principles

Hospital areas	Studies
Vaccination room	El Faiomy and Shaban [30]
Discharge process	Reddy and Shammari [31]
Emergency department	Al Owad A et al [32]; Abdelhadi A [35]; Shakoor M et al [40,48]; Al Owad A et al [45]; Baslyman M et al (2019); Elkholi A et al [54]
Pharmacy	Abdelhadi and Shakoor [34]; Al Kuwaiti A (2016); Alodan A et al [52]
Pathology lab	Almorsy and Khalifa [37]; Baslyman M et al (2019)
Operating room	Hassanain M et al [38]
Performance improvement unit	Hassanain M [41]
Nursing unit	Obaid LM et al [55]
Inpatient unit	Al Kuwaiti and Subbarayalu [39]
Others	Walley P [33]; Al Shahrani S et al [47]; Almutairi A et al [51]

Table 5: Various reasons for the implementation of lean principles in a healthcare setting

Reason for lean implementation	Studies
Improve flow or reduce overcrowding	Al Owad A et al [32]; Shakoor M et al [40]; Al Owad A et al [45]; Al Owad A [50]; Alodan A et al [52]; Elkholi A et al [54]
Improve supply chain	Almutairi MA et al [46,51]; Alodan A et al [52]
Improve waiting time	El Faiomy and Shaban [30]; Alodan A et al [52]; Elkholi A et al [54]
Improve waiting room capacity	Al Owad A et al [45]
Reduce patient discharge time	Reddy and Shammari [31]
Improve hospital-supplier integration	Al Shahrani S et al [47]
Decrease the time in processing of medications	Abdelhadi and Shakoor [34]; Al Kuwaiti A [36]
Decrease the patient treatment lead time	Abdelhadi A [35]
Improve satisfaction of employees	Walley P [33]
Improve utilization	Almorsy and Khalifa [37]; Hassanain M et al [38]
Reduce waste	Almorsy and Khalifa [37]; Al Owad A [50]
Increase efficiency	Hassanain M [41]; Alrashed IA et al [42]; Shakoor M et al [48]
Improve delivering of samples from ER to laboratory	Baslyman M et al [49]
Improve clinical team leader handover process	Obaid LM et al [55]
Reduce HAI	Al Kuwaiti and Subbarayalu [39]

Table 6: The outcomes of implementing lean principles in a healthcare setting

Positive results	Studies
Reduction of lead time	Abdelhadi and Shakoor [34]; Abdelhadi A [35]; Shakoor M et al [40]; Radwan MA [44]
Reduction of patient waiting time	El Faiomy and Shaban [30]; Hassanain M et al [38]; Alkinaidri A et L [43]; Alodan A et al [52]; Elkholi A et al [54]
Improvement of cycle time	Reddy and Shammari [31]; Abdelhadi and Shakoor [34]; Hassanain M et al [38]; Al Kuwaiti A [36]; Alkinaidri A et L [43]
Improvement of hospitalization time	Reddy and Shammari [31]; Hassanain M et al [38]; Almutairi MA et al [46]; Alshahrani S et al [47]
Identification and reduction of waste	Abdelhadi and Shakoor [34]; Shakoor M et al [40]; Radwan MA [44]; Al Owad A et al [45]; Baslyman M et al [49]; Shakoor M et al [48]; Almutairi A et al [51]
Reduction of stocks	Abdelhadi and Shakoor [34]; Hassanain M et al [38]
Reducing the expenditure and reorganization of the hospital space	Abdelhadi and Shakoor [34]
Improved organizational culture and communication	Al Owad A et al [32]; Albliwi SA et al [19]
Increased efficiency	Reddy and Shammari [31]; Al Owad A et al [32]; Abdelhadi A [35]; Hassanain M [41]; Al Rashed and Kang [42]; Al Owad A [50]; Almutairi A et al [53]
Positive impact on quality and safety indicators	Almorsy and Khalifa [37]
Improved satisfaction of employees of hospital	Walley P [33]
Improvement of clinical team leader handover process	Obaid LM et al [55]
HAI reduced significantly	Al Kuwaiti and Subbarayalu [39]

Table 7: Barriers faced during implementation of the lean practices in a healthcare setting

