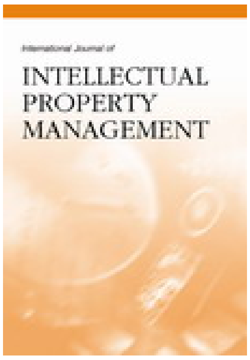

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Use of peel-based activated carbon in wastewater treatment: a study of patents

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Abstract: Clean water is one of the most essential components for almost all industries. Reuse of wastewater is becoming the only weapon to combat the growing scarcity of clean water. Materials such as mineral sorbents, activated carbons, peat, chitin, etc., have been used as adsorbents for the treatment of textile wastewater. Activated carbon has been commercially employed for the removal of contaminants. The current manuscript is a patent study on the use of peels as adsorbents for the removal of contaminants, especially dyes. This review is a quantitative and qualitative analysis of patents on the use of peel-based activated carbon for industrial and textile wastewater treatment.

Further, this review gives landscaping of patents in this domain including non-limiting to country-wise, classification-wise, inventor-wise, etc. This report includes data from the patent database and analytics tool, Relecura. This study is a manual and reflects all the major contributions in wastewater treatment using peels.

Keywords: adsorption; relecura database; innovation: patent analysis: quantitative and qualitative analysis.

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1 Introduction

Water is contaminated primarily due to dyes, heavy metals, and wastes from the pharmaceutical industry, agricultural waste, sewerage, and industrial effluents (Singh et al., 2009) which are let into the water bodies. With the decrease of freshwater assets like rivers, wells, and groundwater, there is a threat to the availability of clean water (Hoff, 2009). Contaminated water is not solely unhealthy for consumption; but it may also mix with alternative water sources and contaminate them further (WHO and WPC, 2006). The worldwide production of dyes is around 8 lakh tons per year. Artificial dyes are used in several industries such as industry paper industry, pulp industry, textile industry, etc. (Ahmed et al., 1998). Dyes from textile and several other industries are toxic and can cause skin irritation, unquiet or blocked noses, physiological reactions, and sore eyes (Ahmed et al., 1998). Textile wastewater also contains metals like chromium, arsenic, copper, etc. which may cause many health issues, including nausea, severe skin irritation, and hemorrhage. Additionally, it contains several alternative organic and microbial impurities and chemicals such as quinoline, phthalates, bisphenols, benzothiazoles/benzotriazoles, trace components, aniline, etc., which are hazardous (Ananthashankar, 2012; Argüello et al., 2016; Rovira and Domingo, 2019). Phenols, enzymatic substrates, chromium-based materials, and heavy metals are further used as alternative colouring auxiliaries. The contaminated water with colloidal materials not increases the murkiness, which ends in an exceedingly unhealthy look and objectionable odour of water, but also inhibits the permeation of daylight which is important for the method of photosynthesis that is successively disturbing the food supply of aquatic organisms (Chandrashekhar et al., 2020). Textile dyes considerably compromise the aesthetic quality of water bodies, adding to biochemical and chemical oxygen demand (Chen et al., 2020). The regular functioning of cells in the exposed organisms gets disturbed because of chemical pollution, leading to mortality (Cheng et al., 2020). Therefore, it is essential to develop treatment technologies for practical applicability in wastewater treatment, consistency, cost-effectiveness, and efficiency of water treatment. Several methods such as sorption, membrane method, composites materials, electro-coagulation/floatation, ultrafiltration, flocculation, microfiltration, reverse osmosis, electrochemical method, etc. have been used for the treatment of industrial and textile wastewater (Farahmand et al., 2020; Fazal et al., 2020; Hassaan and Nemr, 2017; Hiew et al., 2018; Jackman and Baber, 1903; Jarrah et al., 2020; Kaur et al., 2020; Karim and Ambika, 2021; Khattab et al., 2020).

Among all the above technologies, sorption has proven to be a cost-effective, eco-friendly and quick methodology to get rid of hazardous dyes. This technique involves using a variety of materials such as mineral sorbents, activated carbons, lignite and chitin (Sushkova et al., 2022; Kumari et al., 2022; Di et al., 2022; Qiao et al., 2022). Among all these, activated carbon has been used commercially and can be prepared from a variety of materials. The use of activated carbon is widespread due to its large surface area and high porosity (De Gisi et al., 2016). Activated carbon may be prepared from fruit peels like banana peel, pineapple peel, pomegranate peel, orange peel, mangosteen peel, genus citrus peel, dragon fruit peel, jackfruit, soyabean peel, etc. (Ramutshatsha-Makhwedzha et al., 2022; Tavker and Sharma, 2020; Kallem et al., 2022; Fan et al., 2022; Unugul and Nigiz, 2020; Shakibi et al., 2020; Le et al., 2020; Mangesh et al., 2022: Eri et al., 2022).

The present review aims to conduct a thorough patent literature survey, including the study of patenting trends, highlights of patented technologies and to discuss future directions in this domain with peels for industrial and textile wastewater treatment. Patents are one-of-a-kind resources, as they represent a valuable source of information developed by businesses (Saksupapchon and Willoughby, 2021; De La Torre et al., 2019). Patents protect the technical characteristics of inventions (Guo-Fitoussi et al., 2019). Patents have increased knowledge development, which is fuelled by the emergence of new firms (Kashyap et al., 2020). However, the transition from science to patents is a black box when it comes to the mechanisms that explain the discrepancies in patent breadth (Beukel, 2019). The analysis includes patent classification concerning year, country, technologies, sub-technologies, international patent classification (IPC) codes, and cooperative patent classification (CPC) codes, class codes from the USA patent classification, inventors, assignees, star rating, publication type, forward citations, and backward citation. It also includes a patent summary of granted key patents.

A patent landscape provides various insights on the hidden patent data, useful for business, scientific and technological trends. The patent data reveals that studies are being carried out globally to use several peels and synthesise activated carbon from peels for wastewater treatment. The patent analysis has been carried out using the various insights from the Relecura database-related patent information to further the various innovation trends useful to the researchers and stakeholders, emphasising on-going research on peel-based activated carbon in wastewater treatment. It was found necessary to know the current standing of the patents in this field of wastewater treatment, using peels as adsorbents, to help the researchers understand the work done in the recent past and ascertain the kind of work with existing scope leading to innovation. This detailed study was carried out with patents in the mentioned domain, country-wise, classification-wise, based on inventors, sub-technology, star rating, publication type, and year-wise publication. The study's non limiting objectives are to:

1 identify top inventors and assignees

2 identify leading technologies and sub-technologies, identify research gaps in different technologies

3 evaluate the performance of countries involved in the field use of peel-based activated carbon in wastewater treatment.

