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REVIEW PAPER - EXPLORATION ENGINEERING

Insights into the applications of waste materials in the oil and gas industry: state of the art review, availability, cost analysis, and classification

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Abstract

This study investigates different types of waste materials and their applicability in the oil and gas industry as well as analyzing various applications of these waste materials in the petroleum industry. This study also explores the availability of these waste materials by performing a statistical analysis in a good number of countries worldwide. The statistical study was performed starting with a study on which countries generate waste the most overall, followed by examining multiple countries and investigating their top three most available waste. The results showed that the USA is the leading country in terms of municipal solid waste generation of 258 million metric tons, followed by China that generates around 220.4 million metric tons and then India that generates 168.4 million metric tons of municipal solid waste. The regions that generate the most food waste are North America and Oceania, providing the availability of food waste in those regions. Most of the palm tree wastes are available in the Middle East and some parts of the USA, while green waste can be found in the USA, China, and the UK. Sawdust wastes are mostly available in Europe and North America, while hay waste is abundant in the USA. Waste materials were also examined for various petroleum industry applications. Food wastes were found to be effective in drilling and completion fluids. Various food waste products were utilized to alter the drilling fluid properties such as potato peels and mandarin peels. Food wastes were also effective in altering the pH of the drilling fluids. Some plant-based wastes such as date trees were effective treatments used to stop lost circulation. Based on biodegradability and toxicity basis, waste materials were also classified into four main categories, which are eco-friendly, biodegradable, non-biodegradable, and toxic using color category classification. In summary, waste materials have the potential to be used in the petroleum industry, and they might as well be a good alternative for the future. As an example, the drilling fluid average cost approximately one-tenth of the total cost of the drilling operation, which is considered a tangible cost. By using waste materials as drilling fluid additives, the cost of the drilling fluid can be minimized. Further investigation and research should be carried out to get a better understanding of the importance of waste materials, and how they can be exploited for future applications in the oil and gas industry.

Keywords Review · Waste materials · Applications · Environment · Oil and gas industry

Introduction

Waste materials are the unwanted or the unusable materials that are discarded after primary use. Waste material is an unavoidable by-product of human activities (Solid Waste Management 2005). These materials are worthless, defective, and of no use. Waste materials can be in liquids or solids forms. The liquid wastes include any waste that is in the form of liquid such as wash water from the houses and waste liquids from industries. This type of waste is out of the focus of this work. On the other hand, solid wastes include any

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waste in the form of non-liquid such as food waste, old furniture, tries, and plastic bottles. There are many sources of wastes such as municipal, medical/clinical, agriculture, automobiles, constructions/demolition, and electronic sources of waste (Environmental Protection Agency 2019).

Many waste materials are disposed to the environment every day. Without exception, the waste materials create a serious menace to the environment. The origins of waste are plentiful and can be produced from diverse sources; they involve waste created from food, households, unsafe waste, build trash, radioactive waste, wastewater, and numerous others as epitomized below (John Hopkins University 2006):

- The inedible parts of the food or any part of the food that is usually discarded by people can be considered as food wastes, for instance lemon peels, avocado peels, potato peels, pomegranate peels, orange peels, date seeds, sunflower seeds' shell, etc.
- Household garbage is divergent, and it can be constituted of safe and unsafe items, including but not limited to batteries, cans, papers, and household cleaners.
- If the personal safety and the environment can be jeopardized by the wastes, so these wastes will be categorized by hazardous wastes for instance chemical additives, pesticides, solvent-based paints, etc.
- Construction materials are generated by structures and building industries. Most widespread kinds encompass bricks, wood, concrete, etc.
- Wastewater is water that has been impacted by some sort of waste.
- The waste materials that are generated by radioactive substances and nuclear production can be named as radioactive wastes.

Waste items as characterized above are diversified and can be created from several origins. Plainly, various sorts of waste materials are available and can be easily obtained in plentiful areas as well as each one of them has its own set of unique functions (Environmental Protection Agency 2015). However, not all waste materials can be applied in the oil and gas industry; hence, comprehensive research on which waste materials may be utilized is crucial. To achieve these goals, it is essential to investigate all the various waste materials to understand if they can be utilized in the petroleum industry. Some examples of waste materials that cannot be utilized in the oil and gas industry, including but not limited to some household wastes such as paper, bottles, and cans, as there is no application for them now in any area of the petroleum industry. Dangerous waste items should be disregarded since they are poisonous, and they can threaten the lives of people and the environment. Thus, nuclear or radioactive wastes have to be also avoided in the petroleum industry because they can cause serious threats. The kinds of waste materials that have the applicability to be utilized in the petroleum industry involve food waste, biodegradable waste, and construction waste, as shown in Fig. 1 which demonstrates only examples of food waste that can be used in the petroleum industry. Nonetheless, Fig. 2 elucidates more examples of possible wastes that are not hazardous such as grass, hay, sawdust, and palm leaves. These wastes are safer to be handled, and they can be utilized for laboratory investigations to distinguish if they can meet the criteria for the petroleum industry applications, while Fig. 3 shows popular household wastes that are unfavorable and have to be avoided because of their toxicity and inconvenience of handling and utilizing in the oil and gas industry.

Waste materials are a rising common problem in modern society as they can cause many undesired effects, which can affect the environment and the safety of the public. To reduce these issues, it is crucial to evolve a substitutional resolution to overcome these issues. These waste materials may be utilized in the petroleum industry by taking advantage of them for different targets rather than throwing the unfavorable waste. For instance, the inedible food wastes can be used for other uses such as altering the drilling fluid properties (Al-Hameedi et al. 2019a). Another waste additive that has the feasibility to be utilized in the petroleum industry is grass. Grass powder (GP) has the ability to be utilized as an eco-friendly material to be invested in the drilling mud (Al-Hameedi et al. 2019b). In addition, palm tree leaves can be also utilized in the petroleum industry as a multifunctional additive according to Al-Hameedi et al. (2019c). Al-Hameedi et al. (2019d) examined mandarin peels powder (MPP) to enhance the filtration and rheology of the drilling fluid. The findings showed that MPP decreased filtration and improved rheological properties. Potato peels powder (PPP) is another example of food waste investigated by Al-Hameedi et al. (2019e). The findings showed that PPP is an effective drilling fluid additive. PPP increased the plastic viscosity, minimized yield point and gel strength, and decreased filtration, while showed no effect on mud weight.

