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Solid waste generation from oil and gas industries in United Arab Emirates

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Abstract

Solid wastes generated from oil and gas industrial activities are very diverse in their characteristics, large in their amounts and many of which are hazardous in nature. Thus, quantifying and characterizing the generated amounts in association with their types, classes, sources, industrial activities, and their chemical and biological characteristics is an obvious mandate when evaluating the possible management practices. This paper discusses the types, amounts, generation units, and the factors related to solid waste generation from a major oil and gas field in the United Arab Emirates (Asab Field). The generated amounts are calculated based on a 1-year data collection survey and using a database software specially developed and customized for the current study. The average annual amount of total solid waste generated in the studied field is estimated at 4061 t. Such amount is found equivalent to 650 kg/capita, 0.37 kg/barrel oil, and 1.6 kg/m^3 of extracted gas. The average annual amount of hazardous solid waste is estimated at 55 t and most of which (73%) is found to be generated from gas extraction-related activities. The majority of other industrial non-hazardous solid waste is generated from oil production-related activities (41%), The present analysis does also provide the estimated generation amounts per waste type and class, amounts of combustible, recyclable, and compostable wastes, and the amounts dumped in uncontrolled way as well as disposed into special hazardous landfill facilities. The results should help the decision makers in evaluating the best alternatives available to manage the solid wastes generated from the oil and gas industries.

Keywords: Solid waste management (SWM); Waste generation; Oil and gas industries; Hazardous waste; Asab field; United Arab Emirates

1. Introduction

A key factor in achieving successful management policies in the oil and gas industry is the availability of adequate and reliable records of generation rates, characteristics, and distribution of different wastes produced by the industry. This is irrespective of the fact that such rates and distributions are highly site-specific and significantly vary from one location to another. It has been noticed that the number of studies addressing such topic in direct and focused way is rather few as most relevant works have broader scopes and objectives. As a result, the data acquired in those studies are limited and of non-diversified types.

The objective of this study is to provide a comprehensive analysis of the solid wastes produced by one of the most important oil and gas industrial sites in United Arab Emirates, called Asab field. The analysis provides average generation rates of solid wastes referenced to the oil and gas production levels and to the site population, generation rates of different types and from different sources, generation rates of solid wastes having different chemical and biological characteristics, in addition to identifying the types of hazardous wastes and their generation rates.

2. Relevant studies

This section presents a number of studies related to solid waste generation and characterization in oil and gas industries, some of which were conducted in the UAE and oth-

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ers were conducted in Asab field, the application site of the present study.

The study of selected petroleum refining residuals [1] revised the waste generated from petroleum, petrochemical and refinery industries. The study included a list of sludge from different types of oil and gas processes/equipment besides residuals from the petroleum refinery industry. Twelve oil and gas processes were described to give an overview of waste sources for each process. These processes are: refining, crude oil desalting, hydrocracking, isomerization, extraction, alkylation, polymerization, residual upgrading, lube oil processing, H_2S removal and sulfur complex clay filtering, and residual oil tank storage process. The detailed chemical and physical characteristics of liquid and solid waste are then tabulated for each process's waste. Examples of these wastes are: crude oil tank sludge, catalysts from hydrorefining, sulfur complex sludge, spent caustic, desalting sludge, and off-spec product, residual upgrading.

SHELL specialists [2] have revised a waste management guide in February 1996. The guide provides oil and gas industries with a waste management system compatible with the group health, safety and environment management system (HSE-MS) and complies with the group's standards for health, safety and environment. A separate chapter for hazards and effects related to waste disposal highlighted the characteristics of hazardous wastes. SHELL International [3] developed waste classification guidelines in September 1995 to give oil and gas industry guidance in classifying waste streams. Practical aspects of classifying waste are addressed in the context of EP (exploration and production) operations, focusing on pragmatic assessment of HSE hazards at all stages in the waste life cycle. A manual of comprehensive environmental management and procedures was produced by SHELL Egypt in 1992 [4]. The manual covered all management aspects from policy and objectives up to audit. A chapter related to this paper, titled as "Operational Techniques" considered all aspects of waste management elements (i.e. environmental management system, identification, characterization, inventorization, waste management hierarchy, treatment and disposal, handling and records, and plan integration). The chapter contained a list of known waste products classified by their source of generation in addition to brief descriptions of some waste treatment techniques.

Noyes [5] in two chapters of his handbook titled "The Pollution Prevention Technology Handbook" discussed topics relevant to the present work. The fist (Chapter 21) is titled "Oil and Gas Exploration and Production" and the second (Chapter 25) is titled "Petroleum Refining". Both chapters concentrated heavily on effluent and emission while a few sections discussed the prevention method of solid wastes. The study noted that the solid waste management practices employed by the petroleum refining industries are changing significantly, thus no one unique solution was given. The Industrial Pollution Prevention Handbook [6] contributed to the topic of solid waste management (SWM) in two of its chapters; Chapter 44: Pollution Prevention in the Chemical Industry [7], and Chapter 45: Pollution Prevention in the Petroleum Refining Industry [8]. Both chapters identified the process of mass balance, identified sources of wastes, and proposed a system outline to prevent pollution. Chapter 45 listed six waste streams from petroleum industry, four of which are solids namely; spent caustics, spent catalysts, miscellaneous process wastes, and maintenance and materials handling wastes. Wentz [9] listed hazardous wastes from specific and non-specific sources extracted from the EPA hazardous wastes lists of commercial chemical products, intermediates and residues. Five hazardous waste products are listed under Petroleum refining category four of which are sludge/solid from the petroleum refining industry; Slop oil emulsion solids, Heat exchanger bundle cleaning sludge, tank bottoms (leaded), and API separator sludge.