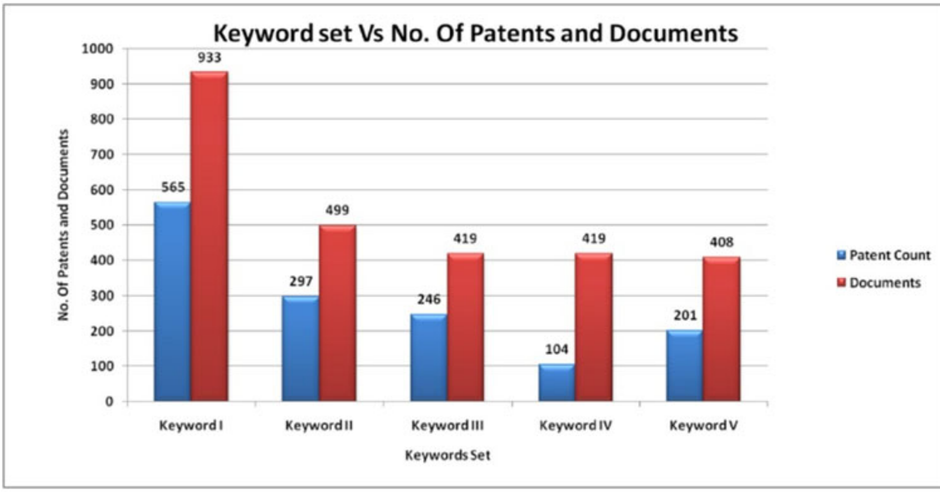
The researcher should focus on the patent classification to identify different technologies, gaps, and needs for innovation, as these are the areas in which future innovation will occur.

2 Data sources, selection criteria, and keywords

The keywords play a vital role in finding documents from a large amount of data; importantly, the conjunctures 'AND' and 'OR' are important in categorising patent documents. The search on the data was then confined to adsorbents, adsorption, peels, dyes, activated carbon, and wastewater in the keyword set (1)–(5) Table 1 keyword set 3, given in 246 publications Figure 1. Table 1 shows a summary of all the keywords which were used for executing patent searches.

The relevant keywords give more insightful and appropriate information on innovation trends. The best possible combination of keywords was carefully chosen to produce the best results. The search was carried out using the keywords 'adsorption' AND 'peels' AND 'dyes' AND 'activated carbon' AND 'wastewater,' which resulted in 565 publications (1985 to 2021). The following search was then limited to adsorbents, adsorption, peels, dyes, activated carbon, and wastewater in the keyword set I-V Table 1 keyword set 3, given in 246 publications (Figure 1). Table 2 shows the number of patents issued each year, whereas Table 3 shows the categories of publications and the number of patents issued. Figure 2 shows the number of patents for peel-based activated carbon in wastewater treatment per year.

Figure 1 The number of patents vs. keyword set I-V (1985 to 2021) (see online version for colours)



Source: https://relecura.com/ (accessed on 24 March 2021)

Table 1 The applied keywords in the Relecura database search have been summarised

Sr. no.	*Keyword 1*	*Keyword 2*	*Keyword 3*	*Keyword 4*	*Keyword 5*
(1)	Adsorption AND	Adsorbents AND	Adsorbents AND Adsorption AND	Adsorbents AND	Adsorption AND
(2)	Peels AND	Peels AND	Peels AND	Peels AND	Peels AND
(3)	Dyes AND	Dyes AND	Dyes AND	Dyes AND	Dyes AND
(4)	Activated	Activated	Activated	Activated	Activated
	Carbon AND	Carbon AND	Carbon AND	Carbon AND	Carbon AND
(5)	Wastewater	Wastewater	Wastewater	Textile wastewater	Textile wastewater
Patent count	565	297	246	104	201
Document	933	499	419	419	408

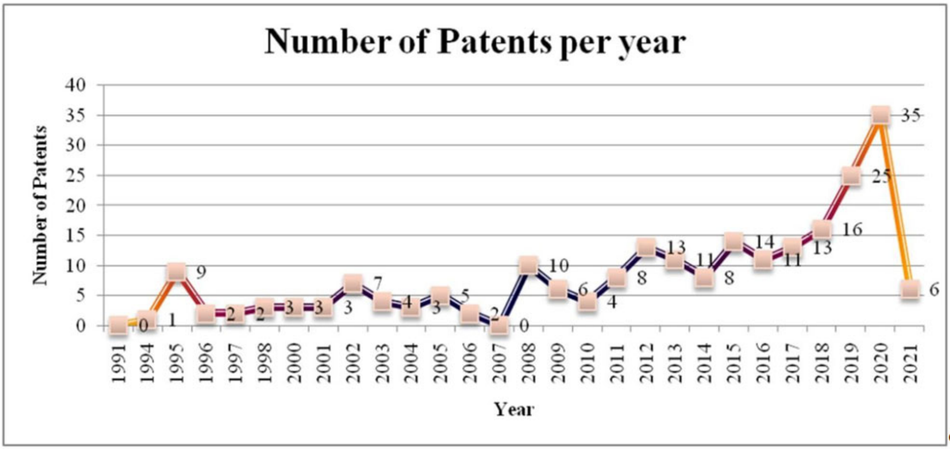
Source: https://relecura.com/ (accessed on 24 March 2021)

Table 2 The number of patents per year for peel-based activated carbon in wastewater treatment (1985 to 2021)

Year	*Patent count*	*Year*	*Patent count*	*Year*	*Patent count*	*Year*	*patent count*
1991	0	2001	3	2008	10	2015	14
1994	1	2002	7	2009	6	2016	11
1995	9	2003	4	2010	4	2017	13
1996	2	2004	3	2011	8	2018	16
1997	2	2005	5	2012	13	2019	25
1998	3	2006	2	2013	11	2020	35
2000	3	2007	0	2014	8	2021	6

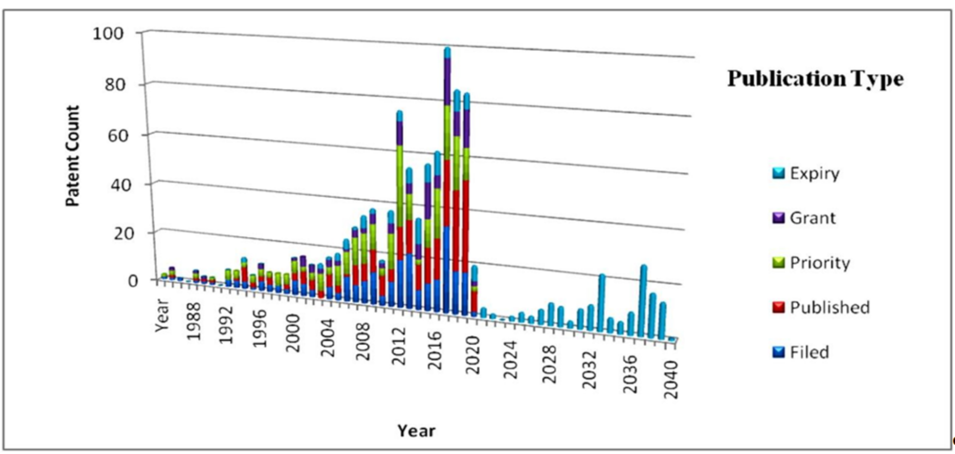
Source: https://relecura.com/ (accessed on 24 March 2021)

