



## Knoevenagel Condensations Catalyzed by New Oil Shale Recyclable Catalyst at Room Temperature and Assisted by Ultrasounds Irradiations

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### ABSTRACT

Functionalized alkenes were successfully synthesized via a clean procedure in a short time by using a new recycled heterogeneous catalyst prepared from Moroccan oil shale, this catalyst is characterized by different technics such XRD, BET-BJH, MEB-EDS, and TGA, before it's has been used in the Knoevenagel condensation between different aldehydes and active methylenes. The results showed that coupling the catalyst with ultrasound irradiations could improve the catalytic system in this transformation by achieving the products in a very short time, the results showed clearly that this catalyst could be considered as excellent recyclable support in Knoevenagel condensation.

**Keywords:** Oil Shale, Knoevenagel, Heterogeneous catalysis, Ultrasound.

### INTRODUCTION

Since the first report of Knoevenagel condensation in 1895, the synthesis of their products is becoming and still guard an important position in the scale of organic transformations knowing that it is considered as indispensable intermediates in many organic reactions<sup>1</sup>. This transformation is getting its importance from the capability of the generation of double bond carbon-carbon from condensation between carbonyls and active methylene compounds

to afford the desired functionalized alkenes.

The products synthesized by Knoevenagel condensation are widely used in the synthesis of reaction intermediates or as final products themselves for pharmaceutical uses, perfumes and polymers<sup>2,3</sup>, bioactive compounds like pesticides, antifungal products, and anti-bacterial<sup>4,5</sup>. The functionalized alkenes obtained by Knoevenagel reaction also have broad medicinal activities such as antiviral, anti-tubercular, anti-Parkinson, anti-



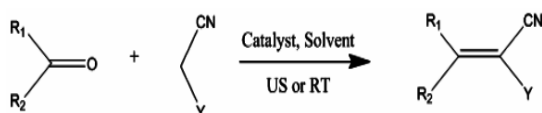
diabetic, anti-oxidant, and anti-cancer activity<sup>6-12</sup>.

Too many catalysts have been reported since the first synthesis of Knoevenagel condensation which was catalyzed by diethylamine<sup>13</sup> and showed then that this transformation needs a basic catalyst. In this regard, researchers developed many basic catalysts which could generate this transformation such as metal oxides such mesoporous Mg–Fe bi-metal oxides and Fly ash supported calcium oxide<sup>14,15</sup>, Metal-organic framework<sup>16-18</sup>, phosphates catalysts<sup>19,20</sup>, Dolomite<sup>21</sup>, alkali metal hydroxide such LiOH<sup>21</sup> and a limited variety of acid catalysts were also reported, we mentioned in this regard polymer-metal complex PS-TiCl<sub>4</sub><sup>23</sup> and Nano-crystalline HoCrO<sub>4</sub><sup>24</sup>.

Ultrasounds assisted heterogeneous catalysts have become a more attractive way to ameliorate catalytic systems in many transformations by its rapidity and high reaction yields under eco-friendly conditions, this sonor technic has proved also its capability to ameliorate catalytic systems toward Knoevenagel condensation, a variety of catalysts were used under ultrasound conditions to achieve Knoevenagel products such alkaline-doped saponites<sup>25</sup> Potassium sorbate<sup>26</sup> and KF/Al<sub>2</sub>O<sub>3</sub><sup>27</sup>.

On the other hand, oil shale considering as a source of energy by conversion the raw oil shale to energy and chemical products by the thermochemical conversion technology<sup>28</sup>, many environmental alternatives were also developed by using Moroccan oil shale as an adsorbent material to remove industrial colorant, heavy metals and radioactive elements<sup>28-37</sup>.

On our part, we will broaden and develop for the first time the application of oil shale raw material by elaboration of a new stable and recyclable heterogeneous catalyst and investigate its catalytic activity toward Knoevenagel condensation using different aldehydes with active methylenes to achieve high valued intermediate compounds of functionalized alkenes either at room temperature or under ultrasound irradiations Schema 1.



Scheme. 1. Knoevenagel condensation in the presence of the catalyst

## MATERIALS AND METHODS

### Materials

The raw material of oil shale supplied from the region of Tarfaya morocco, the sample which was used as supports is crushed and sieved in particles between (50-200 microns), and the catalyst is obtained by calcination in air at 900°C for 2 hours, the obtained catalyst was analyzed by X-ray diffraction using (Philips diffractometer 1710), using Cu-K $\alpha$  ( $\lambda = 1.5418 \text{ \AA}$ ) with 2 $\theta$  range from 10 to 80. The thermal evolution of the sample was monitored from ambient temperature to 800°C by heating rate 10°C/min under an inert atmosphere using TGA Verstherme (Thermoscientific), the morphology of the catalyst was examined using a scanning microscope HIROX S4000.

