Civil and Sustainable Urban Engineering

Review
Volume 2(1), 2022, 12-20
https://doi.org/10.53623/csue.v2i1.74

A Review on the Treatment of Petroleum Sludge and Use as Construction Materials

Nurul Noraziemah Mohd Pauzi[1,*], Mohamad Shazwan Ahmad Shah[2]

[1]School of Civil Engineering, College of Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia
[2]School of Civil Engineering, Faculty of Engineering, Universiti Teknologi Malaysia (UTM), 81310 Skudai, Johor Bahru, Johor, Malaysia

*Correspondence: nurulnoraziemah@gmail.com

SUBMITTED: 20 March 2022; REVISED: 25 April 2022; ACCEPTED: 27 April 2022

ABSTRACT: Petrochemical is a vital pillar industry for the national economic growth wherein the past few years, it has produced a huge amount of petroleum sludge. Petroleum sludge (PS) contains toxic and carcinogenic-mutagenic compounds and heavy metals, which are a major source of pollution in the environment. Thus, it needs to be properly treated and disposed of. Correspondingly, this paper presents a review of the techniques to treat petroleum waste to effectively immobilize the heavy metals and highlights their possible application as construction materials. This review concludes that each treatment method (i.e., solidification, stabilization, incineration, bioremediation, centrifugation, etc.) has its own merits and demerits and may be more suitable for certain applications than others. The use of pyrolysis, solidification, and stabilization techniques has been demonstrated to be potentially beneficial in protecting the environment from contaminants in PS and further recycling PS as cementitious materials. However, the selection of suitable treatment methods has to be made based on the chemical composition of the waste, method capacity, costs, and disposal standards. Therefore, an overall evaluation is required prior to treatment method selection to ensure the safe disposal or recycling of petroleum waste. This review could improve basic knowledge of PS treatment and disposal techniques and serve as a future guide for recycling PS as a building material.

KEYWORDS: Waste; petroleum sludge; treatment method; construction material

1. Introduction

Petrochemical is a vital pillar industry for the national economic growth wherein the past few years, the national consumption of petroleum had increased up to 600 million tons [1]. Islam estimated that the international consumption of petroleum was roughly 88 million barrels per day [2]. However, there has been a surge of worldwide concern regarding the industry's attribution to the excessive release of petroleum waste into the environment. The petroleum industry has generated millions of metric tons of waste involving hydrocarbons and oil whereby the waste content includes but is not limited to petroleum wastewater, drilling fluid, petroleum effluent treatment plant sludge, and bottom tank sludge. Petroleum sludge (PS) was identified as one of the major solid wastes generated in the petroleum industry, which necessitates a proper disposal system and effective treatment [1]. In general, the production of 105,000 barrels of petroleum per day would generate approximately 50 tons of sludge per year [1,3]. According to previous studies, Malaysia's second-largest waste was generated from petroleum refinery activities, which produces more than 3200 m^3 of PS each year [4,5], and the huge amounts of PS need proper disposal and valorization. Due to the fact that the treatment of PS is complex and high-cost, therefore, considerable studies have been conducted to determine the best option for the treatment of PS. Furthermore, in order to select the best treatment technique for PS, the composition, microstructure, and type of application must be taken into consideration. In summary, the significance of this paper is that it provides a review of the techniques to treat the petroleum waste, and highlighted its possible application as construction materials. Considering the growing volume of petroleum waste and the concerns about its toxicity, techniques related to petroleum waste treatment that could effectively immobilize heavy metals were highlighted in this paper. This paper also identified the possible application of recycling PS as a construction material. Such data may help engineers and researchers select the best treatment techniques based on the physical and chemical properties of PS and tailor them to obtain the desired properties for recycling applications. This paper provides some directions for future research on recycling PS.