Figure 2 Number of patents per year for peel-based activated carbon in wastewater treatment (1985 to 2021) (see online version for colours)



Source: https://relecura.com/ (accessed on 24 March. 2021)

Figure 3 Publication types and number of patents for peel-based activated carbon in wastewater treatment (see online version for colours)



Source: https://relecura.com/ (accessed on 24 March 2021)

Figure 3 shows the number of patents and publications for peel-based activated carbon in wastewater treatment. The types of publications in search results included granted, expired, priority, published, and filed patents. In 2018, 34 patents were filed, 25 were issued, 20 were considered priority documents, 17 were granted, and four were considered expired, as portrayed in the graph. The above search revealed that China and Japan have the highest publications in peel-based activated carbon in wastewater treatment. In contrast, Hungary and Romania have fewer patent publications. The patents from 1985 to 2021on peel-based activated carbon in wastewater treatment were extracted from the patent database and analysed using analytical tool Relecura.

Table 3 Publication types and number of patents for peel-based activated carbon in wastewater treatment

Year	*Filed*	*Public shed*	*Priority*	*Granted*	*Expired*	*Year*	*Filed*	*Public shed*	*Priority*	*Granted*	*Expired*
1985	1	0	1	0	0	2014	22	13	10	4	6
1986	1	1	2	1	0	2015	8	10	2	6	10
1987	1	0	0	0	0	2016	11	14	11	14	7
1988	0	0	0	0	0	2017	13	16	19	5	9
1989	1	1	2	1	0	2018	34	25	20	17	4
1990	1	1	0	1	0	2019	17	31	20	9	8
1991	1	1	1	0	0	2020	17	35	12	14	6
1992	0	0	0	0	0	2021	2	8	2	2	6
1993	3	0	4	0	0	2022	0	0	0	0	4
1994	3	1	3	0	0	2023	0	0	0	0	2
1995	3	6	2	0	2	2024	0	0	0	0	0
1996	1	2	3	0	0	2025	0	0	0	0	2
1997	4	2	3	2	0	2026	0	0	0	0	4
1998	3	3	2	0	0	2027	0	0	0	0	3
1999	3	0	5	0	0	2028	0	0	0	0	6
2000	2	2	4	0	0	2029	0	0	0	0	9
2001	6	3	5	1	0	2030	0	0	0	0	8
2002	5	5	2	4	0	2031	0	0	0	0	3
2003	3	4	3	3	0	2032	0	0	0	0	8
2004	0	3	7	2	2	2033	0	0	0	0	10
2005	5	5	3	3	1	2034	0	0	0	0	22
2006	3	3	8	2	3	2035	0	0	0	0	6
2007	10	1	9	1	4	2036	0	0	0	0	5
2008	7	8	11	3	1	2037	0	0	0	0	9
2009	9	7	12	2	5	2038	0	0	0	0	27
2010	13	9	10	4	2	2039	0	0	0	0	17
2011	4	8	3	2	1	2040	0	0	0	0	14
2012	10	5	14	4	5	2041	0	0	0	0	1
2013	19	13	31	9	4						

Source: https://relecura.com/ (accessed on 24 March 2021)

3 Results and discussion

3.1 Country codes

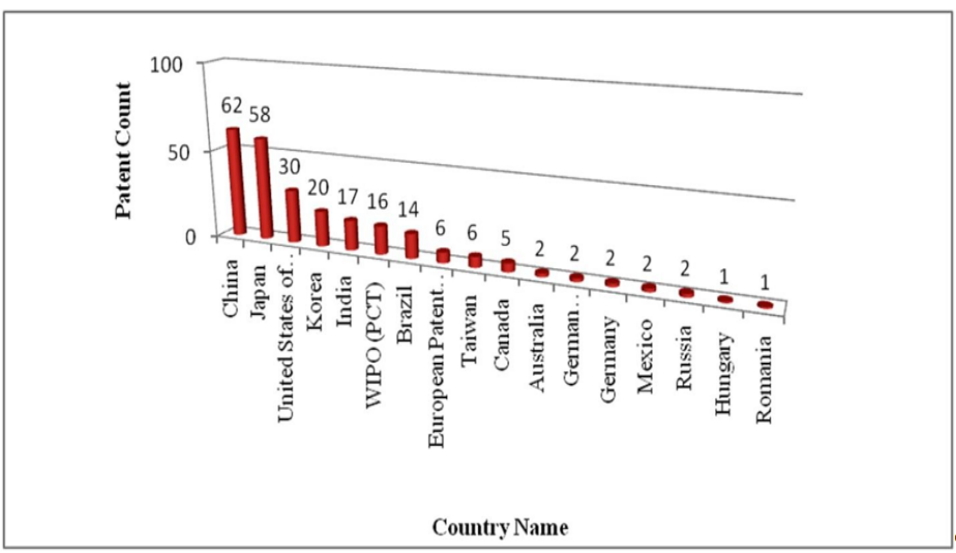
Two letters represent the country and are mentioned as country code or jurisdiction wherein the patent gets published Table 4. The patent data was retrieved using Relecura for peel-based activated carbon in wastewater treatment and was segregated by patent publishing country Table 5, where China contributed significantly, as shown in Figure 4.