Barriers	Details of the barriers	Lean component getting affected	Studies
Patient-related barriers	Patients leaving the ward without informing the nurse	Poka Yoke	Reddy and Shammari [31]
	Attrition and inadequate follow-up of patient	Poka Yoke	Hassanain M [41]
	Patient path track unclear	Value Stream Mapping	Al Owad A et al [45]
	Unpredictable patient demand	Production (service) leveling	Almutairi AM et al [53]
Staff-related barriers	Low motivation or resistance of hospital staff to accept continuous quality improvement concepts	Continuous improvement	Al Owad, A et al [32]; Walley P [33]; Al Owad A et al [45]; Almutairi AM et al [53]
	Shortage of staff	SIPOC (suppliers, inputs, process, outputs, customer)	Hassanain M [38]; Al Owad A [45]; Al Owad A [50]; Almutairi AM et al [53]
	Inexperienced staff or lack of properly trained staff	Total Productive Maintenance	Al Owad A et al [32]; Walley P [33]; Hassanain M [41]; Al Owad A et al [45]; Al Owad A [50]; Almutairi AM et al [53]
	Delays in starting the first case	Right first time	Hassanain M [38]
	Miscommunication or disagreement between staff	Visual management	Al Owad A [50]; Almutairi AM et al [46,51,53]
	Lack of communication	Andon	Almutairi AM et al [46,51]
	Lack of teamwork or support of staff	Teamwork; Workload balancing	Walley P [33]; Al Owad A [50]; Almutairi AM et al [46]
	Lack of the involvement of other departments in the organization	Multidisciplinary task training; Workload balancing	Albliwi SA et al [19]
	Inability to identify waste in the supply chain	Value Stream Mapping	Almutairi AM et al [53]
	Limited understanding of the lean principles	Andon	Walley P [33]

Resource-related barriers	Infrastructure issues	Gemba	Hassanain M [38]
	Low availability of beds and resources	Value Stream Mapping	Al Owad A [50]
	Lack of hospital–supplier integration	Value Stream Mapping	Almutairi AM et al [46]
Organization-related barriers	Site of the organization	Gemba	Walley P [33]
	Slow pace of the organization	Continuous improvement	
	Notifying the laboratory regarding the arrival of the samples	Total Productive Maintenance; 7 Wastes	Baslyman M et al[49]