Fig. 1 Examples of food waste

Fig. 2 Non-food waste materials: grass, palm leaves, sawdust, and hay (Hall 2016; Neel 2019)

Fig. 3 Examples of household hazardous waste (Falmouth Massachusetts Health Department 2019)

Other biodegradable wastes involve palm tree leaves powder (PTLP), Al-Hameedi et al. (2019c) conducted an experimental study on PTLP. Their findings showed that PTLP reduced the alkalinity and the filtration of the mud. The PTLP mainly affected the yield point and gel strength, where it significantly reduced them, suggesting it to be used as a fluid thinner additive. Other authors have addressed studies about utilizing waste additives through different uses in the petroleum industry. Grass waste can be used to analyze filtration properties and mud rheological properties (Hossain and Wajheeuddin 2016). Waste created from trees can be used in drilling fluids as well as it can be invested as a lost circulation additive to improve the seepage loss according to Ramasamy and Amanullah (2018). Other applications of petroleum besides drilling fluids can use waste materials such as production and well completion. Carpenter (2015) conducted the application of biodegradable material that can be utilized during refracturing a horizontal well by plugging the perforations. Babey et al. (2015) introduced a case study about two wells that were treated by using biodegradable additives in new completion fluids. Hence, the availability of waste materials is considerable, and these wastes can be invested in many applications in the petroleum industry.

The conventional chemical drilling fluid additives are used in every drilling operation, and they can pose a major threat to personnel safety and environment, as well as the cost of these chemicals is high. The most toxic drilling fluid chemical additives are lime, sodium hydroxide, and caustic soda. Table 1 summarizes the compositions of the most common drilling fluid additives with their potential hazards. In addition, Fig. 4 shows a real example from the South Rumaila field, Iraq, of the cost of the drilling fluid compared with the total cost of the drilling operation. The drilling fluid average cost approximately one-tenth of the total cost of the drilling operation. The cost of conventional chemical drilling fluid additives is a tangible cost of the drilling fluid (Al-Hameedi et al. 2019d). By using waste materials, this cost can be significantly reduced.

The aim of this work is to recognize various waste materials, their applications in the petroleum industry, and their availability worldwide. In addition, providing a robust method to categorize those wastes based on their biodegradability and toxicity. Consequently, understanding these abundant waste materials can contribute to reducing the negative effects on the environment and personnel safety.

Table 1 Some of the conventional toxic additives for the drilling fluids (Basra Oil Company 2017; Halliburton 2018; Baker Hughes 2010; Newpark Drilling Fluids 2012; Al-Hameedi et al. 2019a)

Additive	Composition	Hazards
Bentonite	Montmorillonite > 90%, quartz < 10%, mica < 10%	Respiratory effect: possible slight irritation from dust
Barite	Quartz 10–12%, barite 80–94%. mica/illite < 6%, calcite < 2%	Carcinogen, skin and eye irritant, respiratory irritant
Caustic soda	Sodium hydroxide > 97%, non-hazardous and other components 1–2.5%	Severe irritation or burns to the eyes, skin, gastrointestinal tract, and respiratory system
Soda ash	Sodium carbonate 60–100%	May cause eye, skin, and respiratory irritation
Sodium bicarbonate	No ingredients as hazardous	Product dust may be irritating to eyes, skin, and respiratory system
Calcium carbonate	Calcium carbonate 97–100%	Causes eye irritation May cause skin and respiratory tract irritation
Lime	Calcium hydroxide 100%	Harmful in contact with eyes. Risk of serious damage to eyes. Irritating to skin. Prolonged exposure may cause chronic effects
Attapulgite clay	Hydrated aluminum-magnesium silicate 95–99%, quartz 1–5%	Slightly hazardous in case of skin contact, of eye contact, of ingestion, of inhalation
CMC	Sodium carboxymethylcellulose 100%	Harmful in contact with eyes
Sodium hydroxide	Sodium Hydroxide 95–100%, Sodium Carbonate < 3%	Causes eye and skin burns. Causes digestive and respiratory tract bums. Hygroscopic
Sodium chloride	Sodium chloride 100%	May cause eye irritation and skin irritation. May cause irritation of digestive tract. May cause respiratory tract irritation
Biocide	Magnesium nitrate	May cause sensitization by skin contact. Very toxic to aquatic organisms.
Sodium sulfite	Sodium sulfite 100%	Causes skin and eye irritation
Sodium carbonate	Sodium carbonate 100%	Harmful if inhaled. Causes eye and skin irritation. May cause respiratory tract imitation
Sodium nitrate	Sodium nitrate 100%	Causes eye and skin irritation. Harmful if swallowed May cause irritation of digestive tract

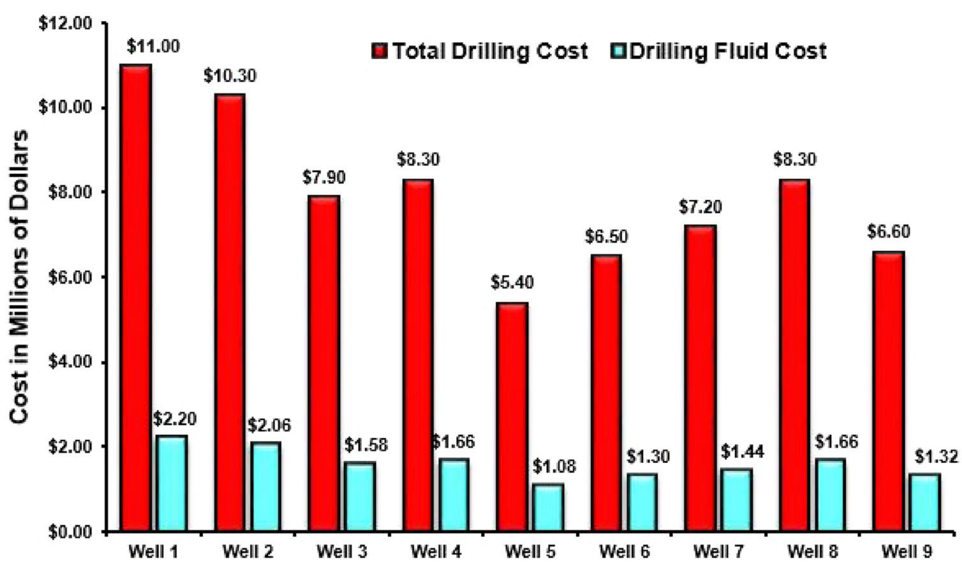

Fig. 4 Total cost of the drilling fluid compared to total cost of the drilling operations (Al-Hameedi et al. 2019d)

The availability of waste materials

Waste materials are vast and considered abundant worldwide. There are multiple types of waste materials each from a different source, and they are generated daily. That means waste materials are widely available due to the significant amount of waste generated globally. Waste materials can generate problems to the environment and public health if not managed properly. With the huge amount of available waste worldwide, it is time to investigate where all these waste materials wind up for further investigation of their availability. Landfills are a popular destination for most of the waste materials worldwide (Budget Dumpster 2019). Landfills are designed to store waste, but not to break it down or recycle it. Another destination where waste materials wind up is recycling facilities, where waste materials are recycled and processed into new products in a method known as reusing.