Table 4 Country name and country code

Country	*Country code*	*Country*	*Country code*	*Country*	*Country code*
China	CN	Brazil	BR	Germany	DE
Japan	JP	European patent office	EP	Mexico	MX
Romania	RO	Taiwan	TW	Russia	RU
Korea	KR	The USA	US	Hungary	HU
India	IN	Australia	AU	Canada	CA
WIPO (PCT)	WO	German Democratic Republic	DD		

Source: https://relecura.com/ (accessed on 24 March 2021)

Figure 4 The number of patents published by the different countries for peel-based activated carbon in wastewater treatment (see online version for colours)



Source: https://relecura.com/ (accessed on 24 March 2021)

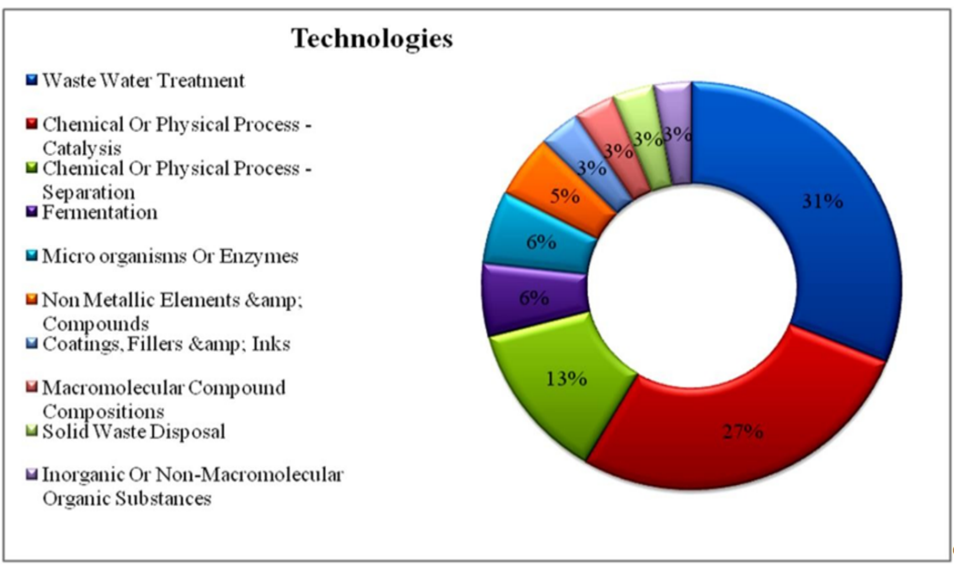
Figure 5 showed technology-wise patent classification and was studied for the mentioned duration. Almost 31% of total patents extracted were on wastewater treatment technology. Figure 6 shows an analysis of sub – technology-wise patent classification studied for the mentioned duration. Almost 35% out of the total patents filed were extracted, which were related to the treatment of water, wastewater, or sewerage.

Table 5 Number of patents by different countries for peel-based activated carbon in wastewater treatment

Country code	*Publication*	*Country code*	*Publication*	*Country code*	*Publication*
CN	62	BR	14	DE	2
JP	58	EP	6	MX	2
US	30	TW	6	RU	2
KR	20	CA	5	HU	1
IN	17	AU	2	RO	1
WO	16	DD	2		

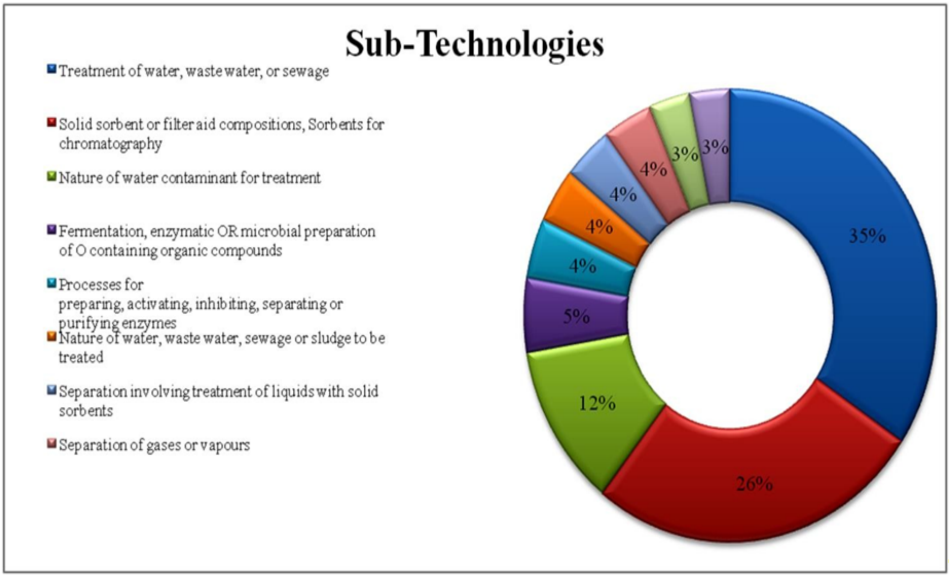
Source: https://relecura.com/ (accessed on 24 March 2021)

Figure 5 The number of patents and technologies for peel-based activated carbon in wastewater treatment (see online version for colours)



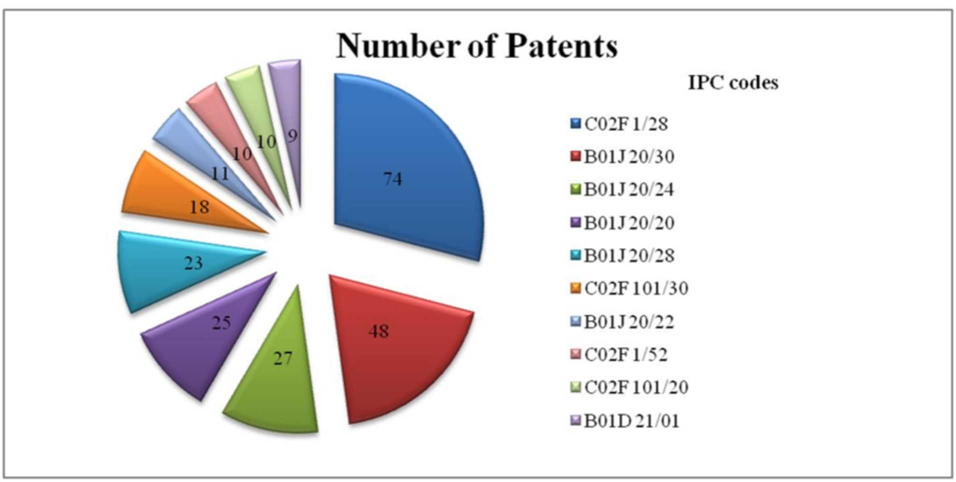
Source: https://relecura.com/ (accessed on 24 March 2021)

Figure 6 The number of patents and sub-technologies for peel-based activated carbon in wastewater treatment (see online version for colours)



Source: https://relecura.com/ (accessed on 24 March 2021)

Figure 7 IPC codes and number of patents (see online version for colours)

