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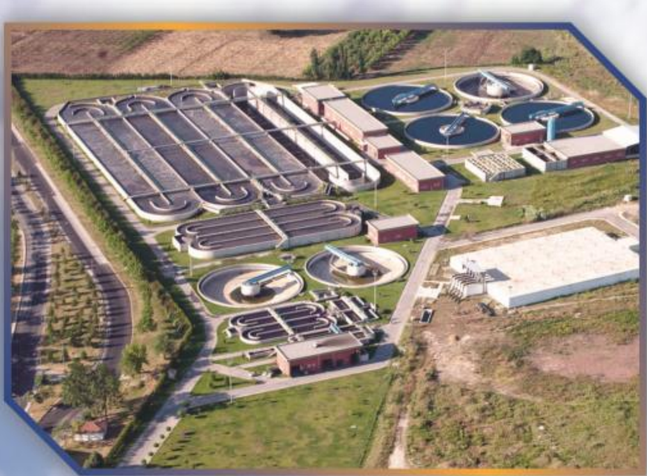

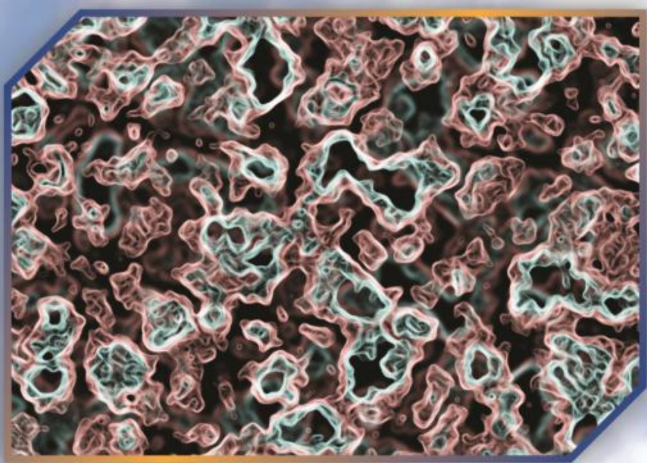

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RESEARCH ARTICLE

Analysis of the world scientific production on public's opinion on environmental issues

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ABSTRACT

The aim of this study is to investigate the scientific production related to public attitude, behavior and acceptance of environmental issues through a bibliometric analysis. The databases Scopus was used to analyze the papers published in the subject area of environmental science. Bibliometric analysis was performed for authors, institutions, source type, document type, number of citations and countries in relation to publication year. An analysis of keywords of publications was also performed. The number of publications shows an overall exponential trend after 1965 until 2017. The most productive institution is the Wageningen University and Research Centre, followed by the Chinese Academy of Sciences Beijing Normal University. The keywords of the categories associated with "Ecology", "Sustainability," and "Environmental Policy-Management" are the most commonly used in most studies. It seems that there is room for more intensive research on fields related to public's opinion on specific environmental issues. The findings of the research will contribute to a better understanding of the current state of the art, identifying key research areas in the field of public opinion on environmental issues and identifying future research trends and directions.

Keywords: Public opinion, environmental issues, bibliometric analysis, research trends, Scopus, social acceptance

1. INTRODUCTION

The global community is experiencing several environmental threats such as climate change, biodiversity loss [1], pollution and the overexploitation of natural resources. To address the world's environmental problems, it is essential that engineers and social scientists work together [2]. Engineers can provide the best, safest and most efficient solutions, whereas social scientists can facilitate better understanding of the reasons for public acceptance or resistance to a proposed environmental policy. Social scientists can also suggest ways in which public policy makers may be able to increase citizens' acceptance and find solutions which are more acceptable for the community.

The implementation of effective environmental policies depends on the broad public support [3]. So, the results of surveys exploring social acceptance on environmental issues are very important as they can help policy makers better understand and design policies to minimize resistance of the citizens. The findings are also key information for public policy makers as they convey the nature of the communication message that is likely to be effective and they provide guidance to public policy makers about interventions that are likely to increase public acceptance.

One of the most widely used and accepted tools to measure the scientific research productivity in any particular field of research is bibliometric analysis. Bibliometrics, firstly introduced by Pritchard [4], is considered as a well-established research method for conducting systematic analyses [5]. Bibliometrics uses quantitative analysis and statistics to analyze the bibliometric characteristics of a given field, evaluate the performance of authors, academic institutions or countries, discover the hot topics, reveal the research tendency in future and help researchers to recognize novel schemes within research [6]-[8].

The field of environmental science shows a remarkable growing volume of scientific production. Bibliometric analysis has been used to study particular environmental fields, such as: water conservation and consumption [8]-[11], waste management and

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recycling [12]-[16], energy consumption and solar energy [17]-[20], air pollution [21]-[24] or soil degradation [25]-[29]. Other studies treat more general environmental problems, but rather focus on certain geographic areas or countries [30], [31].

Bibliometric analysis was applied in the aforementioned studies to investigate the tendency of the literature in specific environmental issues. The use of bibliometric analysis on the investigation of public opinion and acceptance on environmental issues is limited. Literature review reveals limited studies investigating the research trend on the public's views on the environment. Indicatively, reference [32], by using content analysis and studying three specific energy journals, attempted the assessment of the journals production, aiming at pointing out the key trends in these journals. Reference [33], by selecting several studies related to social and public acceptance of energy systems, highlighted the emerging trends and identified the main research areas. Reference 34, using content and bibliometric analysis, investigated the literature trend related to social acceptance of energy technology and fuels.

Therefore, this study aims to investigate and analyze the scientific production related to public attitude, behavior, perception and acceptance of environmental issues through a bibliometric analysis. To accomplish this, we perform an analysis of publications, journals, institutions, source type, and document type, number of citations and countries in relation to publication year. An analysis of keywords of publications was also performed. The scientific research productivity in this particular field of research is of great importance. The research will contribute to a deeper understanding of the importance of public opinion on several environmental issues, as public participation is considered one of the key factors in the effective implementation of environmental policies. In addition, research findings will highlight the fields that gain the interest of scientists and will indicate future directions of research.

2. METHODS

Elsevier's Scopus database covers a significant part of the world scientific production and was selected for its vast abstract and citation collection of over 22,000 journals from 5,000 international publishers. We conducted a search using Scopus for topics containing three combinations of keywords. The first one comprises the "public": ("public" OR "social"), the second one denotes "acceptance": (opinion OR perception OR acceptance OR attitude OR knowledge OR behavior OR behaviour) and the last is the component: "environment*" (referring to the keywords produced by the combination of the root "environment" and any suffix). The option of having these words in the title, abstract and keywords is selected.

We restricted this search to material published until 2017, as 2018 is ongoing and the number of works changes every day. Also, only the works published in English are selected (more than 93% of the total documents). Moreover, "trade publications" and "undefined" of the "source type" are excluded (about 660 documents). The research is performed from 12 to 16 of March 2018.

This initial search returned 145,277 documents. The number of documents per subject area is: Medicine: 51,602, Social Sciences: 36,691, Psychology: 22,075, Environmental Science: 20,398, Agricultural and Biological Science: 13,805, Computer Science: 13,196, Engineering: 11,877, Business, Management and Accounting: 9,112, Biochemistry, Genetics and Molecular Biology: 9,015, Arts and Humanities: 8,985, etc. These results show that the component "environment" is related to different fields (such as social, work, health) and does not have the narrow sense of environmental science. Since the research focuses on the public's opinion on environmental issues we choose to limit our research on the 20,398 documents related only to environmental science.

We extracted and analyzed the following data: year of publication, document type, country, institution, authors, and number of citations in Scopus. In order to enhance the analysis of the main issues, we also surveyed the keywords given by authors and by Scopus. The impact factors (IFs) were obtained from the Journal Citation Reports (JCR) Science Edition 2016. The total publications and citations per country were obtained by SCImago Journal & Country Rank. SCImago Journal & Country Rank is a portal that includes the journals and country scientific indicators developed from the information contained in the Scopus database.

3. RESULTS AND DISCUSSION

3.1. Analysis of publications and citations per year

In order to have a comprehensive overview of the research production on public opinion on environmental issues, the publication and citation number of each year is analyzed (Fig 1). According to the current Scopus documents coverage, the first publication on the topic was published in 1951 and until 1964 only 5 documents were published. The number of publications shows an overall exponential trend after 1965 until 2017. This trend can be divided into three periods: 1965–1989, 1990-2007 and 2008-2017 and the growth rate of each period can be described using a best-fit line. The display of these best-fit lines in the figure makes it difficult in reading, so the equation of each one is simply recorded to the text of the article. During the first period ($y=3.5246x-6{,}933.2$, $r^2=0.9282$), the number of publications appeared is quite low: 1 in 1965 and 92 in 1989, total 873 publications in 25 years. It is obvious that the research on the topic was just at the beginning. At the second period ($y=34.347x-68{,}320$, $r^2=0.936$) an increase of the number of publications begins: 108 in 1990 to 692 in 2007, total 5,788 publications in 18 years. During the third period ($y=163.4x-327{,}481$, $r^2=0.976$), the number of publications is growing even more: from 734 in 2008 to 2,223 in 2017, total 13,732 publications in 10 years. The results show that the research has rapidly developed and attracted widespread attention increasingly. The exponential growth in the production of scientific articles of the last decade in environmental science has been also reported by previous studies [34], [35].

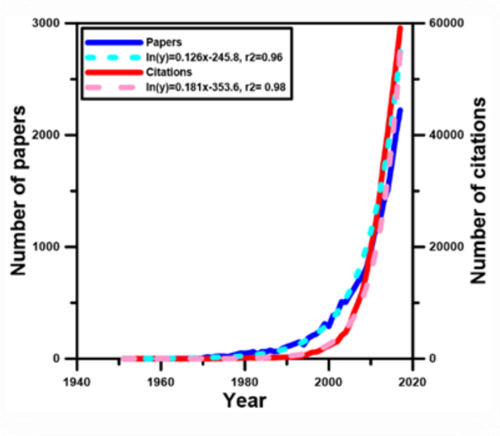

Fig 1. Number of documents and citations per year

Looking at the amount of citations in these 20,398 articles, there are 384,927 citations distributed along the study period, with an average of 18,89 citations per published article. The number of citations increases gradually every year with the amount of publications per year (Fig 1). Fig 2 shows the distribution of publications and their citation grouped into 10-year periods and confirms the increase in the amount of publications and citations. Moreover, the average number of citations per article has increased in each period. The increasing trend in the number of publications and citations in the field of environmental sciences is also highlighted in previous studies [34], [35].

3.2. Document and source type

Of the 20,398 publications recorded to Scopus from 1951 to 2017 in our search, twelve document types are identified: The peer-reviewed journal articles is the most common type (16,103 papers or 78.9% of all 20,398 publications), followed by reviews (1,769 papers, 8.7%), conference papers (1,321 papers, 6.5%), book chapters (508 chapters; 2.5%), books (166, 0.8%) and article in press (156, 0.8%). The predominance of articles as the most widespread way of disseminating and communicating scientific knowledge has been also highlighted by previous studies in the field of environmental research [36]. Other document types includes editorials (125, 0.6%), notes (109, 0.5%), short surveys (70, 0.3%), letters (42, 0.2%), conference reviews (28, 0.1%) and report (1). As a consequence of the previous results, the majority of documents are published in journals (18,534, 90.86%), following by books (848, 4.16%), conference proceedings (660, 3.24%) and book series (355, 1.74%).

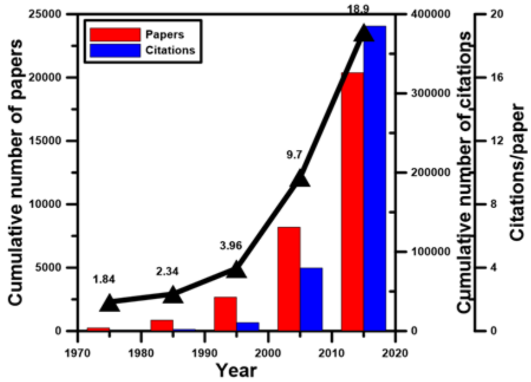

Fig 2. Cumulative publications and citations per period of 10 years

We extracted from Scopus the total citations for the most common document types (articles, reviews and conference paper) and it has been calculated the ratio Total number of each document type/Total citations of each document type, as shown in Table 1. The comparison of the aforementioned ratios reveals that reviews are the most cited document type (with almost 40 citations/document) although it counts significant less total number of publications. Articles received almost 19 citations/document and conference papers quite less, 12 citations/document.

3.3. Analysis of the major sources of publication and citation

There is an export limit of 160 terms when searching to Scopus; consecutively, all journals which published the articles of our research cannot be extracted. Thus, we analyze only the first 160 journals based on the number of publications. Almost 66% (13,353 papers) of the total number of papers have been published in the first 160 journals. Fig 3 shows the cumulative percentage of articles covered by these journals as a function of the number of journals that publish them, in decreasing order of journals, according to the number of articles they have published. It can be seen that, even if the journals with the highest number of publications occupy a significant part of the total articles published, a high predominance of a few journals is not observed (for example, about 70 journals have published only the 50% of the articles).

Table 1. Total citations of the most common document types

Document type	Total number of document type (1951-2017)	Total citations of document type (1951-2017)	Total number of document type/Total citations
Article	16,103	302,796	18,80
Review	1,769	69,249	39,15
Conference Paper	1,322	16,324	12,35

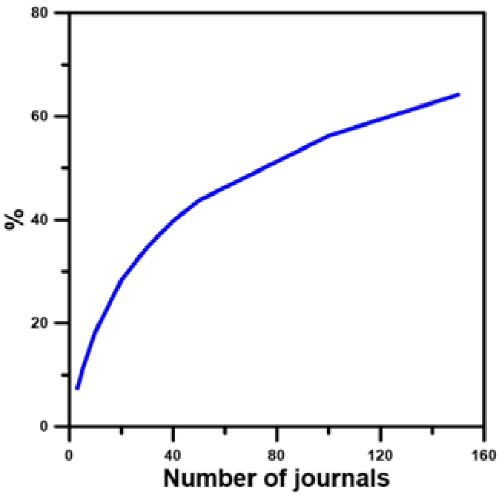

Fig 3. Cumulative percentage of papers published as a function of the number of journals have published them

The 20 main sources of publication and citation are grouped in decreasing order from the most productive to the least productive journal (Table 2). The 20 first sources of publication account for 28% of the total number of publications. Environmental Management, have published 563 publications, is the first on the journal list covering the 2.8% of the total documents; meanwhile, the second most productive journal is Journal Of Environmental Management with 480 publications (2.4%), followed by International Journal Of Environmental Research And Public Health (464 documents, 2.3%).

The columns "Rank Citations" and "Rank Publications" in Table 2 show the classification of the journals based on the amount of citations and publications. Interestingly, there is no correlation between the number of publications and the number of citations. For example, Environmental Health Perspectives has the highest number of citations (16,161), but ranks in the fourth position regarding the amount of publications (382) (Table 2).

Taking into consideration the index citations/documents, Global Environmental Change is in the first place of the ranking with 71.9 citations per document published, followed by Environment and Behavior (48.5 citations per document) and Environmental Health Perspectives (42.3 citations per document). Average citation per document is considered as a parameter that can express the influence of a journal in the research community (36 Jin et al., 2018). All the aforementioned journals have also been characterized by having high impact factor, between 3.378 and 9.776 (Table 2). As a result, we can draw a conclusion that these journals had an important influence on research related to public opinion towards environmental issues.

3.4. Analysis of countries

Table 3 shows the publication contribution of the top 10 productive countries. Undoubtedly, the most productive country is the USA in terms of the number of total publications from single-country articles and international collaborations (6,442 papers), followed by United Kingdom (2,717), Australia (1,624), Canada (1,371), Germany (976), China (946), Netherlands (867), Spain (807), Italy (743) and Sweden (718). The predominance of USA and United Kingdom to the scientific production has been also revealed by previous studies [37].

The contribution of the top ten countries in the field of environmental science as pointed out in the database of SCImago Journal and Country Rank [38], based on the total publications and the H-index, is shown also in Table 3. The H-index of each country is an index used for the evaluation of the country's scientific performance in the environmental field. This parameter integrates measures of quantity (represented by the number of publications) and measures of quality (represented by the total citation scores) [39]. The h-index of each country was obtained by SCImago Journal & Country Rank portal [38]. The position of each country in the list of the top ten productive countries for the search performed here is quite close to the position in the fields of environmental science extracted by SCImago 2017.

In addition, we calculated each country's ratio of citations per document of our search to total citations per total documents (for all subject categories and for the subject area "environmental science") (Table 4). The data of the total documents and total citations per country was extracted by SCImago Journal & Country Rank for the period 1996-2017, for all subject areas and for the subject area "environmental science". The ratio for all subject categories (Table 4) is roughly stable for the countries United Kingdom, Australia, Canada, Germany and Netherlands, close to 1.2. The low ratio of United States (1.02) and the high ratio of China and Sweden (1.78 and 1.58 respectively) reveals that these countries produce respectively much lower and higher citable works than the other countries.

The corresponding ratio for the subject category "environmental science" is also roughly stable for the countries United States, United Kingdom, Australia, Canada, Germany, China and Netherlands, close to 1.1 to 1.2. The low ratio of Spain (0.84) and the high ratio of Sweden (1.58) reveals that these countries produce in the field of environmental science respectively much lower and higher citable works than the other countries, for the specific research issue. The great production and influence of USA and the lowest production and influence among the north European countries (such as Spain and Greece) in the environmental field, has also been indicated by previous studies [40].

Table 2. Ranking of 20 journals in terms of publications and citations

Journal name	Documents	Document ranking	Citations	Citation ranking	Citations/ Documents	Impact Factor 2016*
Environmental Management	563	1	13,252	4	23.5	1.878
Journal Of Environmental Management	480	2	13,490	3	28.1	4.010
International Journal Of Environmental Research And Public Health	464	3	3,563	17	7.7	2.101
Environmental Health Perspectives	382	4	16,161	1	42.3	9.776
Science Of The Total Environment	371	5	8,086	10	21.8	4.900
Journal Of Cleaner Production	362	6	5,867	14	16.2	5.715
Sustainability Switzerland	305	7	981	20	3.2	1.789
Environment And Behavior	290	8	14,068	2	48.5	3.378
Ecological Economics	275	9	9,231	6	33.6	2.965
Ecology And Society	254	10	7,364	12	29.0	2.842
Environmental Science And Policy	243	11	5,716	16	23.5	3.751
Energy Policy	232	12	6,900	13	29.7	4.140
Proceedings Of The Royal Society B Biological Sciences	219	13	8,610	7	39.3	4.940
Landscape And Urban Planning	205	14	8,112	9	39.6	4.563
Society And Natural Resources	197	15	5,818	15	29.5	1.534
Environmental Science And Technology	196	16	8,204	8	41.9	6.198
Water Science And Technology	195	17	2,450	19	12.6	1.197
Conservation Biology	192	18	7,999	11	41.7	4.842
Ocean And Coastal Management	182	19	2,587	18	14.2	1.861
Global Environmental Change	170	20	12,231	5	71.9	6.327

* The impact factors of the journals were obtained from the Journal Citation Reports (JCR) Science Edition 2016

Table 3. Contribution of the top 10 productive countries

Country	Documents	Document ranking	Total Documents (SCImago 2017, Environmental Science)	Document Ranking (SCImago 2017, Environmental Science)	H-Index
United States	6442	1	470,621	1	545
United Kingdom	2717	2	134,007	3	262
Australia	1624	3	73,849	7	281
Canada	1371	4	90,369	5	303
Germany	976	5	106,899	4	320
China	946	6	219,409	2	262
Netherlands	867	7	43,460	12	287
Spain	807	8	63,273	10	245
Italy	743	9	59,101	11	226
Sweden	718	10	33,675	14	254

Fig 4 shows the comparison of the growth trends of the top seven most productive countries for the period 1990-2017, where all countries have started their publication activity. USA has a predominant role in publications, while China's history in the field of publications starts only in 1990, very recently in relation to the rest of the top seven countries. From 1990 to 2008, the increase in speed of annual publication is slower for China. Beginning in 2009, the annual number of publications from China increases rapidly. By 2015, the annual number of publications from China is in upward trend. This reflects the fact that China has made considerable progress and has made great contributions to the research fields around the world, which is mainly a result of the rapid economic and industrial development. However, the annual number of publications from other countries (such as Australia Canada, Germany, and Netherlands) shows a tiny increase from 2001 to 2015 and from 2015 to 2017 a tiny decrease.

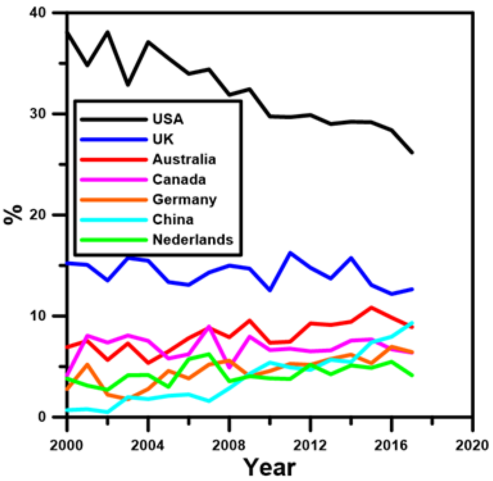

Fig 4. Comparison of the growth trends of the top seven most productive countries (1990-2017)

3.5. Analysis of institutions

Among the first 160 most productive institutions extracted by Scopus, the Wageningen University and Research Centre is the most productive institution with 213 papers, followed by the Chinese Academy of Sciences with 190, the United States Environmental Protection Agency with 160, the University of East Anglia with 154, the University of Queensland with 153, the USDA Forest Service with 50, the Australian National University with 141, the University of Oxford with 140, the University of British Columbia with 138 and the University of Washington, Seattle with 138.

The columns “Rank Citations” and “Rank Publications” in Table 6 show the classification of the institutions based on the amount of citations and publications. The institution with the highest number of publications is not necessarily the most widely cited. For example, Wageningen University and Research Centre is the institute with the largest number of publications, totalling 213, but it ranks in the second position in terms of citations, with 8.580 citations, while University of East Anglia has the largest number of cited articles (10,764 citations), being in the fourth position regarding the amount of publications (154). It is worthy of notice that the Chinese Academy of Sciences occupies the second place in the ranking of documents but is found only in the 10th place of citation ranking. This is a consequence of the fact that China started publishing articles much recently in relation to other countries and, thus, the time period to accumulate citations is much shorter.

3.6. Analysis of the keywords

Keyword investigation helps researchers choose appropriate keywords and contributes to access to research theme from scientific database with the correct term [41]. Identifying publication themes from keywords is an important means of enhancing visibility and scientific communication, thereby promoting higher quality research and discussion.

When searching to Scopus for a specific topic the extracted keywords are a combination of author keywords (assigned to the documents by the authors) and indexed keywords (controlled vocabulary terms and indexing vocabulary terms from subject-specific databases assigned to the documents by Scopus). To our research a total of approximately 4,000 keywords (109,480 total frequencies) were given by authors and by Scopus. In the top five terms (based on frequency of use) across both author-supplied and Scopus keywords, only one specific keyword (environmental protection, frequency 2,286) concerning the environment is found. The rest of the top five keywords were general and obviously given by Scopus (article, human, humans, United States).

For further analysis, the first 160 keywords (extracted by Scopus with the highest frequency) are categorized according to their content. There are created nine broad categories of these 160 keywords, shown in Table 6.

The terms of the categories "Environment" and "Social" are the most related terms to the research issue and to the keywords used in the search of articles. 60 keywords of total frequency 38,883 are included in the category "Environment" and 23 keywords of total frequency 13,299 are included in the category "Social". These two main categories cover the 52% of the amount of the 160 keywords and the 48% of total frequency obtained. The number of articles corresponding to the category "Environment" and "Social" is 14,165 documents and 8,403 documents respectively. The rest of the categories ("Human", "Methodology", "Policy-Management", "Geography", "Paper", "Health", "Psychology", "Animals") includes 77 keywords of total frequency 57,298; 52% of total frequency obtained. A further elaboration of the category "Environment" is performed, according to the context of each keyword, and 7 subcategories has been created (Table 7).

Table 4. Comparison of research documents and citations with corresponding data of Scimago Journal (all subject categories and subject category "environmental science")

	Research			Scimago Journal & Country Rank (all subject categories)				Scimago Journal & Country Rank (Environmental Science)			
Country	Documents	Citations	Citations per Document	Total Documents	Total citations	Total Citations/Total Document	(Citations/Documents)/(Total Citations/Total Documents)	Documents	Citations	Citations per Document	(Citations/Documents)/(Total Citations/Total Documents) (Environmental Science)
United States	6,442	155,489	24.14	10,193,964	240,363,880	23.58	1.02	470,621	9,962,559	21.17	1.14
United Kingdom	2,717	71,073	26.16	2,898,927	60,988,844	21.04	1.24	134,007	3,132,493	23.38	1.12
Australia	1,624	33,816	20.82	1,111,010	20,363,776	18.33	1.14	73,849	1,496,355	20.26	1.03
Canada	1,371	34,950	25.49	1,468,796	31,052,115	21.14	1.21	90,369	1,904,667	21.08	1.21
Germany	976	21,796	22.33	2,570,206	49,023,207	19.07	1.17	106,899	1,995,033	18.66	1.20
China	947	12,060	12.73	4,595,249	32,913,858	7.16	1.78	219,409	2,327,649	10.61	1.20
Netherlands	867	25,451	29.36	816,316	20,136,037	24.67	1.19	43,460	1,135,221	26.12	1.12
Spain	807	13,986	17.33	1,148,258	18,244,660	15.89	1.09	63,273	1,301,472	20.57	0.84
Italy	743	13,868	18.66	1,449,301	25,366,435	17.50	1.07	59,101	1,047,193	17.72	1.05
Sweden	719	26,748	37.20	552,343	13,028,361	23.59	1.58	33,675	854,016	25.36	1.47

As shown in Table 7, there are seven thematic subcategories of the category "Environment". In the subcategory "Ecology-Environment" is included 20 of the total 60 terms related to wider environmental concepts. The total frequency of these keywords is 12,703, 33% of the total frequency of the category "Environment". The next category "Environmental policy-management" includes 13 terms of total frequency 9,164; 23% of the total frequency of the category "Environment". The subcategory "Sustainability" includes the less number of keywords, only five, of total frequency 6,518 but cover the 17% of the total frequency of the category "Environment". Researchers' interest in the concept of sustainability has been highlighted by previous studies [35], [42] and reinforced by the fact that sustainability is a rather new concept that has emerged in recent years; its definition took place in the Brutland report in 1987 [43].

