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Research Article

A Preliminary Study of Banana Stem Juice as a Plant-Based Coagulant for Treatment of Spent Coolant Wastewater

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The effectiveness of banana stem juice as a natural coagulant for treatment of spent coolant wastewater was investigated . Three main parameters were studied, namely, chemical oxygen demand (COD), suspended solids (SSs), and turbidity of effluent. Coagulation experiments using jar test were performed with a flocculation system where the effects of spent coolant wastewater pH as well as banana stem juice dosage on coagulation effectiveness were examined. The highest recorded COD, SS, and turbidity removal percentages by banana stem juice were 80.1%, 88.6%, and 98.5%, respectively, observed for effluent at pH 7 using 90 mL dosage. The inulin concentration in the banana stem was examined to be 1.22016 mg/mL. It could be concluded that banana stem juice showed tremendous potential as a natural coagulant for water treatment purposes and could be applied in the pretreatment stage of Malaysian spent coolant wastewater prior to secondary treatment.

1. Introduction

Coolant is widely used to provide a degree of lubrication and for cooling in various metal-working operations. It also improves the machinability, increases productivity, and extends tool life by cooling and lubricating the parts and cutting tools. They are largely based on water-soluble oils: synthetic, semisynthetic, and biodegradable [1]. The main problem with coolants, however, is that they can easily become polluted over long use, losing their effectiveness and properties [2], and may develop rancid odours due to the presence of complex chemicals and biocides [3]. Thus, a large amount of spent coolant wastewater generated from metal-working operations which is generally in high COD (Table 1) has become a great concern for the manufacturing industries. Due to its high surface-active and organic pollutant loads, this waste creates a serious danger to the environment [2, 4, 5]. It is estimated that more than 2×10^9 litres of metal-working fluids (MWFs) were used worldwide annually, and the waste could be more than ten times the usage, as the coolants have to be diluted prior to use [3].

There are several treatment methods used to treat waste metal-cutting fluids [2], namely, chemical coagulation [6], adsorption [7], microfiltration, and ultrafiltration [8–10], as well as biological (aerobic and anaerobic) process [11–14]. Due to high energy consumption or application of variety of chemicals, this would decrease the processing efficiency and increase cost of process [15]. For biological treatment, large area requirement, high maintenance, long retention time, and odour problems are usually associated with pond treatment methods.

Coagulation is a common process in the treatment of both industrial wastewater and surface water. Its application includes the removal of dissolved chemical species and turbidity via the addition of widely used chemical-based coagulants such as alum ($AlCl_3$), ferric chloride ($FeCl_3$), polyaluminium chloride (PAC), and synthetic polymer. Nonetheless, many disadvantages are associated with the usage of these coagulants such as relatively high procurement costs as well as detrimental effects on human health and environment. It is, therefore, the use of natural organic coagulant from plant-based which is cost effective may be an interesting alternative.

Table 1: The characteristics of MWF [2, 3, 12, 21–24] and regulatory discharge standard limits [32].

Parameters	MWF effluent (mg/L)	Regulatory standard discharge limit (mg/L)	
		A	B
pH	7.06	6.0–9.0	5.5–9.0
Chemical oxygen Demand (COD)	560–68000	50	100
Suspended solid (SS)	110	50	100
Turbidity	15,350 NTU	—	—
Color	White	—	—

All values except for pH and turbidity are expressed in mg/L.

Banana is a herbaceous plant of the genus *Musa* spp. of the family Musaceae. Banana is one of the most widely grown tropical fruits because of its high food value and an important addition to the diet. In Malaysia, the production of commercial varieties of banana has increased by 24–27% over the decades giving an amount of 27,453 hectares in 2009 with Johor, Pahang, and Sarawak as the largest banana-producing states [16]. The stem from which the fruit bunches have been taken should be cut off because it will never again grow fruit. The stem will be left abundantly in the plantation and normally will just rot or be used as fertilizer.

