



Analysis of Landfill: A Case of China

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Received: 22 May 2014;

Accepted: 31 July 2014;

Published online: 17 March 2015;

AJC-16991

Technology, operation and management of sanitary landfills in China draw particular attention as China generated the most municipal solid waste in the world. The paper analyzed the growth and development of landfill research productivity in China in terms of publication output as reflected in science citation index for the period 1997-2012. The study revealed that the output of landfill research in China has rapidly increased over the 16 year. Chinese authors contributed 863 publications out of which 837 were journal articles, 17 reviews, 3 editorial materials, 1 correction and 1 meeting abstract, from 498 institutions. About 7.02 % of publications were contributed by Tongji University, followed by Chinese Academic of Science (5.66 %) and Zhejiang University (4.79 %). That impact factors of the top 20 journals publishing most papers were between 0.30 and 5.23. Leading 20 authors published at least 13 articles per person. The annual share of publications varied from 0.12-20.13 % per year, showed a particularly high growth speed in this field. The share was highest in the year 2012 at 20.13 %. An analysis of the title-words showed that "leachate", "waste", "treatment", "municipal" and "solid", other than the string word "landfill" were recent major topics of landfill research in China. The results could help researchers understanding about the characteristics of research output and search hot spots of landfill field in China.

Keywords: Landfill, Science citation index, Histicite, Journal citation report, China.

INTRODUCTION

Rapid economic development, with urbanization, industrialization, population growth and improvement in living standard together, has been occurred in China since its reform and open policy started in 1978. However, that more municipal solid waste (MSW) generated is one of the negative results of the development and urbanization¹ and no other country has ever experienced as much and as fast an increase in solid waste quantities as that China is now facing². Therefore, sanitary disposal of municipal solid waste has become a research hotspot attracting more and more Chinese environmental researchers. Landfills, first presented by American, provide the most economical and simple means of disposing waste globally^{3,4} and landfilling was chosen as the most frequently used disposing method of municipal by most countries⁵. Disposing capacity and technology level of sanitary landfills in China has not reached the municipal solid waste disposal demand and problems about landfill operation and supervising were urgent to be solved⁶.

Many aspects about landfill have been more and more attracted to Chinese researchers. For example⁷, assessed hazards of soil heavy-metal pollution at Shanghai Laogang

Landfill, Wang *et al.*⁸ used anaerobic sequencing batch reactor (ASBR) and modified sequencing batch reactor (SBR) for removal of ammonia nitrogen (NH₄⁺-N) and chemical oxygen demand (COD) from landfill leachate, Han *et al.*⁹ evaluated organic contamination in urban ground water near a landfill in Zhoukou, China. Huang *et al.*¹⁰ conducted numerical simulations of flow slides in municipal landfills based on smoothed particle hydrodynamics (SPH). Li *et al.*¹¹ studied that how operational practices affect landfill storage capacity. A scientometrics analysis on research trends and performance of landfill study was conducted by our group and that treatment of landfill leachate and soil remediation of landfill were found as the hot spots about landfill research based on the analysis of title-words and keywords. Besides, China has been observed as the country that had the second most publication quantity and the most rapid growth on publication quantity by the distribution analysis of countries/territories. However, no scientometrics study focus on the research output of landfill in China was found.

HistCite, used in this study, developed by Garfield and his colleagues¹²⁻¹⁵, is an analytical and visual tool which can help researchers analyze subjects, identify the most significant works on interested topics and trace evaluation¹⁶. This software can also be used to identify highly productive and cited authors

in any chosen area of research, particularly top and high impact journals and prominent institutions¹⁷. We attempted to use HistCite in this study to analyze the trend of research output of landfill in China. The total local citation score (TLCS) and the total global citation score (TGCS)¹⁸ were also calculated in this paper. Total local citation score is the number of times an author's papers included in a collection have been cited by other papers also in the collection. TGCS is the number of times an author's papers included in a collection have been cited in the Web of Science. In addition, research output of pheromone biology in India has just been analyzed by Rajagopal *et al.*¹⁷. This analysis method has been accepted as an effective and efficient approach to studying the contribution of some countries/organizations to the world literature of narrow specialties.