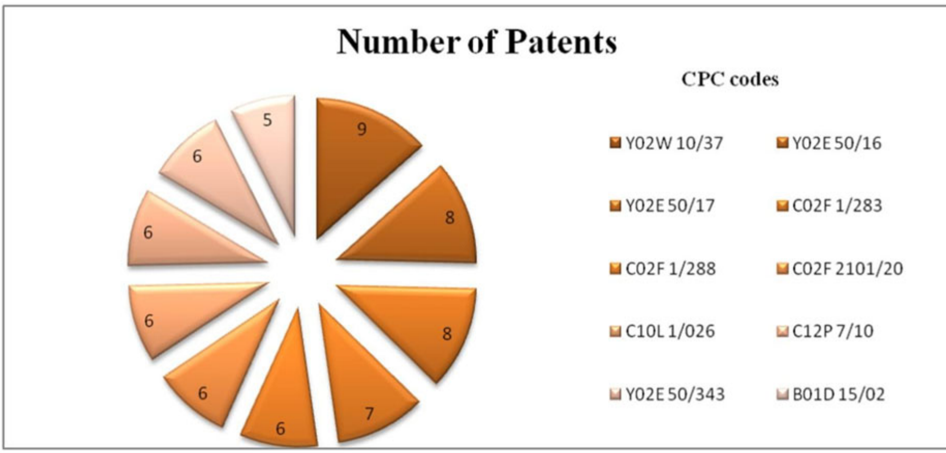


Source: https://relecura.com/ (accessed on 24 March 2021)

3.2 *Patent classification*

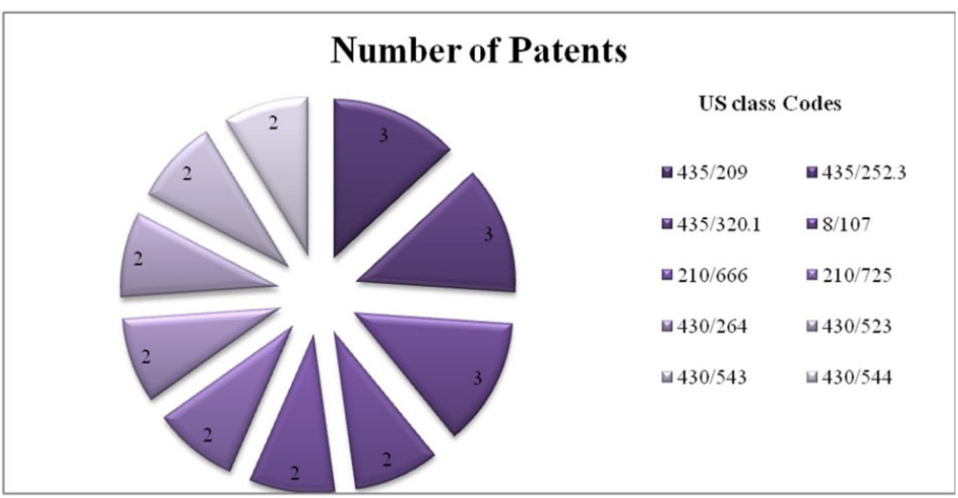
Figure 7 shows IPC codes and the number of patents. The class code, C02F 1/28 portrayed 74 patents. IPC code C02F 1/28 is said to be chemistry and metallurgy for wastewater treatment by sorption and had the highest number of patents (74). IPC codes B01J 20/30 and B01J 20/24 were for chemical and physical processes, for example, catalysis and colloids chemistry and showed 48 and 27 patents. Figure 8 shows CPC codes and the number of patents. In that class code, Y02W 10/37 gave 9 relevant patents. CPC Code, Y02W 10/37 possessed nine patents and was associated with technologies for wastewater treatment by solar emery. CPC codes Y02E 50/16 and Y02E 50/17 possessed 8 patents each which were related to non-fossil fuels production of cellulosic bi ethyl alcohol and grain bioethanol, respectively. Figure 9 shows US class codes and the number of patents. US class codes 435/209, 435/252.3, and 435/320.1 were related to chemistry, and molecular biology microbiology, which gave three patents each.

Figure 8 CPC codes and number of patents (see online version for colours)



Source: https://relecura.com/ (accessed on 24 March 2021)

Figure 9 US class codes and number of patents (see online version for colours)

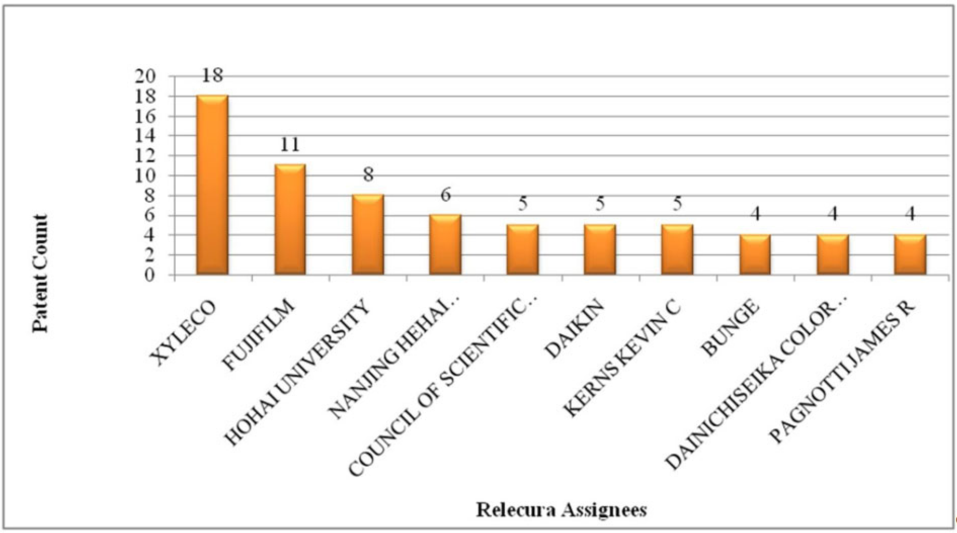


Source: https://relecura.com/ (accessed on 24 March 2021)

3.3 Inventors statistics

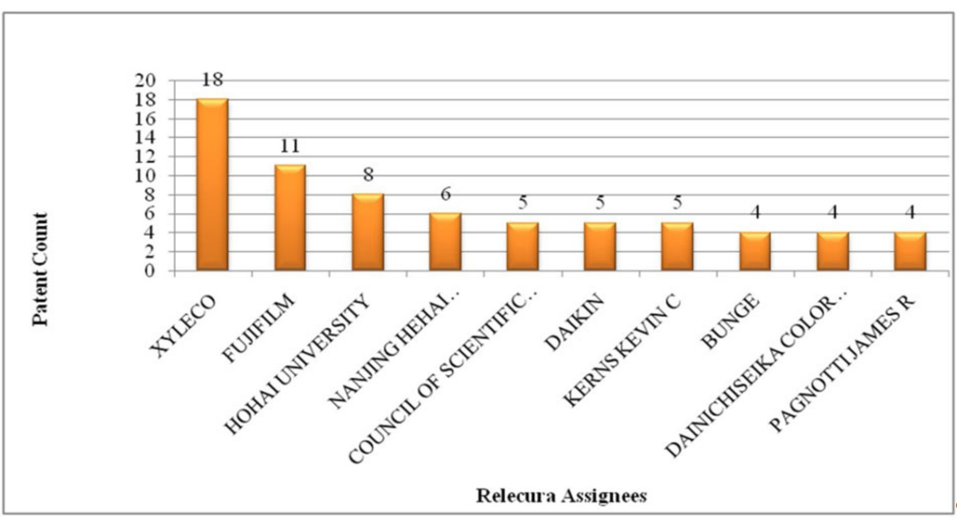
Figure 10 portrays ten inventors by count contributive within the field peel-based activated carbon in wastewater treatment Figure10, to trap the contribution of inventors. Marshall Medoff, Thomas Craig Masterman, and Robert Paradis were shown to be the top three inventors with seven patents each.