Rendel Scientific Services Ltd. [10] has prepared a comprehensive consultancy study for Environmental Protection study for the Emirate of Abu Dhabi in November 1990. The Abu Dhabi National Oil Company, ADNOC identified the scope of work to consider one of the most comprehensive environmental studies conducted in the area. Chapter 5 of the study, titled "Waste Survey" presented the gathered data in five sections. The first section covered the origins of waste in the oil and gas industry presented in a map identifying seven onshore sources and 10 offshore sources. The second section identified and discussed 29 types of waste produced from oil and gas activities; 17 of which are solid waste products. The third section listed the quantities of waste produced by the three sources; domestic, industrial, and hazardous. The highest quantity of solid waste was estimated to be 673 t of metal scraps and general industrial waste. The fourth section discussed PCB wastes while the fifth section addressed the future trend in waste production and estimated at 20% over the following 10 years.

In coordination with AbuDhabi Gas Industries Ltd. (GASCO), Webster conducted an environmental protection study for Asab NGL Extraction Plant in March 1995 [12]. The study focused on air emission and very briefly considers solid wastes. The existing status of Asab Solid Waste handling was compared with reference standards and compliance with a recommended approach. While comprehensive inventory figures were listed for gas emissions and liquid effluents, solid waste data were not listed due to the unavailability of these data except for six waste products classified as non-hazardous industrial waste. Recommendations from the compliance audit for solid waste indicated the importance of properly classifying waste and keeping records of relevant inventory lists. In April 1999, a waste management audit was conducted jointly by ADCO and ADNOC auditors for the contractors in Asab area [13]. The audit team visited and interviewed 16 service providers/contractors in the area to determine their compliance with waste management and environmental regulations. Lacking of waste inventory was a common finding amongst most of the contractors. The audit highlighted the necessity of following a common approach in managing the waste generated by contractors' activities and the importance of obtaining a SWM database system. Hyder Consulting conducted an Environmental Baseline Study for the Asab area [14]. The study covered the entire major companies operating in Asab area and evaluated the compliance of gas emissions, liquid effluents and solid waste standards. The final assessment endorsed the difficulty of finding data for solid waste and pointed out the variation in disposal methods and managing standards. The accuracy of the provided data is dependent on the survey method. ADCO environmental engineers doubted the comprehensiveness of this study as it failed to provide accurate figures and logical discussion of the prevailing problems.

3. SWM database system

Solid waste management databases are important tool to quantify and characterize the amounts of different types of solid wastes generated from the oil and gas industrial sites and from other sites as well. Requirements of solid waste management databases pertinent to oil and gas industries were addressed by few studies. The SHELL Egypt Environmental Management and Procedures Manual [4] specifically addressed inventorization and other database related topics. A section titled "Waste inventory database" discussed the methods of data collection and listed common sources of information that would help in database development. The Scientific Software Group developed a municipal solid waste management database [11] that logs waste inventory from the generation source up to final disposal. A built-in library with default values of parameters and unit costs helps the users to produce the desired output when short of data; otherwise, users can specify their own parameters. Waste management methods like recycling, transportation and disposal are provided for decision-making processes. Another library lists nineteen recyclable wastes along with relevant 15 cost variables. The SWM-Plan report-generator can generate 18 tables, 5 sub-reports, 8 pie graphs and 50 bar graphs. Even though the database is designed mainly for municipal solid waste, it can be customized for any type of waste including solid wastes from oil and gas industry.

The database developed and utilized in this work is structured into four modules; user input, library, math/query and output. Each module contains several components where each component is represented by one or more database tables. The database table consists of fields under which relevant data are stored. Microsoft Access and Visual Basic were employed to develop the SWM database system. The database was specifically structured and customized to fulfill the required work for solid waste in oil and gas industry. However, it can be easily adapted and customized to handle solid wastes from other sources in addition air emission and liquid effluents.

4. Application site and data collection survey

Asab oil field is an onshore field located in the southwest region of AbuDhabi City, the Capital City of United Arab Emirates (UAE). There are three major companies located in the area and working in oil and gas processing. Five main contracting companies in addition to other small companies are also present for the purposes of exploration and drilling, labor and equipment supply, civil works, and other general services.

A survey was developed and distributed to the working companies in the field to gather information about the types and quantities of solid waste generated by each source. A continuous review of the surveying process was conducted over one full year as several improving modifications were incorporated throughout the surveying period. Few surveys/interviews conducted to determine the generated amounts from each source did have missing records/information; i.e., generated amounts and/or types of wastes. Such data were based on personnel experience, expenditure of budget, and recent generation figures. Analyses of the collected data using the developed database revealed that a total of 92 solid waste types are present in Asab field. The average breakdown of these wastes by generation source showed that 70 types (76% of all types) are produced by industrial activities, 14 types (15%) by domestic activities, and 8 types (9%) are hazardous (industrial/domestic) waste.