This paper used HistCite to analyze the trend of research output of landfill in China during 1997-2012. The objectives of this study are as following: (1) To study the year-wise growth of publications; (2) To study the document type-wise contributions, authorship pattern, source of publications, institution with subdivision and subject domain with global citation score and local citation score; (3) To analyze the research trends of landfill in China.

EXPERIMENTAL

Methodology: The data used in this study were based on the database of the SCI published by Thomson Reuters Web of Science, Philadelphia, PA, USA. "landfill*" was used as the string to searching of titles, abstracts and keywords during the period of 1997-2011. And then all publications on landfill having 'China' in address field were downloaded from Science Citation Index. HistCite was used to process the data and find out the contribution of Chinese institutions in the field of landfill research during the period of 1997-2012. The year of publication, journals and authors were analyzed and displayed in tables using HistCite. The global citation scores and local citation scores are examined to identify the pattern of research contribution on landfill research. The impact factor values from Journal Citation Reports (JCR) 2011 were also added for the identified journal titles.

Analysis

Year wise distribution and languages of research

output: The publication output of landfill research in the study period 1997-2012 is summarized in Table-1. Journal articles, reviews, corrections, meeting abstracts, proceeding papers published in the study period were considered for this study. It was observed that Chinese authors contributed 836 publications, including 708 journal articles (29 were proceeding papers), 19 reviews, 3 corrections and 4 meeting abstracts. The number of articles increased more than 160 times from 1 article in 1997 to 166 in 2012. All publication in the study period were written in only two kinds of language, English was the most-frequently used language, making up 97.3 % (840) of all the published articles, while Chinese took a share of 2.7 % (23).

The comparison between China and USA on research output of landfill is demonstrated in Fig. 1. Although there was a huge gap between USA and China on landfill research output before 2009, the gap kept decreasing. The output from China and USA both showed an increasing trend, while China had a quicker increase obviously. It may be attributed to the rapid growth of Chinese population and national economy in the past decades. While the growth rate decreased during the period of 2009 to 2012, which may be attributed to more use of other disposal technologies such as incineration and that more strict has policy about food waste disposal become. Fig. 2a,b showed the comparison among numbers (a) and disposal capacity (b) of sanitary landfill sites, composting plants of refuse and waste incineration plants⁶. Both Fig. 2(a,b) showed that more and more solid waste was disposed by incineration technology in China. Technical code for food waste treatment provided that food waste must be disposed individually, other than co-treated with municipal solid waste.

Global and local citation score of landfill researches:

863 publications, cited by 6,414 works, were found out. A global view of authors' works on landfill and the impact during the 16 year period could be obtained based on Table-1. For each publication, both local and global frequencies of citation were listed for analysis. It was found that TLCS and TGCS increased significantly from 0 and 6 in 1997 to 197 and

TABLE-1
CHARACTERISTICS OF RESEARCH OUTPUT ON LANDFILL

Year	Journal articles	Review	Correction	Meeting abstract	Proceedings paper	Total No. of papers	TLCS	TGCS
1997	1	–	–	–	–	1	0	6
1998	2	–	–	–	–	2	0	3
1999	7	–	–	–	–	7	39	175
2000	6	–	–	–	3	6	25	108
2001	14	–	–	–	2	14	59	357
2002	19	–	–	–	2	19	94	325
2003	14	1	–	1	2	16	32	273
2004	20	–	–	–	1	20	49	251
2005	31	–	–	–	1	31	75	389
2006	55	2	–	1	6	58	197	922
2007	64	–	1	–	2	65	138	738
2008	77	3	–	–	4	80	136	787
2009	130	1	1	–	1	132	197	1092
2010	109	4	–	2	2	115	86	507
2011	122	1	–	–	3	123	53	315
2012	166	7	1	–	3	174	12	166
Total	837	19	3	4	32	863	1192	6414