The N<sub>2</sub> adsorption-desorption of the catalyst was measured using a 3Flex Micromeritics instrument. The data were processed by the 3Flex Software version 4.01. Specific surface area and pores size distributions were calculated according to Brunauer-Emmett-Teller (BET) equation and Barrett-JoynerHalenda (BJH) method respectively. The isolated products were identified using <sup>1</sup>H nuclear magnetic resonance (NMR, 500 MHz) and <sup>13</sup>C NMR (151, MHz) recorded on an NMR spectrometer JNM-ECZ500R/S1 FT NMR SYSTEM (JEOL) using trichloromethane as a solvent.

### General Procedure for the Synthesis of the functionalized alkenes

Equimolar mixture (1.5 mmol) of different aldehydes and active methylene, specific weight of catalyst was added in a volume of solvent at room temperature. The reaction mixture was stirred using a magnetic stirrer or assisted with ultrasound. After completion of the reaction the mixture was extracted with ethyl acetate to give the product which is purified by simple recrystallization in ethanol, the catalyst recovered off by simple filtration, and the formed alkenes identified by their melting points, infrared spectroscopy, and <sup>1</sup>H NMR, <sup>13</sup>C NMR.

The recovered catalyst was washed with methanol, then dried and calcined at 900°C for 30 min before the re-utilization.

## RESULTS AND DISCUSSION

### Catalyst characterization

After the preparation of the catalyst, it's has been characterized by different analytical technics. At first, we aimed to visualize the morphology of its surface the things which was conducted by scanning electron microscopy Figure 1.

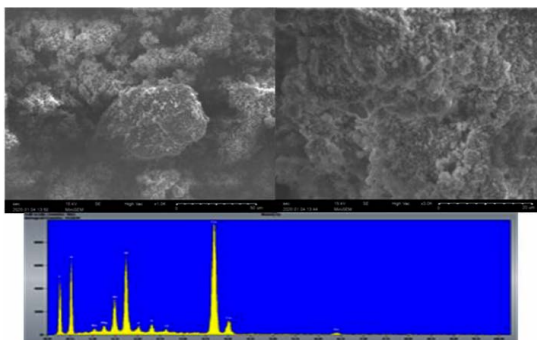


Fig. 1. SEM-EDS of the catalyst

The micrographs show us clearly that the morphology is represented by the heterogeneous dispersion of surface grains. These micrographs also evince a porous structure of the catalyst, which represents a good and promoted sign for using it as a catalyst. Furthermore, the elemental analysis by energy-dispersive X-ray spectroscopy (EDS) indicates the presence of C, O, Ca, and Mg as main elements.

The XRD spectrum of the catalyst Fig. 2, represents a mixture of different phases, the pattern reveals the presence of Ca and Mg oxides, CaO ( $2\theta = 32, 37, 54$  and  $64$ ) and MgO ( $2\theta = 37, 43$  and  $62$ ) which have been identified due to calcination process, other oxides have been found such silica  $\text{SiO}_2$  ( $2\theta = 21, 26$  and  $50$ ) and alumina  $\text{Al}_2\text{O}_3$ . Other different oxides have been reported at a state of traces such as  $\text{Fe}_2\text{O}_3$ ,  $\text{K}_2\text{O}$ ,  $\text{Na}_2\text{O}$ , and  $\text{P}_2\text{O}_5$ .

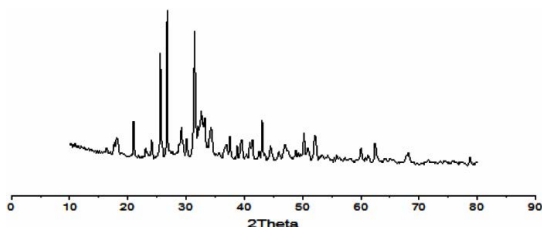


Fig. 2. XRD pattern of the catalyst

To confirm the thermal stability of the catalyst, we conducted a TGA analysis Fig. 3. This analysis showed us that there are two main weight losses. The first corresponds to a small weight loss

of water molecules, and the second, at  $600^\circ\text{C}$ , could represent the decomposition of the carbonates which are still present in the support. These results show that this catalyst is thermally stable.