2. Sources, Characteristics, and Toxicity of Petroleum Sludge

Petroleum waste's hazardous nature and its high discharge volume make it inevitably a major source of environmental pollution that exhibits all or combinations of harmful properties such as toxic, corrosive, reactive, flammable, and ignitable. The major type of waste generated from petroleum refinery activities is in the form of sludge, which is composed of a complex mixture of various amounts of oil, wastewater, sand, and minerals [2]. Sludge is the residual collected from the bottom of the tank, wastewater treatment process, interceptors, refinery product tanks, contaminated soil, oil tanks, biotreatment, desalter, filter clay, oil spill, filter dust, tar rags, and elsewhere during oil production and processing, which produces approximately 0.5 kg per ton of feedstock per oil processing plant [1,2,5].

The properties of petroleum sludge depend on the exposure conditions such as the cooling temperature, evaporation process, mixing materials, and water content. The sludge that settles in the bottom of tanks and other storage vessels contains 10% to 30% hydrocarbons, 5% to 20% solids, and 50% to 85% water [1]. Meanwhile, the petroleum sludge collected from the oil storage tank contains valuable paraffin, asphaltene, and hydrocarbons. However, Islam claimed that in general, the petroleum sludge comprises 40% oil and the remaining 60% are combinations of oil and water [2]. Other than that, Da et al. suggested that the local petrochemical industry in Xian produces approximately 100,000 tons of spent petroleum refining catalysts (SPC) powders annually which are disposed into landfills, prompting appropriate measures to resolve the environmental threats they carry. Furthermore, in China alone, roughly one million tons of SPC are disposed of annually and this is expected to increase by 5% every year [6]. Thus, proper disposal and treatment of petroleum effluent are crucial not only due to its detrimental impacts on human health and the environment, but also because of the sheer volume it produces.

The Environmental Quality (Scheduled Waste), Environment Protection Act, and Hazardous Waste Handling Rules state that petroleum waste must be disposed of at a licensed landfill site [2,5]. This condition was regulated as petroleum waste is categorized as hazardous waste due to its high content of oil and toxic contaminants, which include aliphatic hydrocarbons and polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and heavy metals (barium, lead, zinc, mercury, chromium, arsenic, and nickel). This toxic contaminant removal is required prior to any disposal process to avoid soil contamination that could alter the soil nutrient content [2,3]. In addition to the toxic contents, the corrosive effect and diminishing capacity for oil storage also precipitate an environmentally friendly disposal solution, which, however, imposes a high cost. The aforementioned cost includes processing and disposing of expenses through removing, treating, transporting, and landfilling the byproducts [1]. In addition, the petroleum sludge precipitated in the tanks must be removed for maintenance purposes, which involves the producers' tanks, refiners, and transporters. Hence, an effective recycling approach is required not only to regulate the increasing volume and hazardous nature of petroleum waste to benefit the environment, but it is also crucial to streamline the operating procedures as well.

3. Treatment Methods

Table 1. Summary of treatment and disposal methods

Methods	Process	Advantages	Disadvantages	Application	References
Stabilization/ Solidification (waste fixation)	Adding additives to make the contaminants into least soluble, mobile, or toxic	Simple and fast process, low cost, widely available, easy to handle	Increase volume, higher concentration of petroleum hydrocarbon, retention rely on physical entrapment	Road material, concrete, building block /landfill	[2,3,7-12]
Incineration	Combustion to make the waste less bulky and toxic	Volume reduction, suitable for low quality sludge	High capital and operating costs, emission of pollutants is toxic and need further treatment and may cause pollution	Final disposal, Energy recovery	[2,3,13]
Bioremediation	Using microorganism	Low energy consumption, cheap, simple operation procedure	Slow, require a large area	Removal of toxic from soil, landfill	[3,13-16]
Freeze/thaw	Via demulsification process	Simple, effective, suitable for cold zone	Not effective for desorption, low sludge settleability	Fuel oil	[3,17-19]
Centrifugation	Separation of gaseous, aqueous and pasty phases	Low energy consumption, clean, low space usage, low cost	Generate noise and vibrations, less efficient for the separation of oil and water	Oil for burning in boilers, Energy producers	[3,13,20,21]
Solvent extraction	Filtration and distillation	Low energy consumption, low cost, fast	Less recovery, Low efficiency for large scale operation, high variability	Fuel oil	[3,22,23]
Sludge pyrolysis	Thermal decomposition via heating at 500 to 1000 °C	Fast, pollution control, low space usage, oil can be used directly for fuel diesel engines, removed heavy metals, ideal operational conditions	Expensive, high energy consumption, low extraction	Fuel oil, oil for paraffin products or refinement, fuel gas for combustor	[3,24-27]