5. Waste classification

Waste characterization (classification) is identifying the category of waste by various classification methods, such as; the chemical and physical properties (inert, flammable, organic, etc.), the source of the waste (industrial, domestic, institutional, medical, etc.), environmental risk hazardous impact, the quantity and frequency of generated waste (minute, frequent, interim, patches, etc.), or the applied management method (recycle, reuse, disposal, etc.). According to Shell International [4] it was narrated that a major purpose of waste classification is to determine whether or not the waste is hazardous. The physical and chemical properties of the waste determine its hazardous characteristics and environmental impeccability. Waste characterization is also required to determine and assign the waste stream categories and select options for segregation, minimization, treatment and ultimately disposal.

Classification is not limited to the generated waste only, but includes the generation source as well. Companies working in oil and gas fields (the waste generators) are categorized by their type of activity. This classification is necessary to determine the types of waste generated by each activity. Obviously there are common wastes that could be generated by most of these activities while there are other specific and unique types of waste associated with the nature of the activity. In this work, the site activities are classified

Table 1
Classification and coding method of different solid wastes

Source (coding)	Content (coding)	Type (coding)	No. of wastes
Hazardous (H)	Hazardous (HH)	Corrosive (HHC)	1
		Eco-toxic (HHE)	1
		Harmful (HHH)	3
		Ignitable (HHI)	0
		Oxidizing (HHO)	0
		Pathogenic (HHP)	1
		Radioactive (HHR)	1
		Toxic (HHT)	1
Sub-total			8
Domestic (D)	Inorganic (DI)	Inert (DII)	2
		Metal (DIM)	1
		Sub-total	3
	Organic (DO)	Cardboard (DOC)	2
		Food (DOF)	3
		Mixed (DOM)	1
		Plastic (DOP)	2
		Sludge (DOS)	1
		Textile (DOT)	0
		Wood (DOW)	2
		Sub-total	11
Sub-total			14
Industrial (I)	Inorganic (II)	Devices (IID)	12
		Inert (III)	15
		Metal (IIM)	24
		Sub-total	51
	Organic	Cardboard (IOC)	2
		Plastic (IOP)	11
		Sludge (IOS)	0
		Textile (IOT)	2
		Wood (IOW)	4
		Sub-total	19
Sub-total			70
Grand total			92

into three groups; petroleum activities, domestic activities, and services activities. The petroleum activities include exploration, drilling, oil processing, gas processing, and shipping. The domestic activities include accommodation and catering. The services activities include office, garages and transport, civil construction, workshops, storage warehouses, clinic, and laboratories.

Since the recovery opportunities associated with the generated wastes in oil and gas industry is of interest to the operating companies, it is also desired to categorize the generated wastes according to the potential treatment technologies. Such technologies in the current study are classified into physical, chemical, biological, and thermal techniques. Recycling and disposal are separately considered as possible management techniques.

The method used in classifying the surveyed solid wastes in the present study is best described in Table 1. Three levels of classification were applied; the first identifies the generating source, the second characterizes the waste content, and the third identifies the waste type determined by its chemical and physical properties. The first level of classification has three sources: (1) hazardous waste originated from either domestic or industrial sources; hazardous to human health and safety and/or the environment; flammable, toxic, reactive, radioactive, explosive, infectious and eco-toxic wastes, (2) domestic waste such as office activities and accommodation camps; paper, food, gardening waste, sewage sludge, and general rubbish, (3) industrial waste generated during oil/gas exploration, production and processes, and which is not hazardous. Examples are; pipes, drilling cuttings, non-hazardous chemicals, construction waste, and waste produced from civil activities and services. The second level of classification has also three sources too: (1) hazardous waste; either organic or inorganic wastes, such as asbestos, hydrocarbon sludge, chemicals, and contaminated materials, (2) organic waste that contains non-hazardous organic matters, such as food waste, paper, cardboard, tree trim, wood, and plastic, and (3) inorganic (non-hazardous) waste that does not contain organic matters, such as metals, concrete, sand, glass, grit, and fibers. Table 1 does also list the number of waste types identified for different classes of wastes.

6. Results and discussion

Several variables (transactions) are critically analyzed using the developed solid waste management database software. Such variables include overall waste generation, generation per different grouping criteria, recyclable wastes, combustible wastes, compostable waste, and disposable waste. Many of these variables are estimated considering two scenarios (high and low) to account for the uncertainties associated with the calculated amounts of generated wastes. The first scenario represents high generation amounts reflected during shutdowns and maintenance periods while the second scenario reflects the normal operation periods. Uncertainties are also present in the considered unit costs and in the output ratios employed in calculating the output products according to various management options. The results pertinent to the analyzed variables are further discussed in the following sections.

6.1. Generation per source, production unit, and population

This section addresses the solid waste generation units from the activities directly related to oil and gas industries in association with the factors influencing the generated amounts, such as the site population, the amount of produced crude oil, and the amount of extracted natural gas liquids (NGL). The total waste generations for oil and gas industries grouped by source are summarized in Table 2. The table lists the relevant unit generation of solid waste; i.e., per capita, per produced oil barrel, and per cubic meter of processed NGL. The generation units of domestic waste are estimated per capita considering all sources and classes since there is a direct relation between the amount of domestic waste gen-