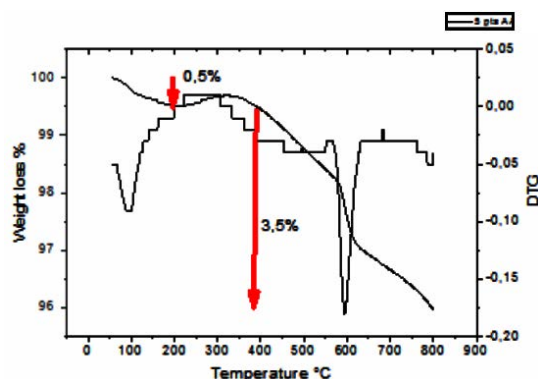


Fig. 3. Thermal gravimetric analysis (TGA) of the catalyst

The pattern of a typical IUPAC type IV with a hysteresis loop showed us that the catalyst has a Brunauer–Emmett–Teller (BET) surface area (SBET) of  $3.313 \text{ m}^2 \text{ g}^{-1}$  and total volume pore  $0.004440 \text{ cm}^3/\text{g}$  Fig. 4a. Furthermore, the corresponding pores size distributions curve determined by Barrett–Joyner–Halenda (BJH) method which showed that the pore size distribution is centered approximately  $25.20 \text{ \AA}$  Figure 4b.

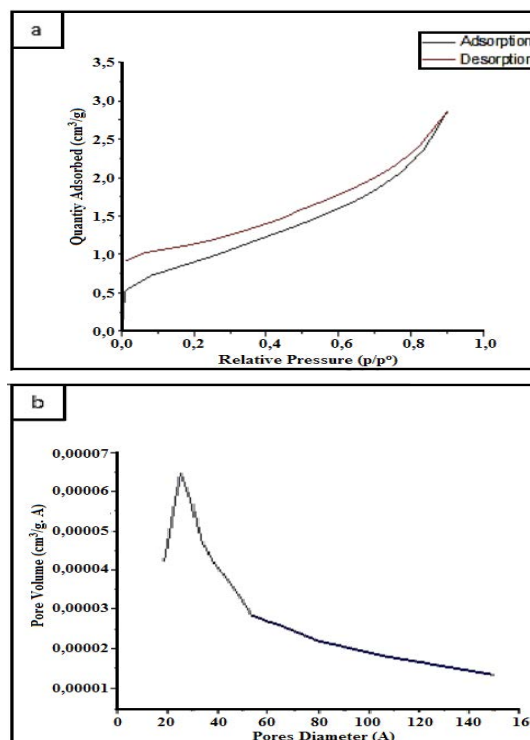


Fig. 4. Nitrogen Adsorption-desorption isotherms of the catalyst (a) and BJH pore size distribution (b)

### Catalytic Activity

First, we inaugurated the catalytic investigation by studying the effect of the catalytic weight on the yield of the product using benzaldehyde and ethyl cyanoacetate as a model reaction at room temperature for 120 min, a yield of 67 was achieved. The raising of the reaction time to 180 min allowed us to achieve a very significant increase in the yield by getting a yield of 92% Figure 5.

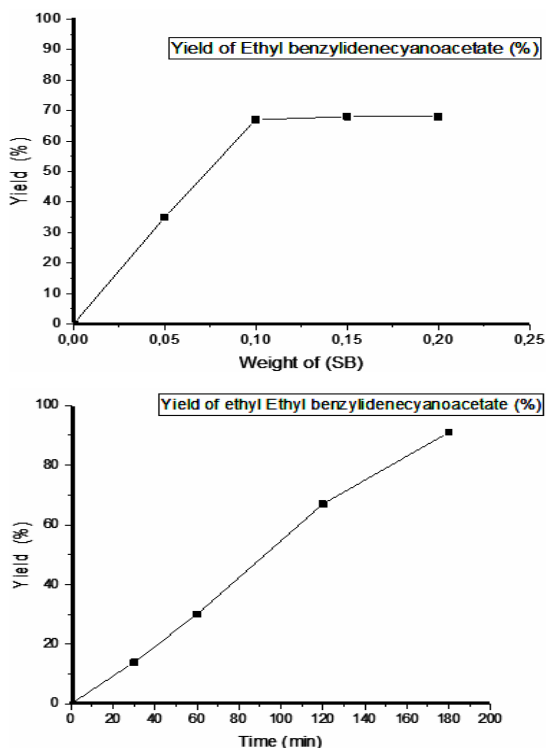


Fig. 5. Influence of catalytic weight and reaction time on the yield of the reaction

To ameliorate the catalytic activity of the catalyst toward Knoevenagel condensation, we combined it with ultrasound irradiations. The tests were carried out in ultrasounds bath with no agitation. Different parameters have been studied, such as catalyst weight, nature and volume of solvent, and the kinetic of the reaction.