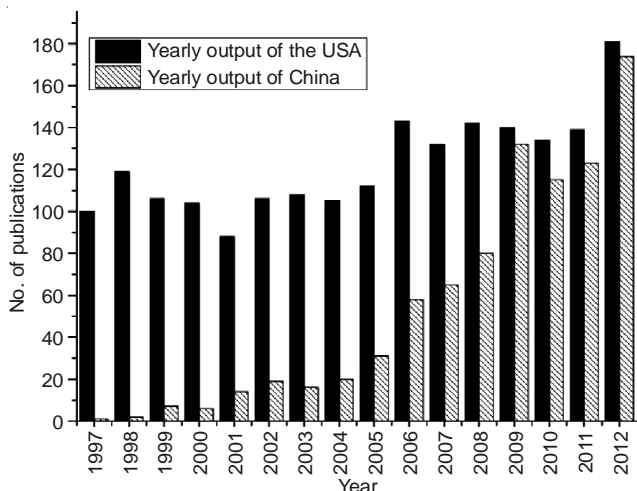


Fig. 1. Comparison between China and the USA on yearly outputs of publications

1,092 in 2009, respectively. Both TLCS and TGCS reached their peak values in 2009.

Source-wise distribution of research output: Out of 863 publications, 73 (8.5 %) publications were published in Journal of Hazardous Materials, 69 (8.0 %) in Waste Management and 49 (5.7 %) in Journal of Environmental Sciences-China (Table-2).

Table-4 also presented that impact factors of the top 20 journals were between 0.30 and 5.23. It is to note that the leading global citation scores were listed for Journal of Hazardous Materials of 1116 followed by Waste Management (648), Chemosphere (440) and Water Research (238), etc. It also must be mentioned that Water Research with an impact factor of 4.87 and Environmental Science & Technology (5.23), which have only about ten published works, scored about 200 concerning global citation, reflecting their high quality of landfill research outputs.

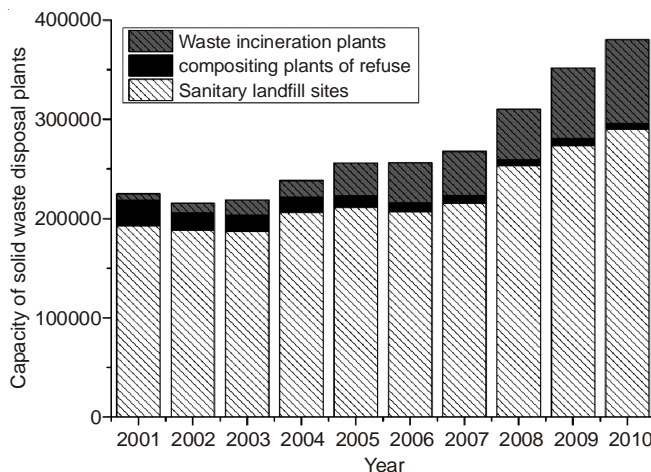
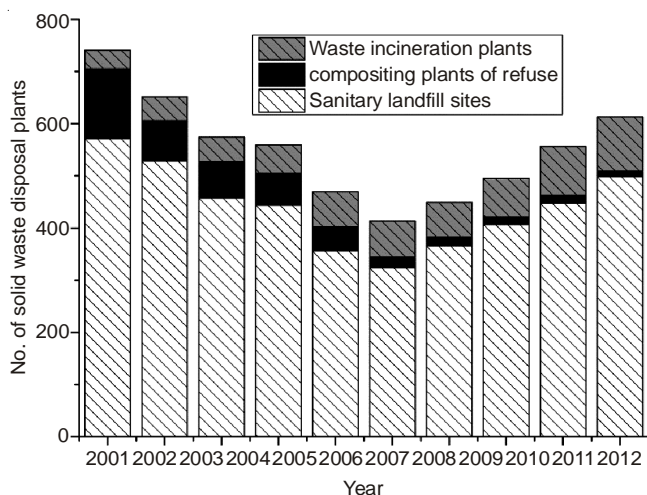


Fig. 2. (a) Comparison among numbers of sanitary landfill sites, composting plants of refuse and waste incineration plants. (b) Comparison among disposal capacity of sanitary landfill sites, composting plants of refuse and waste incineration plants