Table 5. Contribution of the top 10 productive institutions

Institution	Documents	Document ranking	Citations	Citation ranking	Citations/Documents
Wageningen University and Research Centre	213	1	8,580	2	40.3
Chinese Academy of Sciences	190	2	3,348	9	17.6
United States Environmental Protection Agency	160	3	5,382	5	33.6
University of East Anglia	154	4	10,764	1	69.9
University of Queensland	153	5	3,195	10	20.9
USDA Forest Service	150	6	5,768	3	38.5
Australian National University	141	7	5,426	4	38.5
University of Oxford	140	8	4,217	6	30.1
The University of British Columbia	139	9	4,123	8	29.7
University of Washington, Seattle	138	10	4,171	7	30.2

Table 6. Keywords categories

Keywords categories	Total frequency	Keywords categories	Total frequency	Keywords categories	Total frequency
Environment	**33,833**	**Human**	**13,345**	**Policy-Management**	**9,216**
Environmental Protection	2,286	Human	3,500	Decision Making	1,913
Sustainable Development	1,798	Humans	2,935	Public Policy	947
Environmental Management	1,610	Female	1,544	Stakeholder	939
Environmental Impact	1,559	Male	1,449	Economics	734
Climate Change	1,481	Adult	1,178	Policy Making	678
Sustainability	1,452	Nonhumam	851	Local Participation	667
Environmental Policy	1,207	Middle Aged	594	Policy	641
Conservation Of Natural Resources	1,198	Child	481	Governance Approach	503
Environmental Monitoring	1,141	Aged	464	Government	455
Environmental Exposure	1,061	Young Adult	349	Adaptive Management	419
Environment	988	**Social**	**13,299**	Management	398
Biodiversity	855	Perception	2,092	Risk Management	343
Ecology	833	Public Attitude	1,352	Planning	299
Environmental Planning	831	Public Opinion	866	Economic Aspect	280
Water Management	788	Social Behavior	805	**Geography**	**8,083**
Water Supply	768	Risk Perception	792	United States	2,099
Waste Management	751	Economic And Social Effects	775	Europe	891
Urban Area	691	Knowledge	703	Eurasia	832
Water Quality	675	Education	529	United Kingdom	699
Agriculture	638	Attitude	504	China	680
Environmental Economics	634	Socioeconomics	425	Australia	659
Ecosystem	608	Environmental Education	424	North America	547
Land Use	591	Social Aspect	418	Canada	430
Environmental Impact Assessment	590	Demography	402	Asia	358
Conservation	589	Consumption Behavior	382	Spain	316
Environmental Health	580	Behavior	373	European Union	287
Pollution	549	Social Aspect	368	Developing Countries	285
Environmental Factor	540	Willingness To Pay	352	**Paper**	**7,413**
Ecosystems	540	Social Environment	324	Article	4,224
Recycling	520	Public Participation	298	Priority Journal	1,901
Water Pollution	489	Socioeconomic Factors	296	Review	917
Air Pollution	486	Communication	283	Conference Paper	371
Resource Management	474	Behavioral Research	268	**Health**	**5,142**
Forestry	458	Concentration (composition)	268	Public Health	1,680
Conservation Management	431	**Methodology**	**9,552**	Health Risk	681
Waste Disposal	423	Risk Assessment	1,636	Health Hazard	576
Ecosystem Service	418	Questionnaire	616	Health Risks	512
Urban Planning	401	Questionnaire Survey	544	Health	474
Pollution Exposure	391	Surveys	539	Physiology	313
Environmental Issue	390	Participatory Approach	527	Health Impact	312
Forest Management	356	Methodology	513	Major Clinical Study	308
Environmental Engineering	333	Procedures	464	Toxicity	286
Air Quality	330	Research	397	**Psychology**	**2,246**
Water Resources	330	Attitudinal Survey	397	Controlled Study	1,109
Drinking Water	321	Risk Factor	388	Adolescent	477
Nature-society Relations	320	Regression Analysis	356	Psychology	358
Pollution Control	320	Conceptual Framework	354	Adaptation	302
Water	320	Learning	341	**Animals**	**2,301**
Environmental Pollutants	318	Models, Theoretical	339	Animals	995
Environmental Change	316	Comparative Study	337	Animalia	660
Rural Area	313	Analysis	330	Animal	646
Nature Conservation	305	Numerical Model	322		
Environmental Assessment	297	Questionnaires	319		
Environmental Values	296	Integrated Approach	287		
Natural Resource	294	GIS	277		
Water Pollutants, Chemical	293	Statistics And Numerical Data	269		

Table 7. Further elaboration of keywords related to environment

Keywords subcategory	Total frequency	Keywords subcategory	Total frequency
ECOLOGY-ENVIRONMENT	13,023	SUSTAINABILITY	6,518
Environmental Protection	2,286	Sustainable Development	1,798
Environmental Impact	1,559	Climate Change	1,481
Environment	988	Sustainability	1,452
Biodiversity	855	Conservation Of Natural Resources	1,198
Ecology	833	Conservation	589
Ecosystem	608	WATER	4,407
Environmental Health	580	Water Management	788
Pollution	549	Water Supply	768
Ecosystems	540	Water Quality	675
Environmental Factor	540	Water Pollution	489
Ecosystem Service	418	Waste Disposal	423
Pollution Exposure	391	Water Resources	330
Environmental Issue	390	Drinking Water	321
Environmental Engineering	333	Water	320
Nature-society Relations	320	Water Pollutants, Chemical	293
Pollution Control	320	LAND USE	3733
Environmental Pollutants	318	Urban Area	691
Environmental Change	316	Agriculture	638
Nature Conservation	305	Land Use	591
Natural Resource	294	Forestry	458
Fish	280	Urban Planning	401
ENVIRONMENTAL POLICY-MANAGEMENT	9,164	Forest Management	356
Environmental Management	1,610	Rural Area	313
Environmental Policy	1,207	Protected Area	285
Environmental Monitoring	1,141	WASTE	1271
Environmental Exposure	1,061	Waste Management	751
Environmental Planning	831	Recycling	520
Environmental Economics	634	AIR	1087
Environmental Impact Assessment	590	Air Pollution	486
Resource Management	474	Air Quality	330
Conservation Management	431	Atmospheric Pollution	271
Pollution Control	320		
Environmental Assessment	297		
Environmental Values	296		
Environmental Risk	272		

The rest four subcategories are exclusively thematic and are determined by the key components of the concept of the environment which are water, land use, waste and air. The total frequency of the terms of these four categories is 10,498, 27% of the total frequency of the category "Environment". The total number of articles corresponding to these four subcategories is 7,251 documents. Among these four subcategories, it seems that the most frequent subject of research is water, followed by land use, waste and air. In the subcategory "Water" is included nine keywords of total frequency 4,407, 11.33% of the total frequency of the category "Environment". The subcategory "Land use" includes 8 terms of total frequency 3,733; 9.6% of the total frequency of the category "Environment". The subcategory "Waste" includes only two terms of total frequency 1,271; 3.27% of the total frequency of the category "Environment". At last, in the subcategory "Air" is included three keywords of total frequency 1,087, 2.80% of the total frequency of the category "Environment". The number of articles corresponding to each subcategory is 2,500 documents for "Water", 2,954 documents for "Land use", 1,038 documents for "Waste" and 759 documents for "Air".

From the categories of the keywords and the related frequencies it seems that most articles in the research field, concern public opinion on more general environmental issues that are primarily related to ecology, sustainability and environmental policy and management. Publication themes concerning public opinion on specific environmental issues related to water, waste, air, land use appear to be much less.

4. CONCLUSIONS

Based on the 20,398 publications obtained from Scopus (for the time period 1951 to 2017), restricted to subject category of environmental science, we conducted a scientific research on public attitude, behavior, perception and acceptance of environmental issues by using bibliometric analysis. Article is the most commonly used document type but reviews are the most cited document type. The notable increase of annual number of publications after 1965 suggests that the research on the specific field developed rapidly and has increasingly attracted researcher's attention. 62% of the total documents were distributed into 160 different journals during the years 1951–2017. Environmental Management, Journal of Environmental

Management and International Journal of Environmental Research and Public Health ranked the top three on the journal list. In this study, we also found that the 20,398 publications with author's address information represented 160 countries and more than 160 institutions. Among the 160 countries, the USA, the UK, and Australia were the top three productive countries, followed by Canada, Germany and China. Among the first 160 most productive institutions extracted by Scopus, the Wageningen University and Research Centre took the leading position, followed by the Chinese Academy of Sciences and the United States Environmental Protection Agency. It is worthy of notice that the Chinese Academy of Sciences occupies the second place in the ranking of documents, but in the 10th place of citation ranking. This is a consequence of the fact that China has started publishing articles much recently than other countries and thus the time period to accumulate citations is much shorter. In addition, the keywords are categorized according to their content. The main research fields on public's opinion on environmental issues were related to ecology, sustainability and environmental policy and management, and less to specific environmental issues, such as water, waste, air, land use. These topics may become new research fields in the future.

The findings of the research activity related to public opinion on environmental issues contribute to a better understanding of the current state, identifying key research areas in this field and identifying future research trends and directions. Results can also be a useful tool for policy makers to establish future research priorities.

Main limitation of the research is that it was restricted to data obtained only from database Scopus. Future research should seek to include a larger database or to extract data from different databases enabling the comparison between the different sources and identifying general trends.

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RESEARCH ARTICLE

Barriers and opportunities to operate photovoltaic systems in commercial buildings in Nigeria

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ABSTRACT

The rapid growth of energy consumption worldwide has increased rapidly, and has raised concerns over problems of energy supply, energy sustainability, and exhaustion of energy resources. These problems can be solved by contributing significantly to the utilization of renewable energy sources. Most developed countries are taking counter measures by implementing building energy standards in order to reduce building energy consumption by recognizing new energy policies and encouraging investment in PV system which is one of the biggest renewable energy sources and, thus, achieve sustainable energy efficient buildings. However that is not the case in a developing country like Nigeria, as there is a huge gap between the demands for electricity and demand for sustainable energy in the country. The use of PV technology in Nigeria is not new, but it still encounters many barriers for its penetration into the commercial sector. In respect to that, this research paper investigates the key challenges in the adoption of Photovoltaic systems and identifies the effective strategies of implementing PV systems in commercial buildings in Nigeria. The study focuses on identifying renewable energy sources for commercial buildings in Nigeria; examining the need for PV systems in commercial buildings in Nigeria; Identify the effects of PV systems on energy optimization in commercial buildings; review the policy context for renewable energy in Nigeria; identify the barriers in adopting photovoltaic systems in commercial buildings in Nigeria; and recommend possible ways of overcoming the barriers.

Keywords: Energy, renewable energy sources, photovoltaic system, PV barriers, building

1. INTRODUCTION

Energy is an essential requirement for all earthly operations; it is vital and of great importance to socio-economic doings of the present society which is revolved around the central point of the availability of energy. The 1973 oil disasters brought on by the Arab oil embargo, in European countries fetched an unexpected worldwide understanding to the use of renewable energy resources such as wind energy, wave energy, solar energy (photovoltaic), hydropower, biomass and bio fuels [1]. According to [2] the demand for the utilization of renewable energy resources is growing to be more desirable these days as a result of the finite nature of fossil fuel energy resources and in many cases the greenhouse gases emission which a great number of scientists clearly believe today is the cause of global warming. Effective utilizations of renewable energy resources to improve the supply of energy from fossil fuel energy resources will augment availability of energy with little or no environmental consequence.

As a reaction to international interest in the utilization of renewable energy resources, the Energy Commission of Nigeria (ECN) was founded in 1979. The Energy Commission currently has six centres open out across the country. The centres are:

1. Sokoto energy research centre (SERC) at Usman Dan Fodiyo University, Sokoto.

2. National centre for energy research and development (NCERD) at University of Nigeria, Nsukka.

3. National centre for energy and environment (NCEE), University of Benin, Benin City.

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4. National centre for energy efficiency and conservation (NCEEC), University of Lagos, Lagos.

5. National centre for hydropower research and development (NCHRD), University of Ilorin, Ilorin.

6. National centre for petroleum research and development (NCPRD), Abubakar Tafawa Balewa University, Bauchi

These energy research centers have the order to engage in energy studies and improve renewable energy technologies and likewise to make well known the benefits of the utilization of renewable energy resources in the entire country.

Nigeria as a country is endowed with substantial amounts of fossil fuel energy sources which include natural gas, petroleum, tar sands, lignite, coal, and also renewable energy resources. However, the renewable energy sources include animal waste, solar radiation, hydropower, crops residue, wind, and fuel wood. According to [1] petroleum and electricity which is produced from either burning fossil fuels or possibly hydro plants provides a huge proportion of energy services in the industrial, residential, commercial, and 3 transport sectors in Nigeria. Solar radiation basically is copiously present in Nigeria, and is most certainly one area of major concentration among the other renewable energy resources in Nigeria. According to [3] the normal solar radiation acquired in Nigeria is approximately 7.0 kWh m^{-2} day^{-1} (25.2 MJ m^{-2} day^{-1}) in the distant north while it's about 3.5 kWh m^{-2} day^{-1} (12.6MJ m^{-2} day^{-1}) in the coastal latitudes. Due to the fact that the country is located in the high solar radiation zone of the world, most of the energy institutes are helping to make huge strides in the manufacture of solar energy technologies as a means for the utilization of solar energy. The energy research centers have also been helping to make serious efforts to spread the need for the applications of these devices to be used as household commodities and also installed in commercial buildings. Some state government authorities, in cooperation with non-governmental agencies supported a couple of projects in some rural communities on solar energy. The estimate of solar energy capability in Nigeria with 5% device conversion efficiency is 5.0 x 1014 kJ of efficient energy per annum [4] this is obviously about the same as 258.62 million barrels of oil produced each year and approximately 4.2 x 10^5 GWh of electricity production per annum in the country [5].

Several Nigerians and foreigners who base in Nigeria reside in rural communities in which you may hardly find any good road, difficult terrains, electricity grids, and also no easy accessibility to fossil fuel energy resources. Efficient maximizing of solar radiation with the use of solar energy technologies to enhance energy supply from fossil fuel energy resources would definitely increase availability of energy for socio-economic activities as well as to make improvements to the normal standard livelihood of the people. With this ugly situation, there are expectations to improve the standard of energy supply in the country, employing the essential items needed in other to take advantage of solar energy (photovoltaic) which will definitely improve the standard of livelihood of the people.

2. PRIMARY ENERGY CHALLENGES IN NIGERIA

Inefficient energy utilization, ineffective and undependable energy supply system, environmental challenges, energy financing, lack of adequate technological know-how in the energy sector and poor institutional framework [6] nevertheless, before reviewing these problems there is certainly a need to consider the recent energy consumption patterns of the country.

In Nigeria the primary energy consumers could very well be categorized into three (3) major sectors particularly: commercial, residential, and industrial sector. The industrial sector in some nations around the world constitutes the major consumer of electric energy which is then pursued by the residential and commercial sector [7]. Based upon existing information, the pattern observed in Nigeria appears to be the reverse. In 2000, the total amount of electric energy consumed amounted to 29.12 PJ, where the residential sector consumed 51.65% (15.04 PJ), whereas the commercial and industrial sectors consumed 25.89% (7.54 PJ) and 22.46% (6.5 PJ) respectively of the over-all total consumed [8].

It has also been found that the commercial sector's electricity consumption has also been increasing too, although not nearly as fast as the residential sector's electrical energy rate of consumption. However, the commercial sector relates to the energy consumed by wholesale and retail trade; post and telecommunications; the operation of hotels and restaurants; real estate, renting and business activities; maintenance and repair of motor vehicles and motorcycles; the collection, purification and distribution of water, etc. The above listed commercial sectors in Nigeria consume energy amounting to about 81,537 tons of oil equivalent from 1971 to 1999 [9]. By all indications, the biggest consumer of electric energy in Nigeria is the residential sector, which is then accompanied by the commercial and the industrial sector [10]. Table 1 below shows the past trend of electricity consumption in residential, commercial, and industrial sectors of the Nigerian economy.

The decreasing trend in the total amount of electrical energy consumed between 1995 and 2000 was not attributed to the energy conservation measures and technologies [11], and also that of the industrial sector; rather, it is as a result of the continuous irregular and lack of adequate power supply in the country [7].

2.1. Energy Situation in Nigeria

Although Nigeria is a major oil producer and investor in the electricity sector, Nigeria holds a low 69th place in per capita electricity consumption globally [12]. The country has large amounts of natural resources utilized for energy generation (both conventional and renewable sources); but yet is bedeviled with unexpected and long periods of power outage, or fluctuating currents. Ibitoye and Adenikinju [13] gave an estimate that up to 60% of the populations are unconnected to the national grid.

There are presently more than 150 million people living in Nigeria, and the power sector has the capability of producing only around 3,500 MW of electricity, which is very much below all economic projections and the country's end users and business needs, regardless of the governments investment of around USD 1 billion per annum in the sector [14].

Energy use in the commercial sector in Nigerian offices is dominated by electricity supply. Cooling, lighting, hot water, and powering of appliances are all powered by electricity. It is obvious that high cost of electricity and inadequate power supply continues to be a primary concern to every sector of the Nigerian economy: especially the industrial, commercial, and domestic sectors. However, several unexpected power line cuts, which seem to have grown to be a daily regular occurrence in Nigeria, usually leads to equipment not functioning properly, which adds to the difficulty to produce goods and provide efficient services.

Due to the inconsistent and undependable supply of electricity in the country, it has forced the industrial and commercial sector into self-generation of electricity by means of purchasing of privately owned generating plant and in doing so decrease their reliance on general public source electricity power supply, and thus, adding a significant amount to their operating and capital costs. The trend of using fossil based fuel to power back-up generators in Nigeria has negative impacts on climate change, pollution, and profit for businesses.

3. RENEWABLE ENERGY SOURCES

Renewable energy is basically the energy that comes from natural sources that are constantly and sustainably replenished such as hydro energy, solar energy, geothermal energy, wind energy, and certain bio fuels [15].

Renewable energy can be used for various purposes since it can support small as well as large applications. Electricity and heat can be produced for use by using renewable energy from wind, sun and geothermal technologies. Many of these technologies contribute to renewable power generation, and amongst all renewable technologies, photovoltaic increased the fastest at a rate of 60% annually between the years 2004 – 2009 [16], which is one of the areas of renewable technologies that have received the most attention.

Solar Energy: This is basically the most successful of all sources of renewable energy taking into account all its quality. The sun radiates its energy at the speed of about 3.8 × 1023 kW per second [17]. However, a large amount of this energy is spread evenly as electromagnetic radiation which happens to be approximately 1.5 kW m^{-2} at the boundary of the atmosphere. According to [17], once the suns radiation goes across the atmosphere, a square meter of the earth's surface area could possibly receive near the amount of 1kW of solar energy, which is averaging almost 0.5 in total of the hours of daylight. Solar energy makes use of the sun rays to generate electricity. However, The energy which is produced from the sun can be used by a direct means of employing the use of photovoltaic (PV), or via an indirect means in which the energy or light from the sun is focused to heat water and afterwards used to generate electrical energy, the indirect means is referred to as 'concentrating solar power' (CSP). On the other hand, all the other renewable energy sources besides geothermal and tidal get their energy from the sun.

Hydropower: Hydropower or hydroelectricity is the application of gravitational force of flowing water or water in motion to generate electricity [18]. The hydropower is regarded as the most common and largest type of renewable energy source that is widely available in virtually most part of the world. Generally the hydropower plants are usually built and positioned in huge dams which have good gravitational forces. However, the hydroelectric is regarded as the type of renewable energy that has a much lesser level of output of the greenhouse gas 'carbon dioxide' (CO_2) because it does not generate any waste directly or indirectly. The hydro power was estimated to make up for 20% of the world's electrical energy, as well as 88% of the total amount of electrical energy generated from renewable energy sources.

Table 1. Past electricity consumption trend in the residential, commercial and industrial sectors [8]

Year	Residential sector (KWH)	Commercial sector (KWH)	Industrial sector (KWH)	Total Consumption (KWH)
1970	445,000	242,000	459,000	1,146,000
1975	1,023,000	597,700	1,098,000	2,718,700
1980	1,320,000	770,000	1,643,000	3,733,000
1985	3,189,000	750,000	2,213,000	6,152,000
1990	3,953,100	1,116,000	2,037,700	7,106,800
2000	4,940,000	2,763,000	1,029,000	8,732,000
2011	4,181,100	2,096,000	1,818,000	8,095,100

3.1. Photovoltaic (Solar) System

Photovoltaic System (PV) which is also known as solar panel systems or solar photovoltaic (PV), gets the sun's energy by means of photovoltaic cells, it produces electricity by converting the energy from the sunlight, which can be used to run appliances in buildings. The solar Photovoltaic (PV) system is a reliable technology. It provides 0.1% of the total global electricity generation and is projected by 2050 approximately

11% of global electricity will be generated by photovoltaic systems [19]. Fig 1 below shows a typical PV array mounted on a building's roof. Individual modules are attached to a racked system and wired together to form an array.

Fig 1. A typical PV Array Individual modules are attached to a racked system and wired together to form an array [10].

Over the years, the solar photovoltaic (PV) industry has enjoyed substantial growth. According to the Solar Energy Industries Association (SEIA) and GTM Research, cumulative grid-connected PV in the United States has now reached 3.1 GW — 10 times the size of the country's solar capacity in 2005. While some projections call for this segment to hit a speed bump this year, considering the uncertain effects of the U.S. Treasury 1603 tax grant program possibly expiring at the end of the year, coupled with the U.S. government's reaction to a call for import duties on Chinese manufactured PV cells and modules, most analysts anticipate the solar industry will continue on its expansion path. These systems are no longer installed exclusively by specialty solar contractors a situation that opens up on-going revenue streams for electrical contractors, who are being asked to broaden their scope of work and provide PV installation services.

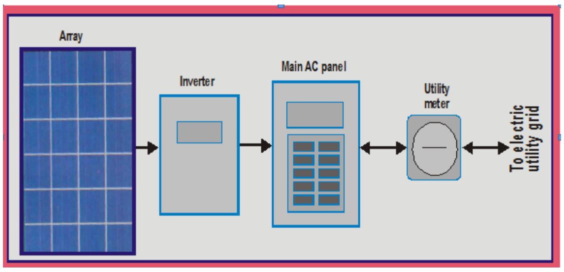

Fig 2. A grid-direct PV systems' major components [17].

In these systems, an array is connected directly to an inverter which in turn is connected directly to the electric utility grid. The arrows in the figure indicate the potential current flow within the system.

According to [20] the following are some of the benefits of using Photovoltaic (solar) electricity in building:

Cut your electricity bills: The PV gets its energy from the sunlight which is free, so electricity costs will be reduced. The more electricity the device can generate, the higher it costs on the other hand the more it could actually save.

Easy to maintain: Solar (PV) panels are quite easy to maintain as they just need to be cleaned and kept in a position where it get enough sunlight and it lasts for 25 years or more.

Reduces carbon footprint: Solar electricity is sustainable, and doesn't emit any dangerous carbon dioxide (CO_2) or various other pollutants. A standard home solar Photovoltaic system could possibly save over a tonne of CO_2 per annum which is definitely more than 30 tons over its lifetime.

3.2. The Need for Renewable Energy Technologies (PV System)

Sustainable development is starting to become an objective, to which several countries all over the world wish to have. In general, there are several ways in which sustainability has been defined, and it is usually thought about to have up to three different components: environmental, social and economic sustainability [21]. Basically sustainable development generally will involve the achievement of environmental, social and economic sustainability concurrently. However, it is indeed very challenging to achieve this balance. Although among the three components of sustainability mentioned above, energy is not one of them, it is indirectly linked to each. To be precise, in most of the economic sectors, for example: industry, commercial, residential, transportation, etc. it is actually energy resources that drives most, if not all of the world's economic activity. Moreover, energy resources either of fossil fuels or renewable, are gotten from the natural environment, same as wastes materials are gotten from energy processes either through manufacturing, transportation, storage, or domestic usage are usually discharged to the natural environment. Eventually, the services which are made available by the energy supplied are appropriate for good standards of living, and frequently encourage social stability and likewise cultural and social growth. Having looked at the related links between energy and the fundamental components of sustainable development, it is indeed obvious that the fulfilment of energy sustainability is a very important perspective on attaining sustainable development, in every country and around the world.

Though the simultaneous achievement of environmental, social and economic sustainability has indeed been so challenging, Renewable energies technologies has been recommended by many scientist as a means of combating the situation. Renewable energy as the name implies, are continually replaced by naturally occurring processes and are for that reason are limitless in supply. In addition they can also function without causing any pollution to the environment. Technologies have already been designed to take advantage of any of these energies and this sort of technologies is referred to as renewable energy technologies (RETs) or in some instances also referred to as 'clean technologies' or 'green energy'. Due to the fact that renewable energy are continuously being restored from natural resources, at the same time they also have guarantee of availability, not like fossil fuels, that happen to be traded on the international market and determined by international level of competition, in some cases might even result in wars and shortages [22]. They offer important advantages which will be stated as follows:

The rate in which they are used will not have any negative effect on their availability in future, in other words they are in-exhaustible.

- They are well distributed across the world, despite the fact that temporal variations occur. As a result, every part of the world possesses at least one or more kinds of renewable energy source.

- They don't pollute the environment, which means they are natural sustainable form of energy.
- They can be cheaply and harvested continuously and therefore a source of sustainable energy.

In contrast to the nuclear and fossil fuels plants, which are owned by the large organizations, governments, or state owned enterprises, renewable energy could possibly be constructed in small models which are thus ideal for the society management and private ownership [23]. Using this method, value from renewable energy development projects can be kept in the society. In Nigeria, this seems to have specific importance considering the fact that the power grid does not spread out to the remote parts, in addition to being very expensive to extend the electrical grid to remote parts. This offers a distinct chance to build up energy power plants close to the locations where they really are seriously required. By doing this, essential wages and income, skill and work transfer as well as manufacturing options available for small enterprises could very well be set up in rural cities.

3.3. Improving Energy Optimization with PV Technology in Nigeria

In the span of a typical building majority of the energy consumed is not from construction, but rather during the operation phase when the building is in use. The demand for energy within and around a building is put to use generally for the purposes of heating, cooking, lighting, cooling and ventilation. All of these activities are executed either crudely or perhaps through the use of electrical appliances or a mixture of both with related GHG pollutants. "Typically more than 80% of the total energy consumption takes place during the use of buildings and less than 20% during construction of the same" [24]. aspects of environmentally friendly homes and office buildings use advanced and modern-day energy efficient practices such as sensor controlled and compact fluorescent lighting, photovoltaic cell arrays, geothermal heating, high efficiency heat pumps, optimum use of fresh air and natural light, utilizing natural conditions for cooling and insulation into design so as to cut down electrical energy used in operational phase of buildings and prevent GHG emission [25]. Although in Europe, Asia and America traces of energy intelligent structures exists. Also in some African countries like South Africa and Kenya their designs are becoming green oriented. In Nigeria, according to [26] technological innovation in the case of climate change mitigation or in regards to renewable energy and energy efficiency is absolutely Zero. Other than the sparing use of photovoltaic devices for street lighting in recent times, buildings of this nature are alien to nearly all Nigerian residents. Existing innovative developments for green buildings that are energy efficient include the application of biogas produced from fermented excreta, food or crop wastes using bio digester; windmills which offers an economical and cleaner electrical energy source rather than fossil fuel; tidal turbines fastened to the seafloor; Solar panels and photovoltaic cells that transforms sunlight energy to electric energy and the utilization of ground source heat pumps which utilizes the earth energy to exchange heat within a building [27]. The application of pale colours on walls and ceilings is effective in reducing energy intended for lighting by five to ten percent; this also is applicable to all sorts of buildings with the exception of industries [28].

3.4. Barriers in adopting PV

There actually are many different factors that affect the use of PV generally and the following barriers according to the [29], has been identified and summarized as follows:

- Market Barriers
- Technical Barriers

Market Barriers

Market barriers are associated with the cost of BIPV and also the lack of awareness with regards to the added benefits of PV systems for the building sector.

- Innovations in the Building sector are usually independent
- prices for Solar panel are specified in € W^{-1}, while for architects € m^{-2} is more convenient
- the benefits of BIPV as a multi-functional building part is not known
- BIPV is still very expensive

On numerous occasions, PV systems are usually not taken into consideration in the early stages of the building design, which is as a result of the high cost of the materials. The fact remains simple, that PV systems are very expensive when compared with other formal building components which BIPV could possibly replace for example laminated glass, parapet units, roofing tiles, and of course low cost traditional bricks. However, what it is that is neither properly noticed nor taken into consideration is the fact PV systems can generate electricity. This implies that the total energy consumed in a building is going to be reduced and therefore the PV system will eventually pay back its initial investment cost.

PV systems are multifunctional building materials and, apart from the electricity generation, they are able to fulfill several other purposes for example weather protection, shading systems, heat insulation and sunlight modification providing good lighting effects.

Technical Barriers

Technical barriers are associated with the structural issues technical engineers, architects and installers experience when designing, and setting up PV systems into the building envelope.

- Missing understanding between engineers and architects/technical requirements.
- The use of PV systems makes up quite a good choice for building components to be taken into consideration by architects. They could be used to replace existing building components. However, architects today neglect this because of lack knowledge and understanding.

- Standards for PV are still lacking
- Most countries have its own regulations and requirements on qualifications or guarantees for BIPV, thereby making it challenging to enter the market.
- Producers manufacture their own standard PV systems in terms of dimensions

Every manufacturer of solar panels builds its own size, dimensions and efficiency of its modules. As a result of this the designer's tend not to integrate the use of photovoltaic panels into the buildings.

Why Photovoltaic System in Commercial Building?

Though the application of Photovoltaic system is not wide-spread in Nigeria, a quite a few sectors have started implementing photovoltaic system in projects, some commercial sectors, private firms and government sectors in Nigeria has recently embarked on applying the Photovoltaic system on a couple of projects especially in rural areas and has started working together with top manufacturers and subcontractors who have the ability to install and implement photovoltaic systems. Both private and government sectors are setting up policies and machineries for the production and installation of photovoltaic system. These sectors have also started reviewing the environmental and commercial tools available for proper production and installation of photovoltaic system, but still a huge population of Nigerians complain of poor power supply, and literature has shown that over 90% of organizations in Nigeria use diesel/petrol generators as back-up for electricity supply which is not healthy for the environment and the people. Therefore, photovoltaic system can be considered to be a justifiable issue for the study on identifying the barriers and opportunities in adoption of photovoltaic system in commercial buildings in Nigeria.