Initially, we optimized the reaction conditions for the synthesis of ethyl benzylidenecyanoacetate as a reaction model product by the investigation of the influence of different parameters under ultrasound irradiation. In the first instance, 0.1 g of the catalyst was found to be the optimum catalytic weight to realize this transformation.

Regarding ultrasound-assisted organic

synthesis, the nature of the solvent plays an important role either by lowering the viscosity of the medium or by making it uniform and miscible<sup>38</sup>. In this regard, we evaluated different polar primary and secondary alcohols as solvents on the yield of the reaction, such as Et-OH, Me-OH, Pr-OH, Bu-OH, Hex-OH, iso-Bu, and iso-Pr (Table 1).

Table 1: Influence of different solvents on the yield

Solvent	Yield%
Methanol	63
Ethanol	46
Propanol	46
Butanol	45
i-propanol	39
i-Butanol	40
Hexanol	33

The results which are shown in Table 1 give us a clear vision that the reaction could be carried out by using different alcohols as solvents. It is noteworthy that the best yield was obtained when we used methanol as a solvent. This result could be explained by the low viscosity of methanol, the thing which makes it easier for the cavitation phenomena created by ultrasound irradiations<sup>38</sup>. This explanation takes more credibility when we compare the results of methanol with other solvents with higher viscosity. The optimization in Table 2 showed that 0.2 mL of methanol was found to be sufficient to carry out this reaction in a good yield by obtaining 66% of the desired product. The augmentation of the solvent volume to 1 mL decreased the yield to 40%. This result is explained by the dispersion of reagents and, by consequence, limiting the contact surface-substrates.

Table 2: Reaction Optimization Condition under ultrasounds irradiations

Entry	Amount of catalyst	Time	Solvent Volume	Yield%
1	0.05	30	Methanol, 0.5 mL	30
2	0.1	30	Methanol, 0.5 mL	66
3	0.15	30	Methanol, 0.5 mL	65
4	0.2	30	Methanol, 0.5 mL	65
5	0.1	15	Methanol, 0.2 mL	50
6	0.1	30	Methanol, 0.2 mL	63
7	0.1	45	Methanol, 0.2 mL	75
8	0.1	60	Methanol, 0.2 mL	75

The optimum reaction time was found via the kinetic study when we got a satisfying yield of 75% after 45 minutes. After this time, the yield stayed the same.

According to these findings summarized in Table 2, the optimum reaction conditions using

ultrasound, irradiations were found to be 0.1 g of catalyst, 0.2 mL of methanol as the minimal quantity of solvent which could accelerate the reaction, and 45 min as the reaction time.

The recyclability of the catalyst has been studied. This feature is considered the most important advantage when it comes to heterogeneous catalysts. The recovered catalyst was washed with methanol and treated thermally at 900°C for 30 min before reuse. This treatment showed its efficiency by giving the catalyst the capability of reuse several times without a significant decrease in the yield Figure 6.

Various alkenes were prepared using the optimized conditions at room temperature and under ultrasound irradiation Table 3. The comparison of

the obtained results at room temperature and the ultrasound method demonstrates that the ultrasonic approach is very effective for this transformation. The reaction time decreases significantly to 1 min in some entries, as presented in the table.

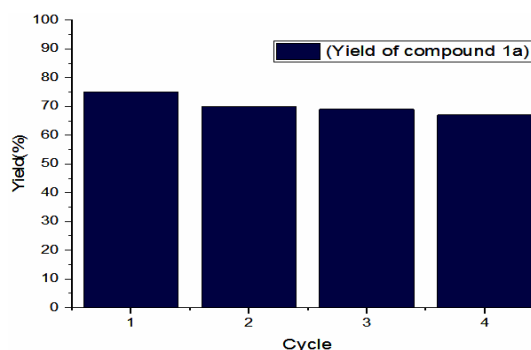


Fig. 6. Reusability of the catalyst in the synthesis of Ethyl 2-cyano-3-phenylacrylate