TABLE-2
LEADING JOURNALS PUBLISHING CHINESE WORKS ON LANDFILL RESEARCH

S. No.	Journal title	Number of publications	TLCS	TGCS	Publication country	Impact factors JCR-2013
1	Journal of Hazardous Materials	73	220	1116	Netherlands	4.17
2	Waste Management	69	155	648	England	2.43
3	Journal of Environmental Sciences-China	49	64	217	China	1.66
4	Bioresource Technology	37	70	233	England	4.98
5	Chemosphere	27	93	440	England	3.21
6	Water Science and Technology	26	13	109	England	1.12
7	Waste Management & Research	24	27	82	England	1.19
8	Journal of Central South University of Technology	17	2	20	China	0.3
9	Science of The Total Environment	15	18	150	Netherlands	3.29
10	Environmental Engineering Science	14	26	70	USA	0.88
11	Environmental Technology	14	7	32	England	1.41
12	Environmental Science & Technology	13	12	198	USA	5.23
13	Spectroscopy and Spectral Analysis	13	7	16	China	NA
14	Journal of Environmental Management	12	24	138	England	3.25
15	Water Research	12	71	238	England	4.87
16	Fresenius Environmental Bulletin	11	9	32	Germany	0.66
17	Desalination and Water Treatment	9	2	10	USA	0.62
18	Water Air and Soil Pollution	9	15	75	Netherlands	1.63
19	Desalination	8	4	65	Netherlands	2.59
20	Ecological Engineering	8	18	80	Netherlands	3.11
	211 Other Journals	403	335	2445	-	-
	Total	863	1192	6414	-	-

TABLE-3
LEADING AUTHORS IN THE AREA OF LANDFILL RESEARCH

Sl. No.	Author	P	TLCS	TGCS	Average TLCS	Average TGCS
1	P.J. He, Tongji University, State Key Pollution Control & Reclamat, Shanghai	48	133	376	2.77	7.83
2	L.M. Shao, Tongji University, State Key Pollution Control & Reclamat, Shanghai	46	133	339	2.89	7.37
3	Y.C. Zhao, Tongji University, State Key Pollution Control & Resource reuse, Shanghai	45	140	294	3.11	6.53
4	H. Zhang, Wuhan University, Department of Environmental Engineering, Wuhan	35	105	411	3.00	11.74
5	D.S. Shen, Zhejiang University, Department of Environmental Engineering, Hangzhou	30	76	175	2.53	5.83
6	B.D. Xi, Chinese Research Institute of Environmental Science, Beijing	19	40	82	2.11	4.32
7	Y.M. Chen, Zhejiang University, MOE Key Lab Soft Soils & Geoenvironmental Engineering, Department of Civil Engineering, Hangzhou	17	19	55	1.12	3.24
8	R. He, Zhejiang University, Department of Environmental Engineering, Hangzhou	17	63	122	3.71	7.18
9	C.R. Fang, Zhejiang University, Department of Environmental Engineering, Hangzhou	16	31	74	1.94	4.63
10	G.H. Huang, Hunan University, Department of Environmental Science and Engineering, Changsha	16	21	138	1.31	8.63
11	S.Q. Zhou, South China University of Technology, College of Environmental Science and Engineering, Guangzhou	16	35	120	2.19	7.50
12	X.L. Chai, Tongji University, State Key Lab Pollution Control & Resource Reuse, Shanghai	15	22	95	1.47	6.33
13	D.J. Lee, Tongji University, State Key Pollution Control & Resource reuse, Shanghai	15	85	188	5.67	12.53
14	Y.Y. Long, Tsinghua University, School of Environmental, Beijing	15	15	48	1.00	3.20
15	Y. Zhao, NE Agr University, Life Science College, Harbin	15	13	49	0.87	3.27
16	Z.Y. Lou, Shanghai Jiao Tong University, School of Environmental Science and Engineering, Shanghai	14	27	63	1.93	4.50
17	Y.F. Nie, Tsing Hua University, Department of Environmental Science and Engineering, Beijing	14	24	54	1.71	3.86
18	H.T. Wang, Tsinghua University, School Environment, Beijing	14	15	59	1.07	4.21
19	X.S. He, Chinese Research Institute of Environmental Science, State Key Lab Environmental Criteria & Risk Assessment, Beijing	13	20	33	1.54	2.54
20	F. Lu, Tongji University, College of Environmental Science and Engineering, State Key Lab Pollution Control & Resource Reuse, Shanghai	13	19	61	1.46	4.69

TABLE-4
AUTHORSHIP PATTERN

S. No.	Authors	Contributions	Per cent (%)
1	Single author	8	0.93
2	Double authors	91	10.54
3	Three authors	167	19.35
4	Four authors	230	26.65
5	Five authors	173	20.05
6	Six authors	98	11.36
7	Seven authors	50	5.79
8	Eight authors	30	3.48
9	Nine authors	12	1.39
10	Ten authors	2	0.23
11	Eleven authors	1	0.12
12	Thirteen authors	1	0.12