According to Namasivayam et al. [17], waste banana pith can be used effectively as an adsorbent for the removal of 87% Rhodamine B from textiles wastewaters at pH 4. Another research also on colour removal showed that the pith of banana stem can effectively remove the direct red colour and acid brilliant blue from aqueous solution through adsorption. The adsorption capacities were 5.92 and 4.42 mg dye per gram of pith for direct red and acid brilliant blue, respectively [18]. Other than that, banana pith also could be a useful biosorbent in the preliminary removal of cuprum from electroplating wastes [19]. The usage of banana stem juice as a natural coagulant in COD, SS, and turbidity removal, however, is known to be limited in the published literature.

This paper reports on the potential of juice produced from banana stem as a natural coagulant for the removal of COD, SS, and turbidity from spent coolant wastewater. Jar test with a flocculation system was used and the effects of spent coolant wastewater pH on coagulation effectiveness were examined. The coagulation/flocculation effectiveness of the banana stem juice was compared with Malaysian standard effluent discharge limit.

2. Experimental

Spent coolant wastewater was collected from camera lens manufacturer company in Shah Alam, Selangor, Malaysia. The spent coolant wastewater was collected from the site with excessive oil from the machine-processing operation. The oil on the top of the coolant was separated through skimming process, and spent coolant wastewater (without any excessive oil) was collected at the spent coolant storage prior to the treatment process within the plant operation.

Figure 1: Pith of banana stem after separated with foliage.

Figure 2: The banana stem juice.

The samples were collected in accordance with standard method for the examination of water and wastewater [20]. The samples were transferred into 20 L plastic containers and then closed, sealed tight, and labelled to avoid any oxidation and contamination before being transported to the laboratory. The samples were stored at 5°C to prevent spent coolant wastewater from undergoing further biodegradation due to microbial activities.

2.1. Banana Stem Juice Preparations. Matured banana plants were collected from Serdang, Selangor, Malaysia. The thorns were removed and the pith of the stem (Figure 1) was then separated from the foliage. 100 g of small pieces of the pith were mixed with 10 mL of distilled water using a mixer. The mixed pith was then filtered and the juice was collected. The fresh juice of banana stem (Figure 2) was stored in a refrigerator at 7°C to ensure its freshness. To avoid any fermentation, the coagulation experiments using this banana stem juice as a natural coagulant were carried out on the same day.

3. Methods

3.1. Coagulation Jar Test Experiments. Coagulation experiments using jar test were performed in the laboratory with a bioblock flocculation that comprises six-paddle rotor (24.5 mm × 63.5 mm) for 600 mL high-shape beakers, and all tests were conducted at room temperature. The desired amount of coagulant was added to spent coolant wastewater and stirred at the "flash mixing" speed of approximately 120 rpm for 1 minute. The speed was then reduced to slow at 30 rpm for 20 minute to keep flocs particles uniformly suspended. The settling of flocs particles was then observed and recorded. The mixture was left for 1 hour and later the supernatant was collected to determine the COD, SS and turbidity using the standard method. All the analyses were done in triplicates. pH of wastewater samples was controlled by adding 1.0 M H_2SO_4 or 1.0 M NaOH.

3.2. Analytical Analysis. Turbidity test was measured using portable turbidimeter (Model HACH 2100P). The principle of the turbidity measurement is based on a comparison of the intensity of light scattered by the sample. The sample cell was placed into the turbidimeter and the turbidity value was shown in NTU unit. The total turbidity percentage removal was calculated as follows:

$$\text{turbidity percentage removal} \approx \frac{A-B}{C} \times 100, \quad (1)$$

where A is turbidity of raw spent coolant wastewater (NTU), B is turbidity after treatment (NTU), and C is turbidity of raw spent coolant wastewater (NTU).

pH meter brand Mettler Toledo was used in this paper to measure the pH value of the sample. Suspended solid was measured using glass fiber disk filtration method. The glass fiber filter disks were dried in the oven at 100–105°C for one hour to remove any moisture that can affect the suspended solid measurement. The dried filter disk was then cooled and weighted. It was then used to filter 10 mL of the supernatant using vacuum filter, and the disk was carefully washed using 10 mL of distilled water. The disk was then dried again at 100–105°C for one hour and weighted again after it was cooled. The total suspended solid removal percentage was calculated as follows:

$$\text{suspended solid} \approx \frac{A-B}{C} \times 10^6, \quad (2)$$

where A is weight of the disk + solids (g), B is weight of empty filter disk (g), C is volume of sample (mL).