The first thing that needs to be investigated regarding the availability of waste materials is the global generation of municipal solid waste worldwide to have an idea about which countries generate the most waste. Once this information is obtained, a general idea can be acquired on where most of the waste is located in the world and where it is mostly available. The United States Environmental Protection Agency (EPA) refers to unwanted items or trash as municipal solid waste (MSW), and it includes various items that are thrown away after used such as trash or garbage consists of everyday items that are consumed and then disposed like bottles, clothing, food, paper, batteries, appliances, and many more (Environmental Protection Agency 2019). These wastes can be originated from households, schools, commercial, and industrial locations. Figure 5 displays the amount of municipal solid waste generated worldwide in 2017, broken down into countries that generate the most solid waste. The USA generated 258 million metric tons of municipal solid waste in 2017 (World Bank 2017).

After examining the nations that generate the most waste, a thorough investigation can be applied to those countries. The research is targeted to observe the top three waste available in those selected countries. Figure 6 shows a list of countries and their top three most generated waste by the material. The USA produces more than thirty percent of the planets total waste, and a vast majority of these wastes consists of goods that are used only briefly (Environmental Protection Agency, 2015). The top three wastes available in the USA are paper and paperboards, food wastes, and yard trimming wastes such as grass. In 2015, the total generation of MSW in the USA was 262.4 million tons, which shows around 1.34% increase in the amount of generated MSW than the previous year (2014) and almost 26% increase in the amount generated MSD than the year 1990 (Environmental Protection Agency 2019). Figure 7 shows the distribution of the MSW by material for the year of 2015 in the USA. These huge scary numbers are only for the USA, and they only include one type of waste sources. Now imagine the numbers for waste materials in the entire world.

China is one of the leading producers of municipal solid waste in the world. Municipal solid waste compositions in China are mainly composed of food waste, which makes up 55.86% of the waste available in China (Mian et al. 2016). Non-combustible wastes such as glass, tin, and aluminum cans make up the second most generated solid waste in China. Plastic waste accounts for the third-highest solid waste in China. India is also notable for generating huge quantities of solid waste. Solid waste generation in India is mainly from organic sources, municipal and urban wastes, animal wastes, farming wastes, food waste, and various industrial wastes (Pappu et al. 2007) . Organic waste is the leading waste materials in India followed by paper waste

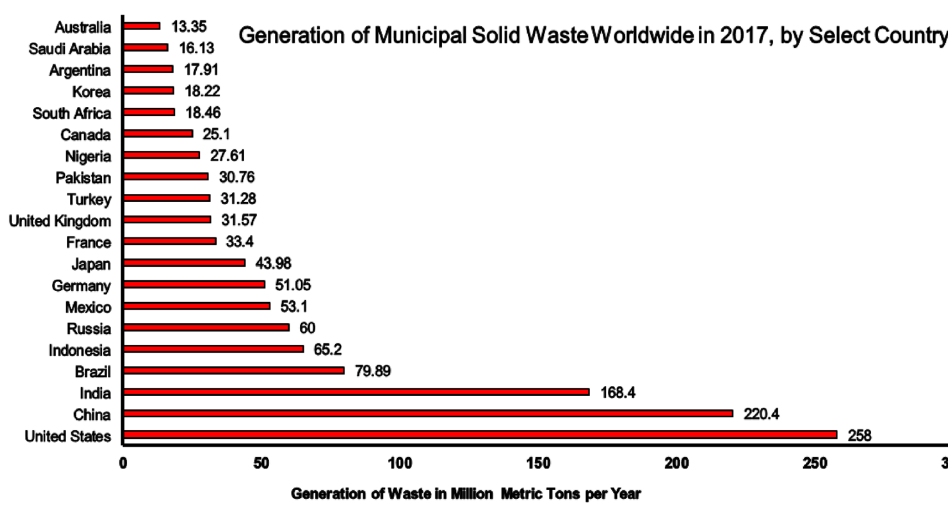

Fig. 5 Generation of municipal solid waste worldwide in 2017 Recreated After World Bank (2017)

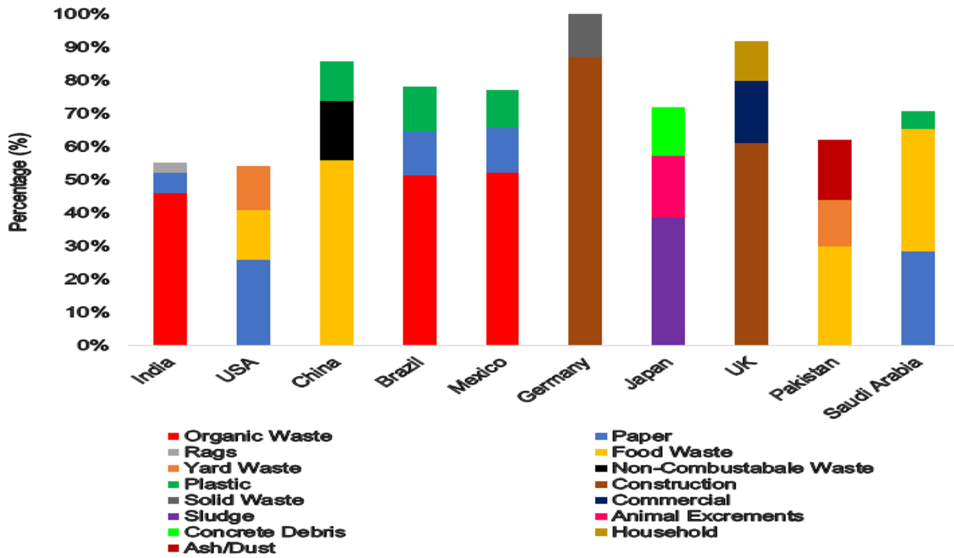

Fig. 6 Composition of waste materials in a good amount of countries (Recreated After Pappu et al. 2007; EPA 2015; Mian et al. 2016; Alfaia and Campos 2017; Rodriguez et al. 2015; Nelles et al. 2016; Amemiya 2018; Government Statistical Service 2019; UN Environment Programme 2016; Miandad et al. 2016)

