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Review Article

Bibliometric Analysis of HHO Gas Production by Electrolysis from 2013 to 2023

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Abstract
HHO gas is one promising alternative as an alternative for fossil fuels, nevertheless, several challenges need to be overcome in order for HHO gas to become a viable option for global use. This paper presentsbibliometric analysis, HHO gases production methods, and challenges of using HHO gas. The primary objective of this review paper is to provide views, assessments, and evaluations of the published literature on HHO gas, both the production and use challenges of HHO gas. This review article uses several software programs including origin for graph visualization, Microsoft excel for processing data, and VOSviewer for analyzing bibliographic mappings. HHO production can be done by adding KOH electrolyte solution. Factors that affect the production of HHO gas include electrolyte properties, electrolyte concentration, and distance between electrodes. An increase in the concentration of the electrolysis solution leads to an increase in the production of HHO gas. The production of HHO gas can also be done with the addition of Na_2CO_3 or K_2CO_3 which can produce high H_2 gas. The pre-combustion mercury removal technique using coal electrolysis produces hydrogen byproducts with 50% less energy than water electrolysis. A single Pt circuit at TiO_2 support (Pt_1/def-TiO_2) forms a highly efficient photocatalyst for hydrogen production. The main challenges of HHO gas in terms of production, storage, distribution, safety, cost of HHO gas production.

Keywords: HHO; electrolysis; production; bibliometric.

1. Introduction

Energy has been consistently recognized as one of the most essential requirements for human existence in all aspects of day-to-day living from one generation to the next (Muthu et al., 2022). Energy is essential due to numerous activities require it, and its importance grows as technology advances. Since fossil fuels are limited, governments and the earth must take safeguards to prevent future suffering (Allard et al., 2020). Nevertheless more countries are focusing on renewable energy, modifying legislation to reduce ecological damage, and researching alternate energy sources. Therefore, hydrogen is a non-polluting energy carrier and does not cause global warming because it is renewable. Green energy sources Reduce dependency on imported fossil fuels, lower greenhouse gas emissions, and decarbonize the energy sector (Salam et al., 2023). The majority of HHO gas is produced by steam reforming natural gas. This process emits greenhouse gases. There are alternative methods for producing HHO fuel gas, such as electrolysis (Essuman et al., 2019), but this method is currently more expensive and less efficient than steam reforming, requiring in-depth research.

This review article discusses the production of HHO gas using electrolysis sourced from articles that have been published in recent years, but most do not consider trends in production methods and the challenges of using HHO gas. The purpose of this review article is to provide views, assessments, and evaluations of the published literature on HHO gas, both the production and use challenges of HHO gas. The use of this bibliometric analysis facilitates the investigation of a particular field of knowledge (Zou et al., 2018).

2. Method

Bibliometric content comes from Scopus, which contains review articles, papers, and scientific articles. Scopus is the best bibliometric database due to its low bias. After collecting information, a bibliometric analysis was done. In order to collect data before processing, the relevant SCOPUS publications were retrieved on April 28, 2023 using the following keywords: HHO, gas, electrolysis and production. After applying filters for English, late publishing stage, and publication date range 2013-2023,32 papersreturned in search results. Additionally, a selection of journals relating to the topic is reviewed. Each article abstract is read to gain insight into the subject matter of each publication. As the final sample for investigation, 32 articles on the production of HHO gas using electrolysis were selected for evaluation.

If the same search is performed at a later date, the exported data may have returned different results. SCOPUS notes can cause this. Years, authors, institutions, and references are exported. Data is processed using softwareVOSviewerfrom Leiden University Science and Technology Studies(Van Eck & Waltman, 2020). Data mining, information analysis, scientific measurements, and graphical plots are used to carry out a review of the literature using knowledge domain (MKD) mapping (Zou et al., 2018). The software also quickly visualizes research status, possible evolutions and developing trends.

Labels or nodes that are connected to one another on a scientific map indicate how data are related to one another. On a scientific map, the colour, density, and depth indicate the relationships between nodes as well as the amount of discussions that are connected (Prashar et al., 2023). Based on SCOPUS data, the VOS viewer develops a network map of scientific publications, journals, researchers, research institutions, countries, and keywords. Linkages also come from co-citation, co-authorship, scientific database files, and co-occurrence (Van Eck & Waltman, 2020). We identify the latest labels and articles by zooming in on the map. Networks, overlays, and data density are shown in the visualization map (Van Eck & Waltman, 2020). Co-occurrence analysis is an analysis that relies on the frequency of term repetition across several publications related to a specific topic, as determined by the proposed keywords provided by a generic keyword database. Keyword map nodes grow with their frequency. Link nodes are thicker when keywords are considered simultaneously across multiple articles. Production of HHO gas using electrolysis is discussed in the SCOPUS data. A complete bibliometric assessment was generated by processing the data in VOS viewer and Origin 13.