4. ANALYSIS AND FINDING

The analysis and management of all data are collected using both quantitative and qualitative methods for the research, which is usually known as triangulation; in essence a research can be carried out using different [30]. For this research all information gathered was as a result of each material analyzed, which will form the foundation from which conclusion will be drawn. A questionnaire of basically 9 questions was put up and sent to individuals working in various organizations in Nigeria electronically by mail using nine (9) contact persons located in Abuja, Lagos, and Port-Harcourt in Nigeria. A total of four hundred (400) questionnaires were sent out by email during the survey. In order to test if the questions met the objectives of the study a pilot test was conducted. However, the pilot survey accounted for fifty-four (54) of the total questionnaires sent out. A 70% response rate was gotten from the pilot survey, which was better than would have been expected. However, the response rate from the main survey was at 64%. A total of 265 questionnaires were received out of the 409 that was posted electronically. Nevertheless, this level of response does not allow a reasonable degree of confidence in the results. The table below shows the number of responses received at each stage.

Table 2. Number of questionnaires received

	Number sent	Number received	% Received
Pilot Survey	54	38	70
Main Survey	355	227	64
Total	409	265	65

Fig 3 and 4 demonstrate the level of response for both the pilot and main survey and the overall percentage contribution to the entire survey, respectively. The following section looks at the data collected from the online questionnaire survey.

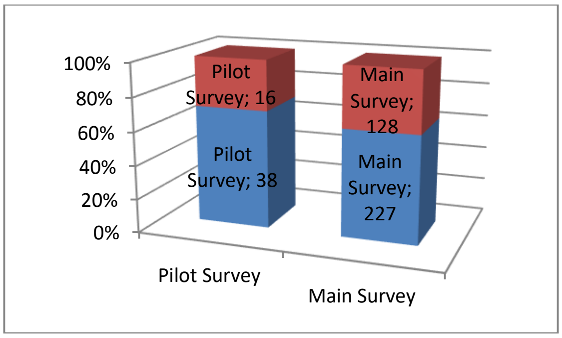

Fig 3. Response rates of pilot and main survey

4.1. Questionnaire Analysis

What alternative source of energy does your organization use?

This research question seeks to understand the type of alternative energy the respondents use besides that of the main energy provider. Fig 5 shows that 80% of the respondents rely on generator plants (Diesel/Petrol), 12% on Hydro power energy, whereas only 8% use solar energy as an alternative source of energy.

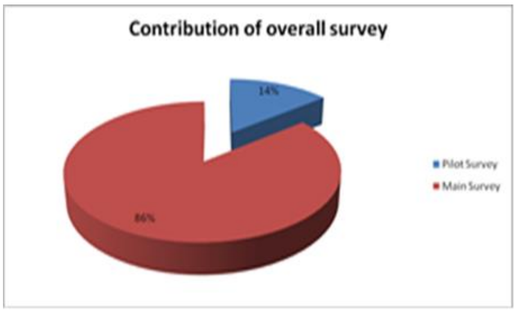

Fig 4. Percentage contributions to overall survey

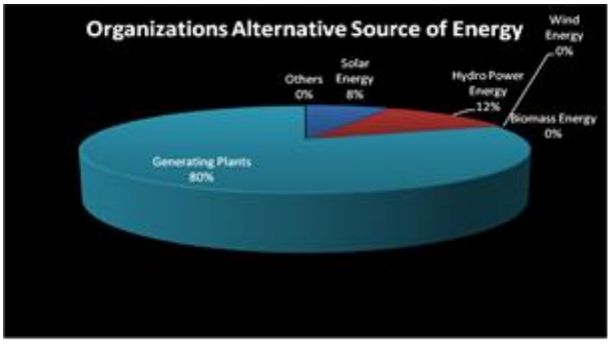

Fig 5. Organizations alternative source of energy

Please state reason why your organization is using the selected choice of alternative energy?

This research question was asked with regards to the first question in order to understand the reason behind the respondents selected choice of alternative energy. Fig 6 demonstrates the respondents' reasons for their selected alternative energy choice. However, majority of the respondents (57%) choose 'poor electricity supply' as the major reason why their organization use their selected alternative energy, This indicates that the energy sector is not meeting up to its requirement which could be as a result of inadequate technological capabilities in the energy sector. whereas, only 4% choose 'reduction of CO_2 emissions' which also indicates there is less concern for the environment.

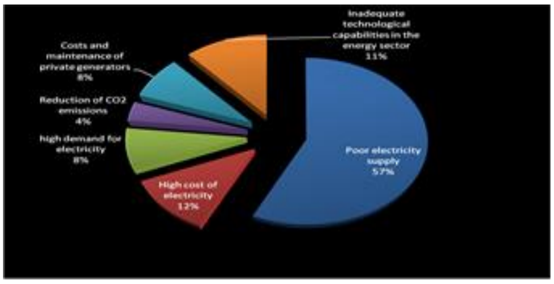

Fig 6. Reason for choice of alternative energy

Do you think that adopting the use of PV systems will improve the energy efficiency in your organization?

This question was thrown open to the respondents to get their view about improving energy efficiency in their organization and also to know if they are knowledgeable about the efficiency usage of PV systems. even so, with regards to the question asked an enormous 95% said 'Yes', and gave their reasons as solar energy is free as it is generated from the sun and the use of PV systems is very cost effective as it will help reduce the cost of energy generated from the main energy provider and also reduce CO2 in the society. Following the response from the respondents, it indicates that most organizations are aware of the benefits of installing PV systems

4.2. Questionnaires comments

The questionnaire survey was effectively carried out and properly analysed. The questionnaire was used as it was the best possible option to take a look at the population's views about the main purpose of the research study. It examines the mind-set and knowledge of the respondents about renewable energy and the use of Photovoltaic systems in buildings. It was ensured that all questions were related to the aim of the study.

5. CONCLUSIONS

Nigeria is a nation which happens to be blessed with ample conventional and non-conventional energy resources. There is certainly the need to facilitate evolvement of an energy mix which will put additional concentration on the need for the preservation of the fossil fuels in quite an effective way which will give rise to their ongoing exportation that will undoubtedly continuously create revenue to the federal and state governments for just as many years as they can. The implementation of renewable energy technologies, such as, Photovoltaic by the country with emphasis on commercial buildings could lead to great internal reduced use of petroleum products and gas. The most important advantages of photovoltaic systems comprise of its environmentally friendliness over conventional energy e.g. fossil fuels, it's easy to maintain, and it cuts down electricity bills. In the course of this study, It was found from the literature review through secondary data that the demand for electricity in Nigeria from end users is extremely high; however, the supply is not adequate and sufficient enough to meet the demand which leaves a large number of Nigerian organizations without any choice other than to be using privately owned conventional energy generating systems which was also confirmed in the analysis. The use of the conventional power generating systems is quite expensive, it's not environmentally friendly, and also it's not easy to maintain. Therefore it is encouraging to adopt the use of PV systems in buildings. However, we can conclude by identifying the various barriers that prevent organizations from adopting the use of PV systems is as a result of its high investment cost; inadequate technical know-how; lack of government financial incentives; and lack of local manufacturing capability and quality control It is recommended that there should be need for a comprehensive national renewable energy master-plan to be designed which will enable the enhancement of the solar energy policy for sustainability, and also a public campaign on the efficiency and environmental friendliness and benefits of PV systems. With regards to this, the Nigerian government needs to initiate a developed National energy policy for the country.

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RESEARCH ARTICLE

Solid waste management in non-State armed group-controlled areas of Syria case study - Jisr-Ash-Shugur-district

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ABSTRACT

The purpose of this study (technical assessment) is to understand the effect of the Syrian crisis on the solid waste management (SWM) sector in Non-State Armed Group (NSAG) controlled areas and define the worst communities located in Jisr-Ash-Shugur-district (JASD)/Idleb governorate of Syria. The assessment showed that: SWM sector, in general, is not supported by Non-governmental organizations (NGOs). The number of communities of JASD is ninety-nine about 262,246 persons (113382 Internally Displaced Persons (IDPs),147,449 resident population, 1,415 returnees, and population) live in it, all these local councils are not received or supported by SW equipment, tools, and machines, About seventy communities out of ninety-nine communities (92,195 persons of 262,246 persons) of JASD does not have dedicated works for solid waste collection , and Eighty 80 communities (120,237 persons of 262,246 persons) do not have SW containers, and 67 communities (77,195 persons of 262,246 do not have solid waste tractors with a trails are necessary for SWM. the average, maximum and minimum of SW production per capita at JASD communities (0.21; 0.79; 0.02) kg day^{-1}. All the landfills of JASD are not sanitary and could be considered a randomly dumps.

Keywords: Jisr-Ash-Shugur, solid waste, the Syrian crisis

1. INTRODUCTION

Waste management accordingly from concept and practices that are used in different countries there are differences, particularly between developed and developing countries [1]. Solid wastes are any non-liquid wastes that arise from human and animal activities and are discarded as useless or unwanted [2]. Currently, several countries have realized that the way they manage their solid wastes does not satisfy the objectives of sustainable development throughout the world [3,4]. There have been lots of solid waste materials disposed into the environment more especially in the developing countries where solid waste management has been a huge problem. [5]. Environmental pollution has affected the human world since early times and is still growing due to excessive growth in developing countries. Municipal solid waste (MSW) normally is a product of human activities [6]. Also, MSW is usually considered as the waste that is generated from human settlements, small industries, commercial and municipal activities [7] the general sources of MSW are showed in Table1.

Though solid waste management (SWM) is one of the mandatory functions for improvement of urban lifestyle [8], an integrated SWM is one of the major challenges for sustainable development [9].

In developing countries such as Syria open randomly dumpsites are common, because of the low budget for waste disposal. It also could be a serious threat to groundwater resources and soil, the contamination of soil by heavy metal can cause adverse effects on human health, animals and soil productivity [10]. The crisis in Syria continues to have a profound impact on people across the country. Countless civilians have been killed and injured as a direct result of hostilities, with 45 percent of the injured expected to sustain a permanent impairment. [11]. SWM systems in Syria are overstrained with the high influx of internally displaced persons (IDPs) destruction and/or damages of basic infrastructure [12,13], and the equipment and heavy machinery normally used for SWM are often

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looted, destroyed, and not functioning due to the need of new spare parts and maintenance. This contributes to large amounts of garbage piled up in the streets, deteriorating the environmental and health situation and further exacerbating difficult living conditions [13].

At NSAG controlled areas of Syria, the local councils which are considered a local authority, these local councils always face difficulties during their work due to lack of the fund, and the main resource of their fund is a grant from local and international NGOs especially which have registration in Turkey, SWM services are primarily provided by local authorities in most parts of Syria and usually provide a basic level of service.

Before the start of conflict in Syria in 2011, nearly 80% of population in Syria were served by well-developed, state-owned, centrally-managed SWM which related to ministry of local administration and environment, the municipality of each village, town, and city is responsible for SWM, The solid waste collection (SWC) method were assessed in 2018 by the collaborative effort of the Whole of Syria coordination team, water, sanitation and hygiene (WASH) partners, From Syria, Turkey, Jordan, Iraq and Lebanon Humanitarian Hubs [13], Table 2 showed collection methods and its percentage for JASD subdistrict [13].

Table 1. The general sources of MSW [7]

Source	Activities, typical amenities, or locations where wastes are generated	Types of SW
Residential	Single-family and multi-family home, low, medium, and high-rise apartments, etc.	Food wastes, rubbish, paper waste, ashes, special wastes.
Commercial and institutional	Warehouses, restaurants, markets, office buildings, hotels, shopping malls, schools, print shops, auto repair shops, medical facilities and institutions, prisons.	Food wastes, rubbish, ashes, demolition and construction wastes, special wastes, occasionally hazardous wastes.
Open areas	Streets, alleys, parks, vacant lots, playgrounds, beaches, highways, recreational areas, marriage halls, etc.	Street sweepings, roadside litter, rubbish, and other special wastes.
Treatment plant sites	Water, sewage and industrial wastewater treatment processes.	Treatment plant sludges.

Table 2. Solid waste collection methods and its percentage of JASD subdistrict

Subdistrict	Solid waste disposed of a household to a dumping location station	Solid waste left in public areas	Public solid waste collection free	Private garbage collection paid	Garbage buried or burned
Jisr-Ash-Shugur	34.04%	6.38%	3.19%	55.32%	6.38%
Badama	1.05%	10.53%	48.42%	40.00%	0.00%
Darkosh	29.47%	29.47%	9.47%	58.95%	3.16%
Janudiyeh	2.11%	1.05%	20.00%	76.84%	1.05%

The author hopes from this research to give a deep understanding about the situation of SWM in the NSAG controlled areas of Syria, these areas suffer from the lack of financial resources to conduct a good SWM, the goals of this research are:

1-Determine the amount of the solid waste generated in the NSAG controlled areas of Syria, case study "JASD which located in Idleb governorate.

2-Determine the quantity and the volume of MSW of some communities of JASD Determine the urgent needs for SWM of JASD.

3-Get a deep understanding of SWM of Non-State Armed Group (NSAG) controlled areas of Syria.

4-Determine the needs of solid waste management of the communities of JASD.

5-Give technical information for the donors and None government organization (NGO) to do a good response in JASD.

2. METHODS

This research focuses on JASD which located at Idleb governorate of Syria as showed in Fig 1, which is located in NSAG-controlled areas since the end of 2012. the total number of populations is about 262,246 persons (113,382 Internally Displaced Persons (IDPs), 147,449 resident population, 1,415 returnees, and population) as showed in Table 3 [15], According to Assistance Coordination Unit (ACU) reports [16]: during 2018 the number of Cutaneous leishmaniases registered cases of Darkosh subdistrict is: 1,062, Janudiyeh subdistrict is: 771, Jisr-Ash-Shugur subdistrict is: 453, and Badama subdistrict is:100, which is considered so risk and related to the bad solid waste management of JASD.

Syrian Engineers for Construction and Development (SECD) organization, which located in Turkey and work inside Turkey and Syria, conducted a WASH response for IDPs in the north of Syria funded by United Nations Office for the Coordination of Humanitarian Affairs (OCHA)/Syria Cross Border Humanitarian Fund (SCHF) as showed in the Fig 2.

Fig 1. Idleb governorate, JASD district and its subdistricts location (green color)

During this response, SECD team conducted a deep technical assessment for solid waste services sector at the communities of JASD using questioners, and physical measures in the field about ten engineers worked in this assessment and SECD staff visited ninety-nine communities located at JASD. The assessment is a consideration as an integral part to the assessment which was conducted by the author and ten technical engineers from SECD team in addition to thirty-nine local councils of the targeted area are involved in the study.

Fig 2. Some pics of SWM of JASD district

Table 3. The total number of populations of JASD communities

Subdistrict	Community	Res pop	Returnees	IDPs	Population
	Upper Sheikh Sindyan	90	0	0	90
	Msheirfeh (Jisr-Ash-Shugur)	676	21	234	931
	Sali	997	49	353	1399
	Maalaqa - Bishlamon	2218	15	501	2734
	Balmis	3105	0	603	3708
	Salhiyeh (Jisr-Ash-Shugur)	201	0	13	214
	Bsheiriyeh - Bello	3469	0	923	4392
	Um Rish	2152	0	198	2350
	Bteibat	120	0	39	159
	Mintar (Jisr-Ash-Shugur)	584	0	56	640
	Upper Shghur	1225	32	1495	2752
	Eshtabraq	58	0	159	217
	Jisr-Ash-Shugur	14518	224	3454	18196
	Bzeit	1058	72	47	1177
	Bkafla	305	0	115	420
	Ein Elhamra	1346	25	948	2319
	Ghassaniyeh (Jisr-Ash-Shugur)	0	0	965	965
	Ein Elsoda (Jisr-Ash-Shugur)	1003	13	1251	2267
	Kafir (Jisr-Ash-Shugur)	1531	98	0	1629
Jisr-Ash-Shugur	Qaysiyeh	1424	15	231	1670
	Alyeh (Jisr-Ash-Shugur)	0	0	214	214

	Jannet Elqora	530	64	439	1033
	Ghanya	196	40	0	236
	Sokkariyeh (Jisr-Ash-Shugur)	1208	0	332	1540
	Sabileh	193	0	130	323
	Western Marj Akhdar	8866	0	718	9584
	Um Elgar	13	15	0	28
	Dgali	879	0	135	1014
	Eastern Marj Akhdar	3814	0	1942	5756
	Tal Awar	723	42	57	822
	Tal Hamki	172	0	28	200
	Frikeh (Jisr-Ash-Shugur)	1540	31	346	1917
	Watba	619	0	33	652
	Marj Elzohur	573	0	86	659
	Kniset Nakhleh	1727	0	673	2400
	Al Areen - Kastanah Fawqan	720	0	192	912
	Jeb Alsafa	526	0	52	578
	Qulaia	344	0	0	344
	Qirmida	308	0	24	332
	Muntar Tahtani	266	0	23	289
	Al Karnaza	222	0	39	261
	Frikka al Abeed	241	5	6	252
	Arzaghan Fawqani	720	0	91	811
	Ziyadiyeh (Jisr-Ash-Shugur)	1073	241	59	1373
Badama	Baksariya	1265	405	1000	2670
	Yunesiyeh	25	0	0	25
	Badama	2845	0	655	3500
	Armala	955	0	1653	2608
	Hanbushiyeh	1840	0	3338	5178
	Ein El-Bayda (Badama)	638	0	2888	3526
	Kherbet Eljoz	2058	0	21534	23592
	Shaturiyeh	1000	0	900	1900
	Najiyeh	1000	0	50	1050
	Ramliyeh	618	0	570	1188
	Maraand	460	0	130	590
	Zoainieh	618	0	515	1133
	Safiyat	65	0	30	95
Darkosh	Sawadiya - Nabhan	1960	0	115	2075
	Turin	215	0	15	230
	Zarzur (Darkosh)	5458	0	2627	8085
	Ghazala - Mgheidleh	1350	0	369	1719
	Jamiliya (Darkosh)	0	0	988	988
	Ramadiyeh (Darkosh)	785	0	145	930
	Mazuleh	1823	0	678	2501
	Matleh - Batlaya	721	0	26	747
	Amud (Darkosh)	1493	0	444	1937

	Sadiyeh - Bsentiya	1038	0	269	1307
	Thahr	1383	0	655	2038
	Andnaniyeh - Farjein	1192	0	729	1921
	Dorriyeh	533	0	5205	5738
	Zahraa - Kherbet Amud	1273	0	1067	2340
	Sheikh Issa Elashury	1058	0	251	1309
	Darkosh	17811	0	7325	25136
	Zanbaqi (co)	783	0	3843	4626
	Mreimin (Darkosh)	2425	0	3141	5566
	Kharab Khalil (Darkosh)	365	0	101	466
	Kharab Amer	625	0	80	705
	Kharab Sultan	396	0	39	435
	Almilk	223	0	0	223
	Alshamra	275	0	83	358
	Magharet Jamous	140	0	31	171
	Alfauri	583	0	25	608
	Al Hamia	621	0	69	690
	Al-Hafriya	1035	0	218	1253
	Haj Nayef	1545	0	483	2028
Janudiyeh	Janudiyeh	8718	0	6268	14986
	Yaqubiyeh	100	0	2640	2740
	Hassaniyeh - Hatya	987	8	2694	3689
	Qaderiyeh - Qayqun	2303	0	1180	3483
	Maland	2658	0	2250	4908
	Qanniyeh (Janudiyeh)	244	0	1920	2164
	Mudiah - Luxin	153	0	605	758
	Nasra (Janudiyeh)	0	0	1035	1035
	Foz - Zuf	698	0	9522	10220
	Tiba - Katrin	0	0	65	65
	Jdidet Eljisr	183	0	2045	2228
	Athar	693	0	165	858
	Hamama - Kafr Debbin	8285	0	3475	11760
	Al Marjeh	378	0	30	408
Total		147449	1415	113382	262246

The SW system of JASD as all other subdistricts of Syria consists of the following parts: SWC

1- SW container.

2- Tractors with a trailer for solid waste collection (SWC).

3- SW compactor which is used only in big cities.

4- Randomly open dump for final disposal of SW.

All communities of JASD use tractor with a trailer for SWC and also only two communities use Solid waste compactor in addition to the tractors with trailers.

3. RESULTS AND DISCUSSION

The technical and need assessments were conducted by the author and SECD team during March and July and August of 2019 for SW system for all the communities which located in JASD. The results of the assessment are shown in Tables 4-7, and Table 8, these tables are so useful to determine the solid waste management needs in each community , the Table 4 and Table5 showed the availability of instruments and machines of SWM of the communities of JASD, such as : Number of SWM workers, number of tractor with a trail, number of garbage tank and Number of garbage compactor, the Availability of support for SWM ,and equipment and stationaries, these values are so important and can give the evidence about SWM ,An example of the community do not have a solid waste workers the value is 0, and if the local council do not have tractor with a trail to collect SM the value is 0, and this is an evidence that the solid waste managment is so bad and the local council need a tractor with a trail,. Also the Table 6 showed SWC methods of the communities of JASD, which give in evidence about the SWM situation, if the greater value of %SW amount left in public areas without collection, the worse the situation, on other hand, if the greater value of %SW collection free by the local council , the better the situation. also, the Table 7 showed the solid waste collection frequency (SWCF) the which give the evidence about the SWM situation, if the greater value of SWCF, the better the situation, and the random method is considered the worst situation.

Table 4. The availability of instruments and machines of SWM of the communities of JASD

Sub-district	Community	Number of SWM workers	Number of tractors with trails	Number of garbage tank	Number of Garbage compactor
Jisr-Ash-Shugur)	Upper Sheikh Sindyan	0	0	0	0
	Msheirfeh (Jisr-Ash-Shugur)	0	0	0	0
	Sali	0	0	0	0
	Maalaqa - Bishlamon	4	1	82	0
	Balmis	0	0	0	0
	Salhiyeh (Jisr-Ash-Shugur)	0	0	0	0
	Bsheiriyeh - Bello	3	1	20	0
	Um Rish	0	0	0	0
	Bteibat	0	0	0	0
	Mintar (Jisr-Ash-Shugur)	0	0	0	0
	Upper Shghur	0	0	0	0
	Eshtabraq	0	0	0	0
	Jisr-Ash-Shugur	12	1	380	0
	Bzeit	0			
	Bkafla	0	0	0	0
	Ein Elhamra	0	0	0	0
	Ghassaniyeh (Jisr-Ash-Shugur)	0	0	0	0
	Ein Elsoda (Jisr-Ash-Shugur)	0	0	0	0
	Kafir (Jisr-Ash-Shugur)	6	1	100	
	Qaysiyeh	3	1	0	0
	Alyeh (Jisr-Ash-Shugur)	0	0	0	0
	Jannet Elqora	0	0	0	0
	Ghanya	0	0	0	0
	Sokkariyeh (Jisr-Ash-Shugur)	0	0	0	0
	Sabileh	0	0	0	0
	Western Marj Akhdar	4	1	0	0
	Um Elgar	0	0	0	0
	Dgali	0	0	0	0
	Eastern Marj Akhdar	0	0	0	0
	Tal Awar	0	0	0	0
	Tal Hamki	0	0	0	0

	Frikeh (Jisr-Ash-Shugur)	0	0	0	0
	Watba	0	0	0	0
	Marj Elzohur	0	0	50	0
	Kniset Nakhleh	3	1	0	0
	Al Areen - Kastanah Fawqan	3	1	0	0
	Jeb Alsafa	0	0	0	0
	Qulaia	0	0	0	0
	Qirmida	0	0	0	0
	Muntar Tahtani	0	0	0	0
	Al Karnaza	0	0	0	0
	Frikka al Abeed	0	0	0	0
	Arzaghan Fawqani	0	0	0	0
	Ziyadiyeh (Jisr-Ash-Shugur)	0	0	0	0
Badama	Baksariya	1	1	0	0
	Yunesiyeh	0	0	0	0
	Badama	4	1	0	
	Armala	0	0	0	0
	Hanbushiyeh	4	1	15	0
	Ein El-Bayda (Badama)	7	1	30	0
	Kherbet Eljoz	2	1	100	0
	Shaturiyeh	2	1	40	
	Najiyeh	3	1	0	0
	Ramliyeh	3	1	0	0
	Maraand	0	0	0	0
	Zoainieh	0	0	0	0
	Safiyat	0	0	0	0
Darkosh	Sawadiya - Nabhan	0	0	0	0
	Turin	0	0	0	0
	Zarzur (Darkosh)	0	3	50	0
	Ghazala - Mgheidleh	0	0	0	0
	Jamiliya (Darkosh)	0	0	0	0
	Ramadiyeh (Darkosh)	0	0	0	0
	Mazuleh	0	0	0	0
	Matleh - Batlaya	0	0	0	0
	Amud (Darkosh)	3	1	0	0
	Sadiyeh - Bsentiya	0	0	0	0
	Thahr	0	0	0	0
	Andnaniyeh - Farjein	2	2	0	0
	Dorriyeh	0	1	0	0
	Zahraa - Kherbet Amud	0	0	0	0
	Sheikh Issa Elashury	0	0	0	
	Darkosh	7	1	10	0
	Zanbaqi (co)	0	0	0	0

	Mreimin (Darkosh)	0	0	0	0
	Kharab Khalil (Darkosh)	0	0	0	0
	Kharab Amer	0	0	0	0
	Kharab Sultan	0	0	0	0
	Almilk	0	0	0	0
	Alshamra	0	0	0	0
	Magharet Jamous	0	0	0	0
	Alfauri	0	0	0	0
	Al Hamia	0	0	0	0
	Al-Hafriya	0	0	0	0
	Haj Nayef	0	0	0	0
Janudiyeh	Janudiyeh	10	1	48	0
	Yaqubiyeh	3	1	0	0
	Hassaniyeh - Hatya	3	1	80	0
	Qaderiyeh - Qayqun	2	1	0	0
	Maland	1	4	0	0
	Qanniyeh (Janudiyeh)	3	1	3	0
	Mudiah - Luxin	1	2	4	0
	Nasra (Janudiyeh)	0	0	0	0
	Foz - Zuf	7	1	35	0
	Tiba - Katrin	0	0	0	0
	Jdidet Eljisr	3	1	14	0
	Athar	0	0	0	0
	Hamama - Kafr Debbin	6	1	50	0
	Al Marjeh	0	0	0	0

Table 5 . The Availability of support for SWM of the communities of JASD

Sub-district	Community	Availability of support		
		Salaries for workers	Fuel for SW vehicle	Equipment and stationaries
Jisr-Ash-Shugur	Upper Sheikh Sindyan	NO	NO	NO
	Msheirfeh (Jisr-Ash-Shugur)	NO	NO	NO
	Sali	NO	NO	NO
	Maalaqa - Bishlamon	NO	NO	NO
	Balmis	NO	NO	NO
	Salhiyeh (Jisr-Ash-Shugur)	NO	NO	NO
	Bsheiriyeh - Bello	NO	NO	NO
	Um Rish	NO	NO	NO
	Bteibat	NO	NO	NO
	Mintar (Jisr-Ash-Shugur)	NO	NO	NO
	Upper Shghur	NO	NO	NO
	Eshtabraq	NO	NO	NO
	Jisr-Ash-Shugur	NO	NO	NO
	Bzeit	NO	NO	NO

	Bkafla	NO	NO	NO
	Ein Elhamra	NO	NO	NO
	Ghassaniyeh (Jisr-Ash-Shugur)	NO	NO	NO
	Ein Elsoda (Jisr-Ash-Shugur)	NO	NO	NO
	Kafir (Jisr-Ash-Shugur)	NO	NO	NO
	Qaysiyeh	NO	NO	NO
	Alyeh (Jisr-Ash-Shugur)	NO	NO	NO
	Jannet Elqora	NO	NO	NO
	Ghanya	NO	NO	NO
	Sokkariyeh (Jisr-Ash-Shugur)	NO	NO	NO
	Sabileh	NO	NO	NO
	Western Marj Akhdar	NO	NO	NO
	Um Elgar	NO	NO	NO
	Dgali	NO	NO	NO
	Eastern Marj Akhdar	NO	NO	NO
	Tal Awar	NO	NO	NO
	Tal Hamki	NO	NO	NO
	Frikeh (Jisr-Ash-Shugur)	NO	NO	NO
	Watba	NO	NO	NO
	Marj Elzohur	NO	NO	NO
	Kniset Nakhleh	NO	NO	NO
	Al Areen - Kastanah Fawqan	NO	NO	NO
	Jeb Alsafa	NO	NO	NO
	Qulaia	NO	NO	NO
	Qirmida	NO	NO	NO
	Muntar Tahtani	NO	NO	NO
	Al Karnaza	NO	NO	NO
	Frikka al Abeed	NO	NO	NO
	Arzaghan Fawqani	NO	NO	NO
	Ziyadiyeh (Jisr-Ash-Shugur)	NO	NO	NO
	Baksariya	NO	NO	NO
	Yunesiyeh	NO	NO	NO
	Badama	NO	NO	NO
	Armala	NO	NO	NO
	Hanbushiyeh	YES	YES	YES
Badama	Ein El-Bayda (Badama)	YES	YES	YES
	Kherbet Eljoz	NO	NO	NO
	Shaturiyeh	NO	NO	NO
	Najiyeh	NO	NO	NO
	Ramliyeh	NO	NO	NO
	Maraand	NO	NO	NO