Figure 10 Top 10 inventors for peel-based activated carbon in wastewater treatment (see online version for colours)



Source: https://relecura.com/ (accessed on 24 March 2021)

Figure 11 Top 10 Relecura assignees for peel-based activated carbon in wastewater treatment (see online version for colours)



Source: https://relecura.com/ (accessed on 24 March 2021)

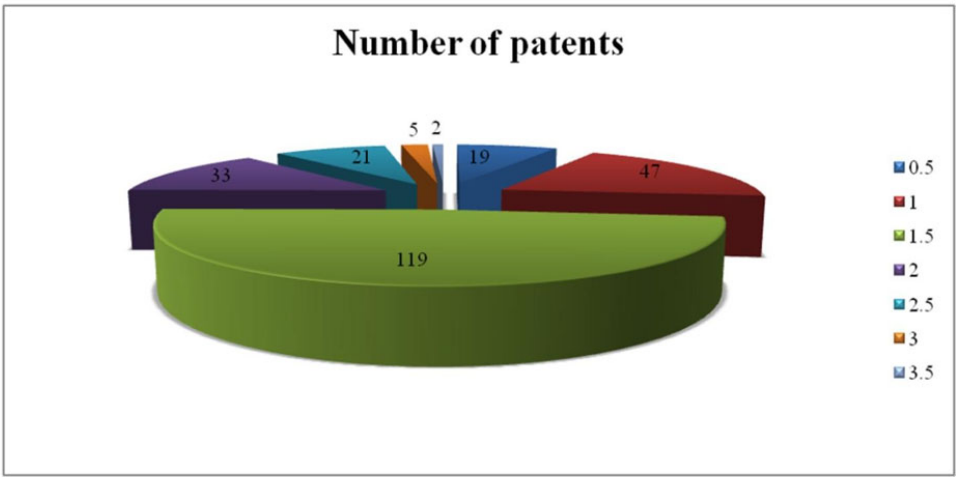
3.4 Relecura assignees (Applicants)

Xyleco, Fujifilm, and Hohai University werer the top 3 Relecura assignees with 18, 11, and 8 patents, respectively Figure 11.

3.5 Star rating

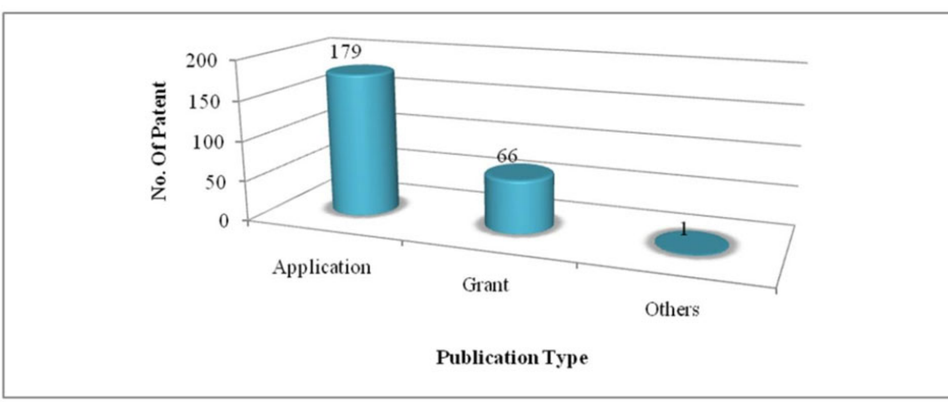
The Relecura has a unique feature, the star rating of patent documents. Star rating begins from 0.5 to 3.5. Almost 19 patents received a 0.5-star rating, and only two with 3.5-star ratings Figure 12.

Figure 12 Star rating and number of patents for peel-based activated carbon in wastewater (1985 to 2021) (see online version for colours)



Source: https://relecura.com/ (accessed on 24 March 2021)

Figure 13 Publication types for the peel-based activated carbon in wastewater treatment (see online version for colours)



Source: https://relecura.com/ (accessed on 24 March 2021)

3.6 Publication types

The Relecura software was employed to review the publication types. From the analysis, 179 applications, 66 granted patents, and 1 other document were found (Figure 13, related to the search).

3.7 Kind codes and document types

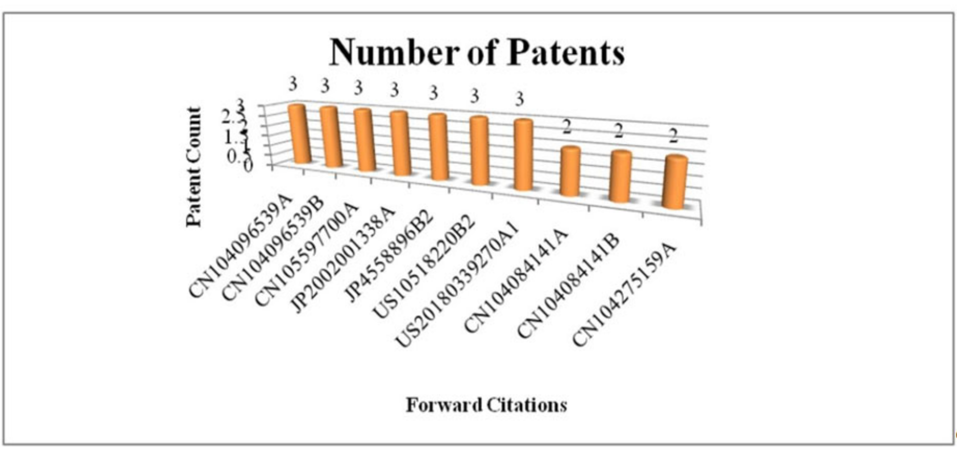
It is important to understand the significance of each letter in a patent number. Each digit has a meaning deduced from its classification, known as kind codes. For example, in patent number CN104096539A, CN (China) represents country code, and A (unexamined patent publication) is kind code. Kind codes, such as A, A1, A2, B, B1, B2, C, T, and so on, have different meanings for different countries. This code indicates if a broadcast document is an application for a patent-issued patent, documents revealed with or without a search report, and so on (Patent kind codes; Espace net; Kind code and numbering of Japanese patent).