Table 3: Generalization of synthesis of different alkenes by Knoevenagel reaction

R	Méthylene	Product	Time(min)/Yield (%)	
			Catalyst	US/Catalyst
			2a	120/67
				180/92
			2b	45/48
				60/50
			2c	60/78
				90/93
			2d	Oct-72
				15/81
			2e	15/78
				20/93
			2f	60/50
				75/65
			2g	15/74
				20/88
			2h	15/80
				20/88

The results showed that the use of ethyl cyanoacetate as active methylene (Table 1, entry 1, 2, 3), gives the desired products in a very good yield but at a time goes from 60 until 180 minutes. These conditions are enhanced when we use the ultrasound method when the time of the reaction decreases.

Carrying out the reaction by using the malonitrile as a starter active methylene which is considered more active than ethyl cyanoacetate leads to the desired alkenes in good yields and a very short time of 1 min (Table 1, entry 4, 5, 6, 7, 8).

### CONCLUSION

An investigation of Knoevenagel condensation between active methylenes and different aldehydes was conducted using a new

recyclable catalyst elaborated for the first time from Moroccan oil shale. This new catalyst showed many advantages such as high catalytic activity compared to the reported catalysts, reusability several times, and easy separation procedure all that under mild reaction conditions. We also demonstrated that this new catalyst could be efficiently coupled with ultrasound irradiations to produce the desired products in a short period with high yields.

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### Conflicts of interest

The authors declare no conflict of interest

### REFERENCES

1. Van Beurden, K.; de Koning, S.; Molendijk, D.; & van Schijndel, J. *Green Chemistry Letters and Reviews.*, **2020**, *13*(4), 349-364.
2. Van Schijndel, J.; Molendijk, D.; van Beurden, K.; Canalle, L. A.; Noël, T.; Meuldijk, J. *European Polymer Journal.*, **2020**, *125*, 109534.
3. Van Schijndel, J.; Molendijk, D.; van Beurden, K.; Vermeulen, R.; Noël, T.; & Meuldijk, J. *Journal of Polymer Science.*, **2020**, *58*(12), 1655-1663.
4. Heravi, M. M.; Janati, F.; & Zadsirjan, V. s. *Monatshefte für Chemie.*, **2020**, *151*(4), 439-482.
5. Ezer, M.; Yıldırım, L. T.; Bayro, O.; Verspohl, E. J.; & Dundar, O. B. *Journal of enzyme inhibition and medicinal chemistry.*, **2012**, *27*(3), 419-427.
6. Barnes, D. M.; Haight, A. R.; Hameury, T.; McLaughlin, M. A.; Mei, J.; Tedrow, J. S.; & Toma, J. D. R. *Tetrahedron.*, **2006**, *62*(49), 11311-11319.
7. Kim, S.; Kim, E.; & Hong, J. H. *Nucleosides, Nucleotides and Nucleic Acids.*, **2015**, *34*(3), 163-179.
8. Ugwu, D. I.; Ezema, B. E.; Eze, F. U.; & Ugwuja, D. I. *International journal of medicinal chemistry.*, **2014**.
9. Unlusoy, M. C.; Kazak, C.; Bayro, O.; Verspohl, E. J.; Ertan, R.; & Dundar, O. B. *Journal of enzyme inhibition and medicinal chemistry.*, **2013**, *28*(6), 1205-1210.
10. Molnar, M.; Brahmabhatt, H.; Rastija, V.; Pavić, V.; Komar, M.; Karnaš, M., & Babić, J. *Molecules.*, **2018**, *23*(8), 1897.
11. Ali, I.; Haque, A.; Saleem, K.; & Hsieh, M. F. *Bioorganic & medicinal chemistry.*, **2013**, *21*(13), 3808-3820.
12. Asati, V.; Mahapatra, D. K.; & Bharti, S. K. Thiazolidine-2, 4-diones as multi-targeted scaffold in medicinal chemistry. *European Journal of Medicinal Chemistry.*, **2014**, *87*, 814-833.
13. Knoevenagel, E. *Chemische Berichte.*, **1894**, *27*, 2345-2346.
14. Gao, Z.; Zhou, J.; Cui, F.; Zhu, Y.; Hua, Z.; & Shi, J. *Dalton Transactions.*, **2010**, *39*(46), 11132-11135.
15. Jain, D.; Khatri, C.; & Rani, A. *Fuel Processing Technology.*, **2010**, *91*(9), 1015-1021.
16. Parmar, B.; Patel, P.; Murali, V.; Rachuri, Y.; Kureshy, R. I.; Noor-ul, H. K., & Suresh, E. *Inorganic Chemistry Frontiers.*, **2018**, *5*(10), 2630-2640.
17. Cai, K.; Tan, W.; Zhao, N.; & He, H. *Crystal Growth & Design.*, **2020**, *20*(7), 4845-4851.
18. Tom, L.; & Kurup, M. R. P. *Journal of Solid State Chemistry.*, **2021**, *294*, 121846.
19. Sebti, S.; Smahi, A.; & Solhy, A. *Tetrahedron letters.* 2002, *43*(10), 1813-1815.
20. Sebti, S.; Tahir, R.; Nazih, R.; Saber, A.; & Boulaajaj, S. *Applied Catalysis A: General.* **2002**, *228*(1-2), 155-159.
21. Yang, H.; Dong, H.; Zhang, T.; Zhang, Q.; Zhang, G.; Wang, P.; & Liu, Q. *Catalysis Letters.*, **2019**, *149*(3), 778-787.