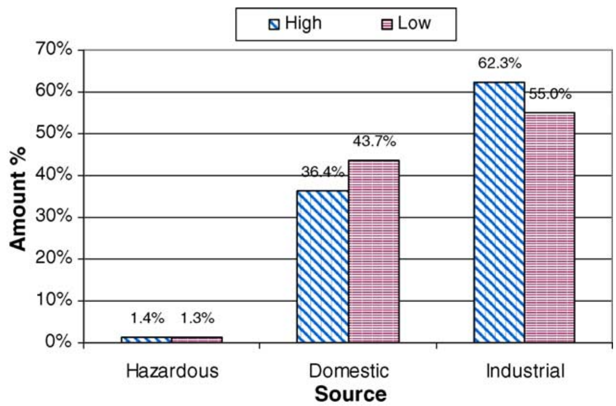

Fig. 1. Amount distribution of annual generated solid waste by their source.

erated and the field population size. On the other hand, the oil-related solid wastes are estimated per oil production unit while the gas-related solid wastes are estimated per oil production unit and per gas production unit since the extracted NGL gas is a subsequent activity of oil production.

The total amount of solid waste generated from all activities in Asab field is found to range from 2907 to 5215 t/yr. The distribution of this amount on different sources; hazardous, industrial and domestic is best described in Fig. 1. Even though the generated amount of hazardous wastes (industrial and domestic) is the lowest amongst all sources (1.3–1.4%), the calculated range of 38–72 t/yr is still high for hazardous wastes and requires special and careful precautions for handling and disposal. When considering the waste generated from the activities directly associated with oil and gas industries only (ranging from 966 to 1429 t/yr), the percentage of hazardous waste mounts up to 3.4% and goes as high as 20% when considering wastes generated from gas-processing activities only. The main contributors to the generated hazardous wastes in the site are drums with spent oil, oil sludge, and acid batteries.

Table 2
Average annual generated amounts per capita and per production units

Class	Total generated waste (t/yr)	kg/capita	kg/oil barrel	kg/m^3 gas
Oil production activities				
Domestic	4.16			
Industrial	1004.3		0.00917	
Hazardous	0.82		0.00007	
Total	1009.2		0.00922	
Gas processing activities				
Domestic	46.52			
Industrial	116.7		0.00107	0.04566
Hazardous	39.96		0.00036	0.01564
Total	203.15		0.00186	0.07951
Oil and gas activities				
Domestic	50.68			
Industrial	1120.9		0.01024	0.43872
Hazardous	40.78		0.00037	0.01596
Total	1212.4		0.01107	0.47451
All field activities				
Domestic	1583	253.3		
Industrial	2421		0.2211	0.9476
Hazardous	55		0.0050	0.0215
Total	4059	649.4	0.3707	1.5887

Note: Blank dark cells are not relevant.

As for the surveyed year of 2002, the amount of oil production in Asab field ranges from 250 to 350 thousand barrels per day depending on the market demand and the corresponding extracted natural gas liquids (NGL) ranges from 6000 to 8000 cubic meters per day. Analysis of the obtained results reveals that 371 kg of solid waste is generated from all field activities for each 1000 barrel of crude oil produced while 1587 kg is generated for each 1000 cubic meter of NGL extracted. The annual population equivalent of waste generation is 649.4 kg per person. It can be noted that the reported generation rates are much lower than what is reported in another study [10] which concluded that for each ton of crude oil produced there are 3–5 kg of waste generated. Since 1 t of crude oil is equal to seven barrels, the average equivalent generation unit according to this study is 571 kg of waste per 1000 barrel of crude oil. However, this difference can be best explained as follows: (1) the amount of oil produced from Asab field is huge in comparison with other fields in the UAE and other countries as well, (2) oil produced from Asab field is self-pressurized so that no mechanical pumping is required eliminating all of its related processes, (3) the quality of oil produced from Asab is light or sweet and both do not contain high impurities as this will eventually reduce the amounts of solid waste in general and hazardous waste in particular generated in the area. The quality of produced oil will also eliminate the need for sophisticated purification/sweating process, sulfur removal, and alkyl wash units, and hence minimizes the amounts of associated wastes.

Oil production industries are the highest waste generators of industrial waste in oil and gas fields, while gas processing is the highest generator of hazardous waste. The calculations show that 41% of industrial waste is generated from oil production industries, while 73% of hazardous waste is generated from gas-processing activities. This is directly related to the process technology practiced by each industry. Oil production industries have huge structures, scattered in the desert, with large storage tanks and long net of pipelines, while gas processing involves sophisticated filtration and liquefaction units with high technology equipment and controlling devices.

Table 2 also reports an average domestic waste generation of about 254 kg per person per year as 5500–7000 employees represented the field workforce throughout year 2002. One can notice that the variation of the population is not as much as it is for the total generated waste. This is due to the fact that most of the workforce usually stays on site after the project in place ends waiting for another project, minimizing the demobilization and reallocation costs. The slight increase in

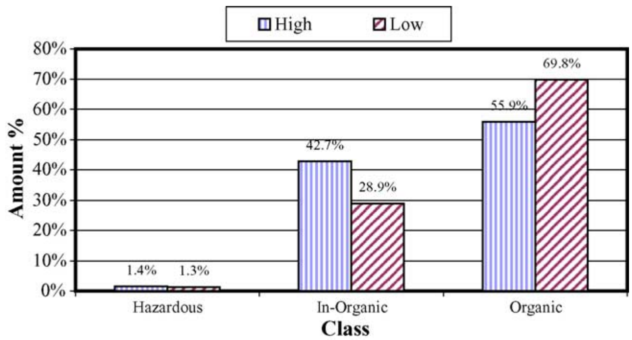

Fig. 2. Amount distribution of generated solid waste by their class.

work force is usually taking place during the time of project implementation. Therefore, the variation of domestic waste is not as great as for industrial waste.