3.8 Forward and backward citations

The backward citation is a reference to the patent's previous art, whereas the forward citation is a reference to the patent in question from another patent. The citation analysis assumes that the amount and character of forward and backward citations are indicators of patent value proposition, with a higher number of forward citations indicating a higher value.

Figure 14 shows the forward citation. The Chinese patents revealed to be dominating in this sphere. Table 6 details the citation counts of the top 10 forward-cited patent documents. The patent documents US9371550B2, US9816231B2, US10066339B2 had more citation counts and larger family sets, demonstrating their technological relevance and commercial importance.

Figure 14 Top 10 patents considering forward citation (see online version for colours)



Source: https://relecura.com/ (accessed on 24 March 2021)

Table 6 Top 10 patents considering forward citation

Sr. no	*Publication number*	*Filing date*	*Published date*	*Priority date*	*Backward citations count*	*Forward citations count*	*Family members count*	*Reference*
(1)	CN1033 81357A	2013-07-30	2013-11-06	2013-07-30	4	20	0	(Cao et al., 2013)
(2)	US9371 50B2	2014-06-09	2016-06-21	2013-03-08	131	13	320	(Medoff et al., 2016)
(3)	US9816 31B2	2016-06-10	2017-11-14	2013-03-08	141	12	605	(Medoff et al., 2017)
(4)	JPH07112182A	1994-07-15	1995-05-02	1993-07-16	0	11	6	(Sugimoto, 1995)
(5)	CN103657600A	2013-11-28	2014-03-26	2013-11-28	3	10	1	(Fang et al., 2014a)
(6)	JPH084716B2	1991-12-09	1996-01-24	1991-08-29	0	9	7	(Sugimoto, 1996)
(7)	CN103464111B	2013-08-22	2015-09-30	2013-08-22	2	8	1	(Cao et al., 2015)
(8)	US10066339B2	2017-10-11	2018-09-04	2013-03-08	155	6	605	(Medoff et al., 2018)
(9)	CN103752280A	2014-01-07	2014-04-30	2014-01-07	5	6	1	(Fang et al., 2014b)
(10)	US10518220B2	2018-07-31	2019-12-31	2013-03-08	165	0	605	(Medoff et al., 2019)

Source: https://relecura.com/ (accessed on 24 March 2021)

Table 7 Top10 Patents considering backward citation

Sr. no.	*Publication number*	*Filing date*	*Published date*	*Priority date*	*Backward citations count*	*Forward citations count*	*Family members count*	*Reference*
(1)	WO2011046815A1	2010-10-08	2011-04-21	2009-10-16	231	30	18	(Dayton et al., 2011)
(2)	WO2011046812A1	2010-10-08	2011-04-21	2009-10-16	219	32	21	(Barton et al., 2011)
(3)	WO2008036863A2	2007-09-21	2008-03-27	2006-09-21	198	29	18	(O'donoghue and Barton, 2008)
(4)	US10518220B2	2018-07-31	2019-12-31	2013-03-08	165	0	605	(Medoff et al., 2019)
(5)	US9512382B2	2014-08-19	2016-12-06	2009-10-16	156	12	17	(Dayton et al., 2016)
(6)	US9045712B2	2010-10-08	2015-06-02	2009-10-16	155	32	18	(Dayton et al., 2015)
(7)	US100663 39B2	2017-10-11	2018-09-04	2013-03-08	155	6	605	(Medoff et al., 2018)
(8)	US981623 1B2	2016-06-10	2017-11-14	2013-03-08	141	12	605	(Medoff et al., 2017)
(9)	US937155 0B2	2014-06-09	2016-06-21	2013-03-08	131	13	320	(Medoff et al., 2016)
(10)	US104873 16B2	2016-05-25	2019-11-26	2009-10-16	28	0	21	(Barton et al., 2019)

Source: https://relecura.com/ (accessed on 24 March 2021)

Table 8 Summary of key patents

Sr. no.	*Publication number*	*Summary*	*Reference*
(1)	CN110237828B	Bio-adsorbent from waste goat wool was made by steam flash explosion and liquid nitrogen crushing. The above method was an efficient and environment-friendly pretreatment method, the particle size of the processed goat hair powder was as low as 20µm, the crystallisation index was as low as 2.6%, the amorphous area of the goat hair powder increased, dye removal rate reached 95% with the adsorption capacity can 426mg/g	(Hou et al., 2020)
(2)	CN106215882B	The method involved the preparation of adsorbent from a watermelon peel to treat dye wastewater. The preparation and adsorbing material disclosed in the patent had the advantages of large surface area, good chemical strength, adsorbing effect, and easiness in regeneration. As compared with the similar adsorbing agents, the prepared adsorbing material according to this patent was better based on the adsorbing effect and the adsorbing capacity of the said adsorbing material, for reactive brilliant red under the acidic conditions, with maximum adsorption 279.06mg/g, which was four times that of activated carbon	(Cao et al., 2018)
(3)	TWI617515B	The method for removal of dye from wastewater by using rice bran was reported. The invention was for an adsorbent, which was selected from the group consisting of acid-modified rice bran, alkali modified rice bran (un-extracted and extracted), magnetically modified rice bran (extracted), and magnetically modified alkali revised rice bran (extracted). These adsorbents of the present invention were low cost and simple, which were produced from agricultural waste byproducts	(Hong and Lin, 2018)
(4)	TWI227703B	A method involved the preparation of cross-linked chitosan beads. It included dissolving chitosan in acetic acid to form chitosan solutions and keeping it undisturbed for 24hrs after which it completely dissolved in the acidic solution. Cross-linked chitosan beads were made through chemical cross-linking action by adding sodium hydroxide and cross-linking agent and then shaking the solution in a tank at 25 to 55oC for 6hrs. The adsorbent prepared could adsorb mass dyestuff in `acid or neutral wastewater	(Chiou, 2005)
(5)	US10557098B1	In this method, hydrochar was prepared from jackfruit peel biomass that included hydrothermal carbonisation of jackfruit peel biomass by autoclaving at 150°C to 250°C for about 3hrs to produce a hydrochar. The hydrochar was activated by treatment with phosphoric acid, hydrogen peroxide, or a combination thereof. The said hydrochar was effective against the removal of azo-dyes, and specifically methylene blue, from aqueous solutions such as industrial wastewater	(Khan et al., 2020)
(6)	BRPI0703218B1	Modification of rice hull fiber and modified rice husk fiber was done by chemical reaction with amino-propyl triethoxysilaneorganosilane. The modified rice husk was dried at a temperature between 20°C to 30°C, resulting in a product characterised by the amino group, increasing the silicon content at the fiber surface. As per the disclosure, the fiber-modified rice hull could be used at pH correction acids in aqueous effluents since it enables increasing the pH of the medium	(Benedini et al., 2016)