	Zoainieh	NO	NO	NO
	Safiyat	NO	NO	NO
Darkosh	Sawadiya - Nabhan	NO	NO	NO
	Turin	NO	NO	NO
	Zarzur (Darkosh)	NO	NO	NO
	Ghazala - Mgheidleh	NO	NO	NO
	Jamiliya (Darkosh)	NO	NO	NO
	Ramadiyeh (Darkosh)	NO	NO	NO
	Mazuleh	NO	NO	NO
	Matleh - Batlaya	NO	NO	NO
	Amud (Darkosh)	NO	NO	NO
	Sadiyeh - Bsentiya	NO	NO	NO
	Thahr	NO	NO	NO
	Andnaniyeh - Farjein	NO	NO	NO
	Dorriyeh	NO	NO	NO
	Zahraa - Kherbet Amud	NO	NO	NO
	Sheikh Issa Elashury	NO	NO	NO
	Darkosh	NO	NO	NO
	Zanbaqi (co)	NO	NO	NO
	Mreimin (Darkosh)	NO	NO	NO
	Kharab Khalil (Darkosh)	NO	NO	NO
	Kharab Amer	NO	NO	NO
	Kharab Sultan	NO	NO	NO
	Almilk	NO	NO	NO
	Alshamra	NO	NO	NO
	Magharet Jamous	NO	NO	NO
	Alfauri	NO	NO	NO
	Al Hamia	NO	NO	NO
	Al-Hafriya	NO	NO	NO
	Haj Nayef	NO	NO	NO
Janudiyeh	Janudiyeh	NO	NO	NO
	Yaqubiyeh	NO	NO	NO
	Hassaniyeh - Hatya	NO	NO	NO
	Qaderiyeh - Qayqun	NO	NO	NO
	Maland	NO	NO	NO
	Qanniyeh (Janudiyeh)	NO	NO	NO
	Mudiah - Luxin	NO	NO	NO
	Nasra (Janudiyeh)	NO	NO	NO
	Foz - Zuf	YES	YES	YES
	Tiba - Katrin	NO	NO	NO
	Jdidet Eljisr	NO	NO	NO
	Athar	NO	NO	NO
	Hamama - Kafr Debbin	NO	NO	NO
	Al Marjeh	NO	NO	NO

Table 6. The SWC methods of the communities of JASD

Sub-district	Community	SW disposed of by household to a dumping location station (%)	% SW amount left in public areas without collection and disposal (%)	%SW collection free by the local council (%)
Jisr-Ash-Shugur	Upper Sheikh Sindyan	65%	35%	0%
	Msheirfeh (Jisr-Ash-Shugur)	%70	%30	%0
	Sali	%30	%60	%0
	Maalaqa - Bishlamon	%0	%35	%65
	Balmis	%30	%30	%40
	Salhiyeh (Jisr-Ash-Shugur)	%65	%35	%0
	Bsheiriyeh - Bello	%10	%30	%60
	Um Rish	%30	%40	%30
	Bteibat	%65	35%	%0
	Mintar (Jisr-Ash-Shugur)	%60	%40	%0
	Upper Shghur	%50	%50	%0
	Eshtabraq	%65	35%	%0
	Jisr-Ash-Shugur	%0	%20	%80
	Bzeit	%60	%40	%0
	Bkafla	%65	%35	%0
	Ein Elhamra	%5000	50%	%0
	Ghassaniyeh (Jisr-Ash-Shugur)	%20	%30	%50
	Ein Elsoda (Jisr-Ash-Shugur)	%60	%40	%0
	Kafir (Jisr-Ash-Shugur)	%10	20%	%70
	Qaysiyeh	%0	%30	%70
	Alyeh (Jisr-Ash-Shugur)	%70	%0	%0
	Jannet Elqora	%60	40%	%0
	Ghanya	%60	%40	%0
	Sokkariyeh (Jisr-Ash-Shugur)	%40	%60	%0
	Sabileh	%60	40%	%0
	Western Marj Akhdar	%5	%20	%75
	Um Elgar	%40	%60	%0
	Dgali	%50	20%	%30
	Eastern Marj Akhdar	%50	%50	%0
	Tal Awar	%50	%50	%0
	Tal Hamki	%40	60%	%0
	Frikeh (Jisr-Ash-Shugur)	65%	35%	%0
	Watba	%40	%60	%0

	Marj Elzohur	%50	50%	%0
	Kniset Nakhleh	%0	%30	%70
	Al Areen - Kastanah Fawqan	%0	%30	%70
	Jeb Alsafa	%30	%40	%30
	Qulaia	%30	%40	%30
	Qirmida	%50	%50	%0
	Muntar Tahtani	%60	40%	%0
	Al Karnaza	%65	%35	%0
	Frikka al Abeed	65%	35%	%0
	Arzaghan Fawqani	70%	30%	%0
	Ziyadiyeh (Jisr-Ash-Shugur)	30%	30%	40%
	The average value:	43%	38%	18%
Badama	Thahr	20%	20%	60%
	Yunesiyeh	50%	50%	0%
	Badama	5%	20%	75%
	Armala	50%	50%	0%
	Hanbushiyeh	0%	0%	100%
	Ein El-Bayda (Badama)	0%	0%	100%
	Kherbet Eljoz	0%	0%	0%
	Shaturiyeh	10%	30%	60%
	Najiyeh	15%	25%	60%
	Ramliyeh	15%	25%	60%
	Maraand	40%	60%	0%
	Zoainieh	65%	35%	0%
	Safiyat	0%	0%	0%
	The average value:	21%	24%	40%
Darkosh	Sawadiya - Nabhan	50%	50%	0%
	Turin	60%	40%	0%
	Zarzur (Darkosh)	20%	20%	60%
	Ghazala - Mgheidleh	60%	40%	0%
	Jamiliya (Darkosh)	50%	50%	0%
	Ramadiyeh (Darkosh)	50%	50%	0%
	Mazuleh	60%	40%	0%
	Matleh - Batlaya	10%	30%	60%
	Amud (Darkosh)	10%	20%	70%
	Sadiyeh - Bsentiya	60%	40%	0%
	Thahr	50%	50%	0%
	Andnaniyeh - Farjein	20%	20%	60%
	Dorriyeh	50%	50%	0%
	Zahraa - Kherbet Amud	50%	50%	0%

	Sheikh Issa Elashury	65%	35%	0%
	Darkosh	0%	20%	80%
	Zanbaqi (co)	50%	50%	0%
	Mreimin (Darkosh)	45%	55%	0%
	Kharab Khalil (Darkosh)	25%	35%	40%
	Kharab Amer	40%	60%	0%
	Kharab Sultan	50%	50%	0%
	Almilk	65%	35%	0%
	Alshamra	60%	40%	0%
	Magharet Jamous	10%	40%	50%
	Alfauri	10%	50%	40%
	Al Hamia	50%	50%	0%
	Al-Hafriya	50%	50%	0%
	Haj Nayef	50%	50%	0%
	The average value:	42%	42%	16%
Janudiyeh	Janudiyeh	0%	10%	90%
	Yaqubiyeh	0%	15%	85%
	Hassaniyeh - Hatya	5%	15%	80%
	Qaderiyeh - Qayqun	5%	25%	70%
	Maland	5%	30%	65%
	Qanniyeh (Janudiyeh)	10%	20%	70%
	Mudiah - Luxin	20%	30%	50%
	Nasra (Janudiyeh)	50%	50%	0%
	Foz - Zuf	0%	0%	100%
	Tiba - Katrin	50%	50%	0%
	Jdidet Eljisr	30%	30%	40%
	Athar	50%	25%	25%
	Hamama - Kafr Debbin	5%	15%	80%
	Al Marjeh	50%	50%	0%
	The average value:	20%	26%	54%
	The average value of JASC:	36%	36%	26%

Table 7. The solid waste collection frequency (SWCF) of the communities of JASD

Subdistrict	Community	More than 3 times per week	Once a week	Once every two weeks or more	Randomly
Jisr-Ash-Shugur	Upper Sheikh Sindyan				Yes
	Msheirfeh (Jisr-Ash-Shugur)				Yes
	Sali				Yes
	Maalaqa - Bishlamon		Yes		
	Balmis				Yes
	Salhiyeh (Jisr-Ash-Shugur)				Yes

	Bsheiriyeh - Bello			Yes	
	Um Rish				Yes
	Bteibat				Yes
	Mintar (Jisr-Ash-Shugur)				Yes
	Upper Shghur				Yes
	Eshtabraq				Yes
	Jisr-Ash-Shugur	Yes			
	Bzeit				Yes
	Bkafla				Yes
	Ein Elhamra				Yes
	Ghassaniyeh (Jisr-Ash-Shugur)				Yes
	Ein Elsoda (Jisr-Ash-Shugur)				Yes
	Kafir (Jisr-Ash-Shugur)		Yes		
	Qaysiyeh		Yes		
	Alyeh (Jisr-Ash-Shugur)				Yes
	Jannet Elqora				Yes
	Ghanya				Yes
	Sokkariyeh (Jisr-Ash-Shugur)				Yes
	Sabileh				Yes
	Western Marj Akhdar	Yes			
	Um Elgar				Yes
	Dgali				Yes
	Eastern Marj Akhdar				Yes
	Tal Awar				Yes
	Tal Hamki				Yes
	Frikeh (Jisr-Ash-Shugur)				Yes
	Watba				Yes
	Marj Elzohur				Yes
	Kniset Nakhleh		Yes		
	Al Areen - Kastanah Fawqan				Yes
	Jeb Alsafa				Yes
	Qulaia				Yes
	Qirmida				Yes
	Muntar Tahtani				Yes
	Al Karnaza				Yes
	Frikka al Abeed				Yes
	Arzaghan Fawqani				Yes
	Ziyadiyeh (Jisr-Ash-Shugur)				Yes
	Baksariya				Yes
Badama	Yunesiyeh				Yes
	Badama	Yes			

	Armala				Yes
	Hanbushiyeh	Yes			
	Ein El-Bayda (Badama)	Yes			
	Kherbet Eljoz				Yes
	Shaturiyeh	Yes			
	Najiyeh	Yes			
	Ramliyeh	Yes			
	Maraand				Yes
	Zoainieh				Yes
	Safiyat				Yes
Darkosh	Sawadiya - Nabhan				Yes
	Turin				Yes
	Zarzur (Darkosh)				Yes
	Ghazala - Mgheidleh				Yes
	Jamiliya (Darkosh)				Yes
	Ramadiyeh (Darkosh)				Yes
	Mazuleh				Yes
	Matleh - Batlaya				Yes
	Amud (Darkosh)				Yes
	Sadiyeh - Bsentiya				Yes
	Thahr				Yes
	Andnaniyeh - Farjein			Yes	
	Dorriyeh				Yes
	Zahraa - Kherbet Amud				Yes
	Sheikh Issa Elashury				Yes
	Darkosh				Yes
	Zanbaqi (co)				Yes
	Mreimin (Darkosh)				Yes
	Kharab Khalil (Darkosh)				Yes
	Kharab Amer				Yes
	Kharab Sultan				Yes
	Almilk				Yes
	Alshamra				Yes
	Magharet Jamous				Yes
	Alfauri				Yes
	Al Hamia				Yes
	Al-Hafriya				Yes
	Haj Nayef				Yes
Janudiyeh	Janudiyeh	Yes			
	Yaqubiyeh	Yes			
	Hassaniyeh - Hatya	Yes			
	Qaderiyeh - Qayqun				Yes
	Maland		Yes		
	Qanniyeh (Janudiyeh)				Yes

	Mudiah - Luxin			Yes
	Nasra (Janudiyeh)			Yes
	Foz - Zuf	Yes		
	Tiba - Katrin			Yes
	Jdidet Eljisr		Yes	
	Athar			Yes
	Hamama - Kafr Debbin	Yes		
	Al Marjeh			Yes

Table 8. The quantity, the volume of SW of the communities of JASD

Sub-district	Community	MSW production (m3)	MSW production liter per capita	Quantity of MSW (kg/day)	Quantity of MSW (kg .cap−1. day−1)	The distance of the random land -fill (km)
	Upper Sheikh Sindyan	N/A	N/A	N/A	N/A	N/A
	Msheirfeh (Jisr-Ash-Shugur)	N/A	N/A	N/A	N/A	5
	Sali	N/A	N/A	N/A	N/A	0
	Maalaqa - Bishlamon	1.5	0.5	300	0.1	1.5
	Balmis	N/A	N/A	N/A	N/A	5
	Salhiyeh (Jisr-Ash-Shugur)	N/A	N/A	N/A	N/A	N/A
	Bsheiriyeh - Bello	1	0.2	200	0.0	1
	Um Rish	N/A	N/A	N/A	N/A	1
	Bteibat	N/A	N/A	N/A	N/A	2
	Mintar (Jisr-Ash-Shugur)	N/A	N/A	N/A	N/A	N/A
	Upper Shghur	N/A	N/A	N/A	N/A	N/A
	Eshtabraq	N/A	N/A	N/A	N/A	N/A
Jisr-Ash-Shugur	Jisr-Ash-Shugur	60	3.3	12000	0.7	4
	Bzeit	N/A	N/A	N/A	N/A	2
	Bkafla	N/A	N/A	N/A	N/A	N/A
	Ein Elhamra	N/A	N/A	N/A	N/A	N/A
	Ghassaniyeh (Jisr-Ash-Shugur)	N/A	N/A	N/A	N/A	N/A
	Ein Elsoda (Jisr-Ash-Shugur)	N/A	N/A	N/A	N/A	3
	Kafir (Jisr-Ash-Shugur)	3	1.8	600.00	0.4	3
	Qaysiyeh	1	0.6	200.00	0.1	5
	Alyeh (Jisr-Ash-Shugur)	N/A	N/A	N/A	N/A	N/A
	Jannet Elqora	N/A	N/A	N/A	N/A	3
	Ghanya	N/A	N/A	N/A	N/A	N/A
	Sokkariyeh (Jisr-Ash-Shugur)	N/A	N/A	N/A	N/A	N/A
	Sabileh	N/A	N/A	N/A	N/A	N/A

	Western Marj Akhdar	2	0.2	400	0.0	2
	Um Elgar	0	0.0	0.00	0.0	N/A
	Dgali	0	0.0	0.00	0.0	1
	Eastern Marj Akhdar	2	0.3	400	0.1	2
	Tal Awar	N/A	N/A	N/A	N/A	1
	Tal Hamki	N/A	N/A	N/A	N/A	N/A
	Frikeh (Jisr-Ash-Shugur)	N/A	N/A	N/A	N/A	N/A
	Watba	N/A	N/A	N/A	N/A	N/A
	Marj Elzohur	N/A	N/A	N/A	N/A	2
	Kniset Nakhleh	0.5	0.2	100.00	0.042	7
	Al Areen - Kastanah Fawqan	1	1.1	200.00	0.2	2
	Jeb Alsafa	N/A	N/A	N/A	N/A	1
	Qulaia	N/A	N/A	N/A	N/A	1
	Qirmida	N/A	N/A	N/A	N/A	N/A
	Muntar Tahtani	N/A	N/A	N/A	N/A	N/A
	Al Karnaza	N/A	N/A	N/A	N/A	1
	Frikka al Abeed	N/A	N/A	N/A	N/A	N/A
	Arzaghan Fawqani	N/A	N/A	N/A	N/A	N/A
	Ziyadiyeh (Jisr-Ash-Shugur)	N/A	N/A	N/A	N/A	3
Badama	Baksariya	N/A	N/A	N/A	N/A	N/A
	Yunesiyeh	N/A	N/A	N/A	N/A	N/A
	Badama	6	1.7	1200	0.3	3
	Armala	3	1.2	600	0.2	2
	Hanbushiyeh	4	0.8	800	0.2	2
	Ein El-Bayda (Badama)	4.5	1.3	900	0.3	2
	Kherbet Eljoz	10	0.4	2000	0.1	N/A
	Shaturiyeh	3	1.6	600	0.3	2
	Najiyeh	2	1.9	400	0.4	1
	Ramliyeh	1	0.8	200	0.2	2
	Maraand	N/A	N/A	N/A	N/A	N/A
	Zoainieh	N/A	N/A	N/A	N/A	N/A
	Safiyat	N/A	N/A	N/A	N/A	N/A
Darkosh	Sawadiya - Nabhan	N/A	N/A	N/A	N/A	N/A
	Turin	N/A	N/A	N/A	N/A	10
	Zarzur (Darkosh)	4	0.5	800.00	0.1	1
	Ghazala - Mgheidleh	N/A	N/A	N/A	N/A	N/A
	Jamiliya (Darkosh)	N/A	N/A	N/A	N/A	N/A
	Ramadiyeh (Darkosh)	N/A	N/A	N/A	N/A	N/A

	Mazuleh	N/A	N/A	N/A	N/A	N/A
	Matleh - Batlaya	N/A	N/A	N/A	N/A	N/A
	Amud (Darkosh)	4	2.1	800	0.4	1
	Sadiyeh - Bsentiya	N/A	N/A	N/A	N/A	4
	Thahr	N/A	N/A	N/A	N/A	N/A
	Andnaniyeh - Farjein	2	1.0	400	0.2	3
	Dorriyeh	2	0.3	400	0.1	2
	Zahraa - Kherbet Amud	4	1.7	800	0.3	2
	Sheikh Issa Elashury	N/A	N/A	N/A	N/A	10
	Darkosh	3	0.1	600	0.0	15
	Zanbaqi	1	0.2	200	0.0	N/A
	Mreimin (Darkosh)	N/A	N/A	N/A	N/A	3
	Kharab Khalil (Darkosh)	N/A	N/A	N/A	N/A	10
	Kharab Amer	N/A	N/A	N/A	N/A	N/A
	Kharab Sultan	N/A	N/A	N/A	N/A	N/A
	Almilk	N/A	N/A	N/A	N/A	N/A
	Alshamra	N/A	N/A	N/A	N/A	3
	Magharet Jamous	N/A	N/A	N/A	N/A	10
	Alfauri	N/A	N/A	N/A	N/A	0
	Al Hamia	N/A	N/A	N/A	N/A	3
	Al-Hafriya	N/A	N/A	N/A	N/A	0
	Haj Nayef	N/A	N/A	N/A	N/A	0
Janudiyeh	Janudiyeh	3	0.2	600	0.04	2
	Yaqubiyeh	4	1.5	800	0.3	4
	Hassaniyeh - Hatya	N/A	N/A	N/A	N/A	10
	Qaderiyeh - Qayqun	1	0.3	200	0.1	5
	Maland	2	0.4	400	0.1	2
	Qanniyeh (Janudiyeh)	3	1.4	600	0.3	5
	Mudiah - Luxin	3	4.0	600	0.8	2
	Nasra (Janudiyeh)	2	1.9	400	0.4	2
	Foz - Zuf	8	0.8	1600	0.2	1
	Tiba - Katrin	N/A	N/A	N/A	N/A	2
	Jdidet Eljisr	N/A	N/A	N/A	N/A	N/A
	Athar	N/A	N/A	N/A	N/A	N/A
	Hamama - Kafr Debbin	8	0.7	1600	0.1	2
	Al Marjeh	N/A	N/A	N/A	N/A	N/A

N/A: Not available because the local council do not collect solid waste and the people through it in a randomly way

1. About seventy communities out of ninety-nine communities (92195 persons of 262246 persons) of JASD do not have dedicated works for solid waste collection, and eighty communities (120237 persons of 262,246 persons) do not have SW containers, and sixty-seven communities (77,195 persons of 262,246 do not have solid waste tractors with a trails are necessary for SWC) as showed in Fig 3, this is considered an evidence of the bad state of SWM, the local councils do not have enough resources for buying SW containers, the cost of each one is about 40$ with capacity 0.1 m^3 that can serve 80-120 persons.

Fig 3. The gaps of solid waste management in JASD

2. The number of local councils JASD is ninety-nine, and all these local councils are not received or supported by SW equipment, tools and machines, and only three local councils (hosted 18,924 persons of 262,246) are supported by salaries for the solid waste workers, fuel for the tractors and solid waste tools of SWM from SECD, as showed in Fig 4, this support is not sustainable, also only for four months. In general the SW sector is not supported by NGOs in a good way so the environment is polluted and cutaneous leishmaniasis registered cases during 2018 [13].

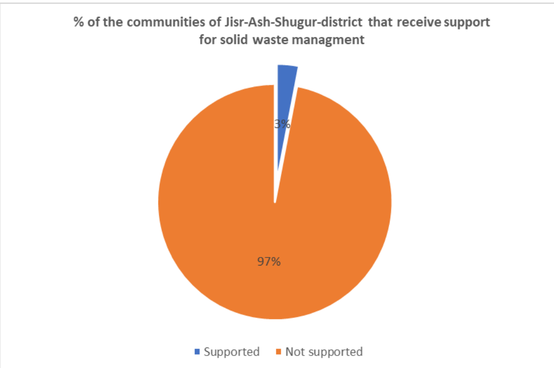

Fig 4. Showed the percent of the communities of JASD that received support for solid waste management

3. Only 26% of SW amount of JASD collected by the local councils (Public solid waste collection) without any fees, The larger the ratio, the better, because it indicates that more waste is collected and transported, and 36% of SW left in public areas which could be the cause of many diseases, and Solid waste disposed of the household to a dumping location station 36%, Darkosh - district considered the worth district of JASD according to SWM because only 16% of SW amount is collected by the local councils ,so during 2018 the number of Cutaneous leishmaniases registered cases of Darkosh subdistrict is: 1062 which considered too high and Darkosh subdistrict need urgent support and solid waste service response.

4. SWCF values differ from one community to other, the SWCF of sixty-eight communities (152,847 persons of 262,246) of JASD is conducted Randomly, two communities (7,136 people) Once every two weeks or more, and thirteen Communities (87,517 of 242,682 persons) the SWCF is at least three times per week, and six Communities (15,569 persons) : Once every two weeks. As showed in Fig 5, before the crisis of Syria at 2011, The SWC was performed daily by the local council, the SWCF once per a week or two weeks are considered too low, it must be at least two times per a week in the crisis [17].

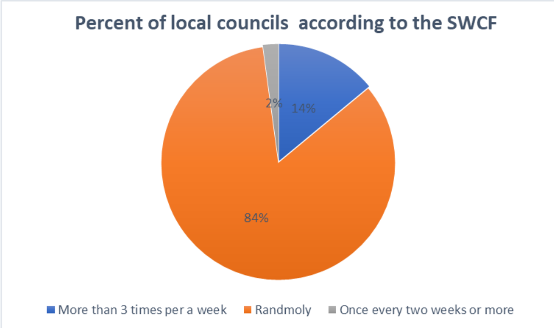

Fig 5. SWCF of JACD communities

5. The total volume of MSW production of JASD cannot measure in an accurate method because the solid waste collection are conducted randomly, But for the communities which the solid waste quantity can be measured, the average, maximum and minimum of SW production per capita at JASD communities is (1.07; 3.96; 0.12) liter day^{-1} and (0.21; 0.79; 0.02) kg day^{-1}. and the average SW production per capita value for JASD is 1.07 liter day^{-1}, 0.21 kg.day^{-1}, these values are similar to the value recognized by the world bank [18] and to SECD assessment [12].

6. There are fifty-eight random landfills at least of JASD. which considered a spot of pollution, resources of bad odors and one of the roots causes of cutaneous leishmaniasis, in other hand the average, maximum and minimum distance between the center of the community and the random landfills is (3.33;15.1) km respectively, it is highly recommended that only one or two sanitary landfills be conducted for JASD instead of 58 randomly landfills.

7. The maximum Cutaneous leishmaniasis cases of Darkosh: 1,062, Janudiyeh: 771, Jisr-Ash-Shugur :453, and Badama:100. cases during the 2018 year [16], which is considered so risk and related to the bad solid waste management of JASD.

4. CONCLUSIONS

The SWM management of Jisr-Ash-Shugur-district controlled areas considered very bad because of the shortage of financial and human resources and the NGOs did not support Jisr-Ash-Shugur-district the solid waste management in general , It is highly recommended that UNICEF (the United Nations International Children's Emergency Fund) , SCHF, and the other donors give the priorities to conduct solid waste management in Jisr-Ash-Shugur so the environment polluted and the cutaneous leishmaniasis increases day by day. The local councils of NSAG area need urgent support and training for operation SWM in a good way.

Effective SWC will reduce the cutaneous leishmaniasis cases and the pollution of the environment.

It is highly recommended to establish a general management of solid waste for JASD to achieve a best service of SWM and use the available resources in a good way and take a benefit of the studies which related to the developing countries to convert solid waste into useful products, such used rubber tire pyrolysis of waste tire rubber to produce liquid fuel. [19], recycling of waste plastics for utilization it as an energy source [20] and Biodiesel production from waste oils [21].

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RESEARCH ARTICLE

The kinetics of the oxidation of ammonia on a V_2O_5/TiO_2 SCR catalyst deactivated in an engine rig. Part I. Determination of kinetic parameters by simulation

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ABSTRACT

It is shown how the deactivation of a diesel SCR (Selective Catalytic Reduction) catalyst by compounds in the exhaust gases influences the kinetics of the catalyst. Results are given for the fresh (4.56 % V_2O_5/TiO_2) catalyst and the ones used in the rig for 890 h and 2299 h. The reactions of 700 ppm NH_3 and 2 % O_2 in Helium yielded N_2, N_2O, and NO at increasing temperatures. Simulations were performed with COMSOL Multiphysics using a 3-D model of the catalyst system. The experimental values of the products N_2, N_2O, and NO were very nicely fitted by the kinetic model used. All three ammonia oxidation reaction rates were of the first order in the concentration of NH_3. A preliminary study using non-isothermal conditions showed the maximal temperature increase to be 0.15 K. Thus, further simulations were done with an isothermal model. The deactivation reduces the pre-exponential factors and the activation energies for the formation of N_2, N_2O, and NO. The formation of N_2 is not substantially influenced by deactivation. The changes in the kinetics of the catalytic NH_3 oxidation by deactivation is reported for the first time in the present study.

Keywords: Oxidation of ammonia, poisoning and kinetics, Vanadia SCR diesel catalysts

1. INTRODUCTION

The Selective Catalytic Reduction (SCR) technique is today a compulsory method for mobile applications like marine and automotive diesel engines in many countries. Marine engines run under conditions, which resemble the ones in stationary diesel power plants. In 2017, there were hundreds of SCR units installed on diesel engines on ships [1]. The lubricating oil for the diesel engine is often a source for deactivation components for the catalyst. A SAE 15W-40 oil contained 0.26, 0.25, 0.068, and 0.061 wt. % of S, Ca, Zn, and P, respectively [2]. These components will influence the performance of the SCR catalyst, as shown in a previous publication [3]. In that study, it was shown how the activity and selectivity in the SCR system are influenced by poisoning. It is interesting to elucidate the role of ammonia oxidation reactions in the SCR system. They do contribute to unwarranted N_2O production and the destruction of NH3 at the high temperatures sometimes reached in diesel applications. Koebel and Elsener [4] studied the removal of 1000 ppm NO with NH_3 using commercial V_2O_5-WO_3-TiO_2 catalysts. They do not state what ammonia reaction(s) they consider but state that the rates of ammonia oxidation reactions are about 500 times smaller than the SCR reaction ones. In 1993 Ozkan et al. [5] studied the role of ammonia oxidation in the SCR over vanadia catalysts. They found that N2, N_2O, and NO were the products. In their extensive study [6] using nitrogen labelling, they found that the ammonia species giving N_2 and N_2O have relative long residence times on the surface. The NO producing species are short-lived. Thus, three ammonia oxidation reactions are assumed. Duffy et al. [7], using V_2O_5/TiO_2 catalysts with varying vanadia contents, also used isotopic labelling studies to conclude that below 300 °C $^{14}N^{15}N$ is always the major product from ^{15}NO and $^{14}NH_3$. At higher temperatures, the product distribution is susceptible to the vanadia content of the catalyst. At 500 °C, 70 % of the product is ^{14}NO. Pure V_2O_5 produces significantly more $^{14}N^{15}NO$, and at lower temperatures than a 1.4 wt % V_2O_5/TiO_2 catalyst. As part of an SCR study, the kinetics of the partial ammonia oxidation giving N_2 was studied between 250 and 300 °C by Efstathiou et al. [8]. They oxidised 1000 ppm NH_3 by 2 % O_2 with helium as background gas over an 8 mol % V_2O_5/TiO_2 catalyst. The selectivity to

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N_2 was from 98.2 to 97.6 % decreasing with temperature. The rate of the ammonia oxidation was only from 1.8 to 2.4 % of the rate of the SCR reaction, much higher than stated above by Koebel and Elsener [4]. They [8] also studied the formation of N_2O between 320 and 380 °C. In this temperature range, the formation of N_2O is almost completely caused by the reaction of NH_3 with NO. Djerad et al. [9] included all three NH_3 oxidation reactions in their study on the effect of oxygen on the reaction rates. Using a 3%V, 9%W on titania catalysts, the effect of oxygen was small between 2 and 15 % O2. A maximum in the formation of N_2 was observed at 425 °C, N_2O was formed above 300 °C while NO only above 425 °C. They found that the formation of N_2O from ammonia oxidation is important in the SCR process. So, we will include all three reactions in our simulation of the ammonia oxidation.