To obtain a clear understanding of the incorporation of petroleum waste as construction materials, it is noteworthy to first identify the common treatment methods involving petroleum waste. Table 1 shows the summary of treatment methods involving petroleum wastes as studied by various researchers, which were claimed as successful in the aspect of environmental and economic sustainability. Several methods are available for the recovery and disposal of petroleum waste, including stabilization/solidification (S/S), incineration, bioremediation, centrifugation, solvent extraction, freeze-thaw, and sludge pyrolysis.

The more conventional treatment method for utilizing petroleum waste as construction materials and disposal of hazardous waste is the S/S technique, wherein a binder is applied to reduce the risk of contaminant release into the environment. Stabilization of petroleum wastes is performed through the addition of additives to reduce the moisture content, mobility, and toxicity levels, while solidification of PWs would remove the free liquid, increase the mechanical strength, and produce a monolithic solid product. The end product can be applied as construction materials depending on certain properties [3,8,9]. Fly ash, lime, and Portland cement are among the additives used for the S/S of petroleum waste.

Other than S/S, incineration and bioremediation are also variations of treatment methods for the disposal of petroleum sludge. Incineration is the complete combustion process of petroleum waste to reduce the volume and toxicity, while bioremediation incorporates microorganisms into its treatment to alter the compositions of petroleum waste into harmless substances by accelerating the microbial degradation of petroleum hydrocarbons. Both methods are applied to the disposal of petroleum waste, which simultaneously recovers the valuable oil and hydrocarbons as well. The valuable oil could also be retrieved from the petroleum sludge through freeze-thaw, centrifugation, solvent extraction, and sludge pyrolysis methods [10].

Past studies [3,17,19] reported that freeze/thaw treatment had achieved the highest percentage of oil recovery from petroleum sludge compared to other treatment methods. Freeze/thaw treatment involves a demulsification process in which during the freezing stage, the water freezes before the oil, which leads to internal disarrangement whereby the oil will progressively freeze. Through the thawing stage, the oil will coalesce and result in the separation of oil and water by gravitational forces [17,18]. The freeze/thaw method has proven to be financially effective in colder climates, but would require additional expenses in warmer regions to maintain the required temperature.

All the treatment methods shown in Table 1 were generally designed to reduce the volume of petroleum waste, recover the oil from the sludge, and dispose of the unrecoverable sludge. In addition, Table 1 also highlights that each treatment method has its own merits and demerits that may be more suitable for certain applications than others. According to Johnson et al. [3], the selection of a suitable treatment method is to be made based on the chemical composition, method capacity, costs, and disposal standard. Therefore, an overall evaluation is required prior to treatment method selection to ensure safe disposal or recycling of the petroleum waste.

4. Utilization of petroleum sludge as construction materials

Generally, petroleum waste contains oil, water, and inorganic materials, whereas its main constituents are SiO_2, CaO, Al_2O_3, and Fe_2O_3. Previous research [28–32] proposed using petroleum waste as a raw material for brick production. The application of sludge in brick manufacturing offers a reduction in the requirements for water, clay, and fuel for the firing process, and it lowers the temperature of brick firing, which significantly reduces the amount of raw materials and energy consumption. Moreover, Gorbaev et al. studied the possibility of using oil sludge waste as a combustible additive in the production of building bricks. They discovered that as oil sludge contains impurities and organic substances, the bricks' bulk density would decrease by up to 25% and, hence, offer thinning and combustible properties, which lead to the production of lightweight bricks [32].