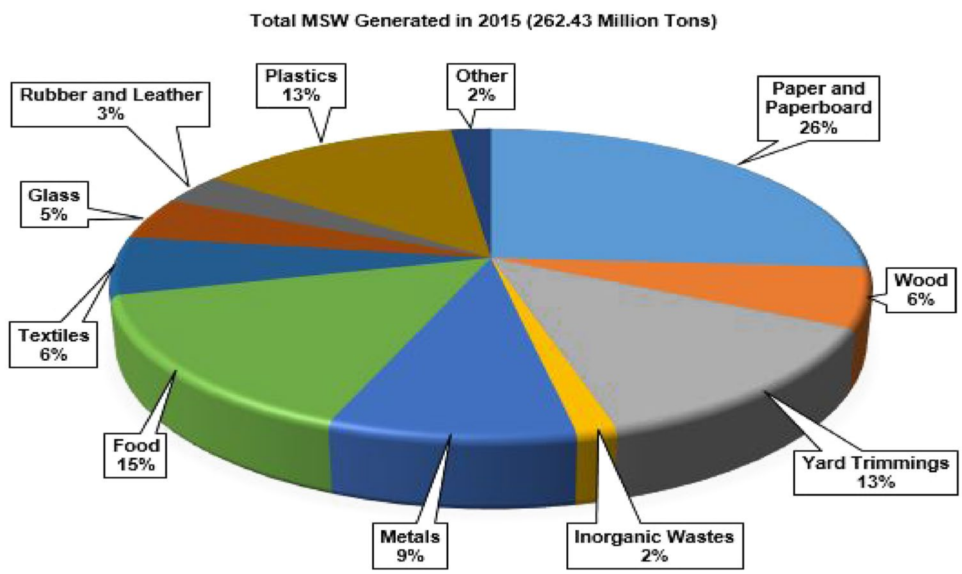

Fig. 7 Total MSW generated in the USA in 2015 (EPA 2019)

and rags. Brazil currently ranks fourth in terms of municipal solid waste generation. The most common types of waste that are present in Brazil include organic matter, which includes food waste, followed by plastic, and then paper materials (Alfaia and Campos 2017). Mexico is among the top countries that experience municipal solid waste. Studies show that the highest waste material generated in Mexico is the organic materials, which make up food and garden wastes. This is followed by paper products, which includes cardboard. Plastics are the third most abundant waste materials present in Mexico (Rodriguez et al. 2015). Germany is among the countries that have a municipal solid waste problem. In Germany, the amount of waste that is produced is relatively high (Nelles et al. 2016). The top three waste materials generated in Germany are the construction waste, waste from production processes along with commercial waste, and municipal solid waste. In Japan, the waste materials are classified into two categories, which are municipal waste and industrial waste (Amemiya 2018); with the industrial waste covering up to 89.9% of the total waste in Japan, while the municipal waste accounts for 10.1% of the of waste in Japan. The most generated waste material in Japan is sludge. Next is the animal excrements followed up by concrete debris. In the UK, it is estimated to generate 41.1 million tons of commercial and industrial waste in 2016 (Government Statistical Service 2019). The compositions of the most abundant waste materials in the UK are construction, demolition, and excavation, followed by commercial and industrial waste, and then household wastes. Research studies on waste management in Pakistan found

Table 2 Solid waste generation by material in the Arabian Gulf Countries (Al-Maaded et al. 2012)

Country	Organic (%)	Paper (%)	Plastic (%)	Glass (%)	Metals (%)
Qatar	57	11	14	4	9
Bahrain	59.1	12.8	7.4	3.4	2.1
Kuwait	51	19	13	4.5	5
Oman	60	8	12	10	9
UAE (Dubai)	42	6	10	3	3
UAE (Abu Dhabi)	49	6	12	9	6

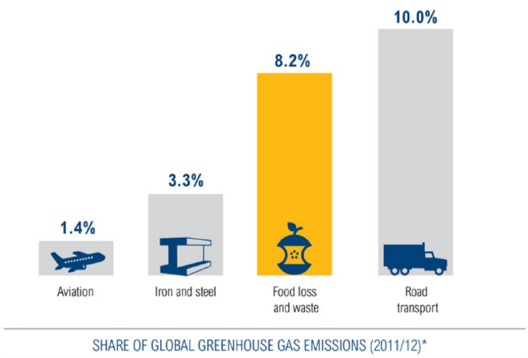

Fig. 8 Green house emission (FAO 2015)

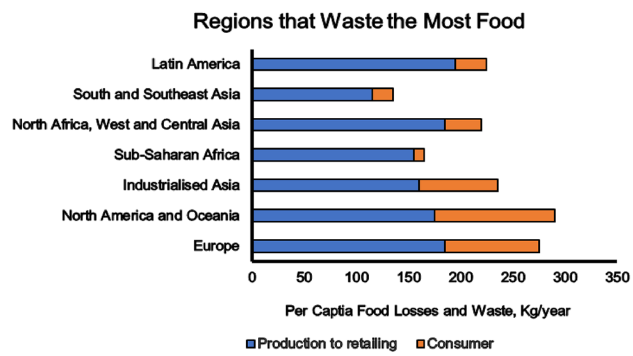

Fig. 9 Regions that generate the most food waste (Recreated After FAO 2015)

that the top three most generated wastes are food wastes; ash, bricks, and dart; and then yard wastes such as grass (United Nations Environment Programme 2016). In Saudi Arabia, the top three waste materials include food waste, paper, and metals (Miandad et al. 2016). The food waste is mainly composed of fruits and vegetables. Paper waste is composed of cardboard, newspapers, bags, tissue, and magazines. Qatar's main sources of solid waste generation include organic waste, followed up by plastic waste, and then finally paper waste (Al-Maaded et al. 2012). Other neighboring countries in the Middle East exhibit high organic waste generation as well as plastic and paper waste. Table 2 shows solid waste generation and composition of waste materials in the Arabian Gulf countries.