The inspiration for the present study comes from the excellent results obtained earlier using COMSOL Multiphysics as means of performing FEM analysis of catalytic reactors [10,11]. An excellent paper on global kinetic modelling of SCR over vanadia on titania was published by Roduit et al. [12]. Only the SCR reaction and the oxidation of NH_3 to N_2 were included though. They presented results on the ammonia coverage of the catalyst as a function of temperature and ammonia concentration. These values were the base for our assumed influence of temperature on the coverage of NH_3. Their values of the adsorption energy of NH_3 was not used. Instead, we relied on the value -100 to -130 kJ mol^{-1}, as presented by Koebel and Elsener [4].

There are not too many studies published using COMSOL Multiphysics to simulate catalytic reactors. One of them is performed by Chen et al. [13]. They used their study to optimise the performance of the reactor for the SCR using the NH_3 to N_2 oxidation reaction and the SCR reaction.

We could not find very much if any, kind of information in the literature on the effect of deactivation on the kinetics of ammonia oxidation over vanadia catalysts. We presented before [3] how the poisons accumulate along the catalyst monolith. The present study presents a simulation of the kinetics of the oxidation of NH_3 with O_2 and how it depends on the degree of the poisoning of the catalyst. The catalysts in this study consist of a thin layer of active components supported on cordierite. Therefore, the effect of deactivation will be more easily detected in our experiments than in experiments on full catalysts.

The data used in the study were measured at two increasing degrees of poisoning by the compounds most likely to be present in commercial use. Therefore, the result could be used in the design of new catalysts for diesel engines which are deactivated by compounds in the lubrication oil.

2. MATERIALS AND METHODS

2.1. *Preparation and deactivation of the catalyst samples*

The catalysts used were made in house by a Swedish catalyst manufacturer and consisted of 5.64 % V_2O_5 on TiO_2 (Rhone Poulenc DT(8)) on the support of cordierite from Corning with a CPSI of 400. Details on the preparation, deactivation and characterisation can be found in Odenbrand [3]. The deactivation was performed in an engine rig using Swedish class 1 diesel fuel. The deactivation cycle, 1 hour long, had a mean temperature of 470 °C and a maximum temperature of 570 °C for 7.5 min in each cycle. Samples were taken from the fresh catalyst, and the catalysts used for 890 and 2299 h in the rig. The accelerated test was supposed to simulate the regular running of a truck for up to 500 000 km (given by the catalyst manufacturer).

2.2. *Measurement of catalyst activity and selectivity*

The centre part (9 x 9 channels wide) of the 10 cm long and 2.5 cm wide monolithic catalysts were cut into 1 cm mini monoliths along their axis. Only piece five from the inlet was used in the ammonia oxidation experiments. The activity and selectivity in the oxidation of ammonia with O_2 were measured at about 700 ppm NH_3 and 2 % O_2. The pressure was 1.24 bar (Space velocity 45 000 h^{-1}). Temperatures were from 340 to 460 °C at 20 °C intervals. Helium was used as a background gas containing about 3000 ppm of Ar for internal calibration as described before [11]. A Balzer QMG 311 mass spectrometer was used for gas analysis. A chopping device was used to decrease the influence of the background signal. The spectra were recorded using peaks 17, 18, 28, 30, 34, 40, 44 and 46 for NH_3, H_2O, N_2, NO, O_2, Ar, N_2O and NO_2. The spectrum was scanned twice first with an open and then with a closed chopper. By subtraction, a difference spectrum representing the composition in the gas stream was obtained. Experimentally determined splitting factors and sensitivity factors, determined from gases of known compositions, were used to calculate the concentrations with a computer program. The background concentrations of N_2 and H_2O were 37.7 ± 0.2 and 31.4 ± 2.5 ppm respectively showing the accuracy of the mass spectrometric data. Inlet concentrations of NH_3 varied somewhat between the three experiments and were 725 ± 18 ppm. The actual concentrations were used in the simulation of each series of experiments.

2.3. *Modelling of the catalyst reactions*

The kinetic scheme used in the simulations is based on first-order reactions in the concentration of ammonia for reactions 2, 4 and 5 in Table 1. In all cases, the effect of oxygen, present in excess (2 %), is included in the rate constant. The eventual effects of any diffusion limitations are also included.

The reactions are demanding more and more oxygen and are being more important at increased temperatures, the higher the number of the reaction is. It is only reactions 2, 4 and 5 that have a significant influence on the kinetics of ammonia oxidation because of deficient concentrations of NO in the system. Thus, reactions 1 and 3 are omitted in this study. Table 2 shows the physiochemical data used in the simulation in non-isothermal and in isothermal cases.

Table 1. Chemical reactions and kinetic expressions used in the simulations

Reaction number	Global reaction	Rate expression
1	$4NH_3+4NO+O_2=>4N_2+6H_2O$	$r_1 = A_1*exp(-E_1/(R*T)) *c_{NO}*\theta_{NH3}$
2	$4NH_3+3O_2=>2N_2+6H2O$	$r_2 = A_2*exp(-E_1/(R*T)) *c_{NH3}$
3	$4NH_3+4NO+O_2=>4N_2O+6H_2O$	$r_3 = A_3*exp(-E_1/(R*T)) *c_{NO}*\theta_{NH3}$
4	$4NH_3+4O_2=>2N_2O+6H_2O$	$r_4 = A_4*exp(-E_1/(R*T)) *c_{NH3}$
5	$4NH_3+5O_2=>4NO+6H_2O$	$r_5 = A_5*exp(-E_1/(R*T)) *c_{NH3}$

$\theta_{NH3} = K_{NH3}*c_{NH3}/ (1+ K_{NH3}*c_{NH3})$, $K_{NH3} = A_0*exp(-E_0/(R*T))$

Table 2. Physical data used in the Transport of Diluted Species and Free and Porous Media Flow nodes in the COMSOL program

Parameter	Open channel	Catalyst Layer	Cordierite[1]
Diffusion coefficients in the fluid *105 (m^2 s^{-1})	9.83 - 13.22	n.a.	n.a.
Diffusion coefficients in catalyst (m^2 s^{-1})	n.a.	Deff=ε/τ*Dfluid τ = ε–(1/3)	n.a.
Porosity of catalyst (ε)	n.a.	0.4	n.a.
Density (kg m^{-3})	0.635 – 0.760	2295	2300
Dynamic viscosity *105 (Pas)	9.25 – 10.39	n.a.	n.a.
Permeability (m^2)	n.a.	6*10-8 [11]	n.a.
Thermal conductivity (W (m^{-1} K^{-1}))	0.090 – 0.101	8.4	1.8
Heat capacity (J (kg^{-1} K^{-1}))	649	1050	880
The ratio of specific heats	1	1	1

n.a. Not applicable

1) Cordierite was substituted by concrete, and alumina was used instead of titania for physical data

The heat source was from the chemical reactions. The system is mostly calculated isothermally. Therefore, the properties of the cordierite are not included in the major part of the simulations. Incompressible flow with a normal inlet velocity of vin in the direction of the reactor axis was used for the Free and Porous Media Flow node. The total flow (Q_{in}) at NTP was 0.9 l min^{-1}. It was distributed over 9*9 square channels and was $1.8519*10^{-7}$ m^3 s^{-1} at NTP for one channel. The inlet open surface area of one channel was $2.1316*10^{-6}$ m^2. The reference pressure (pref) was 1 bar, and the total one (ptot) was 1.236 bar. Thus, $v_{in} = Q_{in}/A_{in}*T_{in}/273.15/ptot*pref$ (0.157 m s^{-1} at 613 K (340 °C)). The program calculates the varying velocities at different temperatures.

The densities for V_2O_5 is 4571 and for TiO_2 3780 kg m^{-3}. Then the solid density of the active catalyst layer is thus 0.0564 *4571+(1-0.0564) *3780 yielding a solid density of 3825 kg m^{-3} for the catalyst layer containing 5.64 % V_2O_5. The porosity is 0.4 as measured before, and so the apparent density is 2295 kg m^{-3}. The apparent density, together with the amount of the active phase (18.2 wt %), is used in calculating the thickness of the active layer to 21 μm, which was used in the simulations. The catalyst layer was supposed to cover all inside walls of the monolith. For calculation speed reasons only one-eighth of the whole reactor was simulated. The mesh used is shown in Fig 1.

Fig 1. Reactor model, showing the mesh, used in the simulations (1/8 of the whole model). The gas inlet is from the left. The mini monolith is 1 cm long and has a 21μm catalyst layer on all walls

The reactor, made of quartz glass, is 100 mm long with the bottom of the catalyst monolith (1 cm long) positioned 60 mm from the inlet on a plug of glass wool. The monolith was surrounded by quartz wool to stop gas bypassing the catalyst. Only a small part of the simulated system is shown (Fig 2) in order to show the mesh used in the calculations. The monolith contains 81 channels, but the model simulates only one of them.

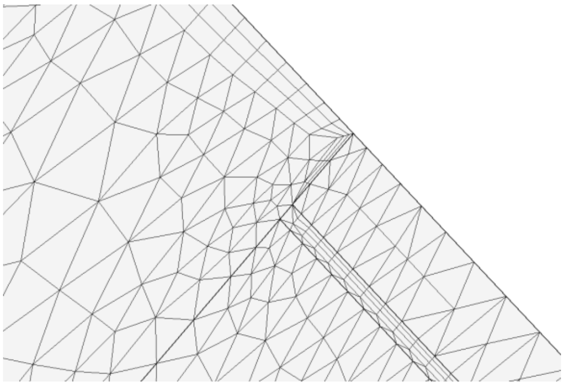


Fig 2. Enlargement of the inlet section of the monolith part of the reactor model, showing the mesh, used in the simulations (1/8 of the whole model). Boundary layers are present both in the open channel and along with the catalyst layer. The gas inlet is from the left. The mini monolith is 1 cm long and has a 21 μm catalyst layer on all walls

COMSOL Multiphysics ver. 5.4 was used in the simulations in a similar way as described before [10, 11] with the data given in Table 2. The reactor was placed in a heated chamber with forced circulation of the air. Heat flux was used as the boundary condition on the outside of the reactor walls for the non-isothermal cases. The heat was transferred by convection from the reactor outside to the air flowing over its outside, according to $q_0 = h*(T_{in}-T)$. The value for h was 100 W/m²/K taken from [14] for forced convection, medium speed flow of air over a surface. The physic-controlled mesh was used with a coarse element size. The degrees of freedom (DOF) for the non-isothermal case was 2 335 934 plus 195 579 internal degrees of freedom (DOF). For the isothermal one, it was 492 990 plus 165 510 internal degrees of freedom. When the physics-controlled mesh is used, three boundary layers close to the walls were introduced to get a fine resolution of the velocity profile in that position. The solution for the non-isothermal case was obtained by performing two separate stationary studies. Study one was performed in 3 steps. The Free and Porous Media Flow node was calculated in step 1 at 773 K. In step 2, the following nodes were used Chemistry, Transport of Diluted Species, and Heat Transfer in Porous Media. Finally, in step 3, all above nodes were used plus the Domain ODEs and DAEs used for calculation of the temperature dependence of the heat of adsorption of ammonia. In the stationary study two, all nodes were used, and initial values of variables were taken from study one step three. The temperature was decreased from 733 K downwards to 613 in steps of 20 K for easier convergency. The solver was PARDISO and the variables u and p were solved in segregated step one, the temperature in step two, all concentrations in step three, and the heat of adsorption of ammonia (E_0) in step four. The isothermal case contained fewer steps and only reactions 2, 4 and 5.

The details of the simulation equations and boundary and subdomain settings are the same as in reference [11].

2.4. Inlet concentrations for the simulation of ammonia oxidation

Table 3 shows the inlet data used in the simulations of the oxidation of NH_3 with 2 % O_2 for the three catalysts studied. The fitted concentrations are N_2, N_2O and NO. The others are the result of the reaction stoichiometry.

Table 3. Inlet concentrations (ppm) used in the simulations of the oxidation of NH3 for the three catalysts studied

Catalyst	NH_3	N_2O	NO	N_2	H_2O
Fresh	728.8	1.2	4.6	37.4	28.2
890 h	745.6	1.0	3.8	37.8	31.6
2299 h	702.0	2.0	4.0	37.8	34.4

Concentrations measured at the end of the reactor were shown by the simulations to be even over the channel cross-section. The measured concentrations are plotted versus the temperature at the exit of the monolith. Manual changes in kinetic parameters are performed in order to fit the simulated values to the experimental ones according to the method described before [11, 12]. First, the concentration of N_2 was fitted with parameters in reaction 2. Then the concentrations of N_2O and NO were fitted according to reactions 4 and 5. Both these components were of the same magnitude, so they were fitted simultaneously

3. RESULTS AND DISCUSSION

3.1. Apparent kinetic data

Table 4 shows apparent kinetic datas which were obtained from assumed first-order dependence on the concentration of NH_3 and experimental conversions and selectivities. These parameters were used as starting values in the simulations.

Rates are given at 340 and 460 °C except for rNO for the fresh catalyst and the one used for 890 h where the lowest temperature is 380 °C.

The activation energies are decreasing with an increased degree of poisoning, as observed before [15, 16]. The poisoning has the most significant effect on the formation of NO. The results of this study can be compared to the results of Chen and Tan [13] who also used COMSOL Multiphysics in the simulation of, in their case, a catalyst bed. Their value of E_2 is 84.4 kj mol^{-1} when corrected for diffusion limitations while our apparent value is 74 4 kj mol^{-1} for the fresh catalyst. The values of k_2 were 6.73*10^7 and 4.13*10^8 s^{-1}, respectively. Good consistency is obtained.

Table 4. Apparent kinetic parameters in the oxidation of 700 ppm NH_3 with 2 % O_2 in Helium at 1.24 atm from 340 to 460 °C on all three catalysts

Parameter	Fresh	890 h	2299 h
A_2 (m^3 g^{-1} s^{-1})	$9.79*10^5$	$9.79*10^5$	$8.95*10^4$
E_2 (kJ mol^{-1})	74	78	52
r_{N2} (mol g^{-1} s^{-1})	$4.27*10^{-8}$-$4.27*10^{-7}$	$4.27*10^{-8}$-$4.12*10^{-7}$	$4.71*10^{-8}$-$2.62*10^{-7}$
A_4 (m^3 g^{-1} s^{-1})	$4.51*10^8$	$6.68*10^9$	$5.53*10^9$
E_4 (kJ mol^{-1})	123	137	123
r_{N2O} (mol g^{-1} s^{-1})	$2.51*10^{-9}$-$1.07*10^{-7}$	$2.99*10^{-9}$-$1.88*10^{-7}$	$1.88*10^{-9}$-$1.31*10^{-7}$
A_5 (m^3 g^{-1} s^{-1})	$3.94*10^{13}$	$5.69*10^{10}$	$4.50*10^{10}$
E_5 (kJ mol^{-1})	201	161	141
r_{NO} (mol g^{-1} s^{-1})	$3.54*10^{-10}$-$1.62*10^{-8}$	$1.32*10^{-9}$-$2.34*10^{-8}$	$7.53*10^{-10}$-$5.30*10^{-8}$

3.2. Results from non-isothermal simulations

Fig 3 shows the temperature rise obtained in a non-isothermal simulation. The temperature increase was shown to be only 0.145 °C at 460 °C in the oxidation of 729 ppm NH_3 for the fresh catalyst. The temperature increase is about the same for all three catalysts. These values are small enough so that the assumption of an isothermal system could be used. Even so, the system was simulated as a non-isothermal one first to study some of its properties. One of the most crucial property is the temperature which influences the rate of reactions in an exponential manner

The catalyst monolith starts at 0 and ends at 0.01 m in Fig 3. Increased temperatures are seen both before and after the monolith part of the system caused by heat conduction — the temperature increases along the system axis in a manner typical for exothermal reactions. A maximal temperature is reached at 0.003 m from the inlet of the monolith.

Fig 4 shows how the velocity in the reactor is increased from about 0.39 m s^{-1} in the centre before the monolith to about 0.55 m s^{-1} inside it. The smaller open channel inside the monolith than in the empty reactor causes this. The flow is developing to a laminar one at about 1 mm from the inlet (not shown here). The pressure drops over the monolith by $5.1*10^{-5}$ bar and by $3.15*10^{-4}$ bar over the whole reactor. The total pressure drop over the monolith was only 0.4 % of the actual pressure in the system.

Fig 5 shows how the NH_3 is evenly distributed over the cross-section of the channel, the catalyst layer and the cordierite wall. The lowest value is 545.9 ppm in the centre of the channel, increasing to 550.3 ppm in the upper part of the catalyst layer. That is the concentration is constant within 0.8 % at these conditions. The heat of the reaction is very well distributed over the exit of the monolith, where the maximum temperature difference is only 0.15 K (not shown here). Fig 6 shows the amount of NH_3 "converted" as a function of the position in the monolith and measured in the centre of the channel.

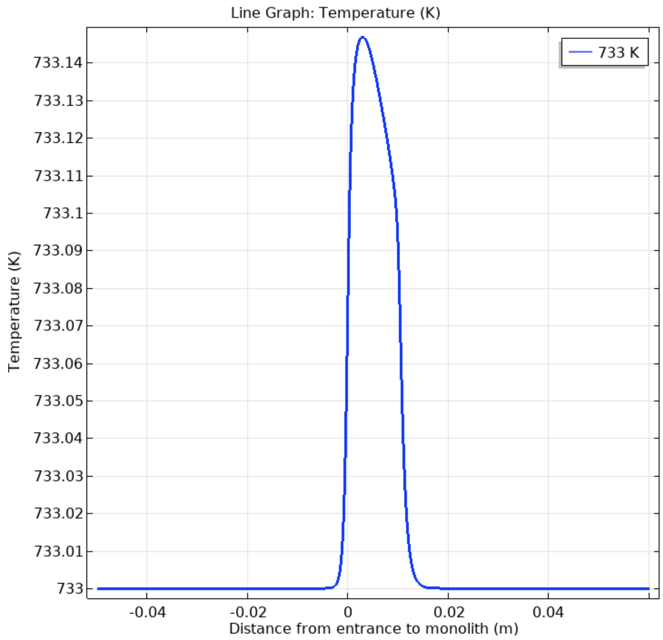


Fig 3. The temperature along the axis of the channel around the monolith for the catalyst used for 890 h. Oxidation of 729 ppm NH_3 with 2 % O_2 in Helium. The inlet temperature was 733 K (460 °C).

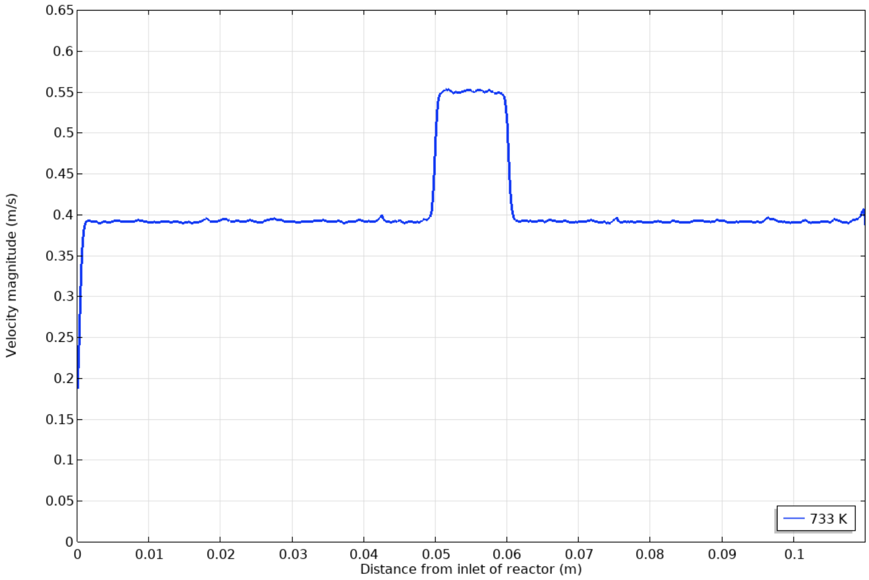


Fig 4. Velocity in the centre of the channel in the reactor. The inlet temperature was 733 K (460 oC), p 1.236 bar

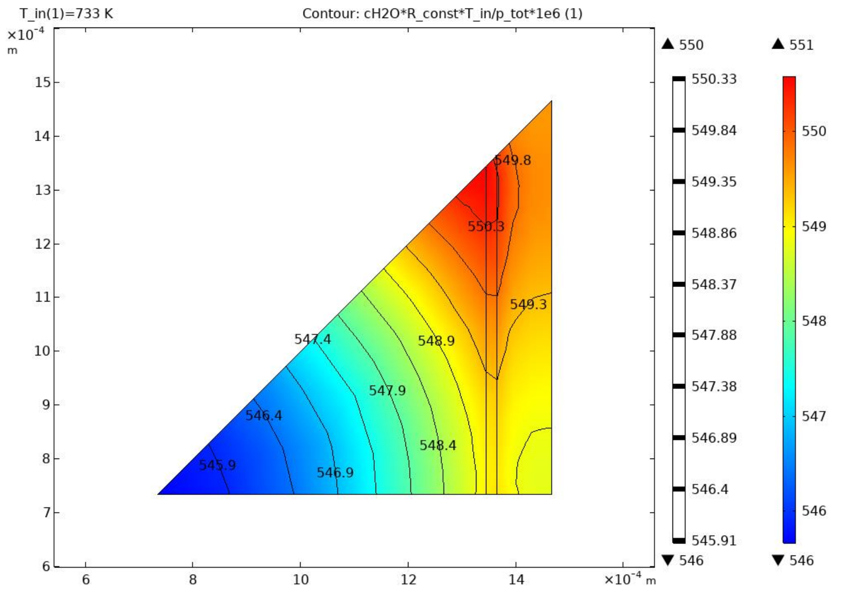


Fig 5. The concentration of NH_3 (ppm) across the surface of the channel, the fresh catalyst layer and the monolith wall at the exit of the monolith. The inlet temperature was 733 K (460 °C)

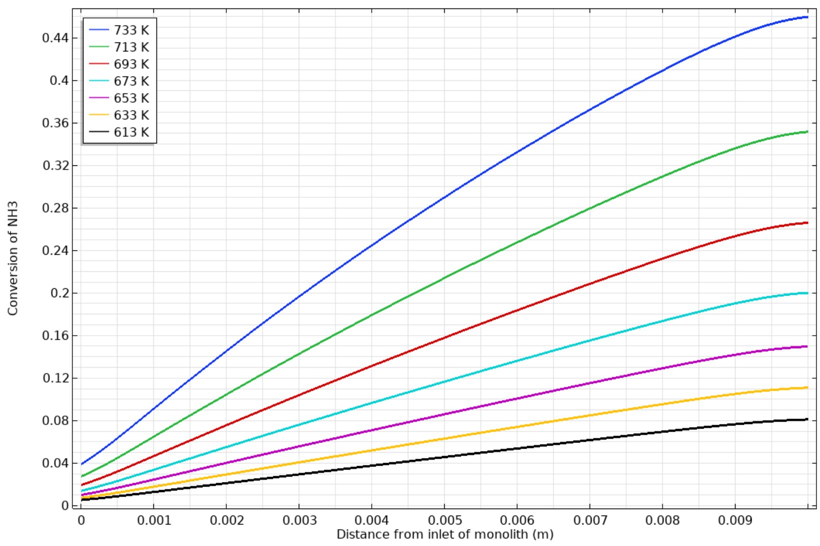


Fig 6. The conversion of NH_3 along the axis of the channel for the fresh monolith. The inlet temperature was 733 K (460 °C)

In the inlet part of the monolith, there is a definite "conversion" caused by a change in concentration as an effect of the increased temperature in this position (Fig 3). One would not expect a conversion before the gas stream is in contact with the catalyst. That is why we use apostrophes around conversion.

The rate of formation of nitrogen is 60 times higher than the rate of formation of nitrous oxide at 340 °C (613 K in Fig 7). At 460 °C the ratio is only 2.26. The rate of formation of NO is even lower and is only 0.39 % of the rate of formation of nitrogen at 340 °C. At 460 °C it increases to 8.6 % of the rate of formation of nitrogen.

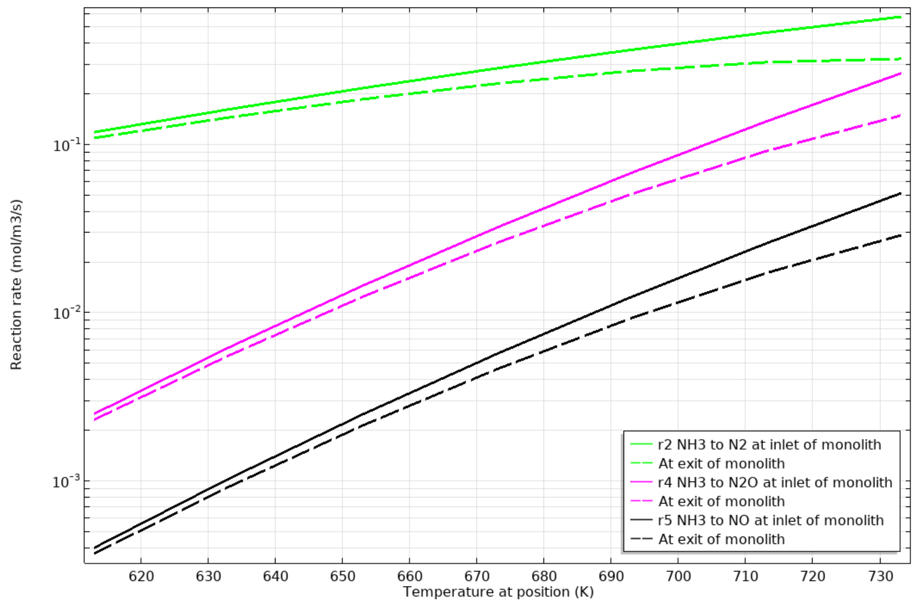


Fig 7. The rates of the individual reactions as a function of the temperature for the fresh catalyst

3.3. Results from isothermal simulations

Since the maximal temperature increase is so low, the rest of the simulations were performed as an isothermal case. Fig 8 shows the concentrations of products formed in the oxidation of about 800 ppm NH_3 with 2 % O_2 along with the simulated values for the fresh catalyst, for the catalyst used for 890 h in the rig, and for the catalyst used for 2299 h.