Appendix 2: Figures

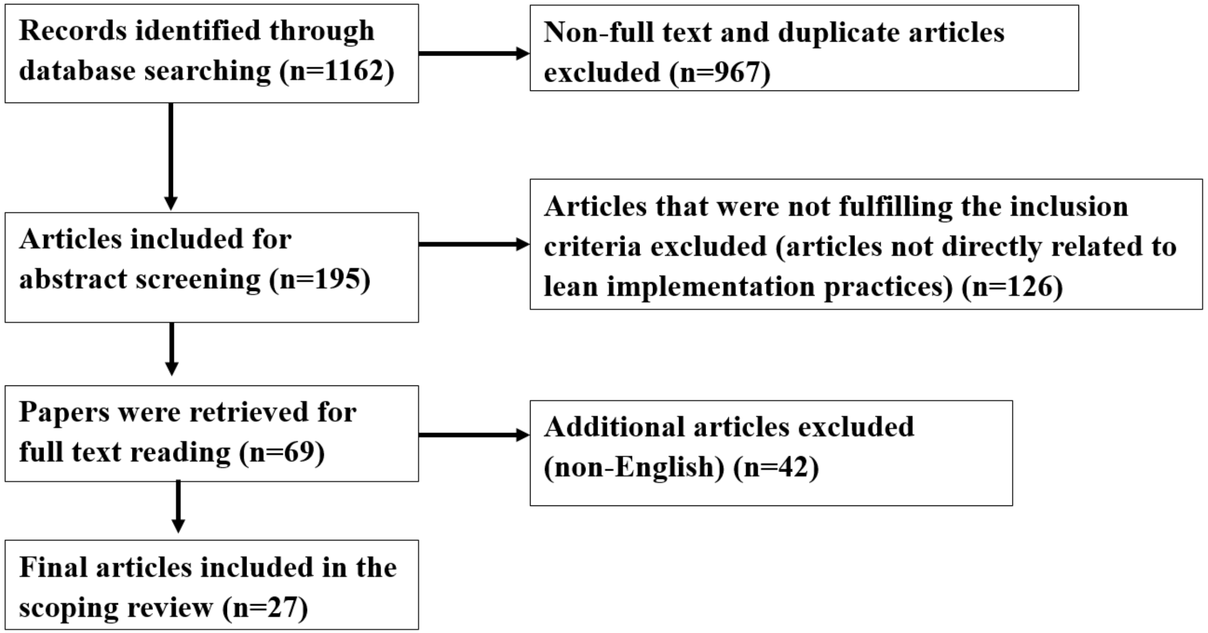

Figure 1: Details of data selection and extraction of the studies

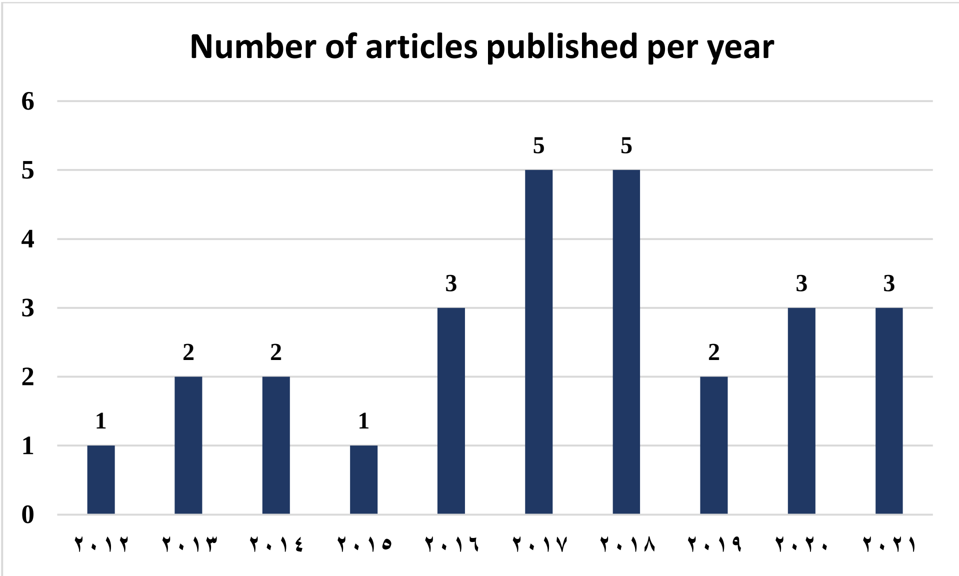

Figure 2: Number of articles published per year

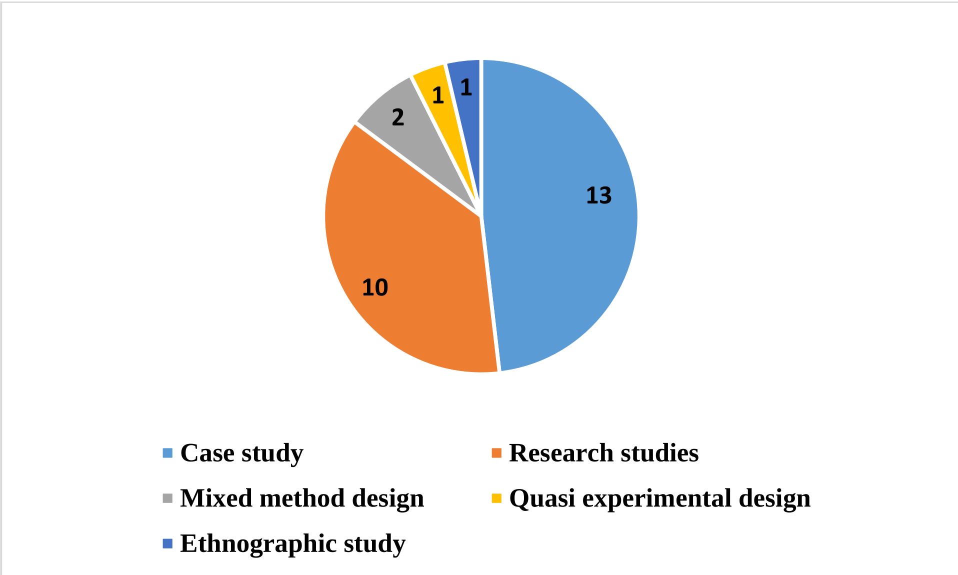

Figure 3: Distribution of studies according to the research methods

تقييم ممارسات وتحديات تطبيق مفهوم الرشاقة في نظام الرعاية الصحية في المملكة العربية السعودية: مراجعه منهجية