Source: https://relecura.com/ (accessed on 24 March 2021)

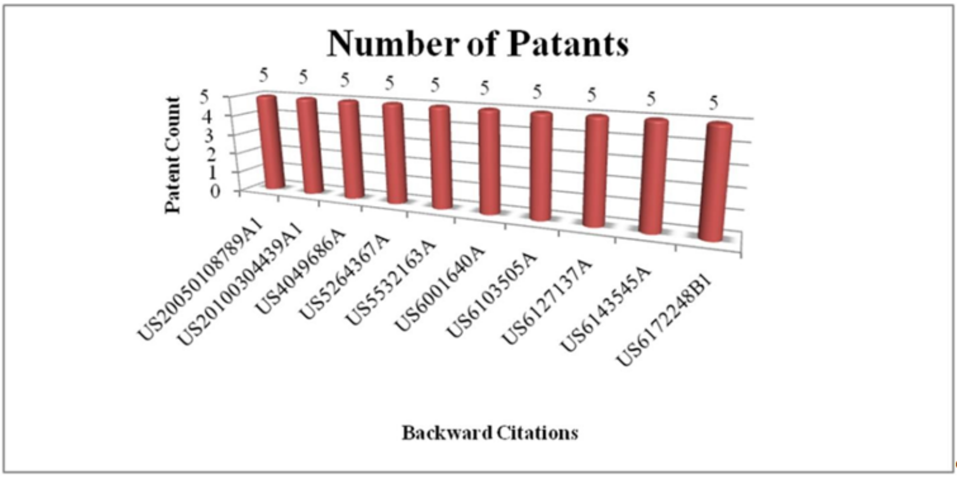
Table 8 Summary of key patents (continued)

Sr. no.	*Publication number*	*Summary*	*Reference*
(7)	CN109513424B	The method of preparation of carbon/hydrotalcite composite adsorbent comprised of the steps of placing raw material solution containing a carbon substrate, a cation source for synthesising hydrotalcite, a carbonate source, and a hydroxide source in a closed container and aging at 90 to130°C to prepare the carbon/hydrotalcite composite adsorbent. The preparation process was simple to operate. The prepared magnetic composite adsorbent could realise quick separation under an external magnetic field was a novel environmentally functional material and could be widely employed in the treatment of domestic sewage and industrial wastewater	(Fu et al., 2019)
(8)	CN108465456B	The photocatalytic titanium dioxide graphene oxide straw composite adsorbent was made by taking titanium dioxide, graphene oxide, and straw core powder as raw materials and attaching the titanium dioxide to the surfaces of the graphene oxide and the activated straw core powder through the self-assembly. The adsorbent was a novel biomass composite material, and the preparation process was simple. The removal rate of the adsorbent was high for cationic dye was high, and the adsorption process was simple and easy to implement, separation was convenient, no secondary pollution was caused after adsorption, the prepared adsorbent had a photocatalysis functionality, the cationic dyes could be degraded, and the reuse of the adsorbent was possible	(Liu et al., 2018)
(9)	CN108262021B	A graphene oxide straw core powder composite adsorbent preparation method was carried out. The straw core powder was added to zinc chloride solution for activation. Self-assembly of the straw core powder and graphene oxide was done in the solution. The graphene oxide straw core powder composite adsorbent was prepared by freeze-drying. The graphene oxide straw core powder composite adsorbent prepared was a novel three-dimensional structured composite. The graphene straw core powder composite adsorbent was used as the adsorbent for the first time, had high adsorption capacity on cationic dye, showed excellent adsorption effect, a method was a convenient separation with no secondary pollution after adsorption, was recyclable, and was an environment-friendly absorption material	(Ge and Liu, 2018)

Source: https://relecura.com/ (accessed on 24 March 2021)

Figure 15 shows the backward citation. The US patents were dominating in this sphere. Table 7 details the citation counts of the top 10 patent backward cited paten. The publication number WO2011046815A1 possessed the highest backward citations, 231, with the highest family count of 605.

Figure 15 Top 10 patents considering backward citation (see online version for colours)



Source: https://relecura.com/ (accessed on 24 March. 2021)

3.9 Summary of key patents

Table 8 presents a summarised form of important contributions. Several adsorbents for wastewater treatment have been developed, including bio-adsorbents made from waste goat wool, watermelon peel, rice bran, hydrochar made from jackfruit peel, and many more.

3.10 Relevance of the study for the global markets

Stakeholders of innovation want to safeguard their intellectual for their profit. Multiple industries require wastewater treatment technologies. They also require the most efficient solution. Technologies that are commercially and industrially viable have readily available raw materials, are simple to operate, and are eco-friendly and urban-friendly, which makes every technology unique

4 Conclusions, research avenues, limitations

The current study examined patents on peel-based activated carbon in wastewater treatment from 1985 to 2021. There were only 5 patents granted in the peel-based activated carbon in wastewater treatment from 1985 to 2000, and patenting trends in peel-based activated carbon increased after 2001. The top three inventors, according to the current study, were Mrshall Medoff, Thomas Craig Masterman, and Robert Paradis, who each received seven patents. With 18 patents, Xyleco was the most prolific Relecura assignee. Only two of the 246 patents received 3.5-star ratings. The three major technological domains that contributed approximately to 71% of patenting activity in peel-based activated carbon in wastewater treatment were:

1 wastewater treatment

2 chemical and physical process-catalysis

3 chemical and physical process-separation.

China led the world in technological innovation in peel-based activated carbon for wastewater treatment. It was determined that approximately 27% of the 246 patents filed in peel-based activated carbon were granted between 1985 and 2021, with the remaining 73% of patents lapsed, revoked, pending, expired, or unknown. The patent study elaborated in this manuscript will serve as a road map for future innovations and inventions in peels for wastewater treatment.

5 Research gaps and research questions

The main research findings through the patent review are as under:

1 Technologies such as inorganic or non-macromolecular organic substances and solid waste disposal have an innovation potential.

2 There is room for innovation in sub-technologies too such as the separation of gases and vapours and separation involving liquid treatment with solid sorbents.

3 There is an opportunity for, India, Romania and Russia and many other countries to innovate in wastewater treatment.

4 The IPC code B01D21/01, CPC code B01D15/02, and US Class Codes 430/544 present an opportunity for innovation.

6 Limitations of the study

To study patents, researchers employ a variety of methodologies and fields such as search duration. There are various databases, datasets, and data search strategies but the data is too dynamic in nature to be frozen.

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