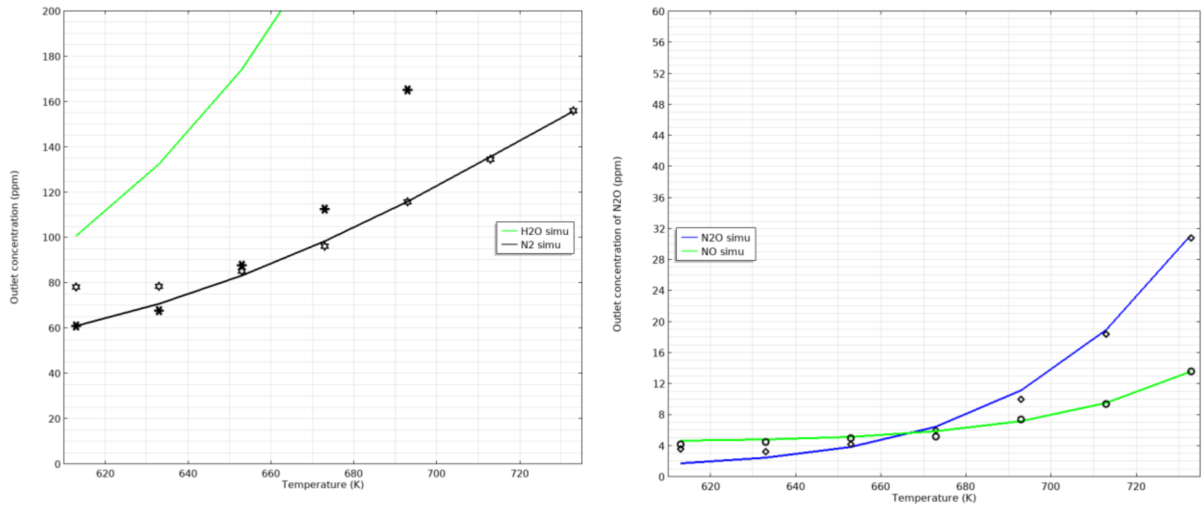
For the fresh catalyst, the fit to N_2 is not very good at low and high temperatures. The experimental values show a curved upward deviation from the simulated ones for the fresh catalyst and the one used for 890 h. The best fit for N_2 is obtained on the catalysts used for 2299 h. The SCR is also active at high temperatures where we know that small amounts of NO are formed from NH_3. So, the high experimental values at temperatures above 700 K values can be explained if the SCR reaction takes place to a small extent. Figure 8 shows that it is quite easy to get a good fit for the contents of N_2, N_2O, and NO except for the lowest temperatures.

The simulated concentration of H_2O is shown in Fig 8 and are also much higher than the experimental ones but with an increased discrepancy at increased temperatures. Also, the experimental value of H_2O is lower for the catalyst used for 2299 h than for the other ones. Whether this is significant is hard to say.

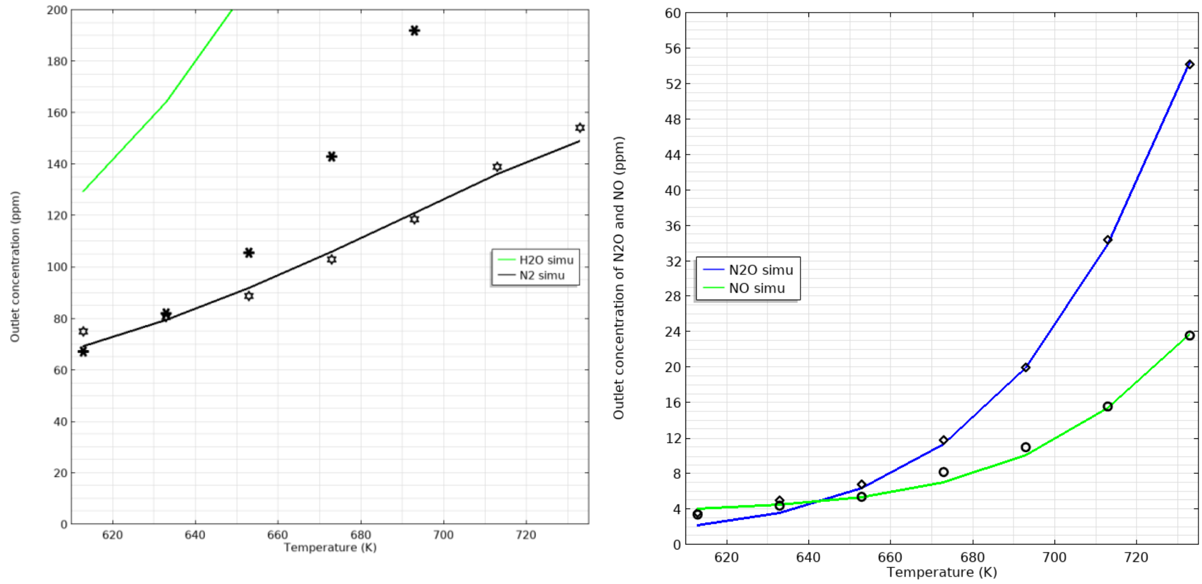
Fig 9 shows the simulated and experimental values of NH_3 when the fitting is performed on the formation of N_2. The best fit is obtained at an intermediate temperature.

At 733 K, the experimental value is 300 ppm, while the simulated one is 400 ppm. All components are measured precisely as before [11], so some effects of the deactivation could explain the not too good fit for H_2O (Fig 8) and NH_3 (Fig 9). A plausible one is that Ca phosphates are present on the deactivated catalysts reacting with and consuming the gas-phase water [17]. This reaction will not give a long-lasting effect, in any case. Furthermore, it will not explain that similar behaviour is observed for the fresh catalyst. A fact is that the mass balance in these experiments is not as correct as in earlier work [11]. The discrepancy increases at increased temperatures. For N_{out}/N_{in} the mean is 0.962±0.034, and for H_{out}/H_{in} it is 0.847±0.074. Values at the lowest temperature are close to 1. For the earlier study, the standard deviation was only 0.9 % and independent on temperature. Thus, the use of N_2 instead of NH_3 for the fitting procedure.

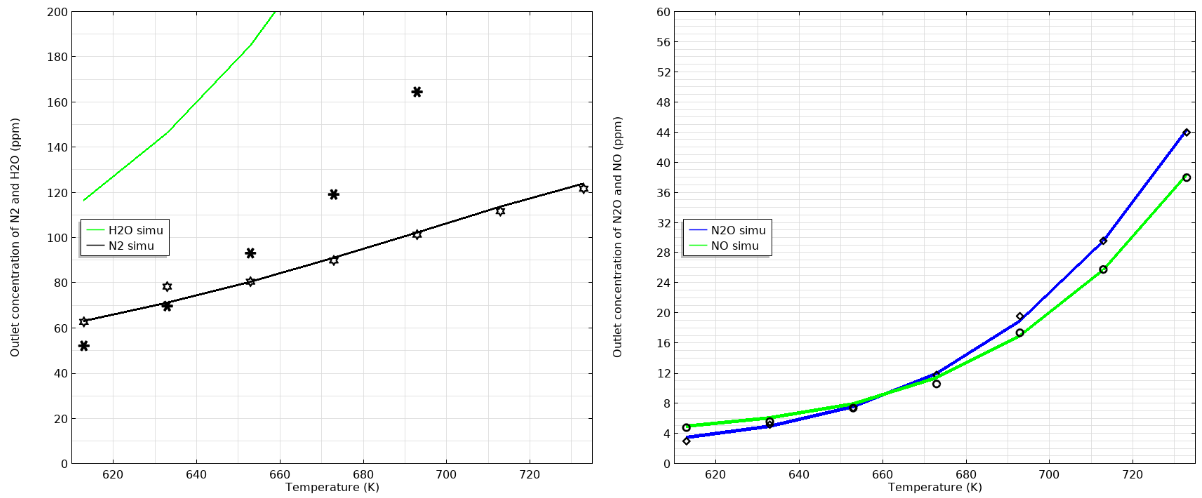
Table 5 shows the obtained kinetic parameters after fitting the simulated concentrations of N_2, N_2O, and NO to the experimental ones at increasing temperatures for the three catalysts studied.



Fresh catalyst



The catalyst used for 890 h



The catalyst used for 2299 h

Fig 8. Simulation of the oxidation of about 700 ppm NH_3 with 2 % O_2 at 1.24 bar over the fresh catalyst and the ones used for 890 and 2299 h. Experimental values for N_2 (stars), H_2O (asterisks), N_2O (diamonds), and NO (circles). Lines are simulated values

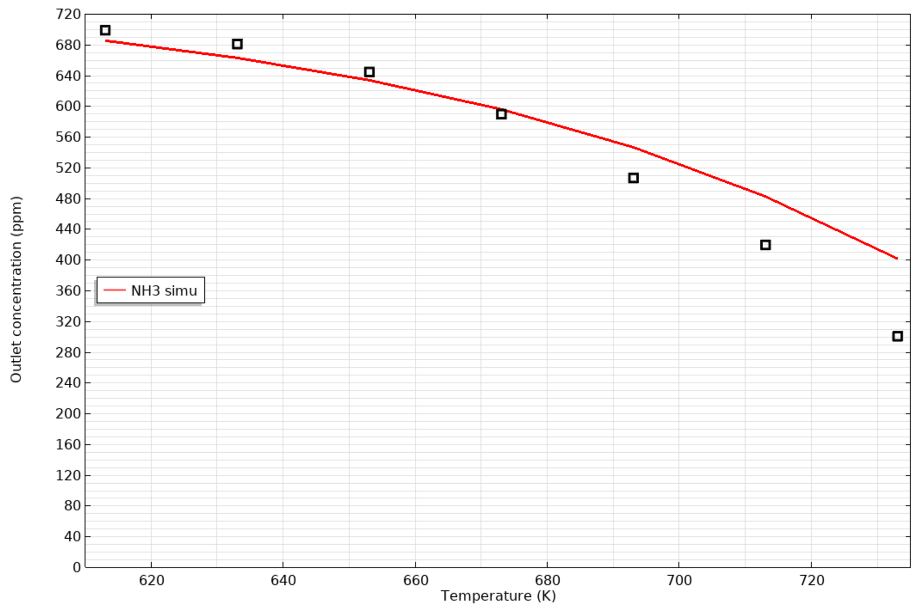


Fig 9. Outlet concentration of NH_3 as a function of temperature for the fresh catalyst. oxidation of 745.6 ppm NH_3 in 2 % O_2 on the fresh catalyst. Squares are experimental values while the line is the simulated ones

Table 5. Simulated kinetic parameters in the oxidation of 700 ppm NH_3 with 2 % O_2 in Helium at 1.236 bar from 340 to 460 °C as a function of time of use for the three catalysts studied. Rates are given at inlet conditions

Parameter	Fresh	890 h	2299 h
A_2 (s^{-1})	$1.51*10^6$	$3.93*10^5$	$1.62*10^5$
E_2 (kJ mol^{-1})	64	56	52
r_2 (mol m^{-3} s^{-1})	$9.3*10^{-2}$ - $5.9*10^{-1}$	$1.3*10^{-1}$ - $5.8*10^{-1}$	$1.0*10^{-1}$ - $4.2*10^{-1}$
A_4 (s^{-1})	$7.17*10^{10}$	$5.78*10^{10}$	$4.01*10^9$
E_4 (kJ mol^{-1})	138	133	118
r_4 (mol m^{-3} s^{-1})	$2.2*10^{-3}$ - $1.5*10^{-1}$	$3.1*10^{-3}$ - $2.6*10^{-1}$	$6.0*10^{-3}$ - $2.1*10^{-1}$
A_5 (s^{-1})	$1.25*10^{11}$	$9.12*10^{10}$	$4.36*10^9$
E_5 (kJ mol^{-1})	153	146	124
r_5 (mol m^{-3} s^{-1})	$2.4*10^{-4}$ - $2.2*10^{-2}$	$5.8*10^{-4}$ - $4.2*10^{-2}$	$2.0*10^{-3}$ - $8.4*10^{-2}$

The formation rates of N_2, obtained in the simulations, as shown in Table 5, increase at 340 °C for the catalyst used for 890 h compared to the fresh catalyst but decrease on further use. At 460 °C it decreases by 2 % after 890 h and decreases by 29 % after 2299 h compared to the fresh catalyst. Earlier results, where an increased content of sulphur increases the rate of reaction in the SCR, especially at low temperatures [15,16] agrees with this finding. At 340 °C the rates of formation of N_2O (r_4) increase by 41 % after 890 h and increase by 273 % after 2299 h from the value for the fresh catalyst. At 460 °C the rate increase after 890 h by 73 % and by 40 % after 2299 h. The lowest rate of formation of NO at 340 °C is observed on the fresh catalyst increasing by 242 % after 890 h and by a 833 % after 2299 h. At higher temperatures, the effects are smaller but except for the catalyst used for 2299 h where an increase by 382 % is observed.

The activation energies for the formation of N_2, N_2O, and NO all decrease when the catalyst is poisoned. The same effect has been observed before [11]. A decrease in the pre-exponential factor, proportional to the number of active sites, is also observed.

Efstathiou and Fliatoura [8] determined the apparent activation energy of 61.4 kJ mol^{-1} for the oxidation of 1000 ppm NH_3 with 2 % O_2 in Helium for an 8 % V_2O_5/TiO_2 catalyst from experimental rates. The rate of N_2 formation at 300 °C was $17.2*10^{-6}$ mol g^{-1} min^{-1} compared to the value in this study of $9.3*10^{-2}$ mol m^{-3} s^{-1} ($2.4*10^{-6}$ mol g^{-1} min^{-1}) at 340 °C. Their E_2 was 61.4 kJ mol^{-1} compared to the value in this study of 64 kJ mol^{-1}. The experimental rate data of Efstathiou and Fliatoura [8] were obtained on the powdered catalyst, but the particle size is not mentioned, so an estimation of diffusion influence is not possible. Taking into consideration that the data from this study are obtained on a layered monolithic catalyst, the activities are similar.

If we assume that, the reaction rate of reaction 2 is the same under SCR conditions as under NH_3 oxidation conditions, we can compare the values of Salehi et al. [18] to ours. They also simulated a monolithic structure with a catalyst layer. Their values of the pre-exponential factor and the activation energy for the formation of N_2 were 6.8*10^7 and 85 compared to the values of this study of 1.51*10^6 and 64 kJ mol^{-1}, respectively. Salehi et al. [18] also used first order in ammonia concentration for the rate of formation of N_2. A calculation of the rate r_2 at 340 °C from their data gives 0.256 mol m^{-3} s^{-1} compared to the value from this study of 9.3 *10^{-2} mol m^{-3} s^{-1} (Table 5). They are in the same magnitude.

Om et al. [19] studied, using Fluent, the SCR in a monolith isothermally. The concentrations of NO and NH_3 were in the range of 1000 ppm, so we believe that their simulation should have been non-isothermal for more precise results. Schaub's data [20] were taken from an experimental study on a catalytic filter consisting of very small catalyst particles, so the values should be close to intrinsic values. Their values of k_2 and E_2 were 6.73*10^7 and 85.4 kJ mol^{-1} while the values of this study were 1.51*10^6 and 64 kJ mol^{-1}, respectively (Table 5). Calculation of nitrogen formation rates at 340 °C from the data of Om et al. [19] gave a value of 0.049 while the value in this study was 0.093 mol m^{-3} s^{-1}. The rates are in the same range at this temperature. At 460 °C, their rate was 4.8, and the value of this study was 0.59 mol m^{-3} s^{-1}.

Chen and Tan [13] simulated a catalytic particle bed for the SCR process. In their simulation, the rate constant for the formation of N_2 from NH_3 by oxidation (k_2) was 6.73*10^7*exp(-84400/R/T). This study's result was a rate constant expression of 1.51*10^6* exp(-64000/R/T). Thus, at 460 °C the rate constants are 65 and 42 s^{-1} respectively, which is again in the same range.

Millo et al. [22] simulated the SCR on a filter catalyst for automotive applications. Besides the standard SCR, the fast and slow SCRs, the oxidation of NH_3 to N_2 was used as model reactions. The activation energy (E_2) was 144.6 kJ mol^{-1} again much higher than this study's value of 57 kJ mol^{-1}. Their rate expression was $r_2 = k_2'^* c_{NH3} {}^* c_{O2}$ and includes the dependence on the oxygen concentration making direct comparisons unsuitable. Their experiments also included water which would decrease the rate of all reactions.

4. CONCLUSIONS

In this study the of oxidation of ammonia with O_2 was simulated using COMSOL Multiphysics showing the three products N_2, N_2O and NO appearing at increasing temperatures. All reactions were of the first order in the concentration of NH_3. Apparent data show strong effects of the deactivation on the kinetics. The apparent activation energies decrease when the catalyst gets deactivated. The effects of the rate of formation of N_2 by poisoning is minimal if any. Both the formation of N_2O and NO show decreased activation energies when the catalysts are deactivated. Their pre-exponential factors decrease considerably too. All products of the oxidation of NH_3 with O_2 could be nicely represented in the simulation when the concentrations of N_2, N_2O, and NO were fitted. The concentrations of NH_3 and H_2O obtained by a mass balance in the simulation were not close to experimental values.

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RESEARCH ARTICLE

Biomass to liquefied petroleum gas cooking energy: A solution to indoor pollution ailments in Temeke Municipality, Dar-Es-Salaam

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ABSTRACT

In 2010 World Health Organization estimated that three people per minute die prematurely in Sub-Saharan Africa from diseases attributable to Indoor Air Pollution (IAP). About 95% of Tanzanians still use biomass cooking fuels (BCF) which is the main source of IAP. Promotion of Liquefied Petroleum Gas (LPG) was done since mid-2000s to substitute BCF. However, the use of LPG accounts for only 7.2% of Tanzanians to date. Therefore this paper examined factors influencing use of LPG in Temeke municipality - Dar-es-Salaam. Data were collected from 160 respondents using questionnaires and analysed by using Probit regression model. Results revealed that education level of a household head, household income and time saved for cooking had significant effect on use of LPG at a probability level of $P<0.1$. The probability of using LPG increased by 3.4% with an increase of one more year of education for household heads attaining formal education. Moreover, the probability of using LPGs increased by 11% among household heads whose monthly income increased by 1million Tanzanian Shillings (USD 409). Surprisingly, the probability of using LPG decreased by 0.2% as households saved an additional minute compared to using biomass fuels. It is recommended that the government, private sector and development partners promote LPG use through awareness creation; incorporating LPG use in education and energy policy and conducting research on 'value engineering of LPG cooking facilities' to reduce costs for users.

Keywords: Indoor air pollution, liquefied petroleum gas, Temeke Municipality, cooking energy, Dar-es-Salaam

1. INTRODUCTION

To date 38% of the world population equivalent to 2.8 billion people and almost 50% of population in developing countries have limited access to clean cooking fuel [1, 2]. Developing countries account for more than 80% of total world biomass fuel consumption [3]. In Tanzania the situation is even worse because about 95% of households continue using traditional biomass fuels. However 20% of the households in Tanzania use a mix of cooking energy sources including biomass fuel and other modern fuels like LPG and electricity [4].

The use of biomass fuel has not gone without effect. Prevalence of Indoor Air Pollution (IAP) diseases is associated with the use of biomass fuels [5]. WHO (2014) [6] estimated that 4.3 million people die prematurely worldwide from diseases attributable to IAP; that is equivalent to the death of 4 people in every minute. The diseases include pneumonia, stroke, ischaemic heart disease, chronic obstructive pulmonary disease and lung cancer (These diseases account for 13% and 44% deaths among children below five years and adults respectively [6-8]. The IAP diseases derived from solid fuels ranks the eleventh overall risk factor mortality that accounts for 2.6% of the global burden of disease [9] and ranks third leading cause of disability-adjusted life years in the globe [10].

International Energy Agency and World Health Organisation projected 1.5 million deaths per annum in Sub-Saharan Africa whereby 4,000 people will die every day in 2030 due to health complications related to In house Air Pollution [11]. Bukarasa, 2011 [12] associated the cough/fever with the biomass cooking fuel in the country. The author discovered presence of

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cough/fever to stand at 10%, 21.3% and 28.1% among households using kerosene, charcoal and firewood respectively in Tanzania. Furthermore, Msafiri, 2009 [13] discovered higher rates of Carbon Monoxide (CO) and Suspended Particulate Matters (SPM) of 325 $\mu g\ m^{-3}$ and 123,534 $\mu g\ m^{-3}$ in Tanzania that exceeds World Health Organisation (WHO) recommended rates of 30 $\mu g\ m^3$ and 150 $\mu g\ m^3$ respectively for households using biomass cooking fuels. The high rates of CO and SPM imply health risks associated with IAP for the public especially women and children who spend about 76% of their time in the house. In fact Ndambuki and Rwanga, 2008 [14] estimated occurrence of cancer to stand at 48 adult cases out of 606,676 if exposed to Lead pollutant for 20 hours per day for fifty years; and 12 cases out of 476,746 among children if exposed to Lead pollutant for 20 hours per day for 10 years compared to the acceptable risk of 1 case out of 1,000,000 people. Moreover, the carcinogenic risk of pollutant Lead was higher among children ($18X10^{-6}$) and adult ($78X10^{-6}$) than acceptable limit of $1 X 10^{-6}$. In Tanzania, indoor air pollution from cooking accounted for an estimated 18,900 deaths in 2011 [15] that is equivalent to 52 deaths per day.

In response to this life threatening situation, various initiatives have been in place to address the use of biomass fuels worldwide and Tanzania in particular. Organizations such as International Energy Agency (IEA) and World Liquefied Petroleum Gas Association (WLPGA) initiated campaigns and projects like Universal Modern Energy Access Case (UMEAC) project, Global Clean Cooking Fuels Initiatives (GCCFI) project, cooking for life and Sustainable Energy for All (SE4ALL) since 2011 through 2012 and 2013 [7, 16, 17]. These campaigns targeted to increase the use of Liquefied Petroleum Gas (LPG) to 100 Million households by 2020 equal to 55% increase from 2005; and one billion by 2030. These efforts would lower the level of carbon monoxide (CO), hydrocarbons and Nitrogen dioxide (NO_2) nineteen times than traditional biomass energy [6, 7]. The above mentioned initiatives have led to increased use of LPGs in Tanzania. The use of LPG as cooking fuels have increased about four folds from 24,470 tons in 2010, to 107,083 tons in 2016 [18, 19] that was used by 0.8% of households in 2011 compared to its use in 2016 which was used by 7.2% of households. However the significant increased utilization of LPG for cooking energy in the country has been outmatched with increased use of firewood that grew by 5% from 66.3% in 2011 to 71.2% in 2016; and the Tanzanian per capita usage of LPG (1.4 kg $year^{-1}$) that is still far below the Sub Saharan Africa consumption of 2.3 kg $year^{-1}$ and Northern African countries whose per capita LPG consumption stood at 55 kg per annum [18]. Moreover, this consumption is far below that of our neighboring Kenya that is four times of Tanzania LPG use [18] regardless of the massive population of 53 million people versus Kenya's population of 45.4 Million people) [21, 22].

Considerable studies have been done in the country's energy subsector [23-29]. While some studies has focused on impacts of substituting clean energy sources to traditional biomass energy [23-24]; others have focused on estimation of costs associated with substituting LPG to biomass fuels in urban households [25] and examining the role of donors on supporting development of efficient renewable energy in Tanzania [26]. Recently, substantial studies have been made towards fuel consumption patterns in different parts of the country [27-29]. However, the studies on energy consumption in the country were done in relatively less urbanised areas with more homogeneous socio economic profiles. This paper contributes to the existing knowledge base by investigating socioeconomic factors affecting the use of LPG in Temeke municipality located in Dar es Salaam Metro-Politan city; where there are residents originating from almost all parts of the country with different socio economic backgrounds that would influence the choice of cooking energy.

2. METHODS

2.1. Theoretical Framework

Conceptually, decision of households to use or ignore LPG for cooking rests on various elements. Income is the main factor that has been hypothesized through Energy Ladder Theory and Energy Stack Theory [30, 31, 32]. Empirical findings in the country and elsewhere in the globe suggest that demographic and socioeconomic factors such as education level, efficiency of the gas in terms of time served during cooking and costs of acquisition & operations influence the LPG use. Household demographic and economic drivers of LPG use include age, gender & marital status of household heads [33]. Moreover, legal and regulatory framework like subsidy, tax wavering, rules and regulations governing the LPG business have been identified as influencers of LPG consumption [33, 34] as they influence LPG's price and eventually the purchasing power of users. Finally, the market development with availability of LPG on time and accessibility were also associated with the use of LPG [33].

Probit regression model has been adopted in this paper over logit regression models as it can be generalized to account for non-constant error variances. However, it is acknowledged that both logistic regression analysis and probit regression models yield similar results such that there is no significant scientific difference between the two models in making inferences to population. In this paper, the decision of household to use LPG fuel in cooking was hypothesized to be a latent variable Y* given demographic and economic characteristics of each individual household as displayed in Eq. (1) and Eq. (2). If Y* is greater than zero, the probability of actual observation given alternatives outcome is equal to one and vice versa.

$$Pr\left[\left(\frac{Y_i^*}{X_i}\right) > 0\right] = \Pr(Y_i = \frac{1}{X_i}) \quad (1)$$

if ($Y^*/X_i > 0$) and

$$Pr\left[\left(\frac{Y^*}{X_i}\right) < 0\right] = \Pr(Y_i = \frac{0}{X_i}) \quad (2)$$

if ($Y^*/X_i < 0$)

1 indicates the use of LPG as a cooking fuel and 0 is for otherwise.

Y_i= Observable outcome.

In other words it can be explained that, if the probability of actual observation (Yi) given Xi, equals to one, the probability of latent variable is greater than zero. Vice versa is also true, such that Pr(Y_i=1,Y*/X_i<0) and Pr(Y_i=0,Y*/X_i<0).

Where Y_i, is given as Eq.(3),

$$Y_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \cdots + \beta_n X_n \quad (3)$$

Thus the Probit model for the case of this study is given as Eq. (4).

$$Y_i = \beta_0 + \beta_j X_i + \mu_i \quad (4)$$

Whereby;

X_i = is a raw matrix representing factors influencing LPG use among households

β_j= is a column vector representing association of marginal effects on LPG use and

μ_i= independently and normally distributed random error terms.

Therefore the Probit model for desired outcome (Y*>0) is expanded in Eq. (5) and for alternative outcome (Y*<0) is in Eq. (6) respectively as follows

$$\Pr\left(\left(\frac{Y^*}{X_i}\right) < 0\right) = Pr(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \cdots + \beta_n X_n) = 0/X_i \quad (6)$$

Whereby;

X_i= Represent a set of social economics features and demographic characteristics influencing the use of LPG for cooking.

β_j = Representing coefficients of marginal effects of Probit model on LPG use for particular individual household and his/her characteristics

μ_i = independently and normally distributed random disturbance (errors) term.

β_0 = Intercept, representing households use of LPGs while X_i hold constants

Where i and j representing 1, 2, 3……….Nth, as a randomness of individual household and his/her characteristics influence on LPG use respectively.

Empirically, the econometrics model is expressed as Eq. (7) below,

$$Y_i = \beta_0 + \beta_1 I + \beta_2 T + \beta_3 E + \beta_4 AT + \beta_5 F + \beta_6 AV + \beta_7 AV + \beta_8 S + \beta_9 G + \mu_i \quad (7)$$

Where,

Y = Dependent variable of either household use LPG or not

β_0 = intercept/constant parameters representing LPG use while other variables fixed.

β_1 = Marginal effects of households' income (I) on LPG use

β_2 = Marginal effects for a minute saving in time (T) on LPG use

β_3 = Marginal effects of households' level of education of household head (E) on LPG use

β_4= Marginal effects for a minute spent to access LPG (AT) on LPG use

β_5 = Marginal effects for unit change in family size (F) on LPG use

β_6 = Marginal effects of LPG availability (AV) on LPG use

β_7 = Marginal effects of household awareness (AW) on LPG use

β_8 = Marginal effects of gender of household head (S) on LPG use

β_9 = Marginal effects of age of household head (G) on LPG use

μ_i = Random stochastic (disturbance) term (error) term.

Table 1. Variables and their measurements

Objectives	Variable	Description	Measurements	Expected sign
Demographic characteristics	Age	Age of household Head	Years	-
	Gender	Sex of household Head	Male/Female	-/+
	Household size	Number of members of household	Number of People	-/+ -
Social Economic characteristics	Income	Income of household head	TZs	+
	Education level	Informal& formal	Years of schooling	+
	Time saving	Time used to prepare meal using LPG Vs charcoal	Minutes	+
Accessibility characteristics	LPG accessibility	Time used to LPG shop	Minutes	-
	LPG availability	Availability of LPG shop in street of residence	Available/not available	+/-

2.2. Data Collection and Analysis

The study employed cross sectional study survey design and the use of multistage sampling technique. At stage one, Dar-es-Salaam city was purposively selected since it is the metropolitan city of the country that hosts about 10% of the national population; and accounts for 70% of the national revenue collection for a period between 1997 and 2011 [35]. This indicates that the use of LPG would be based in DSM since its use is associated with higher incomes of people from the Energy Ladder Theory. Moreover, the 91% of the national LPG storage is located in DSM [18] that renders the gas easily available to consumers for its consumption.

At stage two, Temeke municipal was selected purposively as the study case due to the fact that the main LPG storage facilities are located in the municipal and refining processes are carried out within the municipal. Since 2007 Dar es Salaam port which is also located in Temeke municipal imports more than 95% of Petroleum products; whereby Kurasini Oil Jetty (KOJ) is the major receiving and refining petroleum products point in the country [18, 36]. At stage three, three wards of Temeke, Taongoma and Chamanzi were selected based on population size of the wards.