6.2. Generated amounts per class

The total amounts of generated solid waste categorized by classes; Hazardous, Inorganic, and Organic are presented in Fig. 2. It is noted that Organic waste is the highest amount produced, ranging between 20.3 and 29.1 t/yr while hazardous waste is the lowest generated waste ranging between 38 and 72 t/yr. The high organic content of the generated waste is related to the type of waste generated, such as wood, plastic, and food waste. It should also be noted that waste classified as organic has mainly organic contents, yet it does not necessarily contain 100% organic matters. Waste classified as inorganic has the highest variation between the maximum and minimum quantities. This variation is attributed to the wastes generated from the activities generating high amounts of inert wastes such as concrete debris and metal wastes as many of such activities are considered in the low generation scenarios.

6.3. Generated amounts per waste type

Fig. 3 shows the minimum and maximum amounts of generated wastes for all the types of wastes identified in the study area. The figure shows that a remarkable amount of wood waste is generated in the surveyed field. This type includes the largest number of wastes generated by both domestic and industrial activities; such as tree trim, wire drums, furniture, boxes, etc. Another observation is the high amount of metal wastes that reflects the nature of the location, and type of structures existing in the site (pipes and steel beams). The figure also reports high generated amount of eco-toxic wastes (35–67 t/yr), contributed by drums with spent oil, sludge, and paint/adhesive leftover.

6.4. Generated amounts per activity

Fifteen various activities contributing to solid waste generation from Asab field are registered in the developed database. Fig. 4 shows the total solid waste generated by 10 major activities. The maximum amount of generated wastes is found to originate from civil activities. These wastes include concrete debris, wood, metal and different domestic wastes generated from the accommodation facilities provided for the construction workforce.

Observing the low amount of waste generated from the gas processing activity, it is important to point out the following two remarks: (1) two main companies were still under commissioning during the data collection period and therefore no wastes were classified under gas processing activity, (2) other services conducted for gas processing, such as special services and technology were listed separately.

6.5. Generated amounts per zone

Quantifying and characterizing the solid waste generated from the oil and gas industries grouped per source location (zone) inside the field site is necessary for allocating various management facilities like recycling, composting, combustion, and disposal facilities. Fig. 5 presents the distribution of total annual generated wastes in relation with eight geographical zones covering the whole site. The eight zones are north, northeast, east, eastsouth, south, southwest, and west. The figure shows that the northern part of Asab field generates the maximum amounts of wastes. This zone is a highly populated area of service providers in addition to one major company (ADCO). Also, two projects were just commissioned in this location; construction of ADCO's offices and the new accommodation facility.

6.6. Waste dumping

Dumped solid waste in the current study represents the waste disposed in uncontrolled manner. The collected data show that the total amount of dumped waste ranges from 2550 to 4330 t/yr. Almost all non-hazardous and non-valuable wastes are being dumped. The amount of waste being dumped is directly related to the amount and type of generated waste and to the geographical location as well. Fig. 6 shows the annual amounts of waste dumped from different locations for the two considered scenarios. Since the disposed waste is affected by the amount of the generated waste, there is significant amount of waste dumped from the northern location since high intensities of companies are present in this zone. This finding is useful in selecting the most suitable location of a potential sanitary landfill.

6.7. Landfilling of hazardous waste

The total hazardous waste generated in Asab field is found to range from 38 to 72 t/yr. Only 0.3–1 t/yr is sent to Ruwais Hazardous Waste Facility located at about 120 km north of Asab field. The remaining amounts are either sold (Drums with spent oil and Alkaline batteries) or shipped back to the manufacturer (Smoke detectors contains radio active materi-

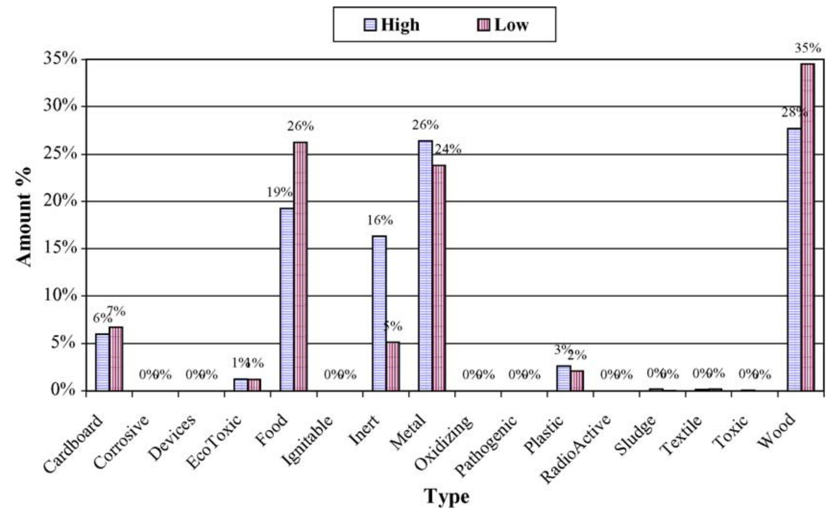

Fig. 3. Amount distribution of generated solid waste grouped by waste type.