Food wastes are a very common problem in the world. Food wastes can cause many problems to public health and the environment if not managed properly. One of the best options for managing food wastes is recycling them to use them in the oil and gas industry (Al-Hameedi et al. 2019a). Research on which countries generate the most food waste is important to provide insights into where food waste is most present in the globe. According to the Food and Agriculture Organization of the United Nations (FAO), it is estimated that around 1.3 billion tons of food are wasted. This includes fruits, vegetables, seafood, dairy products, meats, and cereals (Chainey 2015). As mentioned, food waste can influence the environment. Food waste contributes to 8.2% of the greenhouse gas emissions as shown in Fig. 8. Figure 9 provides per capita food losses and waste and which countries waste food the most. North America and Europe are among the leading nations in food wastes.

There are many examples of non-toxic wastes available to be recycled and used in the oil and gas industry. Some examples include palm tree leaves, grass, palm tree leaves, hay, and date seeds. Palm trees are available in tropical and desert areas. Dates, which are generated from palm trees, are consumed in North Africa and the Middle East. According to Amanullah et al. (2019), 130 million palm trees are available in the world, with more than 88 million trees are available in the Arab countries. Saudi Arabia, Iraq, Pakistan, India, the US state of California, and Northern Africa are examples of the places where palm trees are available. A large amount of waste is produced from palm trees (e.g., dry leaves) that causes many problems to the farming industry. These wastes usually end up in landfills or burned in the farms and can harm the environment (Amanullah et al. 2019; Zafar 2016).

Grass waste is a part of green waste, and it is commonly referred to as biological waste. Grass waste is organic and contains a high concentration of nitrogen. Grass waste is located in areas that have a significant amount of green agriculture and it is increasing globally. According to Worldatlas (2019), human activity is the main source of green waste and the top three countries that generate the most grass waste are the USA, China, and the UK. Discovering methods to use grass waste for the petroleum industry is useful instead of disposing them to landfills, which can harm the environment.

Sawdust waste is a waste that is classified under the wood wastes. Wood wastes are present in areas of industry and factories. Wood wastes are a common waste that can be found everywhere around the globe. Sawdust is a by-product of wood sawing processes. Sawdust is mainly generated from factories or operations that deal with wood such as sawing, milling, or drilling. Sawdust can be found worldwide, but the most common areas that generate sawdust waste are North America and Europe (Kiss et al. 2016).

Hay waste is a waste that is classified under the brown waste category. Brown wastes are biodegradable wastes that mostly contain carbon concentration. Hay waste can be found in areas of farming that have livestock. Therefore, hay waste is common anywhere that has farming industry and agriculture. Hay is mostly used to provide essential nutrients to the animals and any remains that are not consumed quantify to the amount of hay waste generated. Texas produced more hay waste than any other state in the USA. Texas produces the most hay due to the huge amount of livestock present in that state. California is the second-largest hay producer in the USA followed by Kansas who is the third (Worldatlas 2019).

Applications of waste material and uses

Waste materials act like a continuous cycle that keeps on running repeatedly. Once the concept of waste materials and their availability is understood, it can be investigated further for uses in various industries, such as the oil and gas industry. The process of waste materials begins by consuming the type of material. Once it is consumed, the material is then discarded, and thus, the waste generation process begins. The fate of the waste materials can go through two paths after the generation. The waste can either end up in a landfill or be taken to recycling centers where the material is recycled into a new material that can be reused. Then, the reused material can be consumed, discarded, and recycled again following the steps of the waste cycle. The wastes that end up in landfills can pose a significant danger to the environment. Instead of generating more waste, an investigation about using the waste materials for the oil and gas industry and their applications has the ability to be expanded.

The oil and gas extraction is a long cycle that repeats itself, and there are many steps to be accomplished, and each step requires the use of chemical additives. For instance, chemical additives are used in drilling fluid to improve wellbore stability and avoid unwanted consequences in drilling. Each chemical additive has its own set of unique properties, and thus, depending on the desired application, a specific chemical additive may be required to achieve this goal. Specific chemical additives are also used for cement additives, well completion fluids, hydraulic fracturing fluids, and enhanced oil recovery. Thus, with the use of waste materials in the oil and gas industry, a reduction in cost, as well as environmental risks, will be minimized.

Starting with chemical additives of drilling and completion fluids, waste materials have the ability to be used in the oil and gas industry for various petroleum-related applications. Waste materials have the feasibility to be used as additives for drilling and completion fluids. Several authors and researchers contributed by investigating the use of waste materials as drilling fluid additives to be applied in the petroleum industry. Motivations for waste material usage include cost, safety, and environment. After some investigation, most of the authors completed tests on food waste materials for drilling fluid additives. Several examples of food wastes that were used as alternatives for drilling fluids include but not limited to potato peels, mandarin peels, banana peels, and many more. Al-Hameedi et al. (2019d) collected waste material from mandarin peels, dried them, and crushed into a fine powder and then performed several experiments related to drilling fluids, such as filtration characteristics and mud rheological properties. Their results proved to be a success as the waste materials improved the plastic viscosity, yield point, and gel strength. Fluid loss and alkalinity were also reduced in the process. Furthermore, these results were compared to PAC-LV and the findings showed that the mandarin peel powder had the potential to be used as an environmentally friendly additive for the drilling fluid. Al-Hameedi et al. (2019e) used potato peels as another source of waste to be applied in the oil industry as environmentally friendly drilling fluid additives. Their experiments showed that the potato peels maximized plastic viscosity and minimized yield point and gel strength with no effect on the mud density. The fluid loss was also reduced, thus giving potential to replace or at least support conventional chemical additives as cost-effective and eco-friendly.

Lost circulation is a common consequence that can be encountered during drilling operations. It is when the mud in the formation flows through many natural or induced paths from fracturing, thus being lost in the formation. This consequence should be avoided because it can become very costly. Lost circulation materials known as LCMs are widely utilized in the oil and gas industry to stop the mud loss circulation. Conventional LCMs are currently classified into four main categories based upon their appearance as fibrous, flaky, granular, or a combination of all the three (Alkinani et al. 2018). As the current industry is shifting toward eco-friendlier approaches, an investigation on the capability of using waste materials to stop lost circulation is applied. Ramasamy and Amanullah (2018) developed a biodegradable approach to handle lost circulation by using superfine fibrous material derived from date trees fibers to limit seepage-type losses. They used date tree wastes that were available locally as their raw material. The outcome of their experiment showed that date tree wastes reduced filtrate, thus proving to be an excellent alternative or supportive for conventional LCMs. Al-Hameedi et al. (2019b) examined the use of grass powder to control seepage loss and enhance filtration. They collected local grass samples and prepared the sample additives by crushing and grinding process. They compared their results with starch, and their results showed that grass powder decreased fluid loss significantly. The filter cake was improved using the grass powder additive, which shows the potential for grass powder to replace or support conventional additives. Amanullah et al. (2019) investigated the potential use of palm tree leaves wastes as a lost circulation material (LCM) to control mud lost circulation. Their work showed that the palm tree wastes could be used as LCM product. A collection of palm tree leaves from these regions and put them to use in drilling fluids can also be useful according to Al-Hameedi et al. (2019c).