The COD test was measured using UV Spectrophotometer HACH model. Chemical oxygen demand (COD) refers to the amount of oxygen required to oxidize the organic compounds in a water sample to carbon dioxide and water. COD percentage removal was calculated as follows:

$$\text{COD percentage removal} \approx \frac{A-B}{C} \times 100, \quad (3)$$

where A is COD of raw spent coolant wastewater (mg/L), B is COD after treatment (mg/L), and C is COD of raw spent coolant wastewater (mg/L).

3.3. CHN Analysis. Analysis of constituents in banana stem was determined using the CHNS/O Analyzer LECO, CHNS932. Approximately 2.0 mg of very fine cut of oven dried banana stem was placed in a tin capsule and crimped. Three types of crimped capsules were placed in the autosampler for the CHNS/O analyzer (blank, standard-sulfamethazine, and banana stem sample). The temperature of the analyzer oxidation was set at 1000°C. A program runs the analysis automatically and results were given in percentage.

Table 2: Characteristics of spent coolant wastewater.

Parameter	Raw spent coolant wastewater
pH	8.45
Chemical oxygen demand	152,400 mg/L
Suspended solids	8,880 mg/L
Turbidity	81,250 NTU
Color	White

3.4. Inulin Analysis. Inulin analysis in banana stem was determined using high-performance liquid chromatography (HPLC) Agilent 1200. Standard inulin was obtained from a company in Subang, Selangor, Malaysia, with approximately 99% purity. Before injecting for analysis, the juice was filtered using nylon acrodisc filter 0.45 μm to avoid any interference. Shodex column K806 with $NaNO_3$ 0.5 M as eluent has been set. The flow rates of injection were 1 mL/min with 200 μL injection volume. The detector used was refractive index for analysis of carbohydrates component. The data for standard inulin was used to construct the calibration curve. The peak of inulin on the juice sample was recorded. The concentration of inulin was calculated based on the standard inulin calibration curve.

4. Results and Discussion

4.1. Characterization of Raw Spent Coolant Wastewater. Table 2 shows the characteristics of spent coolant wastewater before the coagulation pretreatment. The values were much higher compared to previous results [2, 3, 12, 21–24] except for pH and color. The differences were due to the machinery sources processing the wastewater, and this was indicated by the spent coolant wastewater containing high inorganic and organic substances. It is obvious that treatment of wastewater is required before it can be discharged into the environment since the COD concentration alone is more than 1500 times higher than the Standard B discharge limit.

4.2. CHN Analysis. An elemental analysis (Table 3) was conducted to provide a comparison between the elemental compositions of the banana stem and banana stem juice with those of other natural coagulants: *Moringa oleifera* and cactus *Opuntia*. In this study, it was determined that the foliage of banana stem contained 38.03% carbon, 0.42% nitrogen, and 5.46% hydrogen, meanwhile the stem juice contained 33.42% carbon, 0.49% nitrogen, and 6.17% hydrogen.

The composition of hydrogen was higher in banana stem juice compared to the banana stem. This is due to the high-moisture composition of that compared to the banana stem. The composition of principal elements of the banana stem

TABLE 3: Elemental analysis of banana stem, banana stem juice, and comparison with other natural coagulants.

Parameters	Shelled *Moringa* seeds [33]	Nonshelled *Moringa* seeds [33]	Cactus *Opuntia* [34]	Banana stem (pseudostem) [25]	Banana stem	Banana stem juice
C (%)	54.8	53.3	29.4	36.83	38.03	33.42
N (%)	6.1	5.0	2.3	5.19	0.42	0.49
H (%)	8.5	7.7	1.7	0.93	5.46	6.17