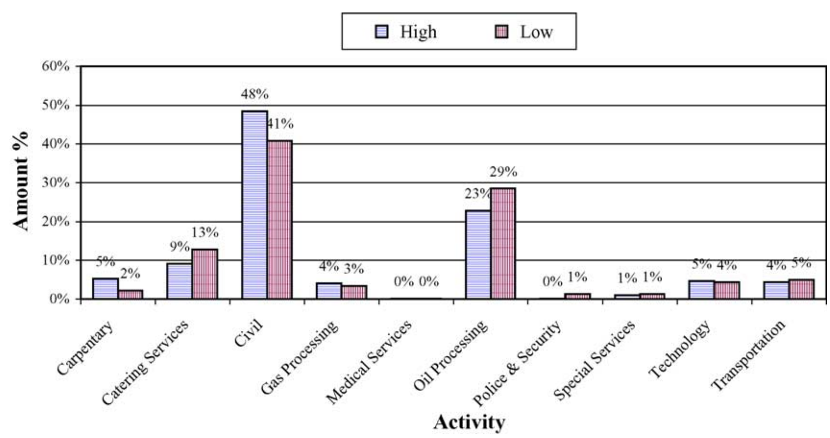

Fig. 4. Amount distribution of annual generated solid waste per activity.

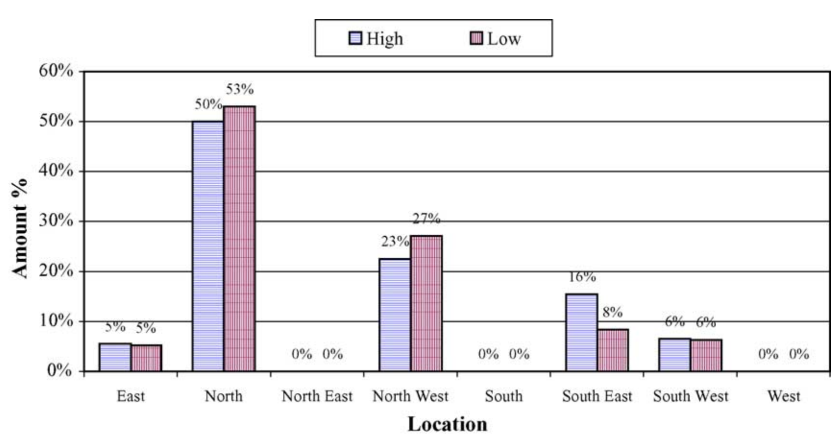

Fig. 5. Amount distribution of annual generated solid waste per geographical location.

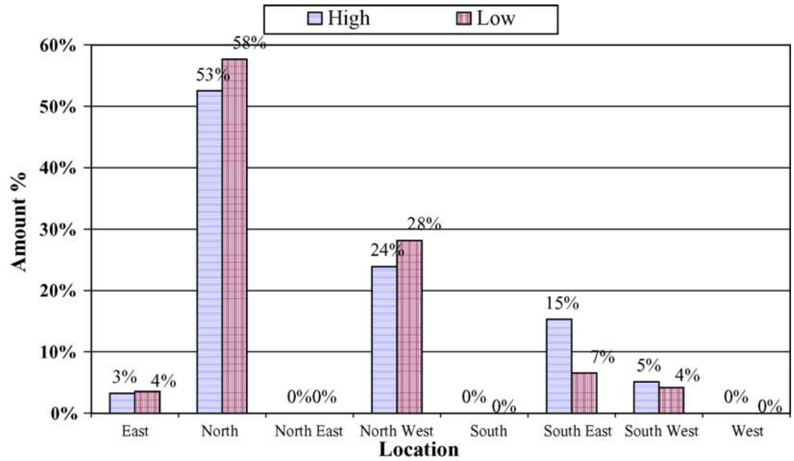

Fig. 6. Amount distribution of annual dumped waste grouped by location.

als) as per the regulation. Fig. 7 presents the type distribution of hazardous wastes sent to Ruwais Interim Hazardous Waste Facility.

6.8. Combustible waste

Burnable and heat recovery waste are mostly organics found either in domestic, industrial, or hazardous waste. The collected data shows that less than 0.01% of the combustible waste is actually combusted. The current practice limits combustion waste to medical waste as a predisposal treatment process. It should be noted that the open burning of waste is neither considered as combusted nor accounted for as input to incineration since it lacks the heat recovery system and control of emission pollutants. In general, the combustible matters at Asab field are found to be highly present in domestic and industrial waste. The analysis shows that 37% of domestic waste, 29% of hazardous waste, and 22% of industrial wastes are combustible. The high inert content of the industrial waste explains its low combustible percentage. Also, the high percentage of combustible matters found in the hazardous waste is attributed to the oil sludge and drums with spent oil. Fig. 8 presents the different scenarios of the potential combustible waste generated from each source.

6.9. Reusable waste

Current amounts of reused waste material at Asab field ranges between 13 and 64 t/yr, while the available waste for reuse ranges between 411 and 1700 t/yr. This indicates that the actual figures are too far from the potential ones. Fig. 8 shows the major recycled items in the site for two scenarios labeled HH and LL. The 'HH' scenario refers to high generated amounts and high output ratios of recyclable material while the "LL" scenario refers to low generated amounts and low output ratios of recyclable material.