Similarly, Al-Hameedi et al. (2019f) investigated the potential use of fibrous food waste material (FFWM) as an environmentally friendly alternative drilling fluid additive. The investigation was implemented to investigate the capability of FFWM to enhance different properties of water-based drilling fluid under various pH environments. The FFWM was first examined at 9.3 pH, and then, the pH was increased to 11.5 using sodium hydroxide (NaOH). The findings of the tests showed that this additive reinforced the rheology and filtration characteristics of the drilling fluid significantly. These results enforce the potential of applying FFWM as a supportive additive for some of the toxic conventional additives used in the drilling operations of oil and gas wells.

Table 3 shows a summary of the performance of palm tree leaves powder (PTLP), potato peels powder (PPP), mandarin peels powder (MPP), grass powder (GP), and FFWM compared with a reference mud (Al-Hameedi et al. 2019b, c, d, e, f).

Waste materials also have the ability to be utilized in other areas of the petroleum industry such as wellbore strengthening. Drilling operations often pose a quite significant amount of expenses. These expenses arise when drilling problems are encountered such as mud loss circulation. Thus, it is important to use additives that strengthen the wellbore from these common problems. Waste materials can have a role in wellbore strengthening besides conventional additives. Specialized treatments using fracture seal materials are necessary when drilling through fractured formations. A study conducted by fellow researchers regarding wellbore strengthening was made using crushed date palm seeds and shredded waste car tires (Alawad et al. 2018). In their study, they used two fracture seal materials made from the waste to test the ability to seal fractured cores under high-temperature and -pressure conditions. The outcome of their experiment proved that date palm seeds and car tires have the ability to seal fractured core plugs at high temperatures and pressures. These waste materials are cheaper than commonly used additives and can protect the environment from many hazards.

Another area within the oil and gas industry that could benefit from using waste materials is known as pH reducing or elevating materials. For instance, when conducting laboratory experiments using drilling fluid additives, it is important to test the physical properties, filtration properties, and pH. Some conventional chemical additives such as caustic soda are usually added to make-up water to maximize pH and to provide an excellent environment of hydration and desperation as well as to have an effective interaction

Table 3 Examples of the effects of some waste materials on the drilling fluid properties

Drilling fluid properties								
Additive	Amount (gm)	PV (cp)	YP (lb/100ft^2)	Initial gel strength (lb/100ft^2)	Final gel strength (lb/100ft^2)	Filtration (cc/30min)	Filter cake (mm)	pH
RF	–	8	12	15	20	12.5	3	11
PTLP	11	9	5	6	11	9.25	1.9	9.1
	22	13	5	7	12	8.5	2	8.7
PPP	6	7	7	9	13	11	1.7	8.4
	12	8	6	8	12	10	1.75	8.2
MPP	6	14	14	10	14	7	1.6	8
	12	24	17	10	14	6	1.4	7.7
GP	7	9	20	22	26	7	2	9.2
	10.5	12	25	26	33	6.25	2.5	8.7
FFWW	10	8	15	17	25	8.5	1.8	9.3
	20	9	17	I8	27	7	1.8	8.9

between the conventional chemical materials, which are utilized to prepare the drilling fluids. In addition, having pH with a range of 9 to 11 will contribute to avoiding corrosion issues. In the same context, it is crucial to avoid having a high range of pH in order to avoid mud clotting and deflocculated problems. Waste materials have the potential to be utilized as a pH reducer or elevator instead of common chemical additives. One example of applying that terminology is the use of food waste additives by using potato peels powder conducted by Al-Hameedi et al. (2019e). Their results showed that the pH was reduced applying potato peels powder. Therefore, waste materials have the potential to replace or at least support chemical additives. In addition, Adebowale and Raji (2015) examined the application of banana peel ash as in drilling fluid to combat corrosion and increase pH. Their results revealed an amelioration in pH after introducing banana peel ash.

Wellbore instability can either result from tensile failure or shear failure. Wellbore instability due to the chemical effect is a huge concern in drilling operations. Wellbore instability can either be caused by mechanical stuck pipe or sloughing and swelling of shale. It is important to understand these risks and failures to develop solutions such as additives to control shale instability. While some chemical additives have been developed, there are some side effects such as cost, safety, and environmental concerns. Therefore, it is important to develop an alternative solution by investigating the use of waste materials to be applied as additives to control shale instability.

During drilling shale, it is crucial to add high-performance clay swelling inhibitors to the drilling fluid as a preventive approach since that will function as a pivotal role in enhancing inhibition characteristics of shales. Aggrey et al. (2019) showed the feasibility of utilizing chromolaena odorata (CO) leaf. Their results showed that CO can serve out as surfactants for inhibiting shale hydration. The inhibitive properties of nonionic surfactant were determined by conducting different measurements such as surface-active properties, inhibition tests, filtration, rheological, and strength test. The laboratory outcomes on CO elucidated that it was robustly harmonious and very steady with traditional water-based drilling fluids and a substantially efficacious shale inhibitor. In addition, it had the potential to work through plugging and viscosity acting effects in the shale system. Aggrey et al. (2019) ended up with some conclusions associated with CO leaf performance, including but not limiting to the similarity between CO crude and industrial potassium chloride (KCL) in all inhibition features, establishing the capability to maximize the shale formation strength as temperature increases, providing a good stability bentonite particles in CO aqueous solution. Finally, CO crude extract is readily extractable at minimal price and easily obtainable as a substitute for commercial KCL.

Other areas of the oil and gas industry that could benefit from the use of waste materials include hydraulic fracturing fluids, wellbore integrity, corrosion inhibitors, cement additives, and enhanced oil recovery. There are many areas that could benefit from using the available waste materials as they are eco-friendly and cost-effective. Further research and investigation should be carried out using waste materials in the aforementioned areas of the oil and gas industry. By applying the same practices observed in drilling fluids, lost circulation, and wellbore strengthening, a new era of the oil and gas industry can be established. This shift from conventional to unconventional can revolutionize the oil and gas industry.