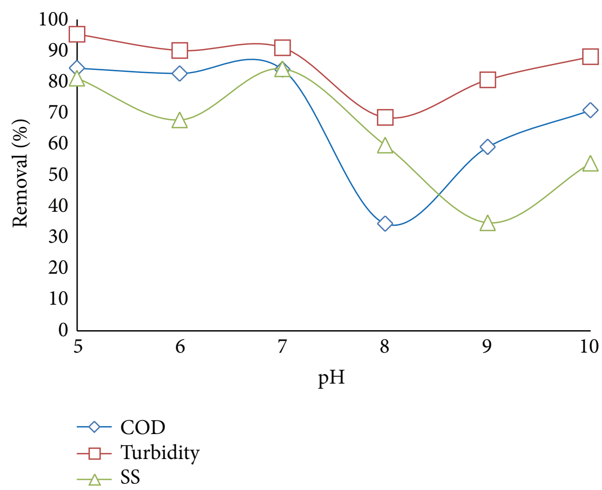

FIGURE 3: Effect of spent coolant wastewater pH on banana stem juice coagulant effectiveness.

was nearly similar with the result obtained by Bilba et al. [25]. They found that the compositions of carbon, hydrogen and nitrogen of the core of banana stem (pseudostem) were 36.83%, 5.19%, and 0.93%, respectively. There were not many differences between the compositions of carbon, hydrogen, and nitrogen in banana stem/juice and the established plant-based coagulants such as nonshelled *Moringa* seeds and shelled *Moringa* seeds.

4.3. Inulin Analysis. From the HPLC result, the peak of inulin was at 10- to 15-minute retention time, and the peak area that has been recorded was equal to 8191004.35. The result showed that inulin can be found in the stem of banana trees, and this is in agreement with the study by Meijer and Mathijssen [26], where most of the inulin is stored in the stem of chicory and Jerusalem artichoke. The result from this study showed that the inulin concentration in the banana stem was 1.22016 mg/mL.

Inulin is a very stable compound; Tadros et al. [27] discovered that the unique behaviour of the polymeric surfactant based on inulin is very stable on high temperature and also can be very stable emulsions in high electrolyte concentrations. Inulin has high bonding capacity as mentioned by Eissens et al. [28]. With this high bonding capacity, it is able to entrap more microfloc to form bridges on the polymer chain of inulin structure. When all the microflocs attached to the polymer chain of the inulin, this will form bigger and heavier flocs. The heavier flocs will easily settle down through the sedimentation process. Therefore, the settlement of the suspended solid will reduce the turbidity and the COD of the sample waste in flocculation process during jar test analysis.

4.4. Effect of pH on Banana Stem Juice. The chemistry of coagulant depends on the pH of any solution during the flocculation process. This can be seen when ferric salts undergo rapid, uncontrolled hydrolysis reactions upon their addition to water, forming a series of chemical products or complexes [26]. Therefore, controlled pH of the spent coolant wastewater determines the effectiveness of banana stem juice in the flocculation process, where it determines the maximum COD, SS, and turbidity percentage removal. Figure 3 shows the effect of pH on the coagulation of the spent coolant wastewater using banana stem juice as a natural coagulant. The volume of spent coolant wastewater used was 300 mL and the volume of banana stem juice used was 50 mL. From the graph, the highest recorded COD and SS removal percentage was observed for effluent pH 7 at 83.9% and 84.1%, respectively. However, percentage removal for turbidity at pH 7 was found slightly less (90.9%) compared to the percentage removal at pH 5 (highest percentage removal, 95.2%). Generally, pH 7 was found to be a good pH for efficient removal of COD, SS, and turbidity by banana stem juice, where the percentages were at 83.9, 84.1, and 90.9%, respectively. This result indicated that at pH 7, the maximum amount of coagulant is converted to solid phase flocs particles. At pH value higher and lower than this pH of minimum solubility, the charges produced by inulin as a natural polymer from banana stem juice for bridging and entrapping the microfloc to form larger floc were very low; thus, the adsorption on the surfaces of precipitated floc particles was very minimal. This result is rather different compared to plant-based coagulant such as *Opuntia* ficus-indica with coagulating-flocculating capabilities where 65% of the initial COD was removed at

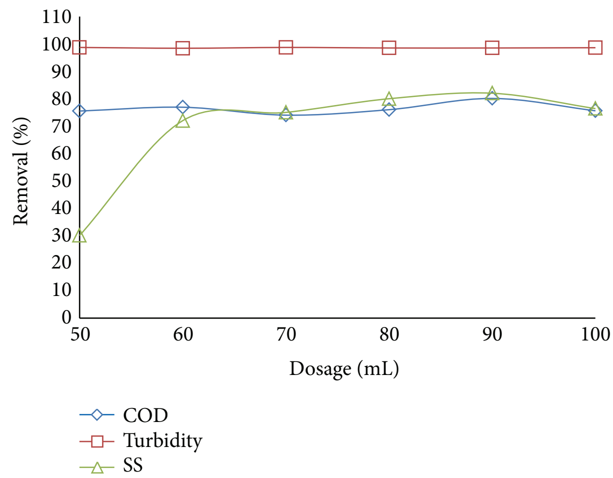

Figure 4: Effect of banana stem juice dosage on the coagulation process of spent coolant wastewater.