The current reusing of waste material in Asab field is limited to five types (Fig. 9), the highest is metal waste followed by wood waste. Metal waste is reused in form of redundant pipes in making fences and road guards or reusing empty drums for road signs and garbage collection. While the generated amount of metal wastes ranges between 692 and 1377 t, the potential recyclable annual amount ranges from 164 to 448 t. A breakdown of metal

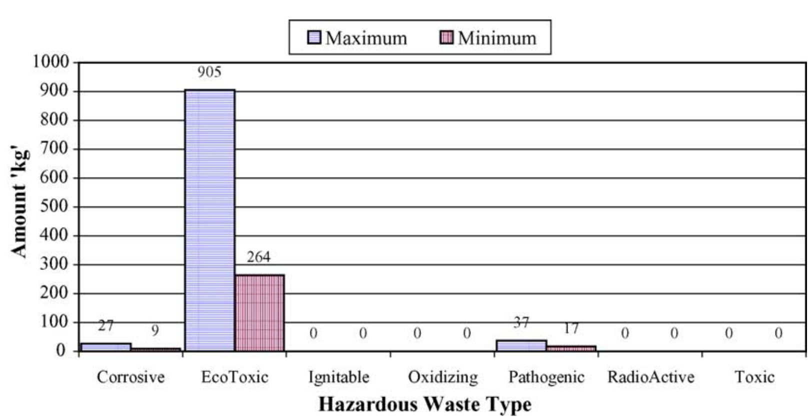

Fig. 7. Amount amounts of hazardous waste sent to Ruwais Hazardous Waste Facility.

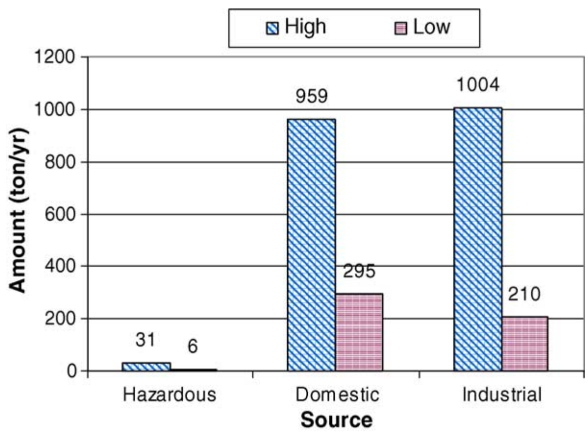

Fig. 8. Potential amount of combustible solid wastes for different sources and scenarios.

waste generation by the company activity is presented in Fig. 10 excluding the civil construction work that is found to be the highest generator of metal waste yielding exclusively 531–1059 t.

Also, although contaminated soil and spent oil are considered as hazardous material, it is the third higher reused waste that is mainly used in paving roads and stabilizing the moving sands.

Paper and glass are both recyclable material and neither one of them is currently recycled in the surveyed site. The paper waste potentially available for recycling is in the range of 19.5–95.1 t/yr generated mainly from the packaging cardboard material, office papers, magazines and newspapers. The total generated amount of glass waste from Asab field is in the range of 36–106 t/yr, a 10–30% of which is potentially available for recycling.

6.10. Amount of composting waste

Organic wastes such as food waste are being composted to produce compost (usually used as fertilizer). The total amount of organic waste generated in Asab field ranges between 1628 and 3650 t/yr. Even though a large amount of this food waste is available for composting;

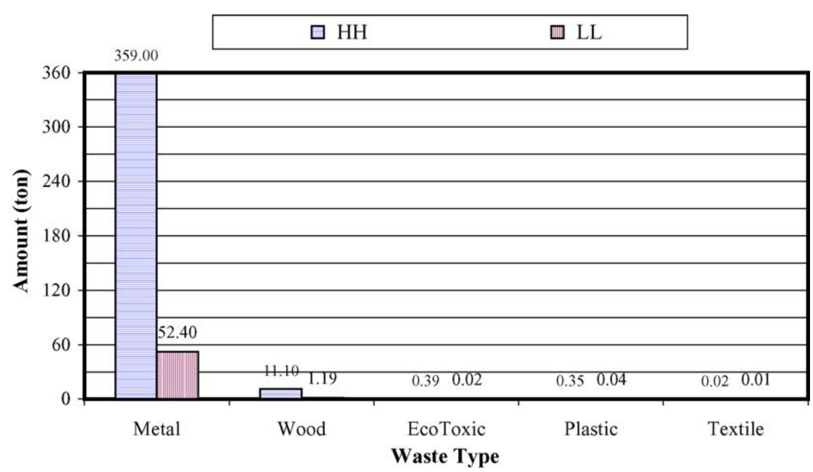

Fig. 9. Actual annual amounts of reused types of solid waste for two scenarios (HH: high generation and high output ratio, LL: low generation and low output ratio).