Another option for petroleum waste recycling lies in the production of base material for road construction. In previous studies, oil sludge was applied as a partial replacement of the asphalt binder for road pavement. Zubaidy and Tamimi discovered that the addition of 4% oil sludge as a partial replacement of asphalt binder fulfills the requirement of the standard limit for asphalt. Results showed that the loss of stability for oil sludge asphalt is 5.3%, which is significantly lower than the maximum allowable limit of 25%. Stability is a strength indicator that indicates the maximum load a sample can withstand. However, a higher percentage of oil sludge would cause a higher loss of stability of the specimens [33].

Previous studies indicated that the usage of petroleum waste in block manufacturing could be a viable solution to the disposal issue of petroleum waste, which, however, requires the blocks to be covered with tiles or plaster to prevent the leaching of hazardous substances into the environment [34,35]. Johnson et al. examined the feasibility of using petroleum sludge as a raw material in building block production. They found that the leachates of blocks containing petroleum sludge would produce a certain amount of toxic substances allowed within the USEPA standard [1]. However, it was discovered that the leaching of these toxic substances is only harmful when the blocks are crushed. Meanwhile, if the blocks were in a monolithic form, they would hardly leach toxic substances due to their low porosity. Hence, the application of petroleum sludge as a binder is found to be promising as an alternative approach to environmentally friendly petroleum solid waste disposal methods.

Numerous studies on the use of petroleum waste as raw materials in cement clinker production have been conducted [28,36-39]. The incorporation of up to 5% petroleum sludge into the clinker has reduced the content of free lime (f-CaO) to around 47%, resulting in improved clinker burnability while maintaining cement clinker quality [37]. Huang et al. claimed that oil sludge could be applied as an alternative fuel during clinker production as roughly 91% of coal could be substituted with oil sludge. In addition, they also highlighted that the exposure temperature should be higher than 1450 °C to maximize the utilization of oil sludge in the production of Portland cement clinker [36].

5. Discussion

Petroleum sludge is a hazardous waste, and its disposal without proper treatment poses threats to the environment and human health. Various treatment techniques could be conducted, such as stabilization/solidification, incineration, pyrolysis, bioremediation, freeze/thaw, centrifugation, solvent extraction, and sludge pyrolysis. Each of the treatment methods has its own merits and demerits and may be more suitable for certain applications than others. However, the selection of suitable treatment methods is to be made based on the chemical composition, method capacity, costs, and disposal standard. Therefore, an overall evaluation is required prior to treatment method selection to ensure the safe disposal or recycling of petroleum waste.

This paper discovers from the review of past studies that pyrolysis, solidification, and stabilization are promising techniques that can reduce the contaminants in PS to acceptable levels that comply with the regulatory standards. In addition, these techniques are claimed to be simple to operate and have a lower cost compared to other techniques such as incineration and bioremediation techniques. Solidification and stabilization are common PS treatment techniques that entrap the contaminants within a cementitious matrix (solidification), and then bind the contaminants into stable and insoluble forms (stabilization). Even though these techniques are quick, "low-technology," and cheaper, their effectiveness depends on the physical entrapment in the binder matrix and sorption on the surface of binder hydration products. Hence, there is a high possibility of release of high toxic concentrations when exposed to environmental leachates. Thus, the leaching of contaminants from stabilized and solidified PS products must be checked and mitigated.

6. Conclusion

Pyrolysis techniques have received a lot of attention due to their high energy recovery and the fact that they only emit a small amount of pollutants. The pyrolysis technique not only reduces the toxic content in PC, but this technique also allows for the recovery of a large quantity of oil and better crude material. In addition, pyrolysis does not lead to any air pollution problems during the process. However, the additive, heating rate, oxygen content, and temperature are the main factors that affect this process and must be given considerable attention. Aiming for sustainable construction, the review of this paper found that the treated PS could be used as raw material in the production of concrete blocks, bricks, road base materials, grout manufacturing, and cement clinker. The treatment process has proven to change the composition and morphological properties of petroleum waste, which creates opportunities for tailoring PS properties as construction materials for specific applications. The review presented in this paper could enhance the essential knowledge and future guide for PS treatment and recycling techniques.