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الملخص

صممت مبادئ الإدارة الرشيقة لتقوم على تحسين خدمات نظام الرعاية الصحية في إطار زمني قصير، وعليه فإن هذه الدراسة تقدم مراجعة منهجية لتقييم ممارسات وتحديات تطبيق مفهوم الرشاقة في نظام الرعاية الصحية في المملكة العربية السعودية، وقد اتبعت هذه الدراسة منهجية المراجعة للأدبيات وفق طريقة نطاق مراجعة محدد به كافة الدراسات التي تضمنت الممارسات والتحديات في تطبيق مفهوم الرشاقة في نظام الرعاية الصحية في المملكة العربية السعودية. وبناء على المسح والتحليل والفرز لكافة الدراسات التي وجدت في نطاق الدراسة وفق معايير ومنهجية البحث المستخدمة، فقد تم تضمين واستخلاص عدد ٢٧ دراسة في معظمها تم الاعتماد على منهجية الستة سيجما، وأجريت معظم هذه الدراسات في قسم الطوارئ لتقليل الازدحام، وقد كان من أهم النتائج الإيجابية التي تم الإشارة إليها في معظم هذه الدراسات هو تحديد مصادر الهدر وتقليلها، إضافة إلى أنه تم الإشارة إلى أهم التحديات والتي تمثلت في العجز الموجود في عدد الكوادر المدربين بشكل صحيح.
وعليه يمكننا القول بأن هذه الدراسة تساهم بشكل فعال في تطوير نماذج واستراتيجيات لتحسين نظام الرعاية الصحية في المملكة العربية السعودية وغيرها من الدول.

الكلمات المفتاحية: نظام الرعاية الصحية، تطبيق مفهوم الرشاقة، المملكة العربية السعودية، العوائق.

المملكة العربية السعودية

وزارة التعليم

جامعة جازان

مجلة جامعة جازان

للعلوم التطبيقية

دورية علمية محكمة

المجلد ١٠ العدد ١ ذو القعدة ١٤٤٣هـ مايو ٢٠٢٢ م

ردمد : ١٦٥٨-٦٩١٣

مجلة جامعة جازان

للعلوم التطبيقية

دورية علمية محكمة

المجلد ١٠ العدد ١ ذو القعدة ١٤٤٣ هـ (مايو ٢٠٢٢م)

المراسلات

توجه جميع المراسلات إلى:
رئيس هيئة التحرير مجلة جامعة جازان للعلوم التطبيقية جازان -المدينة الجامعية -البرج الإداري – ص ب ١١٤. -الرمز البريدي ٤٥١٤
المملكة العربية السعودية أو على البريد الإلكتروني jas@jazanu.edu.sa

بسم الله الرحمن الرحيم

قواعد النشر في المجلة

مجلة جامعة جازان للعلوم التطبيقية دورية علمية محكمة تنشرها الجامعة، وهي تهدف إلى إتاحة الفرصة للباحثين لنشر إنتاجهم العلمي وتقوم المجلة بنشر المواد الآتية :

١- البحث : ويندرج تحت تخصص الباحث ويجب أن يحتوي على إضافة للمعرفة في مجاله .

٢- المقالة الاستعراضية التي تتضمن عرضًا نقدياً لبحوث سبق إجراؤها في مجال معين أو أجريت في خلال فترة زمنية محددة.

٣- البحث المختصر.

٤- نقد الكتب .

٥- الخطابات الموجهة إلى المحرر ، والملاحظات والردود ، والنتائج الأولية .

تقوم هيئة التحرير، بالنظر في نشر المواد المعرفية ذات الصلة بذلك الفرع، وتقدم البحوث الأصلية، التي لم يسبق نشرها، وفي حال قبول البحث للنشر تؤول كل حقوق النشر للمجلة و لا يجوز نشره في أي منفذ نشر آخر ورقيا أو إلكترونياً، دون إذن كتابي من رئيس هيئة التحرير .

تعليمات النشر في المجلة

١- تقديم المواد : يقدم أصل البحث مخرجا في صورته النهائية متضمنا الإشارة إلى أماكن الجداول والأشكال داخل المتن و مطبوع على هيئة صفحات مرقمة ترقيما متسلسلا، مع ضرورة إرفاق قرص ممغنط مطبوع عليه البحث على برنامج Ms Word باستخدام النظام المتوافق مع IBM ، وسيعتذر عن قبول أي بحث لا يلتزم مؤلفه بهذه التعليمات.

٢- الملخصات: يرفق ملخصان بالعربية والإنجليزية للبحوث و المقالات الاستعراضية والبحوث المختصرة على ألا يزيد عدد كلمات كل منهما على ٢٠٠ كلمة، وعلى عمود واحد بعرض كتابة ١٣ سم.

٣- لا بد من احتواء كل بحث على كلمات مفتاحية (Key Words)توضع أسفل الملخصين العربي والانجليزي على ألا تزيد عن عشر كلمات.