Table 4: Compliance of treated spent coolant wastewater using banana stem juice with Malaysian standard effluent discharge limit.

Parameters	Raw spent coolant wastewater (mg/L)	Treated spent coolant wastewater (mg/L)	Standard effluent discharge limit (mg/L)	
		banana stem juice	A	B
pH	8.45	7	6.0–9.0	5.5–9.0
Chemical oxygen Demand (COD)	152,400	30, 300	50	100
Suspended solid (SS)	8,880	1,010	50	100
Turbidity	81,250 NTU	1,235 NTU	—	—

All values except for pH and turbidity are expressed in mg/L.

pH 10 (dose of 50 mg/L) [29]. A similar observation was seen from the findings by Zhang et al. [30], where the lowest turbidity removal percentages recorded using cactus *Opuntia* were at pH 6 and 7 while the optimum pH was 10 for synthetic kaolin wastewater treatment. This might be due to the properties of the banana stem juice during preparation since it was prepared in a solution form where distilled water was mixed with the juice to make the juice more diluted; hence, the concentration of inulin from the banana stem was lower.

4.5. Effect of Dosage of Banana Stem Juice. Figure 4 shows the effect of the dosage of banana stem juice as a coagulant on flocculation effectiveness at optimum pH value 7 for banana stem juice. This pH value was selected based on our findings in this study reported above. For banana stem juice, the dosages ranged from 50 to 100 mL, and the volume of spent coolant wastewater used was 300 mL.

Turbidity removal percentages showed marginal difference in which more than 98% removal was achieved. It appeared that the highest COD removal percentage was 80.1% while for the suspended solid removal percentage was 88.6% (both 90 mL dosage). The lower COD and SS removal percentages might be due to the use of natural coagulant which may increase the organic load in water [31] and result in the possibility for undesired and increased microbial activity [26]. As such, increase in the organic load is responsible for the increase of BOD concentration and subsequently contributes to increased COD concentration in an aqueous solution.

Table 4 analyses the compliance of COD, SS, and turbidity concentrations of spent coolant wastewater treated with banana stem juice with standard effluent discharge limits A and B stipulated by the Department of Environment (DOE), Malaysia. The pH value of treated spent coolant wastewater complied with the pH range (5–8) stipulated by the DOE, Malaysia. However, values for all other parameters were higher than standards A and B. Although banana stem juice is capable of reducing the COD, SS, and turbidity concentrations by giving the values of 30,300 mg/L (80.1%), 1,010 mg/L (88.6%), and 1,235 NTU (98.5%), respectively, these values were still higher than standards A and B. The result from this study indicates that banana stem juice is applicable as a natural coagulant in the pretreatment process of wastewater, and further treatment is needed before it can be discharged into the environment. Nevertheless, banana stem juice showed high potential as a natural coagulant for water treatment purposes.

5. Conclusion

Generally, the percentage of COD, SS, and turbidity removal by using banana stem juice showed tremendous potential as a plant-based natural coagulant in the treatment of spent coolant wastewater. High COD, SS, and turbidity removal percentages by the banana stem juice were observed for effluent at pH 7 where percentages were 80.1, 88.6, and 98.5%, respectively. Banana stem juice contains polysaccharide compounds—inulin (1.22016 mg/mL), which is a natural polymer for bridging and entrapping the microfloc to form larger floc. Therefore this will help in fast settlement of the floc for coagulation of spent coolant wastewater. Although the final discharge did not comply with the standard effluent discharge limits A and B stipulated by the DOE, Malaysia, with percentage of COD, SS, and turbidity removal exceeding 80%, it is suggested that banana stem juice is to be used in the pretreatment stage of spent coolant wastewater prior to secondary treatment. It is also suggested that banana stem should be dried and sieved into fine powder in order to get high concentration of inulin prior to its use. For future study, it is recommended that more experiment should be done such as colour removal, strength of the flocs, and density of the flocs where those parameters influence the floc velocity.