3. Results and Discussion

3.1. Definition of HHO gas

HHO gas is generated through the process of electrolyzing water. In the electrolysis process, a direct current is applied to the water containing electrolytes such as NaOH, KOH, or NaCl, in order to enhance its conductivity. The products of the ionisation reactions that occur during the breakdown of water are hydrogen and oxygen gases. A mixture of hydrogen gas and oxygen gas in nearly stoichiometric proportions known by various names such as hydroxy gas (El-Kassaby et al., 2016), Brown's gas (Brown Y, 1974), HHO (Yilmaz et al., 2010), and oxy-hydrogen (Samuel S & McCormick, 2010). The earliest use of HHO gas was reported by Brown (Brown Y, 1974) who investigated the application of HHO gas for welding. HHO gas brown, neither hydrogen nor oxygen gas is separated from one another. HHO gas is produced from the electrolysis of water (using KOH, NaOH, or NaCl for increased HHO production and optimal molality to preserve resistance-electrical conductivity balance) with a unique electrode design (Yilmaz et al., 2010).

3.2. Analysis of publications and trends

As an effort to analyze how the patterns and trends found in the academic literature correspond to the problem being discussed (Azra Mn et al., 2023) bibliometric analysis was used. The pattern of HHO gas production using electrolysis can be determined using bibliometric analysis, whichAlsocontribute to the exploration of global scientific literature. We studied research trends from 2011 to 2023 on the involvement of journals, reviews, authors, and countries. As a result, the findings of this review point to possible future developments on this subject.

SCOPUS is a source of information used for bibliometric studies. Publications on HHO gas production by electrolysis were screened using SCOPUS' "TITLE-ABS-KEY" function for fields, keywords, titles, and abstracts. This is used to select articles. Because of this, the first keyword entered into the search box to gather data is "TITLE-ABS-KEY." (HHO AND production AND electrolysis AND gas). When applying the journal selection filter in last position, which limits results to include only those written in English and published between 2013 and 2023, a total of 32 documents are found.

The second stage, which consists of screening by reading the abstracts of all linked articles, is required to obtain papers that are relevant to the topic of discussion. Afterreviewabstract, we found that32 relevant documentswith this problem. As a result, the data obtained is valid, and there is no degradation. After document processing inOrigins 13, data cleaning procedures are performed to ensure that processing of the VOS viewer will not result in incorrect or duplicate data.

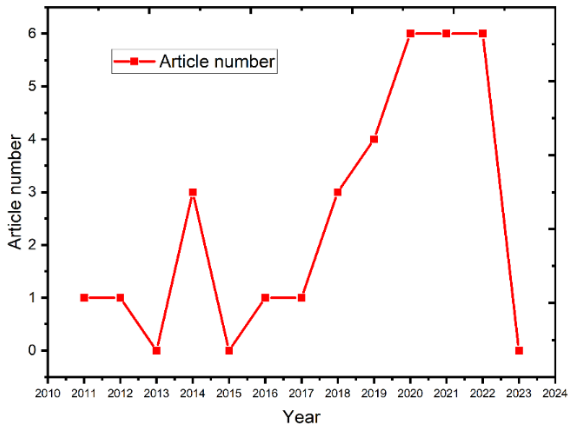

Figure 1. Trending article numbers 2011-2023

Through reading this review, readers will be able to judge how others view trends in HHO gas production. The VOS viewer creates a bibliographical map after cleaning the data for data analysis. Trending article numbers can be seen at Figure 1. It is possible to reach the conclusion that 2020-2022 total 6 articles each. 2013, 2015 and 2023 are the years with the highest number of published articles, namely 0. shows that there is a growing trend of articles discussing the production of HHO gas using electrolysis until 2022 but drops by 2023