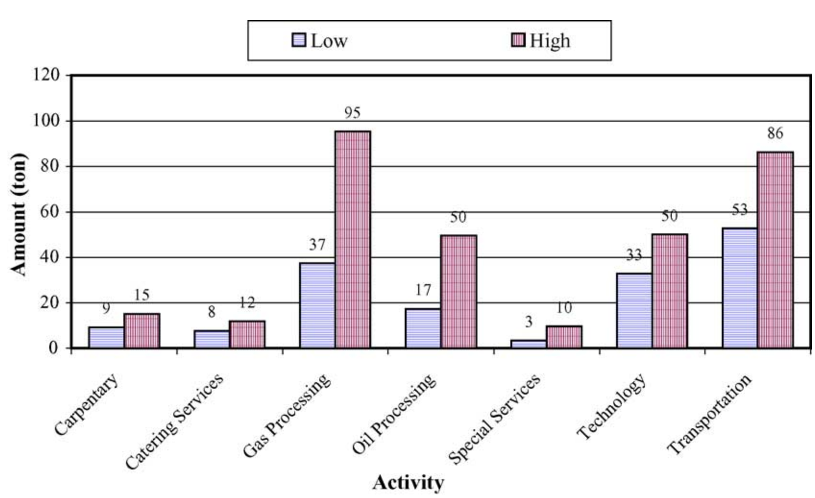

Fig. 10. Actual annual metal waste generation by major activities (excluding the construction work activity).

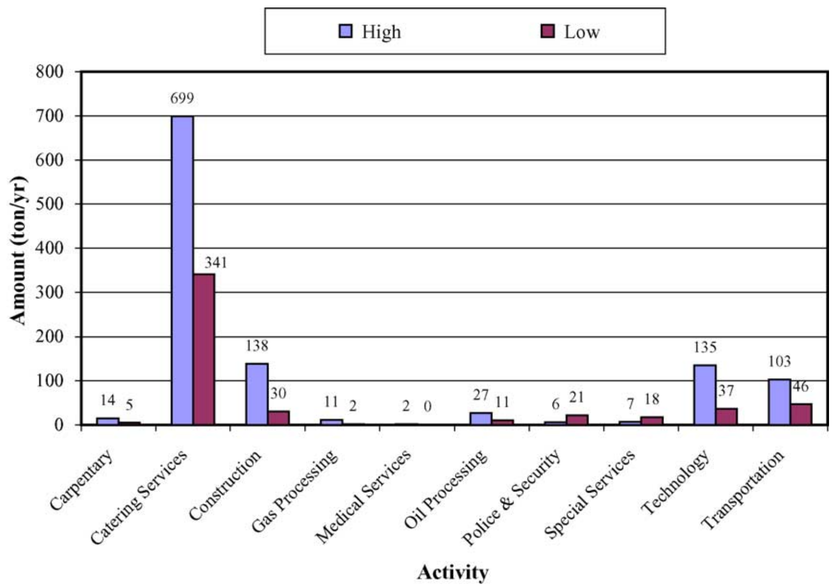

Fig. 11. Potential annual amount of solid waste available for composting by company activity.

Table 3
Summary of numerical results

Variable	Results
Total annual generated waste	Ranges from 2907 to 5215 t
Generated amounts per source	Hazardous: 38–72 t/yr Domestic: 1270–1900 t/yr Industrial: 1600–3250 t/yr
Generated amounts per class	Hazardous: 38–72 t/yr Inorganic: 840–2227 t/yr Organic: 1628–3650 t/yr
Generated amounts per waste type	Maximum from wood waste (1002–1443 t/yr) Followed by metal waste (692–1337 t/yr)
Generated amount per activity	Maximum from civil (1190–2520 t/yr) Followed by oil processing (830–1190 t/yr)
Generated amount per site zone	Maximum from the northern zone (1540–2601 t/yr)
Waste dumping per site zone	Maximum from the northern zone (1470–2270 t/yr)
Land-filling of hazardous waste	Maximum from eco-toxic type (264–905 kgs/yr)
Combustible waste (per source)	Maximum annual potential amounts are 959 t from domestic, 31 t from hazardous, and 1004 t from industrial source
Amount of reusable waste	The actual amount range is 10–60 t/yr The potential amount range is 400–1700 t/yr Actual recycled metal waste is 53–359 t/yr Potential recyclable metal waste is 163–756 t/yr
Amount of compostable waste	Potential amount is 510–1140 t/yr

estimated at 510–1140 t/yr, no composting facility is currently available in the field. Fig. 11 demonstrates the distribution of such potential amounts among the main generating activities. It is obvious that catering services is the highest activity generating solid wastes available for composting due to the type of waste produced; that is food wastes.

7. Summary and conclusion

The number and type of activities and the current population in the surveyed area of Asab field are growing dramatically due to the significant expansion of many industrial activities. The annual amount of total waste generation is found in the range of 2907–5215 t. A large potion of this amount is contributed by non-hazardous industrial activities associated with construction work. The hazardous waste amount ranges from 38 to 72 t/yr including several types such as drums with spent oil, sludge, and paint/adhesive leftover, alkaline batteries, etc. This amount, even though small compared to the total generated waste, needs special and careful precautions for handling and disposal.

The generated amounts of solid wastes and their classification are both related to the operation structure of oil production activities and to the type of process technology used by the gas processing activities. For each 1000 barrel of oil produced in Asab Field, there are 371 kg of solid waste, and for each 1000 m^3 of NGL extracted there are 1588 kg of solid waste generated. About 74% of the total hazardous waste generated in Asab Field is contributed by gas processing activities while 43% of the industrial waste is associated with oil production activity.

An average of 207 t of industrial metal wastes is being recycled per year out of the available average of 460 t. Significant revenues can be achieved in case of recycling all available metal waste.

A large amount of organic waste; 1630–3650 t/yr, is currently generated at Asab field. Waste available for composting ranges between 510 and 1140 t/yr. Table 3 summarizes the main numerical results obtained from the study.

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