Competing Interest

All authors declare that they have no conflict of interest.

References

[1] Johnson, O.A.; Madzlan, N.; Kamaruddin, I. (2015). Encapsulation of petroleum sludge in building blocks. *Construction and Building Materials*, *78*, 281–288. https://doi.org/10.1016/j.conbuildmat.2014.12.122.

[2] Islam, B. (2015). Petroleum sludge, its treatment and disposal: A review. *International Journal of Chemical Science, 13,* 1584–1602.

[3] Johnson, O.A.; Affam, A.C. (2019). Petroleum sludge treatment and disposal: A review, *Environmental Engineering Resources, 24,* 191–201. https://doi.org/10.4491/EER.2018.134.

[4] Pakpahan, E.N.; Shafiq, N.; Isa, M.H.; Kutty, S.R.M.; Mustafa, M.R. (2016). Petroleum sludge thermal treatment and use in cement replacement – A solution towards sustainability, engineering challenges sustainable future. *Procedings 3rd International Conference Civil, Offshore Environment Engineering, ICCOEE.* 251–256. https://doi.org/10.1201/b21942-50.

[5] Zain, A.M.; Mahmud, H.; Shaaban, M.G. (2010). Petroleum sludge stabilization and solidification. *2nd International Conference Chemical, Biology, and Environment Engineering. (ICBEE),* 30–34. https://doi.org/10.1109/ICBEE.2010.5650631.

[6] Da, Y.; He, T.; Wang, M.; Shi, C.; Xu. R.; Yang, R. (2020). The effect of spent petroleum catalyst powders on the multiple properties in blended cement. *Construction and Building Materials, 231,* 117203. https://doi.org/10.1016/j.conbuildmat.2019.117203.

[7] Asim, N.; Badiei, M.; Torkashvand, M.; Mohammad, M.; Alghoul, M.A.; Gasaymeh, S.S.; Sopian K. (2021). Wastes from the petroleum industries as sustainable resource materials in construction sectors: Opportunities, limitations, and directions. *Journal of Cleaner Production, 284,* 125459. https://doi.org/10.1016/j.jclepro.2020.125459.

[8] Tuncan, A.; Tuncan, M.; Koyuncu H. (2015). Use of petroleum-contaminated wastes as sub-base material for road construction. *Waste Management and Resources, 5,* 489–505. https://doi.org/10.1177%2F0734242X0001800511.

[9] Kankia, M.U.; Baloo, L.; Mohammed, B.S.; Hassan, S.B.; Ishak, E.A.; Zango Z.U. (2020). Review of petroleum sludge thermal treatment and utilization of ash as a construction material, a way to environmental sustainability. *International of Journal Advanced Applied Science, 7,* 68–81. http://dx.doi.org/10.21833/ijaas.2020.12.008.

[10] Zain, A.M.; Shaaban, M.G.; Mahmud, H. (2010). Immobilization of petroleum sludge incorporating portland cement and rice husk ash. *International of Chemical Engineering Application, 1,* 234–240. https://doi.org/10.7763/ijcea.2010.v1.40.

[11] Kogbara, R.B.; Al-Tabbaa, A.; Stegemann, J.A. (2014). Comparisons of operating envelopes for contaminated soil stabilised/solidified with different cementitious binders. *Environmental Science Pollution and Resources, 21*, 3395–3414. https://doi.org/10.1007/s11356-013-2276-7.

[12] Karamalidis, A.K.; Voudrias E.A. (2007). Cement-based stabilization/solidification of oil refinery sludge: Leaching behavior of alkanes and PAHs. *Journal of Hazardous Materials, 148,* 122–135. https://doi.org/10.1016/j.jhazmat.2007.02.032.