22. Pasha, M. A.; & Manjula, K. *Journal of Saudi Chemical Society.*, **2011**, *15*(3), 283-286.
23. Rahmatpour, A.; Goodarzi, N. *Catalysis Communications.*, **2019**, *124*, 24-31.
24. Burange, A. S.; Tugaonkar, P. S.; Thakur, S. D.; Khan, R. R.; & Shukla, R. *Nano-Structures & Nano-Objects.*, **2020**, *23*, 100493.
25. Martín-Aranda, R. M.; Ortega-Cantero, E.; Rojas-Cervantes, M. L.; Vicente-Rodríguez, M. A.; Bañares-Muñoz, M. A. *Journal of Chemical Technology & Biotechnology.*, **2005**, *80*(2), 234-238.
26. Liu, Q.; Ai, H.; Li, Z. *Ultrasonics Sonochemistry.*, **2011**, *18*(2), 477-479.
27. Wang, S. X.; Li, J. T.; Yang, W. Z.; & Li, T. S. *Ultrasonics Sonochemistry.*, **2002**, *9*(3), 159-161.
28. Cheikh Moine, E.; Groune, K.; El Hamidi, A.; Khachani, M.; Halim, M.; & Aرسالane, S. *Energy.*, **2016**, *115*, 931-941.
29. Oumam, M.; Abourriche, A.; Adil, A.; Hannache, H.; Pailler, R.; Naslain, R.; Puillot, J. P., **2003**, *28*(4), 59-74.
30. Miyah, Y.; Idrissi, M.; Lahrichi, A.; Zerrouq, F. *Oil shale.*, **2014**, *3*(8).
31. Elhammoudi, N.; Oumam, M.; & Mansouri, S. *International Journal of Chemical Sciences.*, **2018**, *16*(2), 1-10.
32. Elhammoudi, N.; Oumam, M.; Mansouri, S.; Abourriche, A.; Chham, A. I.; & Hannache, H. *International Journal of Recent Scientific Research.*, **2018**, *9*(5A), 26455-26464.
33. Khouya, E.; Fakhi, S.; Hannache, H.; Abbe, J. C.; Andres, Y.; Naslain, R.; Nourredine, A. *Journal of radioanalytical and nuclear chemistry.*, **2004**, *260*(1), 159-166.
34. Khouya, E.; Fakhi, S.; Hannache, H.; Ichcho, S.; Pailler, R.; Naslain, R.; & Abbe, J. C. In *Journal de Physique IV.*, **2005**, *123*, 87-93.
35. Khouya, E. H.; Legrouri, K.; Fakhi, S.; & Hannache, H. *Nature Precedings.*, **2010**, 1-1.
36. Oumam, M.; Abourriche, A.; Mansouri, S.; Mouiya, M.; Benhammou, A.; Abouliatim, Y.; Naslain, R. *Oil Shale.*, **2020**, *37*(2), 139-157.
37. Abourriche, A.; Oumam, M.; Mouiya, M.; Mansouri, S.; Benhammou, A.; El Hafiane, Y.; Hannache, H. *Combined Application of Physico-Chemical & Microbiological Processes for Industrial Effluent Treatment Plant Springer, Singapore.*, **2020**, 187-204.
38. Gharat, N. N.; & Rathod, V. K. *Green Sustainable Process for Chemical and Environmental Engineering and Science.*, **2020**.