The effectiveness of scientific journal publishers from 2011 to 2023 is evidenced by the early use of the VOS viewer software. The publication of the International Journal of Hydrogen Energy is the most prolific publication in terms of publishing HHO gas production using electrolysis related articles over the last decade (as shown in Table 1). This journal publisher focuses on four aspects of energy: energy and mathematics. Other documents cite articles from publications This 124,906 times; thus, this journal is included in the list of most frequently cited journals. The Iop Conference Series on Earth and Environmental Sciences is the Conference and Proceedings that produces the second most new articles. Conferences and Proceedings provide a forum for scholars to explore Earth and Planetary Sciences, environmental sciences, and Physics and Astronomy. The publication from England, which is a journal, enters at number two with a total of 4 publications. Advanced Materials Research from Germany, finished as the third best journal for publishing HHO gas production using electrolysis related research papers between 2011 and 2023.

The results of data processing performed in the VOS viewer are shown in Figures 2. The data illustrates the many ways in which publishers contribute to the journals they publish. The map also includes an explanation that the size of the nodes is proportional to the total number of articles that have been published, and that the thickness of the line connecting the nodes represents the extent to which they have worked together.

Figures 2. VOS viewer bibliographic map of publishers contributed to published journals

Table 1. Number of publications, country of publication, and number of citations from 2012 to 2023

Rank	Journals	Cited Number	Total Publications	Subject	Country
1	International journal of hydrogen energy	171	6	Energy Engineering and Power Technology, Fuel Technology, Renewable Energy, Sustainability and the Environment, Condensed Matter Physics	United Kingdom
2	Iop conference series: earth and environmental science	10	4	Earth and Planetary Sciences (miscellaneous), Environmental Science (miscellaneous), Physics and Astronomy (miscellaneous)	United Kingdom
3	Iop conference series: materials science and engineering	11	2	Engineering (miscellaneous), Materials Science (miscellaneous)	United Kingdom
4	Journal of physics: conference series	3	2	Physics and Astronomy (miscellaneous)	United Kingdom
5	Advanced materials research	3	2	Engineering (miscellaneous)	Germany
6	Journal of advanced research in fluid mechanics	2	2	Fluid Flow and Transfer Processes	Malaysia

Rank	Journals	Cited Number	Total Publications	Subject	Country
	and thermal sciences				

SCOPUS data shows that Subramanian's Production and usage of HHO gas in IC engines was the most cited article in the recent decade (Subramanian B & Ismail S, 2018), published in the International Journal of Hydrogen Energy and cited by 46 articles. This paper reviews the production and properties of HHO gas, which is obtained by electrolysis of water and is a promising alternative fuel. It also addresses the use of HHO gasininternal combustion engine, highlighting its benefits and challenges are discussed in this article.

The study on production optimization and the effect of hydroxyl gas on CI engine performance and emissions of biodiesel blended fuels is the second most cited article(Masjuki et al., 2016). This article was published in the International Journal of Hydrogen Energy in 2016, article was cited 61 times by other articles. This paper investigates the effect of adding HHO gas to a single cylinder diesel engine fueled by a mixture of palm biodiesel. The study found that using an HHO generator resulted in a 2% increase in power and a 5% reduction in fuel consumption, as well as a reduction in CO and HC emissions (Masjuki et al., 2016).

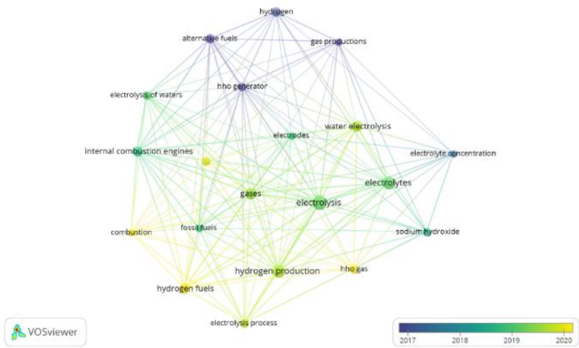

Figure 3. VOS viewer bibliographic maps of the most used and other keywords connected to HHO gas production using electrolysis from publications covering the years 2011 to 2023

The Journal of Cleaner Production published the third most cited article of 2019 (Nabil T & Khairat, 2019). This article, mentioned 34 times, explores the design, fabrication, and experimental testing of HHO dry cell generators for producing oxy-hydrogen gas. Generator performance is investigated, and its potential applications in internal combustion engines and water desalination are explored((Nabil T & Khairat, 2019)The three most frequently cited articles were each originally published in other publications by different authors in different years.