Author rankings: Leading 20 authors in the area of landfill research were listed in Table-3. It was found that P.J. He from Tongji University had published the highest number of 48 works on the field followed by L.M. Shao (46), Y.C. Zhao (45), H. Zhang (35) and D.S. Shen(30), *etc.* Meanwhile, on the high score of global citations, it was observed that H. Zhang's works had 411 citations followed by P.J. He (376), L.M. Shao (339), Y.C. Zhao (294) and D.J. Lee (188), *etc.* Besides, on the high score of local citations, Y.C. Zhao had the highest score of 140 followed by P.J. He (133), L.M. Shao (133), H. Zhang (105) and D.J. Lee (85), *etc.* Other than TGCS and TLCS, average TGCS and TLCS per article should also be considered for the assessment of article quality. Considering average citations per article, D.J. Lee from Tongji University scored highest in both average TGCS (12.53) and TLCS (5.67), showed high quality of his work.

Authorship pattern: It was found that the highest, 26.65 % (230) contributions were by four authors. Single-author publications composed only 0.93 % of the total 863 outputs (Table-4).

Leading Chinese institutions in landfill research: Table-5 shows the leading institutions committing to landfill study. Tongji University ranked first with 113 contributions (7.02 %) followed by China Academic of Sciences (91), Zhejiang University (77), Tsinghua University (49) and Hong Kong Polytech University (45), *etc.* All 498 institutions have contributed the 863 publications over the 16-year period.

Analysis of title-words: The titles of articles present the core information that the authors would like to express. Therefore, all of the single words in the titles of articles were analyzed for development trends of landfill research. Some title-words with general meanings, such as "of" and "using" were not included from the date analysis. The percentages of top 20 title-words were listed in Table-6. Other than the title-word "landfill" which was used for the string of searching the data, "leachate", "waste", "treatment", "municipal" and "solid" were the top 5 most frequently used title-words and used for more than 100 times during the 16-year period. Currently, deposition of municipal and industrial wastes in landfills is considered as the most widespread economical method for waste disposal¹⁹, this fact can explain the frequent use of title-words "municipal", "solid" and "waste". "Leachate" was the most frequently used title-word, except "landfill", which may be attributed to that large amount of leachate generated from landfills are one of the major problems of landfill process²⁰. Leachate, contains various pollutants such as high concentrations of organic

TABLE-5
LEADING CHINESE INSTITUTIONS IN LANDFILL RESEARCH

S. No.	Institution	Number of works	Per cent (%)
1	Tongji University, Shanghai	113	7.02
2	Chinese Academic of Sciences	91	5.66
3	Zhejiang University, Hangzhou	77	4.79
4	Tsinghua University, Beijing	49	3.05
5	Hong Kong Polytech University, Hong Kong	45	2.80
6	Shanghai Jiao Tong Univ, Shanghai	33	2.05
7	Chinese Research Institute of Environmental Science, Beijing	29	1.80
8	Chongqing University, Chongqing	29	1.80
9	South China University of Technology, Guangzhou	29	1.80
10	Peking University, Beijing	25	1.55
11	Wuhan University, Wuhan	25	1.55
12	Harbin Institute of Technology, Harbin	24	1.49
13	Beijing Normal University, Beijing	22	1.37
14	China University Geoscience, Wuhan	21	1.31
15	University of Hong Kong, Hong Kong	18	1.12
16	Nanjing University, Nanjing	17	1.06
17	University of Regina	17	1.06
18	Tianjin University, Tianjin	16	0.99
19	Zhejiang University of Science & Technology, Hangzhou	16	0.99
20	Beijing University Technology, Beijing	15	0.93
	478 Other institutions	898	55.81
	Total	1609	100.00