[13] Jafarinejad, S. (2017). Solid-Waste management in the petroleum industry. In Petroleum Waste Treatment and Pollution Control; Jafarineja, S., Ed.; Butterwoth-Heinemann: Oxfor, United Kingdom, pp. 269 - 345. https://doi.org/10.1016/b978-0-12-809243-9.00007-9.

[14] Tahhan, R.A.; Abu-Ateih, R.Y. (2009). Biodegradation of petroleum industry oily-sludge using Jordanian oil refinery contaminated soil. *International Biodeterioration and Biodegradation, 63* 1054–1060. https://doi.org/10.1016/j.ibiod.2009.09.001.

[15] Mishra, S.; Jyot, J.; Kuhad, R.C.; Lal, B. (2001). Evaluation of inoculum addition to stimulate in situ bioremediation of oily-sludge-contaminated soil. *Applied and Environmental Microbiology, 67,* 1675–1681. https://doi.org/10.1128/AEM.67.4.1675-1681.2001.

[16] Powell, S.M.; Harvey, P.M.A.; Stark, J.S.; Snape, I.; Riddle, M.J. (2007). Biodegradation of petroleum products in experimental plots in Antarctic marine sediments is location dependent, *Marine Pollution Bulletin, 54,* 434–440. https://doi.org/10.1016/j.marpolbul.2006.11.018.

[17] Zhang, J.; Li, J.; Thring, R.W.; Hu X., Song X. (2012). Oil recovery from refinery oily sludge via ultrasound and freeze/thaw. *Journal of Hazardous Materials, 203–204,* 195–203. https://doi.org/10.1016/j.jhazmat.2011.12.016.

[18] Lin, C.; He, G.; Li, X.; Peng, L.; Dong, C.; Gu, S.; Xiao, G. (2007). Freeze/thaw induced demulsification of water-in-oil emulsions with loosely packed droplets. *Separation and Purification Technology, 56,* 175–183. https://doi.org/10.1016/j.seppur.2007.01.035.

[19] Chen, G.; He, G. (2003). Separation of water and oil from water-in-oil emulsion by freeze/thaw method. *Separation and Purification Technology, 31,* 83–89. https://doi.org/10.1016/S1383-5866(02)00156-9.

[20] Kriipsalu, M.; Marques, M.; Maastik A. (2008). Characterization of oily sludge from a wastewater treatment plant flocculation-flotation unit in a petroleum refinery and its treatment implications. *Journal of Material Cycles and Waste Management, 10,* 79–86. https://doi.org/10.1007/s10163-007-0188-7.

[21] Silva, L.J.D.; Alves, F.C.; França, F.P.D. (2012). A review of the technological solutions for the treatment of oily sludges from petroleum refineries. *Waste Management and Resources, 30,* 1016–1030. https://doi.org/10.1177/0734242X12448517.