Classification of the waste materials

Waste materials as mentioned before are diverse and abundant in today's society. The accumulation of all waste materials is a rising global issue, and they can cause severe drawbacks in terms of environmental contamination and many other risks. With all the available waste present in many countries, it is important to classify each type of waste according to their detrimental effects on the environment. Classifying the waste helps identify which type of waste is dangerous and which type is generally safer to handle. This part of the study is intended to classify waste materials into four categories: eco-friendly waste materials, biodegradable waste materials, non-biodegradable waste materials, and toxic waste materials. Along with the classification of the waste materials, the specifications and the tests that are needed to identify these materials will be presented. Procedures will be briefly highlighted on how to classify the main types of waste materials, as it will assist the petroleum industry in identifying which type of wastes to consider for further research and can be handy to be applied in the oil and gas industry.

In order to classify these wastes, the following procedure should be carried out. Color classification will be used to help identify the type of waste (e.g., eco-friendly waste, biodegradable waste, non-biodegradable waste, or toxic waste), as there are several factors to consider when classifying a waste material as biodegradable. The colors that will be used in the test procedure for biodegradability include green, yellow, red, and black. Several examples that will be used for waste material classification include food waste, plastic waste, paper waste, and wood waste. These waste materials are among the most common waste materials that are available in the world, and thus, tests should be carried out to properly classify these waste materials. If the waste material poses no risk to the environment, it will be classified in the green color category as eco-friendly waste material. If the waste material is degraded greater than 20% in an aquatic

Table 4 Color classification test procedure used to determine if a material is biodegradable, recreated after Bertram et al. 2018)

Classification	Color category
Eco-friendly waste	Green
Biodegradable waste material	Yellow
Non-biodegradable waste material	Red
Toxic waste material	Back

medium, it can be considered as a biodegradable waste material, and it will be placed in the yellow color category. If less than 20% of the waste material is degraded in a short period of time, it will be placed in the red color category as non-biodegradable waste material. If the material is too toxic and dangerous, it will be placed in the black color category, and it can be considered as toxic waste material (Bertram et al. 2018). Table 4 summarizes the color codes used to classify the waste materials.

Eco-friendly waste refers to a type of waste material that is friendly to the environment. It can be similar to biodegradable waste in terms of personal safety and the positive impact on the environment. The main difference between these two types of waste is that some biodegradable waste can contaminate the environment such as paper waste, while eco-friendly waste is any waste material that can benefit the environment. Most of the eco-friendly wastes are biodegradable and generated from organic material such as food and plants (Environment Victoria 2016). Examples of eco-friendly waste include food waste products such as banana peels, potato peels, and many more discarded food items. Other examples include non-food waste products derived from plants such as tree wastes, leaves, grass waste, and other waste generated from plant sources. Al-Hameedi et al. (2019a) performed an analysis of eco-friendly waste materials and how they have the potential to be utilized in the petroleum industry.

Biodegradable waste is any type of material that can be broken down into carbon dioxide, water, methane, or simple organic molecules naturally with the aid of water, soil, oxygen, the sun's rays, radiation, or microorganisms and many more mechanisms that are natural. Biodegradable wastes are also referred to as recyclable waste, green waste, organic waste, or food waste. Biodegradable materials are materials that decompose under certain weather, water, and oxygen conditions over a relatively short period of time (Seattlepi 2019). Some items may degrade in a relatively short time, and others may take years but will eventually biodegrade. Biodegradable waste is usually more environmentally friendly in comparison with hazardous or non-biodegradable waste because they cause less contamination to the environment. It is important to start using biodegradable materials to reduce the level of pollution, which is one of the biggest problems that are facing the world. Biodegradability is the ability of a product to be consumed. It is a measurement of how much a given chemical is degraded in an aquatic environment (liquid environment) over a minimum of 28 days (Bertram et al. 2018).

Investigating the biodegradability of a material can be as simple as measuring the weight loss of the material in a specific environment such as aquatic environment, soil, and vermicompost (Bertram et al. 2018; Arikan and Bilgen 2019). The test procedure for this simple method is as follows:

1. Measure the weight of a sample of the tested material.
2. Place the sample in the selected environment (aquatic, soil, and vermicompost).
3. Re-weight the sample weekly or daily depending on the expected rate of degrading.
4. Use Eq. (1) to calculate the amount of biodegradation.

$$w_L(\%) = \frac{\left(w_0 - w\right)}{w_0} \times 100 \tag{1}$$

where W_0 and W are the initial and final weight of the samples, respectively, and W_L is the weight loss of the material.

Arikan and Bilgen (2019) examined the biodegradability of potato peels in a period of four weeks and found that the biodegradability of the potato peels is 71% in moist soil and 100% in vermicompost. This result shows that potato peels, which are considered food waste, is a biodegradable material. Hence, it can be used as an additive for drilling fluids in the petroleum industry. This is only one example of biodegradable material and in the literature, there are many others such as orange and banana peel, apple core and apple peel, hay, and grass (Zheng et al. 2013).

On the other hand, non-biodegradable wastes are substances that cannot be broken down by natural means. These wastes cannot be transformed or reused for other purposes. They cannot be recycled and thus accumulate and causing severe environmental pollution. These materials usually remain for a long time in the environment without getting decomposed by natural mechanisms. Examples of these waste materials include plastics, glass bottles, and metals that will often remain intact in the environment for a long period of time (Seattlepi 2019). The problem with these materials is that they can cause environmental contamination because they remain unchanged for a long period of time, which can cause accumulation of these waste materials, and thus become hazardous to the health and the environment (Arikan and Bilgen 2019). In order to distinguish the differences between non-biodegradable waste and biodegradable waste, several factors must be observed. If a material does not degrade easily by natural agents, it can be classified as non-biodegradable.

Using the biodegradability test procedure mentioned above, Arikan and Bilgen (2019) did not notice any degradation when samples of commercially available bioplastic were tested. There was no degradation in the soil or in the vermicompost environment. However, this is not general for all types of plastics as the biodegradability of plastics depends on both the chemical and physical properties of the plastic, which influence the mechanism of biodegradation (Tokiwa et al. 2009).