TABLE-6
TOP 20 MOST FREQUENTLY USED TITLE-WORDS

S. No.	Title words	TA	S. No.	Title words	TA
1	Landfill	352	11	Organic	68
2	Leachate	267	12	Oxidation	61
3	Waste	163	13	Fenton	48
4	Treatment	131	14	Sludge	48
5	Municipal	121	15	Nitrogen	47
6	Solid	111	16	Wastewater	47
7	Removal	96	17	Analysis	42
8	Using	88	18	Refuse	42
9	Process	78	19	System	42
10	China	72	20	Matter	40

matters (biodegradable and non-biodegradable) and inorganic constituents²¹, which may percolate through soils and subsoils and cause extensive pollution in surface and underground water without proper treatment and safe disposal²², should be treated before discharge in the environment. Technologies meant for leachate treatment can be classified as biological methods and chemical and physical methods²³. Biological treatment, which may be the most efficient and cheapest methods for nitrogen removal, were hampered by the specific toxic substances and/or by the presence of bio-refractory organics that the efficiency of denitrification was reduced by the limited level of biodegradable organics in particular in stabilized landfills. Advanced oxidation processes (AOPs), including fenton process, have been proposed as an efficient alternative of mineralization of recalcitrant organic in landfill leachate²³. Combination of advanced oxidation process (AOPs) and biological processes, if they are proved as compatible, could be considered as a cost-efficient alternative for landfill leachate treatment. Fenton reagent, which was the 13th most frequently used title-words, while it has high removal efficiency for colour and COD, was considered as one of the most cost-efficient AOPs for landfill leachate treatment²⁴. Fig. 3 showed that China had the most

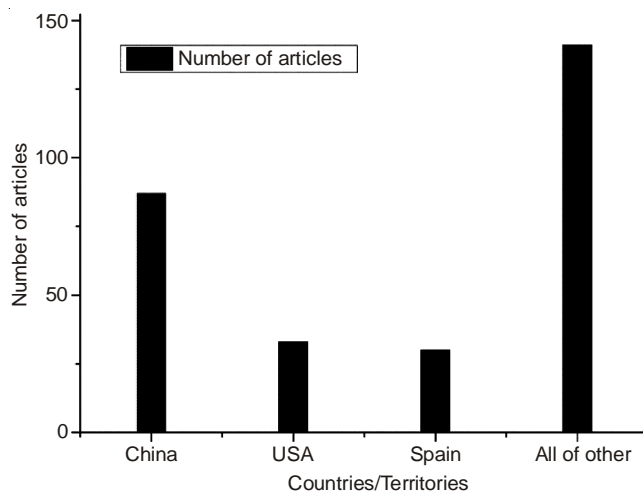


Fig. 3. China had the most publications about leachate treatment using Fenton reagent

publications about leachate treatment using Fenton reagent, using “leachate*” and “Fenton*” as string words in the database of SCI published by Thomson Reuters Web of Science, Philadelphia, PA, USA. The conclusion that Chinese researchers showed special interest on leachate treatment by Fenton reagent could be observed.

RESULTS AND DISCUSSION

The HistCite based analysis of landfill research in China has shown how the field has evolved and has helped in identifying the institutions that are active and the journals in which they publish their works. The publication trend shows that research activities are growing in this area. Institutions such as Tongji University, Chinese Academic of Science and Zhejiang University finished the most publications on landfill research during the period of 1997-2012. Journals such as

Journal of Hazardous Materials, Waste Management and Journal of Environmental Sciences-China published the most Chinese works on MSW research. Journals with high impact factors such as Journal of Hazardous Materials (4.17), Bioresource Technology (4.98), Environmental Science & Technology (5.23) and Water Research (4.87) appeared in the top 20 journals published the most landfill related articles. According to the analysis of title-words, "Landfill", "leachate", "waste", "treatment", "municipal" and "solid" was revealed as the six most frequently used title-words, reflecting the attention paid on leachate by landfill researchers.

Our results indicated that the impacts of the landfill problem were becoming major issues during the past 16 years. Especially for the period after 2006, the output of landfill research increased rapidly. The findings in this study could help researchers understand the characteristics of research output of landfill and search hot spots in landfill field in China.

However, the research output on landfill research from China would be higher than those found indexed in the Web of Science as it is likely that many works might have appeared in publications, including journals not covered by Web of Science. For a comprehensive coverage of research output and analysis, multiple data sources need to be used.

ACKNOWLEDGEMENTS

This work was supported by the Natural Science Foundation of China under Grant [No. 51278212] and Eleventh Five-year National Technology Supporting Plan Program of China under Grant [No. 2006BAC06B04].

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