[22] Zubaidy, E.A.H.; Abouelnasr, D.M. (2010). Fuel recovery from waste oily sludge using solvent extraction. *Process Safety and Environmental Protection, 88,* 318–326. https://doi.org/10.1016/j.psep.2010.04.001.
[23] Schwab, A.P.; Su, J.; Wetzel, S.; Pekarek, S.; Banks, M.K. (1999). Extraction of petroleum hydrocarbons from soil by mechanical shaking. *Environmental, Science, and Technology, 33,* 1940–1945. https://doi.org/10.1021/es9809758.
[24] Wang, Z.; Gong, Z.; Wang, Z.; Li, X.; Chu, Z. (2020). Application and development of pyrolysis technology in petroleum oily sludge treatment. *Environmental Engineering and Resources, 26,* 10–12. https://doi.org/10.4491/eer.2019.460.
[25] Tang, X.; Wei, X.; Chen S. (2019). Continuous pyrolysis technology for oily sludge treatment in the chain-slap conveyors. *Sustainable, 11,* 3614. https://doi.org/10.3390/su11133614.
[26] Chang, C.Y.; Shie, J.L.; Lin, J.P.; Wu, C.H.; Lee, D.J.; Chang, C.F. (2000). Major products obtained from the pyrolysis of oil sludge. *Energy and Fuels, 14,* 1176–1183. https://doi.org/10.1021/ef0000532.
[27] Aimin, L.S.C. (2015). High quality oil recovery from oil sludge employing a pyrolysis process with oil sludge ash catalyst. *International Journal of Water Resources, 5.* 1-12. https://doi.org/10.4172/2252-5211.1000176.
[28] Sengupta, P.; Saikia, N.; Borthakur, P.C. (2002). Bricks from Petroleum Effluent Treatment Plant sludge: Properties and environmental characteristics. *Journal of Environmental Engineering, 128,* 1090–1094. https://doi.org/10.1061/(asce)0733-9372(2002)128:11(1090).
[29] Mahajan, S.A.; Husain, M. (2016). Utilization of waste sludge in brick making. *International Conference on Global Trends in Engineering, Technology and Management,* 274–278.
[30] Johnson, O.A.; Napiah, M.; Kamaruddin, I. (2014). Potential uses of waste sludge in construction industry: A review. *Research Journal of Applied Sciences, Engineering and Technology, 8,* 565–570. https://doi.org/10.19026/rjaset.8.1006.
[31] Kadir, A.A.; Rahim, A.S.A. (2014). An overview of sludge utilization into fired clay brick. *International Journal of Environmental, Ecological, Geological and Marine Engineering, 8,* 528–532.
[32] Gorbaev, A.V.; Gorlenko, N.V.; Timofeeva, S.S. (2020). Use of oil sludge as a combustible additive for the production of bricks. *IOP Conference Series: Materials Science and Engineering, 962*, 042031. https://doi.org/10.1088/1757-899X/962/4/042031.
[33] Al Zubaidy, I.A.H.; Al-Tamimi, A.K. (2014). Production of sustainable pavement with oil sludge. *Road Materials and Pavement Design, 15,* 691–700. https://doi.org/10.1080/14680629.2014.908139.
[34] Hago, A.W.; Hassan, H.F.; Al Rawas, A.; Taha, R.; Al-Hadidi, S. (2007). Characterization of concrete blocks containing petroleum-contaminated soils. *Construction and Building Materials, 21,* 952–957. https://doi.org/10.1016/j.conbuildmat.2006.04.006.
[35] Hassan, H.F.; Taha, R.; Al Rawas, A.; Al Shandoudi, B.; Al Gheithi, K.; Al Barami, A.M. (2005). Potential uses of petroleum-contaminated soil in highway construction. *Construction and Building* Materials*, 19,* 646–652. https://doi.org/10.1016/j.conbuildmat.2005.01.001.
[36] Huang, M.; Ying, X.; Shen, D.; Feng, H.; Li, N.; Zhou, Y.; Long, Y. (2017). Evaluation of oil sludge as an alternative fuel in the production of Portland cement clinker. *Construction and Building Materials, 152,* 226–231. https://doi.org/10.1016/j.conbuildmat.2017.06.157.
[37] Benlamoudi, A.; Kadir, A.A.; Khodja, M. (2018). Petroleum sludge as raw material for cement clinker production. *Communication,* 2018060053. https://doi.org/10.20944/preprints201806.0053.v1.
[38] Waltisberg, J.; Weber, R. (2020). Disposal of waste-based fuels and raw materials in cement plants in Germany and Switzerland – What can be learned for global co-incineration practice and policy?. *Emerging Contaminants, 6*, 93-102. https://doi.org/10.1016/j.emcon.2020.02.001.

[39] Benlamoudi, A.; Kadir, A.A.; Khodja, M. (2017). Petroleum sludge as gypsum replacement in cement plants: its impact on cement strength, *IOP Conference Series: Materials Science and Engineering, 226*, 012059. https://doi.org/10.1088/1757-899X/226/1/012059.