Primary data were collected with structured questionnaires to household heads or their representative (spouse or any adult daughter/son aged above 18 years). Although questionnaire was constructed in English, it was administered in Kiswahili by researchers. Appointments were made one day before the interview through ward officers and street representatives. Six streets of Matumbi, Temeke, Kongowe, Ponde, Msufini and Mwembebamia were randomly selected from each ward for the survey. Interviews were conducted at their homesteads during weekends since most of them were working far away from their homesteads in the city.

Descriptive statistics analysis was conducted with a focus on measures of central tendency and dispersion to depict features of respondents and LPG use as a cooking fuel in the study area. Moreover, Probit Linear Regression model "(7)" was employed to examine factors influencing the LPG usage among households. Then a number of tests were conducted to assess violations of basic assumptions of multiple linear regressions. Initially, the model specification error test was done by using Ramsey's test (Regression equation specification error test (RESET)). Given the results from RESET, the model was well specified. It was hypothesized that Ho: The model is well specified and Ha: The model is not well specified. A Link test command in (Statistical Analysis) STATA was used for model specification test and found that the probability of hat square (P>|t|) was 0.617 statistically insignificant at 10% level of significance. Therefore authors failed to reject the null hypothesis such that the model was well specified (Table 2).

Moreover, correlation and the volatility inflation factors (VIF) were used to test correlation and multicolinearity of variables respectively. However, neither multicolinearity nor correlation of variables were present because there were no variables whose VIF value was greater than 1.35, and mean VIF value was 1.21 (Table 3).

The correlation matrix showed the maximum correlation of 0.45 between LPG availability and LPG accessibility. In this regard correlation was less than perfect correlation (1) (Fig 1). So it was concluded that there was neither multicolinearity nor correlation of variables problems.

In addition to that, regression with standard errors robust was used to solve the heteroskedasticity problem. The probit regression with robust standard errors minimised standard errors and four variables became significant more than two variables that, were significant before using robust standard error. This signifies that, heteroskedasticity problem was causing large standard errors and insignificance of some variables. Income was transformed into natural logarithm to make somehow linear because had higher variations (Table 4).

Table 2. Linktest for model specification error test

LPG Use	coefficient	Standard errors	P. Value
Hat	1.085691	0.2674584	0.000
Hat square	0.0927219	0.1855415	0.617
constant	-0.0434388	0.2313056	0.851
Probit regression Linktest	Number of observations = 160		
LR chi^2 (2)	= 41.60		
Prob > chi^2	= 0.0000*		
Pseudo R^2	= 0.2694		
Log likelihood	= -56.414774		
* = significant at 1%,			

Table 3. VIF test for multicolinearity

Variables	VIF	1/VIF
LPG available	1.35	0.7405
LPG accessibility	1.32	0.7569
Age	1.31	0.7647
Income	1.25	0.8007
Gender	1.22	0.8227
Family size	1.20	0.8301
Education	1.15	0.8704
Time saving	1.09	0.9156
Mean VIF	1.21	

	LPGuse	Age	sex	family~e	Edulevel	income	LPGAvail	LPGacc~s	Tsaving
LPGuse	1.0000								
Age	-0.0653	1.0000							
sex	-0.0303	0.2939	1.0000						
familysize	-0.0522	0.3381	0.1007	1.0000					
Edulevel	0.2626	-0.1772	0.1611	-0.0578	1.0000				
income	0.0472	0.1143	0.2586	0.2257	0.1864	1.0000			
LPGAvail	0.0605	-0.1008	0.1063	-0.0611	0.1413	0.1473	1.0000		
LPGaccess	-0.0967	0.0330	-0.0894	0.1014	-0.0580	-0.1713	-0.4540	1.0000	
Tsaving	-0.1007	-0.0238	0.0427	0.0300	-0.0617	0.1960	0.1699	-0.0173	1.0000

Fig 1. Correlation matrix

Table 4. Estimated coefficients with robust standard errors

Variables	Coefficients.	Robust Std. Err.	P > [Z]
Age	0.0022	0.0102	0.8320
Gender	-0.4943	0.4505	0.2730
family size	-0.0530	0.0435	0.2240
Edulevel	0.1474	0.0453	0.0010*
Time saving	-0.0103	0.0064	0.1060***
lnIncome	0.4964	0.2687	0.0650**
LPG Accessibility	-0.0031	0.0162	0.8460
LPG Availability	0.0901	0.3260	0.7820
_cons	-8.1114	3.3866	0.017
Number of observation			160
Wald $chi^2(9)$			30.46
Prob > chi^2			0.0004*
Pseudo R^2			0.2677
Log pseudolikelihood			-56.541002

3. RESULTS AND DISCUSSION

The study revealed that only 19% of respondents in the study area used LPG cooking fuel. The rest (81%) - were cooking with other energy sources. The low use of LPG for cooking can be associated with the risk perception on the energy that is unsafe. LPG cooking facility ranked the second unsafe fuel with 40% of respondents after electricity that accounted for 50% of the interviewed respondents. Firewood and charcoal were perceived safe since only 7.5% and 1.9% perceived them as dangerous cooking fuel types. However, proportion of households using LPG in the study area is relatively higher than the country statistics reported to account for only 7.2% [38, 39]. The difference might be attributed with the fact that the study was done in the urban areas where incomes of people are relatively high compared to overall country residents that would allow higher usage of LPG. Moreover, importation of LPG was first landed in the study area such that its price would be relatively cheaper due to the reduced transport costs.

Table 5 portrays demographic characteristics of respondents in the study area. The table shows that young headed families accounted for most users (66.6%) of LPG. The pattern indicated the negative association between age and the use of LPG. This would be due to the fact that young are ready to test the new things compared to the old. Similar results were found by Thadeo, 2014 [27] who discovered that 73.7% of LPG consumers are aged between 26 and 40 years old.

Furthermore, the study revealed presence of negative association between household size and LPG consumption since households with size 1-5 members accounted for 70% of all LPG users compared to households with more than 5 members (Table 5). The inverse association would be attributed by the fact that as household size increases burden of living also increase to reduce purchasing power of household heads such that they look for cheaper fuel sources biomass fuels. These findings are similar to results from other studies in the country [36] and elsewhere in Sub Saharan Africa such as [40] in Ghana; [41] in Uganda and [42] in Kenya.

Table 6 Shows results on the univariate analysis of socioeconomic factors influencing household LPG consumption. Households whose heads had primary and secondary education dominated consumption of LPG in the study area as they accounted for 40% each. The heads of households with tertiary education accounted for 16.7%. This could be attributed to the fact that most of Tanzanian population is dominated with people with primary followed by secondary school education. This implies that LPG is used by various groups in the society; hence any efforts geared towards promotion of consumption of LPG would yield significant results on lowering IAP associated diseases.

The income of households using LPG fuel was increasing with increasing of LPG use compared to households which do not use LPGs. When income rises between 300,000 to 700,000, the households which use LPG were 36.7% significantly bigger than 31.5% households of the same income which were not using LPG. Again 3.3% is bigger than 3.1% for households with the same income above 700,000 TZs. The results conform to the energy ladder theory which proposes as households income rises, switches from inefficient traditional cooking fuels to the most efficient modern fuels such as LPG and electricity.

Among households that were using LPG, 60% reported to save up to 30 minutes when compared to traditional charcoal fuels per meal than 53.1% who were not using LPG. Moreover 40% of LPG users reported to save a maximum 60 minutes than 38.5% that were not using LPGs. This implies that, households which use LPG used less time compared to the ones that were using charcoal fuels. Similar findings were reported by [2] that, women prefer cooking with LPG to traditional fuels because it saves up to two hours a day.

Results in Table 7 show accessibility of LPG in the study area. About 93% of household who were using LPG were able to access it within 15minutes walking time, while seven per cent accessed LPG within 16 to 30 minutes. This indicated that, accessibility for LPG is not a limiting factor for its use since it was almost found nearby shops in the study area. Similarly Kilahama [44] found that, about 67% of the respondents were using charcoal fuels in Dar es Salaam because it was accessible within five (5) minutes from their homes.

About 50% of households who used LPG reported that, the gas was available in their streets while 42% who did not use LPG reported the same.

Table 5. The analysis of demographic characteristics on LPG use

Characteristics	Categories	Non-Use LPG		Use LPG	
		Frequency	%	frequency	%
Age	18-40 Years	86	66.2	22	73.3
	41-60 Years	34	26.2	7	23.3
	above 60 Years	10	7.7	1	3.3
Total		130	100	30	100
Family Size	1 – 5	92	70.77	21	70
	6 – 10	30	23.1	8	26.7
	Above 10	8	6.2	1	3.3
Total		130	100	30	100

Table 6. Distribution of LPG users in the study area

Characteristics	Categories	Not Use LPG		Use LPG	
		frequency	%	Frequency	%
Education	Informal Education	1	0.8	1	3.3
	Primary Education	93	71.5	12	40.0
	Secondary Education	33	25.4	12	40.0
	Tertiary Education	3	2.3	5	16.7
Total		130	100	30	100
Income	80,000 -300,000	85	65.4	18	60.0
	300,000 -700,000	41	31.5	11	36.7
	>700000	4	3.1	1	3.3
Total		130	100	30	100
Time Saving	1 - 30 min	69	53.1	18	60.0
	31- 60 min	50	38.5	12	40.0
	Above 60 min	11	8.5	0	0
Total		130	100	30	100

Table 7. The analysis of LPG accessibility characteristics on LPG use

Characteristics	Categories	Not Use LPG	Use LPG		
		frequency	%	Frequency	%
	Less 15 min	100	76.9	28	93.3
Accessible Source	16 - 30 min	28	21.5	2	6.7
	31 - 45 min	2	1.5	0	0
Total		130	100	30	100
LPG Availability	Not available	75	57.7	15	50
	Available	55	42.3	15	50
Total		130	100	30	100

3.1. *Estimation of Parameters and Post Estimation Tests*

Once parameters of the model were estimated with probit regression using Statistical Analysis (STATA) software program, only one variable (education) was statistically significant at 5% level of significant (Table 8). This prompted authors to test for violations of regression assumptions.

Table 9: Various tests for assumptions were done as clearly discussed in section three: data collection and analysis. Finally, the findings were based on Marginal effects of Table 9 as marginal effect gives the direct probability values of the predictor variables to the predicted variable in probit regression than coefficients parameters does. Therefore an additional insight is provided by analysing the marginal effects which is calculated as the partial derivatives of the non-linear probability function (dy/dx), evaluated for each variable sample mean given the objectives of the study.

The results in Table 9 reveal that level of education to have positive influence on LPG Use at 1% significant level. The probability of using LPG increased by 3.4% with an increase of one more year education for household head attaining formal education. This implies that increase of LPG use as a cooking energy can be attained through promoting more people to attain higher levels of education. This pattern can be associated with the fact that as people attain higher levels of education become aware of the hazards derived from usage of biomass fuel; and so opt alternative clean energy. The results are similar to the findings by [44] in India; [45] in Ethiopia; [46] in Kenya and [47] in Nigeria who also uncovered positive association between education levels and the use of cooking clean energy.

Table 8. Probit Regression before standard error robust

LPG Use	Coefficients	Standard errors	P. Values
Age	0.0021656	0.010788	0.841
Gender	0-.4942867	0.4175677	0.237
Household size	-0.0529795	0.0609838	0.385
Education	0.147438	0.0489108	0.003*
Time saving	-0.0102919	0.0074363	0.166
LnIncome	0.496432	0.3149989	0.115
LPG Accessibility	-0.0031421	0.022084	0.887
LPG availability	0.0901329	0.313859	0.774
Constants	-8.111426	3.949429	0.040

Probit regression   Number of observations = 160
LR chi^2 (9) = 41.34
Prob > chi^2 = 0.0000
Pseudo R^2 = 0.2677
Log likelihood = -56.541002
* = significant at 1%

Table 9. Output of marginal effects

Variables	Marginal eff.	z	Robust Std. Err.	P > [Z]
Age	0.0005	0.2083	0.0024	0.8320
Gender	-0.0944	-1.3923	0.0678	0.1630
family size	-0.0122	-1.1961	0.0102	0.2320
Edulevel	0.0340	3.4343	0.0099	0.0010***
Time saving	-0.0024	-1.7143	0.0014	0.0930**
lnIncome	0.1144	1.8392	0.0622	0.0660**
LPG Accessibility	-0.0007	-0.1892	0.0037	0.8460
LPG Availability	0.0209	0.2743	0.0762	0.7840

***, **, and * = significant at 1%, 5% and 10%, respectively

Furthermore Table 9 portrays that incomes of household heads had positive effect on LPG use at 10% statistically significant level. The results indicated that probability of using LPGs increased 11% among household heads whose monthly income increased by 1million Tanzanian shillings (USD 409) provided that other factors remained constant. Therefore efforts towards rising people's income would lead to substitution of cheaper biomass cooking fuels by LPG. This can be done through tariff exemptions to LPG canals, and/or subsidization of the LPG to increase the purchasing power of users. This result is in line with the finding by Arogo [46] in Kenya that households spending promotes households to switch to the use of modern energy (electricity and solar) over wooden fuels and kerosene.

Meanwhile Table 9 shows that time saving had negative influence on LPG Use at 10% statistical significant levels. Suprisingly, probability of using LPG were decreasing as household save additional minute from cooking with LPG over charcoal fuels by 0.24 %. The results differ from the expectation and general rule of wisdom. The results implies that time saving is not the only fact considered by LPG users; but rather the perception risk among the society. This was revealed by the fact that 40% of respondents perceived LPG as the riskiest cooking fuel followed by electricity. The result was similar to findings by Kilabuko and Nikai [48] who found that 80% of the respondents in Dar es Salaam faced the challenge to abandon charcoal fuels despite cooking with LPG were saving time than charcoal fuels. However, the result is contrary with that of [2, 49] who found that time saving was the motive drive for households to use LPG over traditional biomass fuels in third world developing countries and India respectively.

4. CONCLUSIONS

Based on the findings of the study it can be established that the key driving factors for consumption of LGP in Temeke Municipality, Dar-es-Salaam can be grouped into two categories. The first category is to do with risk perception where there is fear that LGP gas can cause hazardous explosions when used for cooking. This perception is linked with limited level of education and older age. So the greater the age with limited level of education the more the perceived risk of using LGP gas for cooking. The second category of driving factors is the level of income. The higher the income the higher the consumption of LPG gas at household level. This is also linked with family size where the income level seems to be affected by the energy demands of the family size. The bigger the family size the greater the demands for basic needs that lessen ability to afford LPG at a given fixed level of income. It is also a fact that most users of biomass energy for cooking are low income earners.

In order to increase consumption of LPG gas at household level; five initiatives need to be done by various stakeholders as a solution for in-house air pollution associated ailments.

First, undertaking of LPG user knowledge campaign on its benefits over biomass fuels is critical to harness the negative perception of current and potential users on the risks of its use in their homesteads. Would the use of LPG be well articulated and adopted, it could serve as a tool to lessen diseases that are attributed to In-house Air Pollution that are more prevalent among children and mothers.

Secondly, adding practical lessons in the curriculum at primary and secondary school levels on the use of LPG for cooking would also help because it matches well with the findings of the study that those with low level of education perceive that there is a high risk of using LPG for cooking.

Thirdly, at policy level the government needs to consider special attention and commitment in promotion of use of LPG at household level. This needs to be incorporated in the energy policy and programmes where objectives and targets regarding LPG promotion should be clearly articulated. This includes the incorporation of LPG use for cooking in the primary and secondary schools curricula and devising an LPG subsidy mechanism to reduce cost of acquiring gas packaging facilities, cookers and the gas itself for low income households. This is against the background of the existing national energy development policies. For example, the Five Year Development Plan II (2015/16 – 2020/21) advocates for promotion of LPG to be done through the development of policy and institutional capacity [50]. However, the National Energy Policy 2015 has put more emphasis on electricity generation such that LPG promotion is not well articulated with clear objectives and targets. Moreover, even in the previous energy programmes and strategies such as EWURA strategic plan 2012/13 – 2016/17 LPG for household use did not receive special attention.

Moreover, the limited attention to LPG prevailed further even in the programmes that came later such as the Power Master Plan 2016 [50] and EWURA strategic plan 2017/18 – 2021/22 [51] where there are no specific objectives for promotion of LPG as cooking energy at household level.

Lastly but not least there are two areas that need attention for further research. First, further research needs to be done on Demand and Supply of the LPG gas for cooking at national level. Currently there is limited information as to how much LPG gas is demanded for cooking at household level and how much is supplied. It is hard to establish whether there is demand gap or a supply gap exists. Information from such studies will be useful to establish the level of promotion required if the demand is short of supply or the supply is short of demand. This will build up a good basis for promotion of the cooking energy by various stakeholders ranging from the government, the private sector, Non-governmental organizations to other development partners as they strive to save lives of people from indoor air pollution ailments.

Another potential area for further research is value engineering of LPG gas facilities. This is to do with finding out possibilities of reducing cost of packaging materials of the gas or increasing efficiency of cookers by cooking more foodstuffs by using less amount of gas.

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RESEARCH ARTICLE

Adsorption of Acid Blue 25 on peach seed powder: Isotherm, kinetic and thermodynamic studies

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ABSTRACT

In the present study peach seed powder (PSP) was used as an adsorbent to remove Acid Blue 25 (AB25) a common basic dye, from aqueous solution. The adsorption experiments were carried out in a batch system and the effects of initial concentration, interaction time and temperature were investigated. The Langmuir, Freundlich and Temkin adsorption isotherms were used to model the equilibrium data. The kinetic parameters were determined by the pseudo first order (PFO), pseudo second order (PSO) and intra-particle diffusion (IPD) models. According to the results, the Freundlich isotherm model is a more convenient option compared with the Langmuir and Temkin models. The Freundlich model coefficients increased as the temperature increased, which shows that the adsorption process becomes more favorable with higher temperature. The experimental and calculated q_e values close to one another indicated that this process fits the PSO kinetic model with higher R^2 values than the other two models. Kinetic constants become closer to both the temperatures and initial concentrations and q_e values increases with the increasing concentration of AB25. The initial dye concentration increased from 25 to 150 mg L^{-1}, while the dye adsorption capacity onto PSP increased from 4.80 to 39.01 mg g^{-1}, from 5.57 to 44.27 mg g^{-1} and from 6.80 to 49.22 mg g^{-1} for 298, 308 and 323 K, respectively. The monolayer adsorption capacity (q_m) of PSP was determined to be 56.18, 64.94, 95.24 mg g^{-1} for 298, 308 and 323 K, respectively. Thermodynamic parameters for free energy (ΔG), enthalpy (ΔH) and entropy (ΔS) of the separation process were determined as -1737,1 J mol^{-1}, 14.776 kJ mol^{-1} and 55,413 J mol^{-1}, respectively. The negative values of ΔG^o showed that this separation process was endothermic and natural. The results of the present study demonstrated that PSP can be used as an alternative material in dye removal.

Keywords: Peach seed powder, dye adsorption, isotherm models, kinetic constants, acid blue 25, thermodynamic parameters

1. INTRODUCTION

Dyes are chemical compounds which bond to surfaces or fabrics to change their colors. As they are complex organic molecules most dyes are resistant to many factors such as the effects of detergents. Dyes can be obtained from different sources and they are commonly used in many sectors [1–6]. These dyes used in ground water tracing for the determination of specific surface area of the activated sludge sewage and wastewater treatment as well [7-9]. The discharge of dyes, especially synthetic dyes into the hydrosphere causes a significant amount of pollution as a result of their recalcitrant nature. Their discharge will also result in an undesirable color in the water body leading to a decrease in sunlight penetration and resisting photochemical and biological attacks to aquatic life [10]. According to up-to-date data, more than 105 commercial dyes are produced at a rate of 7 × 105 tonnes year^{-1} [11]. It is known that more than 10,000 tonnes of dyes used annually worldwide and around 100 tonnes year^{-1} of dyes are released into the environment [12]. However, it is still unknown exactly how much dyes are discharged into the environment as a result of various processes. Nevertheless, the discharge of synthetic dyes has posed many challenges for environmental scientists. It has been reported that synthetic dyes have specifically caused allergies, dermatitis, skin irritations, cancer and mutations in humans [13]. Due to these harmful effects it has

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become imperative to remove dyes from aqueous solutions.

There are various methods are used to remove dyes from wastewater [14-15]. Adsorption is an effective wastewater treatment process used to remove hazardous inorganic/organic pollutants that are present in the effluent [16]. Many textile industries utilize commercial activated carbon to treat dye waste. The aim of the present study was to create an alternative to activated carbon as a cost effective but potential adsorbent. Adsorbents obtained from natural materials, agricultural by-products, industrial wastes and biosorbents has been reported as a feasible option by many researchers [17]. These researchers applied types of physical or chemical treatments to various raw biomass adsorbents to improve their adsorption capacity [18].

Dyes can be divided into different groups and classes depending on their source, general structures and fiber type. Synthetic dyes can be categorized as: non-ionic dyes, cationic dyes and anionic dyes [19-20]. Acidic dyes have been commonly utilized for dyeing leather, silk, polyamide, wool, as well as in industries such as cosmetics, paper, food, and ink-jet printing. The main categories of the acidic dyes are anthraquinone, azo dyes, triphenyl methane, azine, xanthene, nitroso and nitro. Due to their fused aromatic rings, anthraquinone dyes are especially resistant to degradation. In addition, more care and attention must be given to their removal process [21]. AB25 an anthraquinone dye is widely used in detergents, wood, fur, wool, ink, silk, nylon, paper, biological stain and cosmetics. AB25 and other anthraquinone based dyes are resistant to degradation and preserves color for a longer period of time [22]. Due to their toxic effects, dyes have raised concerns relating to their use. They have been found to induce chromosomal fractures, carcinogenesis, mutagenesis and respiratory toxicity. In relation with these detrimental effects, it is extremely important to remove AB25 from aqueous solution [23]. Many adsorbents such as, activated carbon and unmodified and modified biosorbent species have been investigated for the adsorption of AB25 from aqueous solutions. However most of them were not found to be enough efficient [24].

Adsorption kinetics, thermodynamic and equilibrium data are required for the development of an effective design model for the removal of pollutants from aqueous solutions. The isotherm model is considered to be efficient as it provides information regarding the theoretical maximum adsorption capacity and possible interactions between the adsorbents and adsorbate. Various isotherm models including the Langmuir, Freundlich and Temkin models have been commonly used [25]. According to the Langmuir isotherm, all binding sites have equal affinity for the sorbate, which results in a monolayer of the adsorbed molecules [26]. Freundlich isotherm mainly describes adsorption onto heterogeneous surfaces which provide the adsorption sites of different affinities [27]. Temkin isotherm indicates the interaction of solute molecules in the aqueous phase with heterogeneous solid surface [25].

Kinetic studies are of great importance for the determination of the optimum conditions in full scale batch adsorption processes. Kinetic modeling provides information regarding adsorption mechanisms and possible rate controlling steps including mass transport or chemical reaction processes [28]. PFO, PSO and IPD models are the most prevalent kinetic models for explaining the adsorption mechanism [29].

Thermodynamic studies are carried out to determine the adsorption spontaneity, the nature of the adsorbent and adsorbate at equilibrium conditions. Through thermodynamics the temperature range in which adsorption will be favorable or unfavorable can be determined. The primary thermodynamic parameters are as follows; adsorption enthalpy (ΔH) and entropy (ΔS), change of Gibbs energy (ΔG). These parameters can be measured by fitting the data obtained by the adsorption experiments at different temperatures [30].

In the present study, the adsorption performance of peach seed powder (PSP) for AB25 was investigated. Various effective parameters including dye concentration and temperature were examined on the removal of AB25. This dye was selected as the adsorbate as it is one of the most widely used dyes. For this aim, kinetic studies using PFO, PSO and IPD models, isotherm studies using Langmuir, Freundlich and Temkin equations and thermodynamic studies were performed for the AB25 adsorption on PSP.

2. MATERIALS AND METHOD

2.1. Adsorbent (Peach seed powder)

The experiments were conducted with peach seed powder (PSP) from Prunus persica grown in the province of Van, in Turkey. The collected peach seeds were washed with deionized water several times and dried at room temperature for 24 h. The seeds were crushed by using a high-speed cutting machine and cut into small pieces in size. The obtained powder was sieved and particles below 150 μm were collected for the adsorption experiments.

2.2. Adsorbate (Acid Blue 25)

AB25 an acidic dye, was used as the adsorbate in this study. The formula of AB25 is $C_{20}H_{13}N_2NaO_5S$ and it has a molecular weight of 416.38 g mol^{-1}. The powdered dye was purchased from Merck Chemicals, dark blue in color and it was used without further purification. The required concentration of the solutions used in the adsorption process was prepared to the stock solution of AB25 with deionized water to obtain the suitable solution concentrations.

Sulfuric acid (H_2SO_4) 95-97%, A.R grade, sodium hydroxide (NaOH) pallets 98.5% A.R grade were purchased from Merck Chemicals. The other reagents were A.R. grade and used as received.

2.3. Adsorption experiments

In the batch experiments conducted in a temperature controlled water bath, 2 g PSP was treated with 500 mL of the dye solution. Different initial AB25 concentrations (25, 50, 75, 100, 125 and 150 mg L^{-1}) were used for 200 min while the pH was adjusted by adding H_2SO_4 or NaOH solutions (0.1 M). All experiments were conducted in triplicate under the same conditions which were applied for the 298, 308 and 323 K temperatures and the average values were taken to represent the result with all data being considered.

The concentration of MB in solution at a maximum absorption wavelength of 660 nm was evaluated by using UV/VIS spectrophotometer (PG Instruments Ltd, T80 model). A calibration curve was obtained by plotting among absorbance and certain concentrations of the solution. Unknown MB concentration was measured using a calibration curve. The dye adsorption capacity on the adsorbent was analyzed as:

$$q_e = \frac{C_0 - C_e}{W} V \quad (1)$$

where V is the solution volume (L), C_0 and C_e are initial and the equilibrium concentration of the dye (mg L^{-1}) respectively and W is the adsorbent mass (g). Finally, the data obtained from this study were confirmed by fitting in the isotherm, kinetic and thermodynamic relationships for the AB25 dye removal using PSP.

3. RESULTS & DISCUSSION

3.1. *Effect of interaction time and initial dye concentrations on adsorption*

Contact time is an important physical parameter used for plan and operating wastewater treatment plants. As seen in Fig 1-3, the removal of AB25 from the solutions was rapid at the initial period and the velocity at the final period that near the reach of the balance decreased. The surface of the adsorption process was large in the beginning, and thus the adsorption on this surface was fast. In the dye adsorption, the equilibrium time was determined as 120 min for AB25 removal from the solutions.

It can be seen from Fig 6-8 that the rise at the initial concentration of AB25 caused an increase in adsorption capacity for three temperatures, respectively. As the initial dye concentration increased from 25 to 150 mg L^{-1}, the adsorption capacity of the dye onto PSP increased from 4.80 to 39.01 mg g^{-1}, 5.57 to 44.27 mg g^{-1} and 6.80 to 49.22 mg g^{-1}, respectively. These results show that the initial concentration is an important parameter in the dye adsorption capacity and provides a driving force for the interaction between the PSP and AB25. Furthermore, an increase in the initial concentration induces an increase in the removal amount of the dye. Based on the experimental results the maximum dye adsorption rate was obtained with 150 mg L^{-1} initial dye concentration. In the present study, AB25 adsorption on PSP has similarity. Previously reported results from various researchers were available for AB25 adsorption on different adsorbents and biosorbents such as; rubber leaf powder [2], sepiolite [3], lychee peel waste [5], activated carbon [14], diatomite [16], cempedak peel [28], soya bean waste [29], tarap peel and water lettuce [30]. As a result of the comparison of the results of the present study with other studies in literature, the dye adsorption capacity of PSP was found to be good and PSP may be a novel material to be used as an inexpensive adsorbent for dye removal.

3.2. *Adsorption isotherm studies*

Various models were used to identify the dye adsorption on solid surfaces in this study. For the interaction between the adsorbate molecules and adsorbent surface investigations, three isotherm models (Freundlich, Langmuir and Temkin) were chosen to endeavor to simplify the interactions between dye and adsorbent in the present study. Three models were applicable for the descriptions of the experimental results obtained at three different temperatures. The parameters of these isotherm models were calculated by regression using the linear form of isotherm equations [1, 2].

The amount of AB25 adsorbed by per unit of adsorbent and the equilibrium concentrations for three temperatures are presented in Fig 4. The adsorption efficiency increased with increasing initial AB25 concentration.