The article Optimisation of dry cell electrolyzers and production of hydroxy gas for use in diesel engines running with a mixture of orange peel oil in dual fuel mode received 10 citations and was published in 2022. This work describes the construction of a dry cell electrolyzer that creates HHO gas with a minimal input power supply and enhances biodiesel-powered diesel engine output. The study indicated that mixing diesel, orange oil, and HHO gas improved engine performance, which has been cited in 10 different papers (Sekar D et al., 2022).

3.3. Analysis of keywords

Keywords in an article are used to help search engines understand the topics discussed in the article and bring up the article in search results when someone searches for the same topic (Sheffield JP, 2020). Keyword co-occurrence analysis can reveal trends in HHO gas production using electrolysis. 32

articles on HHO gas production using electrolysis using 359 keywords. Keywords with more than 5 occurrences are visualized using VOSviewer (Figure 3). Electrolysis, hydrogen production, and electrolyte dominate the keywords. We group keywords to find new 10 year research topics. Diesel engines, electrodes, electrolysis process, fossil fuels, gases, hydrogen fuels, and hydrogen production are cluster 1. Cluster 2 (6 items) consists of electrolyte concentration, electrolytes, hho gas, sodium hydroxide, and water electrolysis. While cluster 3 (6 items) includes alternative fuels, electrolysis of waters, gas productions, hho generators, hydrogen, and internal combustion engines.

Bibliometric map onFigure 4shows the total repetition of hho gas appearing 6 times in one article, to track publishing trends over the past decade. The bibliometric map shows how hho gas production relates to other studies. The words writers often use to address this topic are darker. Thus, writers around the world prefer dark terms.

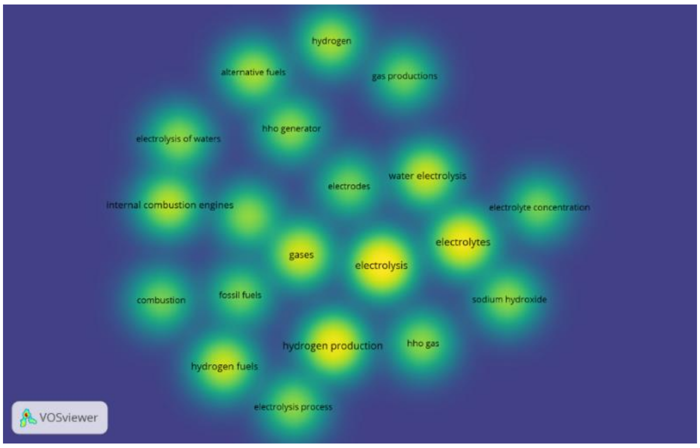

Figure 4. Keyword density related to HHO gas production using electrolysis

3.4. HHO gas production method

The investigation was carried out with a diesel engine including four cylinders and a naturally aspirated intake system. Data collected from the machine at different speeds (1,000 rpm to 1,500 rpm) and load conditions with various concentrations of KOH electrolyte solution to measure the HHO production rate. Fuel consumption, exhaust emissions, and other data are also measured to compare normal operation and hydrogen addition to the combustion chamber (Hassan et al., 2022). The experiment uses data related to the production of HHO gas using alkaline water electrolysis. This includes factors such as the nature of the electrolyte, the concentration of the electrolyte, and the distance between the electrodes. In addition, engine performance and emissions were taken into account when evaluating the results from this experiment (Yusof SNA et al., 2022). The rate of HHO production increases with increasing concentration of the electrolyzing solution (Hassan et al., 2022). CO and HC emissions were reduced by 91.7% and 34.84%, respectively, due to the addition of HHO to a higher concentration of KOH electrolyte solution (10 g/L).

Peng et al produced hydrogen from oilfield effluent using gasification of supercritical water in a continuous system (Peng Z et al., 2023). The thermodynamic investigation demonstrated that supercritical water (SCW) can gasify oilfield wastewater effectively due to coke inhibition. Na_2CO_3 or K_2CO_3 may accelerate steam reforming and water-gas equilibrium processes to create more H2 gas and carbon gasification efficiency. Rabl et al (Rabl H et al., 2004) investigated regulated syngas production via electrocatalytic CO_2 reduction and found MOCHA exhibited maximum Faraday efficiencies (FE) of 55 and 45% for carbon monoxide and hydrogen production, respectively Shao et al (2023) produce hydrogen with catalyst $15NiO/CeO_2$-Al_2O_3. Due to the less active catalyst, the two-stage system produced more hydrogen than the one-stage method. In comparison to the electrolysis of water, the production of hydrogen as a byproduct of the electrolysis of coal would need around fifty percent less energy (Lyu X et al., 2024).