٤- الجداول والمواد التوضيحية: يجب أن تكون الجداول والرسومات واللوحات مناسبة لمساحة الصف في صفحة المجلة ١٦ ٢٤ سم بالحواشي، ويتم إعداد الأشكال الخطية على برامج الحاسب الآلي، ولا تقبل إلا أصول الأشكال. كما يجب أن تكون الخطوط واضحة ومحددة ومنتظمة من حيث كثافة الحبر وتناسب سمكها مع حجم الرسم، ويراعى أن تكون الصور الفوتوغرافية (الضوئية) الملونة وغير الملونة مطبوعة على ورق لماع، أو محملة على برنامج (Adobe Photoshop).مع كتابة عنوان لكل جدول، وتعليق لكل شكل وصورة، والإشارة إلى مصدر المادة إن كانت مقتبسة.

٥- الاختصارات: يجب استخدام الاختصارات المقننة دولية مثل : سم، مم، م، كم، سم، مل، مجم، كجم...إلخ.

٦- المراجع :يشار إلى المراجع داخل المتن بنظام الاسم والتاريخ، وتوضع المراجع جميعها في قائمة المراجع بنهاية المادة مرقمة ومتبعة نظام ترتيب البيانات البيليوجرافية التالي :

أ- يشار إلى الدوريات في المتن بنظام الاسم والتاريخ بين قوسين على مستوى السطر، أما في قائمة المراجع فيبدأ المرجع بذكر الاسم الأخير للمؤلف، ثم الاسم الأول، ثم الأسماء الأخرى أو اختصاراتها بالخط الأسود، ثم سنة النشر بين قوسين، فعنوان البحث كاملا بين علامتي تنصيص" " ، فاسم الدورية، فرقم المجلد، ثم رقم العدد : ثم أرقام الصفحات تفصل بشرطة .

مثال : هادي، أحمد بن جابر. (٢٠١١م):" استخدام تقنية النانو لتعريف الشفرات الوراثية "مجلة جامعة جازان، ١، ١ : ٢٠٠-٢٢٠.

ب- يشار إلى الكتب في المتن داخل قوسين بالاسم والتاريخ . أما في قائمة المراجع، فيكتب الاسم الأخير للمؤلف، ثم الاسم الأول، ثم الأسماء الأخرى أو اختصارا تها، ثم سنة النشر بين قوسين، فعنوان الكتاب بين علامتي تنصيص، ثم بيان الطبعة، فالناشر، فمدينة النشر :ثم صفحات الكتاب إن وجدت.

مثال :

عبدالهادي، محمد علي، (١٤٣٣هـ):" مقدمة في التقنية الحيوية"، جامعة جازان، جازان.

ويجب عدم استخدام الاختصارات المرجعية مثل :المرجع نفسه . المرجع السابق...إلخ.

٧- أ- الحواشي: تستخدم لتزويد القارئ بمعلومات توضيحية، ويشار إليها في المتن بأرقام مرتفعة عن السطر .وترقيم التعليقات متسلسلة داخل المتن. وفي حال الضرورة؛ يمكن الإشارة إلى مرجع داخل الحاشية عن طريق استخدام كتابة الاسم والتاريخ بين قوسين وبنفس طريقة استخدامها في المتن، وتوضع الحواشي أسفل الصفحة التي تخصها والتي ذكرت بها و تفصل بخط عن المتن وبخط أصغر.

ب- يستخدم في تخريج الأحاديث والآثار الطريقة المنهجية المعتمدة في هذا الفن وهي كالآتي : اسم المؤلف - اسم الكتاب - رقم الجزء والصفحة والحديث.

٨- المواد المنشورة في المجلة تعبر عن وجهة نظر صاحبها، ولا تعبر بالضرورة، عن رأي مجلة جامعة جازان.

٩- يتأكد الباحث من صحة اللفظ وسلامة لغة البحث، وخلوه من الأخطاء اللغوية والنحوية.

١٠-للمجلة الحق في تحديد أولويات نشر البحوث.

١١-المجلة غير ملزمة بإعادة البحوث التي تصل إليها سواء أجيزت للنشر أم لم تجز.

١٢-يتم إخضاع جميع البحوث المستلمة لفحص مبدئي، من قبل هيئة التحرير، لتقرير أهليتها للتحكيم، ويحق لها أن تعتذر عن قبول البحث دون إبداء الأسباب.

١٣-تصدر المجلة مرتين في العام.

المملكة العربية السعودية
وزارة التعليم
جامعة جازان

مجلة جامعة جازان للعلوم التطبيقية

دورية علمية محكمة

المجلد ١٠ العدد ١ (ذو القعدة ١٤٤٣هـ - مايو ٢٠٢٢م)

ردمد: ١٦٥٨-٦٩١٣