Toxic waste is any unwanted material in all forms that can pose significant harm to people, and they can endanger the lives of many personnel. Most of the common toxic waste present in today's society comes from toxic chemicals, which are present in many household devices such as televisions and computers that can pollute the air or cause water contamination when disposed of to the environment. Waste is considered toxic if it is poisonous, radioactive, or explosive. Toxic wastes form as a result of industrial, chemical, and biological processes (Aldag 2019). Examples of toxic waste include batteries from electronic devices, pesticides, cellphones, computers, and chemical additives. Toxic wastes are easily identifiable and distinguishable as most of them have safety side effects. These side effects include skin irritation, eye irritation, respiratory irritation, or any form of problem that can endanger a human being. Most of the toxic wastes cannot be degraded as well and contain chemicals that are harmful to the environment (Bertram et al. 2018). These waste materials can endanger the environment if not handled or disposed of properly. Thus, these materials have to be handled carefully to avoid the aforementioned unwanted consequences. The EPA issues regulations on how hazardous waste must be handled and stored.

Measuring the toxicity of a given material can be represented by the LC_{50} value (lethal concentration to 50% population). This value can be measured in an aquatic environment (median lethal dose of the chemical to fish) or soil (median lethal dose of the chemical to earthworms). The value of LC_{50} is expressed in (mg/L). This measurement can be useful in predicting whether the material has a toxicological effect on the tested environment or not. For example, if the earthworms died or lost weight during the test period, this is an indication that the material affected the soil negatively. If the LC_{50} value < 10 mg/L, the material can be classified as high toxic material (Bertram et al. 2018).

McCosh and Getliff (2003) performed tests on the toxicity of several materials that are used as drilling fluid additives and determined the toxic response of the materials by weight loss. Calcium chloride caused a toxic response with an LC_{50} value of 0.75–1%. Although the values of the calcium chloride seem to be high, over time, the accumulation of calcium chloride may result in toxic concentrations.

Generally, to measure the biodegradability of MSW, there are several methods including non-biological and biological methods. The non-biological methods include but not limited to dry matter (DM), loss on ignition (LOI), total organic carbon (TOC), total nitrogen (TN), water-extractable dissolved organic carbon (DOC), biological oxygen demand, chemical oxygen demand, lignin and cellulose content, and cellulose hydrolysis. The biological methods include but not limited to the aerobic specific oxygen uptake rate, the anaerobic biochemical methane potential test, and the dynamic respiration index tests.

To characterize the wastes, it is obligatory to determine the dry matter (DM) and organic matter content. DM can be determined by drying the wastes at 105 ºC, and the latter one by loss on ignition at 550 ºC. The cellulose and lignin content can be determined by several acid detergent methods (Lewin et al. 1996). Total organic carbon (TOC) is a useful measurement to get an overview of the organic content of the waste. The biological methods include introducing microorganisms that decompose the organics as a substrate for their growth. The environment of these kinds of tests can be (1) aerobic conditions, where the oxygen (O_2) consumption or the carbon dioxide (CO_2) production is monitored, (2) anaerobic conditions, where methane (CH_4) and CO_2 production are monitored.

Godley et al. (2004) divided aerobic waste biodegradation test methods into three main types: static respiration index (SRI), dynamic respiration index (DRI), and liquid systems. The SRI method is a closed solid-state method in which the O_2 consumption is measured by the reduction of air in the test vessel after the removal of CO_2, while the DRI method is an open solid-state technique in which air flows through the waste and the O_2 consumption is monitored by comparing inflow and outflow air. Under anaerobic conditions, this test measures the amount of gas produced (Zheng et al. 2013). The recommended duration of the test is 60 days. These types of tests give an indication of the biodegradability of the waste.

The petroleum industry uses many toxic chemical additives in petroleum applications, such as drilling, hydraulic fracturing, and many more. The shift to a more environmentally friendly approach led to several researchers to come up with a solution to use waste materials in the industry to replace these non-biodegradable or toxic conventional practices. Based on this study, it is concluded that eco-friendly and biodegradable wastes are preferred over non-biodegradable and toxic waste. Eco-friendly and biodegradable wastes are also safe and environmentally friendly in comparison with non-biodegradable and toxic waste. Thus, the eco-friendly and biodegradable wastes are the best option for the petroleum industry as they tackle all the environmental concerns and personal safety issues that are commonly encountered in the oil and gas industry.

Conclusions and recommendations

Waste materials are a rising issue in today's society and can pose a significant risk in terms of health and the environment. It is important to assess which type of waste materials are considered safe to use in order to use them in the petroleum industry. Waste materials have the potential to be used as an alternative for chemical additives that are commonly used in the oil and gas industry. Throughout the history of the petroleum industry, chemical additives were used in petroleum-related applications to solve the unwanted consequences that can be encountered. New alternatives are being discovered which include food waste, plant-generated wastes, and wood wastes such as sawdust. Based on this study, the following conclusions were made:

- The USA is the world's leading country in the generation of municipal solid waste, with about 258 million metric tons of municipal solid waste generated in 2017.
- The top three wastes available in the USA are paper, food wastes, and yard trimmings.
- China is the world's second leading country in terms of municipal solid waste generation, with about 220.4 million metric tons of municipal solid waste.
- The top three wastes available in China are food wastes, non-combustible wastes, and plastic wastes.
- India is the world's third leading country in municipal solid waste generation, with about 168.4 million metric tons of municipal solid waste and the top three wastes include organic waste, paper waste, and rags.
- Grass and palm tree wastes are eco-friendly wastes that have the potential to be used in the petroleum industry.
- Grass waste is mostly available USA, China, and the UK.
- Palm tree waste is mostly available in the Middle East, North Africa, Pakistan, India, and the US state of California.
- Hay wastes are eco-friendly wastes and are mostly available in the state of Texas.
- Food wastes have the potential to be used as additives for drilling and completion fluids.
- Date tree wastes have the potential to be used as additives to stop lost circulation.
- Non-food waste such as crushed date palm seeds and shredded car tires have the potential to be applied in wellbore strengthening.
- Food waste can also be used as pH reducer/elevator agents.
- Color classifications are used to classify the waste materials. Green color is used for eco-friendly waste, yellow color is used for biodegradable waste, red color is used for non-biodegradable waste, and black color is used for toxic waste.
- Many methods and standards are available to follow when identifying the biodegradability of waste material. Selecting the optimal method can be challenging and it should be determined by the material intended use. However, there are simple test procedures can be performed to measure the biodegradability of a material, but the environment in which the material is tested must be selected carefully.
- More research should be performed on waste materials to get a better understanding of this topic and gain confidence before using waste materials in the oil and gas industry.

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