Experimental analyzes and kinetic models to evaluate bio-hydrogen production from food waste were also carried out by Pecorini et al (2017). Bio-hydrogen production of 48.9 NlH_2/kgTVS sub from food waste. The modified Gompertz equation was used to fit the experimental data, and the correlation coefficient was found to be 0.998, indicating a good fit. The results are within the range reported by previous studies on bio-hydrogen production from food waste. A single Pt chain on TiO_2 support (Pt_1/def-TiO_2) forms a highly efficient photocatalyst for hydrogen production (Chen Y et al., 2020). The unique structure of the catalyst generates surface oxygen and forms the Pt-O-Ti^{3+} atomic interface, which enhances the separation of electron pairs. This results in high-rate photocatalytic hydrogen production performance with an unexpectedly high turnover frequency of 51423 h^{-1}, exceeding TiO_2 catalyst-supported Pt nanoparticles by a factor of 591.

3.5. HHO gas challenge

Future challenges may focus on optimizing process parameters to increase HHO gas production from food waste. In addition, research can be expanded to evaluate the feasibility of using the HHO gas produced as a waste fuel source (Pecorini et al., 2017). Another challenge is further optimization of the Pt_1/def-TiO_2 photocatalyst by exploring the effects of different Pt loadings, defect types and support materials. In addition, this study proposes to investigate the photocatalytic performance of catalysts under visible light irradiation and other photocatalytic reactions (Chen Y et al., 2020).

Economically, HHO gas is a proposed system in which hydrogen is produced and usedin a manneras an alternative primary energy. The economic success of HHO gas development means innumerable benefits for the environment, energy security, economy and end users (Abe JO et al., 2019). One of the main keys to fully developing HHO gas is safe, compact, lightweight and cost-effective storage of hydrogen. Conventional gas-state storage systems as pressurized hydrogen gas and liquid-state storage systems pose safety and cost concerns; Therefore, they do not meet future goals for the economy.

The majority of hydrogen fuel today is produced through a process called steam reforming, which uses natural gas as a feedstock. This process emits greenhouse gases, which offset the environmental benefits of using hydrogen fuel. There are alternative methods for producing hydrogen fuel, such as electrolysis, but these methods are currently more expensive and less efficient than steam reforming. Hydrogen gas has a low energy density, which means it takes up a lot of space compared to other fuels such as gasoline or diesel. This makes it difficult to store and transport hydrogen fuel. There are several methods for storing hydrogen, including compressed gas, liquefied gas, and metal hydrides, but all of these methods have their drawbacks. The infrastructure for distributing hydrogen fuel is not yet widely available, which makes it difficult for consumers to access. Building a hydrogen fueling network will require significant investment and coordination between government agencies, fuel providers and vehicle manufacturers. Hydrogen gas is highly flammable and explosive, which presents safety challenges for handling, storage and transportation. While safety standards have been developed to address this issue, there is still a perception among consumers that hydrogen fuel is less safe than other fuels. Hydrogen fuel is currently more expensive than gasoline or diesel, in part because of the high costs of producing, storing and transporting it. As technology improves and economies of scale are realized,

4. Conclusion

The primary objective of this review paper is to provide views, assessments, and evaluations of the published literature on HHO gas, both the production and use challenges of HHO gas. HHO production can be done by adding KOH electrolyte solution. Factors that affect the production of HHO gas include the nature of the electrolyte, electrolyte concentration, and the distance between the electrodes. The rate of HHO production increases with increasing concentration of the electrolyzing solution. HHO gas production can also be carried out by adding Na_2CO_3 or K_2CO_3 which can produce high H_2 gas. The pre-combustion mercury removal process through coal electrolysis produces hydrogen by-products during coal electrolysis with 50% lower energy consumption compared to water electrolysis. A single Pt chain on a TiO_2 support (Pt1/def-TiO_2) forms a very efficient photocatalyst for hydrogen production. The main challenges of HHO gas in terms of production, storage, distribution, safety, production costs of HHO gas.

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