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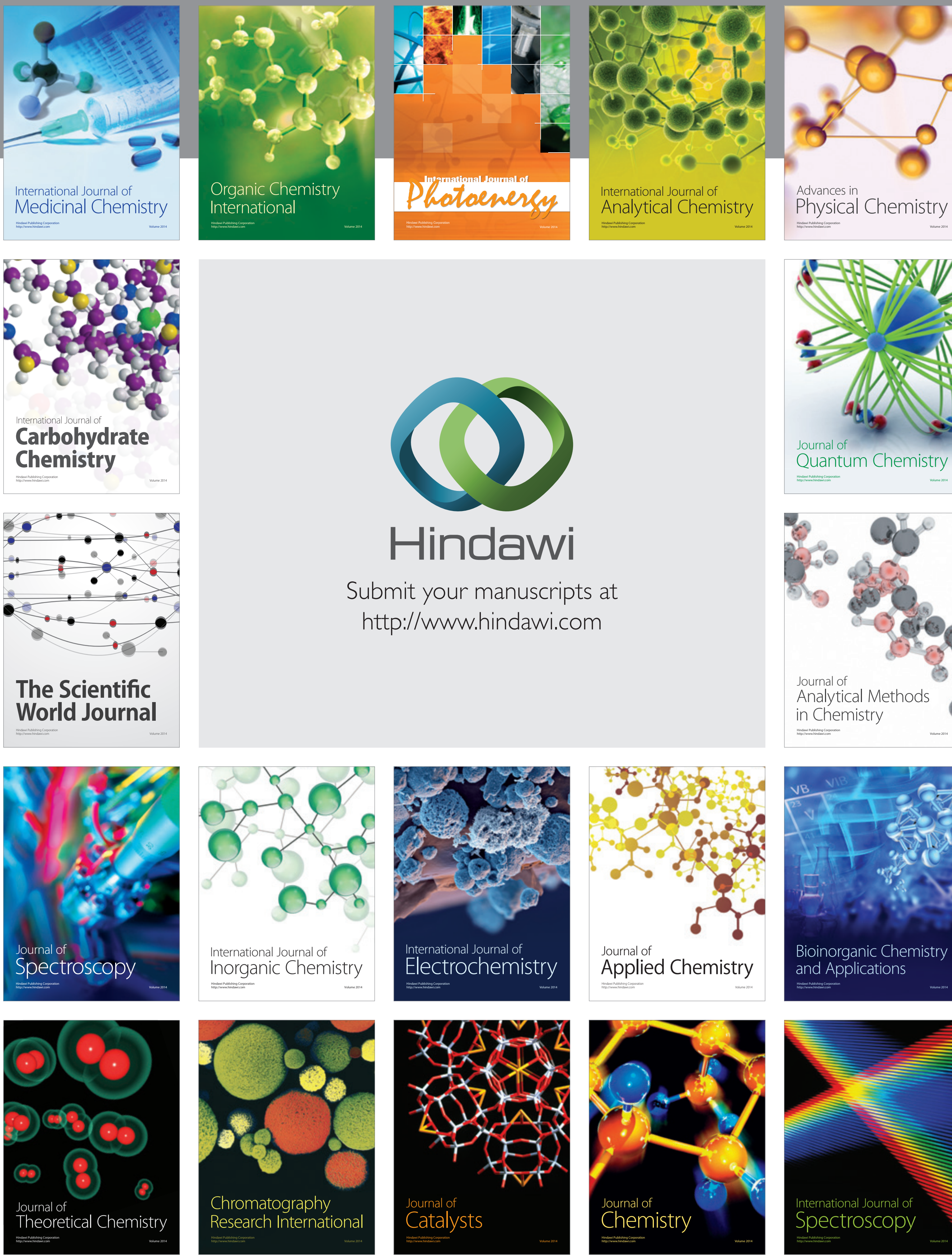
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