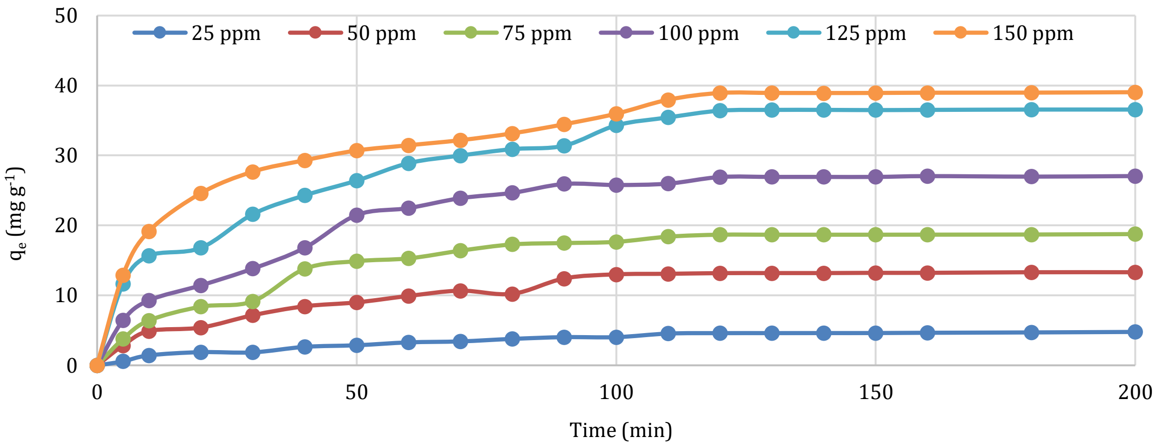

Fig 1. Effect of interaction time and initial concentration on AB25 removal at 298 K

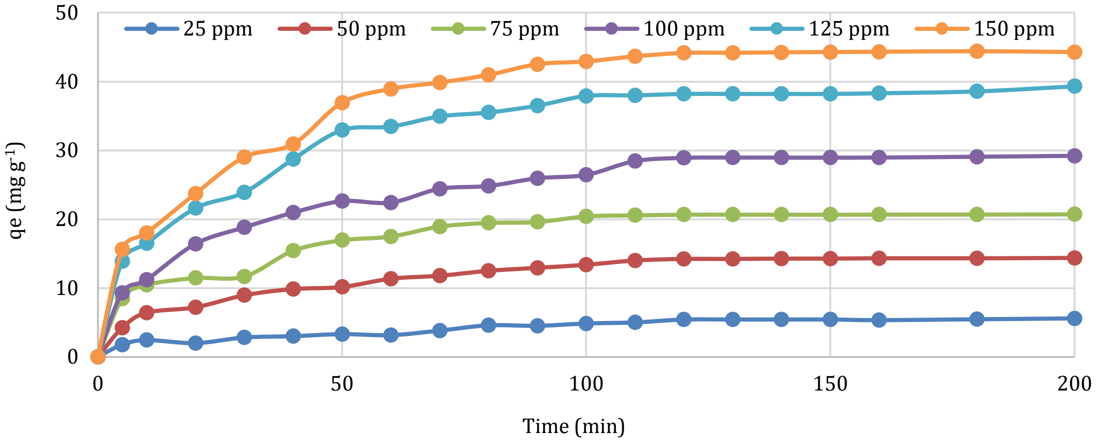

Fig 2. Effect of interaction time and initial concentration on AB25 removal at 308 K

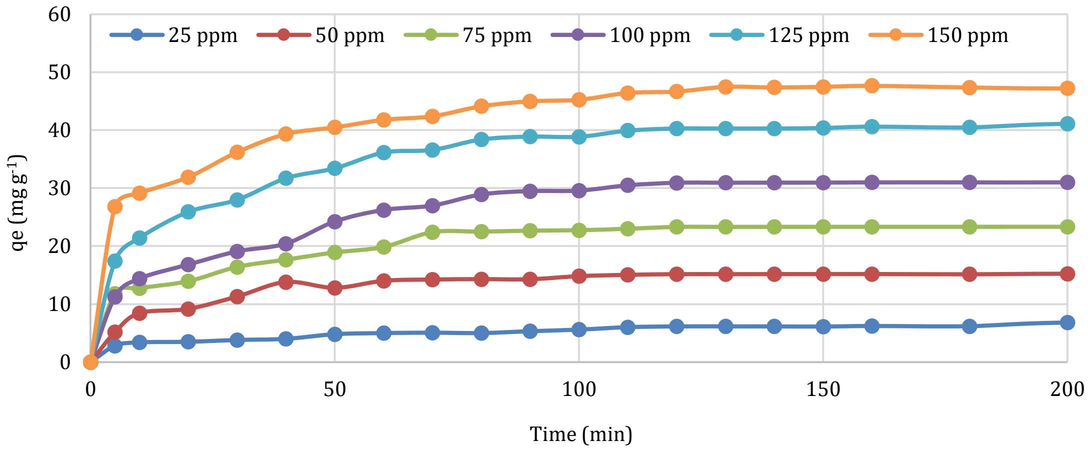

Fig 3. Effect of interaction time and initial concentration on AB25 removal at 323 K

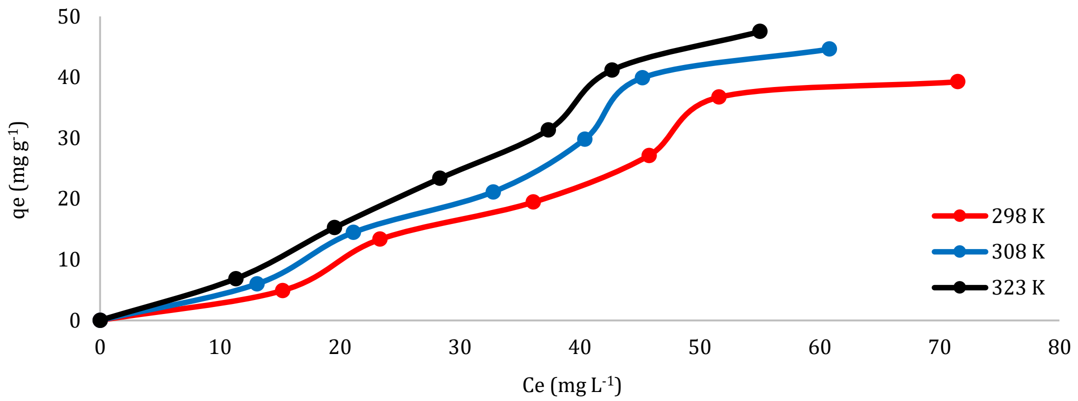

Fig 4. Adsorption isotherms for AB25 on the PSP for different temperatures

Langmuir isotherm has some assumptions for adsorption on a homogenous surface and no interaction between the adsorbates in the plane of the surface. The Langmuir isotherm equation is given with Eq. (2);

$$\frac{C_e}{q_e} = \frac{K_L}{q_{max}} + \frac{C_e}{q_{max}} \quad (2)$$

where q_{max} denotes the maximum capacity of adsorption (mg g^{-1}), C_e represents the equilibrium concentration of the solution (mg L^{-1}), K_L is a Langmuir constant associated with the affinity of the binding sites and energy of adsorption (L g^{-1}). The q_m and K_L values are determined from the slope and intercept of C_e/q_e versus C_e graph. The coefficients of determination R^2 of the Langmuir equation demonstrate that the adsorption onto PSP tracks and isotherm results of AB25 adsorption on PSP for 298, 308 and 323 K gives at Fig 5.

Freundlich isotherm which is an empirical model is based on adsorption on a heterogeneous surface and this isotherm equation is given with Eq. (3);

$$lnq_e = lnK_F + \frac{1}{n} lnC_e \quad (3)$$

where K_F is a Freundlich constant linked to adsorption capacity (L g^{-1}), $1/n$ is an empirical parameter connected to adsorption intensity. The K_F and n values were determined from the intercept and slope of the plot between lnq_e against lnC_e, respectively. The Freundlich isotherm results of AB25 adsorption on PSP for 298, 308 and 323 K are given at Fig 6.

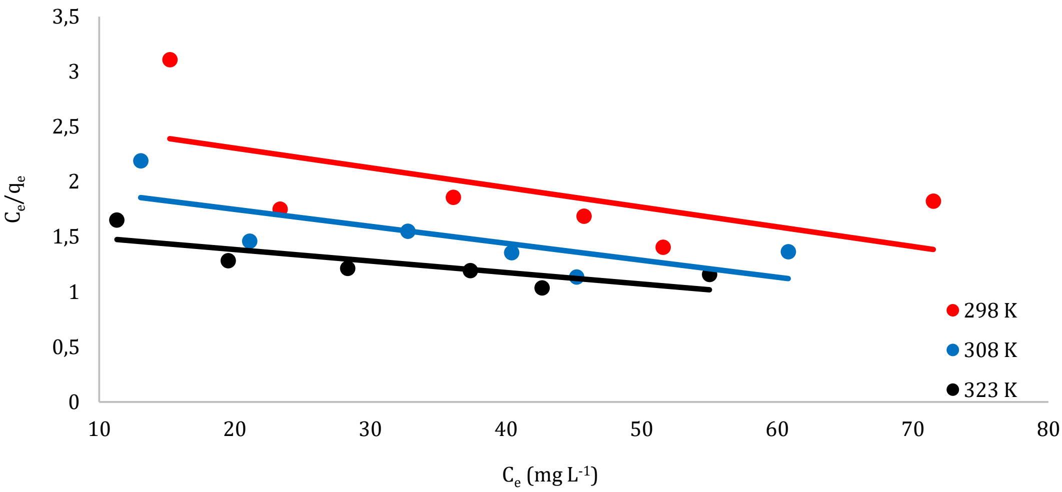

Fig 5. Langmuir isotherms of AB25 adsorption on PSP for different temperatures

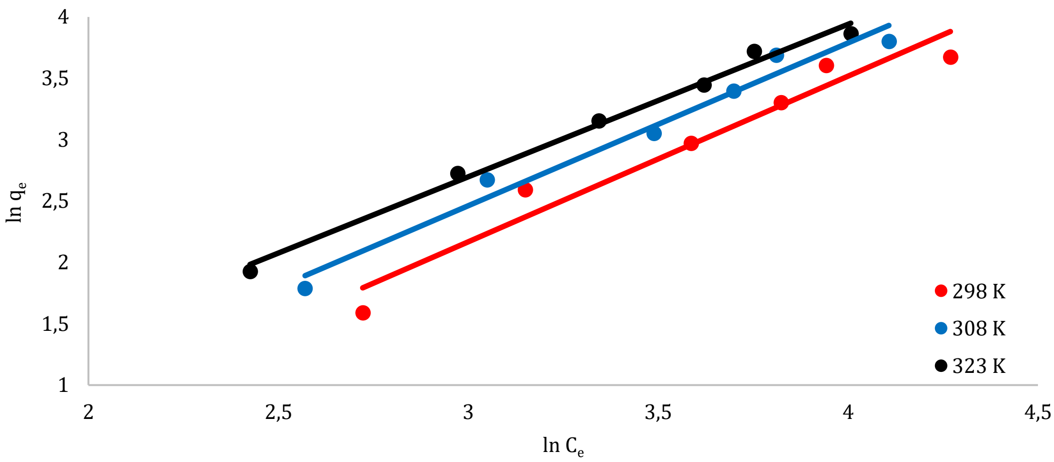

Fig 6. Freundlich isotherms of AB25 adsorption on PSP for different temperatures

Temkin isotherm refers to the interaction of solute molecule from aqueous phase with heterogeneous solid surface. This isotherm is based on the concept that the heat of adsorption decreases on the covering of solid surface. Temkin equation used to calculate the isotherm parameters is given with Eq. (4);

$$q_e = \frac{RT}{b_T} lnK_T + \frac{RT}{b_T} lnC_e \quad (4)$$

where K_T and b_T are related to the binding energy and heat of adsorption, respectively and can be obtained from the slope and intercept of q_e versus lnC_e plot. Temkin isotherm results of AB25 adsorption on PSP for 298, 308 and 323 K are given in Fig 7.

The calculated parameters of the Langmuir, Freundlich and Temkin isotherms for the adsorption of AB25 on PSP are presented in Table 1. Regarding the coefficients determined, the Freundlich model is more fitting than the Langmuir and Temkin models. It should be noted that the K_F and n values increased as the temperature increased and the adsorption is approving at higher temperatures. The R^2 values of these three isotherm models were high, while the R^2 values of the Temkin model were higher than the other model values for PSP. The monolayer adsorption capacity (q_m) of PSP was determined to be 56.18, 64.94, 95.24 mg g^{-1} for 298, 308 and 323 K, respectively. The maximum adsorption capacity (q_m) was calculated with the Langmuir isotherm model for different adsorbents towards AB25 given in Table 2, and different adsorbents such as agricultural, industrial wastes towards AB25 were given in [3, 4].

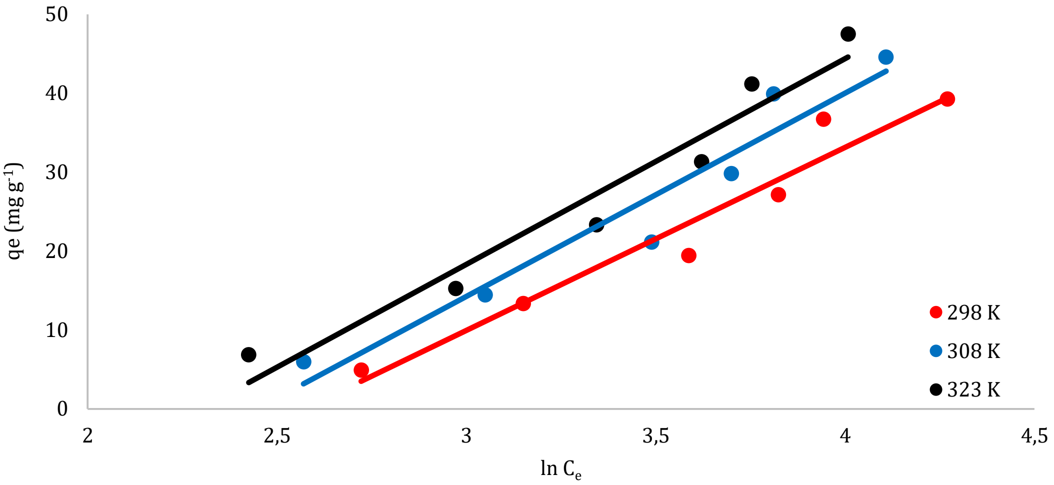

Fig 7. Temkin isotherms of AB25 adsorption on PSP for different temperatures

Table 1. Isotherm model parameters of AB25 adsorption on PSP at different temperatures

Temp	Langmuir			Freundlich			Temkin		
(K)	KL (L g^{-1})	q_m (mg g^{-1})	R^2	KF (L g^{-1})	n	R^2	KT (L g^{-1})	bT (J mol^{-1})	R^2
298	0,0668	56,179	0,371	0,1526	0,7413	0,947	0,0764	106,787	0,908
308	0,0748	64,935	0,537	0,2193	0,7541	0,973	0,0865	99,333	0,934
323	0,0658	95,238	0,631	0,3565	0,8046	0,991	0,1006	103.000	0,948

Table 2. Maximum adsorption capacity of AB25 on various adsorbents

Adsorbent	q_m (mg g^{-1})	References
Rubber leaf powder	28.09	[2]
Natural sepiolite	56.53	[3]
Shorea dasyphylla sawdust	24.39	[4]
Ficus racemosa dead leaves	83.33	[6]
Egg shell modified activated carbon	109.80	[14]
Soya bean waste	38.30	[29]
Azolla pinnata	50.50	[29]
Hazelnut shell	60.21	[31]
Sawdust walnut	36.98	[31]
Sawdust cherry	31.98	[31]
Sawdust oak	27.85	[31]
Sawdust pitch pine	26.19	[31]
Peach seed powder	95.24	This work

3.3. Temperature and adsorption thermodynamics

The effect of the temperature on AB25 adsorption was investigated through the experiments performed with three different temperatures and the results showed that dye adsorption capacity increased with an increase in temperature. This decrease was a result of the escaping of the adsorbed AB25 ions on getting higher temperature or energy, which indicated the physical nature of the adsorption. Thermodynamic investigation is necessary in determining the importance of adsorption process. Thermodynamic parameters such as free energy ($\Delta G°$), enthalpy ($\Delta H°$), and entropy ($\Delta S°$) are significant in detecting heat alteration in the adsorption process for the dye and PSP [9]. These parameters are calculated by the equations given below;

$$K_C = \frac{C_{Ads}}{C_e} \quad (5)$$

$$\Delta G^{\circ} = -RT lnK_C \quad (6)$$

$$\Delta G^{\circ} = \Delta H^{\circ} - T\Delta S^{\circ} \quad (7)$$

$$lnK_C = \frac{\Delta S^{\circ}}{R} - \frac{\Delta H^{\circ}}{RT} \quad (8)$$

where, K_c is the equilibrium constant, C_{Ads} is the dye amount adsorbed on the PSP per litter of the solution at equilibrium, the adsorbent of adsorbent per unit litter of the solution. Furthermore, C_e represents the equilibrium concentration of the dye in the solution. R and T represent the universal gas constant (8.314 J mol^{-1} K) and temperature, respectively. The parameters of $\Delta H°$ and $\Delta S°$ are analyzed from the slope and intercept of the natural plot logarithm of K_c versus *1/T*. From the graphical representation according to Equation (8), namely lnK_c vs. *1/T*, a straight line is obtained in Fig 8. The thermodynamic parameters were presented in Table 3.

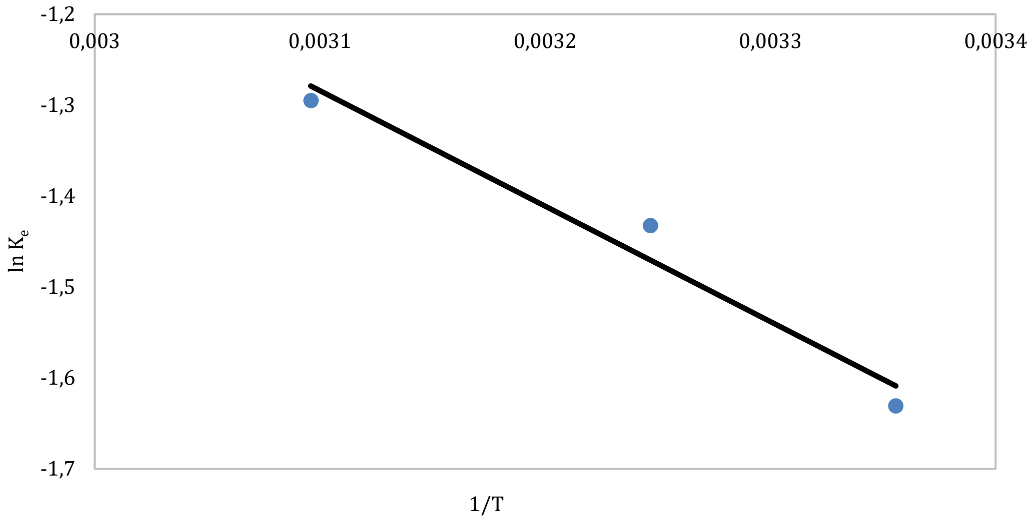

Fig 8. Plots ln K_c versus 1/T for AB25 adsorption on PSP

The thermodynamic parameters of AB25 adsorption onto PSP are calculated with Equations 5-8. The free energy values of AB25 onto PSP were obtained as -1.358, -1.579 and -2.019 kJ mol^{-1} for the temperatures of 298, 308 and 323K, respectively. The enthalpy and entropy values of AB25 adsorption onto PSP were found as 5.211 kJ mol^{-1} and 22.047 kJ mol^{-1} K^{-1} respectively. The negative ΔG° values show that the adsorption was physisorption and ΔG° suggest the feasibility and the spontaneous nature of the adsorption. The absolute values of $\Delta G°$ decreased with the increase in temperature which shows that this separation process was constructive at low temperatures. The positive $\Delta H°$ value shows that the adsorption process was endothermic and the positive $\Delta S°$ value developed the enhanced randomness at the solid–solute interface and the affinity of the PSP for AB25.

Table 3. Thermodynamic parameters of AB25 adsorption on PSP

Temp (K)	K_c	ΔG° (J mol^{-1})	ΔH° (J mol^{-1})	ΔS° (J mol^{-1} K^{-1})	R^2
298	1.731	-1358.561			
308	1.853	-1579.031	5211.464	22.047	0.962
323	2.097	-2019.973			

3.4. Adsorption Kinetic Studies

Kinetic models were performed to check the experimental results of the adsorbates adsorption onto the adsorbents. The dyes adsorption kinetics is significant in choosing the most suitable test circumstances for the adsorption process with the batch technique. The useful kinetic parameters for the estimation of adsorption rate, provide vital knowledge for designing and modeling the adsorption processes [10]. In the present study, the AB25 kinetics was calculated using three kinetic models, namely PFO, PSO and IPD. The well-suited model was chosen depending on the linear regression coefficient of the correlation coefficients of R^2 values. These models were examined in accordance with the experimental data at varied temperatures and initial AB25 concentrations.

The PFO kinetic model is used to separate the kinetics equation depending on the concentration of solution and solid adsorption capacity. This kinetic model can be the first to be used for the characterization of the liquid-solid adsorption systems depending on solid capacity. This model is utilized for the analysis of sorption in liquid-solid systems which states that the number of unoccupied adsorptive sites determines the adsorption rate [4]. The PFO kinetic model is given with Equation (9);

$$\ln(q_e - q_t) = lnq_e - k_1 t \quad (9)$$

where the q_t and q_m (mg g^{-1}) values are adsorption capacities at time t and equilibrium, respectively. k_1 (min^{-1}) is the rate constant of the PFO adsorption. To achieve the constants of the model, the straight line plots of $ln(q_e\text{-}q_t)$ against t are drawn. The constants are detected from the slope and intercept of the plot.

Table 4. PFO, PSO and IPD kinetic model parameters of AB25 adsorption on PSP

	T (K)		25 (mg L^{-1})	50 (mg L^{-1})	75 (mg L^{-1})	100 (mg L^{-1})	125 (mg L^{-1})	150 (mg L^{-1})
	298	$q_{e\ exp}$(mg g^{-1})	4,894	13,331	19,438	27,117	36,707	39,241
	308	$q_{e\ exp}$(mg g^{-1})	5,967	14,447	21,117	29,792	39,891	44,591
	323	$q_{e\ exp}$(mg g^{-1})	6,848	15,237	23,337	31,317	41,164	47,493
PFO kinetic model	298	k_1(min^{-1})	0.0216	0.0311	0.0292	0.0345	0.0325	0.0285
		$q_{e\ cal}$ (mg g^{-1})	4.818	15.365	13.274	29.931	40.658	33.188
		R^2	0.9711	0.9552	0.9168	0.9578	0.9257	0.9151
	308	k_1(min^{-1})	0.0139	0.0278	0.0221	0.0209	0.0189	0.0295
		$q_{e\ cal}$ (mg g^{-1})	4.858	13.339	12.395	21.639	22.603	33.623
		R^2	0.9401	0.9651	0.9037	0.9437	0.9273	0.9515
	323	k_1(min^{-1})	0.0161	0.0355	0.0496	0.0265	0.0262	0.0274
		$q_{e\ cal}$ (mg g^{-1})	5.355	11.698	29.847	22.991	27.924	30.277
		R^2	0.8219	0.9351	0.9521	0.9383	0.9494	0.9637
PSO kinetic model	298	k_2(min^{-1})	0.0052	0.0029	0.0023	0.0017	0.0014	0.0017
		$q_{e\ cal}$ (mg g^{-1})	5.612	14.925	21.0970.	30.030	40.000	41.667
		R^2	0.9876	0.9946	9901	0.9985	0.9907	0.9944
	308	k_2(min^{-1})	0.0043	0.00371	0.00352	0.001931.7	0.0019	0.0016
		$q_{e\ cal}$ (mg g^{-1})	6.557	5.625	2.2720.9	46	41.667	47.619
		R^2	0.9838	0.9929	945	0.9943	0.9966	0.9956
	323	k2(min-1)	0.0068	0.0075	0.00452	0.0022	0.0023	0.0024
		qe cal (mg/g)	7.097	15.8980.	4.509	33.4450.99	42.918	49.751
		R^2	0.9846	9982	0.9967	43	0.9979	0.9984
IPD kinetic model	298	k_{id}(mg g^{-1} min$^{-0.5}$)	0.3453	0.9021	1.2673	1.8136	2.3055	2.2388
		C (mg g^{-1})	0.3705	2.1221	3.4799	5.0379	8.0755	11.526
		R^2	0.9304	0.8919	0.8602	0.8576	0.8882	0.8416
	308	k_{id}(mg g^{-1}min$^{-0.5}$)	0.3723	0.8938	1.2125	1.7907	2.2896	2.6772
		C (mg g^{-1})	0.7421	3.3477	6.2109	7.1607	11.409	12.276
		R^2	0.9356	0.8811	0.8252	0.8754	0.8162	0.8283
	323	k_{id}(mg g^{-1} min$^{-0.5}$)	0.3723	0.8292	1.2494	1.8681	2.2252	2.3386
		C (mg g^{-1})	1.6882	5.4353	8.4852	8.4515	14.113	19.667
		R^2	0.9034	0.7475	0.7795	0.8481	0.7985	0.7476

The PSO kinetic model explained with the chemical bond formation between the adsorptive site and solute molecule is the rate-limiting step based on adsorption capacity given with Equation (10);

$$\frac{t}{q_t} = \frac{1}{k_2 {q_e}^2} + \frac{1}{q_e} t \quad (10)$$

where k_2 is the rate of adsorption (g mg^{-1} min^{-1}), q_m denotes the amount of adsorbate which is adsorbed onto the adsorbent at equilibrium (mg g^{-1}) and q_t represents the amount of dye adsorbed at any time (mg g^{-1}). The plot of t/q_t vs. t has a linear link. The values of k_2 and equilibrium adsorption capacity q_e were identified from the intercept and slope of the plot of t/q_t versus t in accordance with Equation (10);

The adsorption process was slower when intra-particle diffusion (IPD) chosen as the rate controlling step. According to this model the chemical or physical bond between the solute and solid at the interspatial sites of solid control the overall speed of the adsorption. The IPD model equation was proposed by Weber and Morris and was conducted by testing the possibility of IPD as the rate-limiting step using model, which can be represented by Equation (11);

$$q_t = k_{ipd} t^{0,5} + C \quad (11)$$

where k_{ipd} (mg g^{-1} min$^{-1/2}$) is the IPD rate constant and C gives information regarding on the boundary thickness. A plot of q_t against $t^{0.5}$ at different AB25 concentrations gave two phases of linear plots [3].

The PFO, PSO and IPD kinetic model parameters of AB25 adsorption on PSP are given in Table 4. The experimental results indicated that R^2 coefficients were higher than 0.99. The experimental and analyzed q_e values were very close to each other which shows that this process fits the PSO kinetic model. The PSO model is generally preferred for the kinetic adsorption data for most dye adsorption systems.

The experimental and calculated q_e values of 323 K were higher than the 298K and 308K values. According to these tables, it is clear that the q_e values increased with the increasing concentration of AB25. When the kinetic constants were compared, it was seen that the constant values were closer to both temperatures and concentrations for the PSO model [11]. This result showed that AB25 adsorption kinetics on PSP results from PSO and suggested that the rate-limiting step can be the dye chemisorption.

4. CONCLUSIONS

The AB25 adsorption on PSP was examined at different experimental conditions. When the initial AB25 concentration increased from 25 to 150 mg L^{-1}, the adsorption capacity onto PSP increased from 4.80 to 39.01 mg g^{-1}, 5.57 to 44.27 mg g^{-1}and 6.80 to 49.22 mg g^{-1} for 298, 308 and 323 K, respectively. The equilibrium adsorption time was determined as 120 min for dye removal. The isotherm studies demonstrated that the Freundlich model can be considered as a more favorable option for AB25 adsorption on PSP compared to the Langmuir and Temkin models. The monolayer adsorption capacity (q_m) of PSP was determined to be 56.18, 64.94, 95.24 mg g^{-1} for 298, 308 and 323 K, respectively. According to the kinetic studies the adsorption of the AB25 process followed the PSO and suggested that the rate-limiting step could be the dye chemisorption. R^2 coefficients were higher than 0.99 and the evaluated qe values were very close to each other. The kinetic constants for three models were closer to both temperatures and concentrations and q_e values increased with the increasing concentration of AB25. The thermodynamic parameters demonstrated that AB25 adsorption onto PSP was endothermic. The negative $\Delta G°$ values indicated that the adsorption was physisorption and $\Delta G°$ suggested the feasibility and spontaneous nature of the adsorption. All of these results indicated that PSP could be used as a potential adsorbent in removing acidic dyes in wastewaters.

INFORMATION ABOUT PAPER

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