A Typical Case Study:
Solid Waste Management in Petroleum Refineries

[1]Jadea S. Alshammari, [1]Fatma K. Gad, [1]Ahmed A.M. Elgibaly and [2]Abdul Rehman Khan
[1]Department of Chemical and Refinery Engineering,
Faculty of Petroleum and Mining Engineering, Suez Canal University, Egypt
[2]Coastal and Air Pollution Department,
Kuwait Institute for Scientific Research, P.O. Box 24885, Safat 13109, Kuwait

Abstract: The current environmental concerns have forced developed and developing countries to reduce air, water and land pollution for sustainable growth. Solid refinery waste is cocktail of hydrocarbons, water, heavy metal and fine solids and is substantial in quantity. The principal processes of waste management focus mainly on waste source reduction, reusing, recycling, composting, incineration with or without energy recovery, fuel production and land filling. Waste management models have a common approach of assignment of generating sources to landfills, transfer stations sitting, site selection for landfills, etc. but recently new integrated models have been developed and applied. Waste management system in an industrial complexes uses multi-objective mixed integer programming approach for the running of existing facilities in dynamic net work flow models with nonlinear costs of management. The latest multi-objective mixed integer programming techniques are applied to resolve the potential conflict between environmental and economic goals and to evaluate sustainable strategies for waste management. In this approach, material recycling in an economic sense exhibits huge indirect benefits, although the emphasis of environmental quality as a major objective in decision-making drives the optimal solution toward pro-recycling programs. The use of grey and fuzzy system theories as uncertainty analysis tools as an enhancement of this modeling analysis proves to be highly profitable. A multi-objective optimization model based on the goal programming approach has been developed and tested in this study for passable management of solid waste generated by a typical petroleum refining industry in the state of Kuwait. The analytic hierarchy process, a decision-making approach, including qualitative and quantitative aspects of a problem, has been integrated in the model to prioritize the conflicting goals existing in the waste management problems of the petroleum industries. The optimization model is developed based on the goal programming technique that attempts to minimize the set of deviations from pre-specified multiple goals, which are considered simultaneously but are weighted according to their relative importance. A set of data from local petroleum refining industries is obtained and is analyzed using the unique presently developed multi-objective optimization model based on goal programming technique with all treatment options and economic constraints. The successful application of this model has provided the most economically viable solution to be applied for the specified objectives to be accomplished for the management of solid waste generated from petroleum industries.

Key words: Solid waste management, spent catalyst, sludge, hazardous waste, multi-objective model

INTRODUCTION

There is a four fold increase in natural calamities in last two decades reported in press due to increase in pollution levels that is major concern for the future sustainable growth for man and its habitat. The mammoth growth of petroleum products processing have resulted in the generation of enormous amount of waste that burdens the petroleum industries to resolve this burning issue of waste management. The level of natural resources reserves and increase in population with increasing living standards have reinforced the need to utilize the reminder in sustainable way. Thus refinery wastes are regarded as valuable asset (high energy potential) as far as resources are concerned and its management is of great importance.

Corresponding Author: Jadea S. Alshammari, Department of Chemical and Refinery Engineering, Suez Canal University, Tel: 00965-7898867 Fax 00965-4582093

Fuel production, by-product processing, ancillary operations and waste management are the major operations in any oil refining industry. Fuel production encompasses those operations which manufacture petroleum products such as gasoline, polymers and coke. By-product processing covers refinery operations that convert used materials and/or undesirable petroleum constituents into saleable or reusable end products. Ancillary operations are those activities which support refinery functions and recover energy. Finally, waste Management deals with the recovery of useable materials from refinery waste streams, the disposal of solid and hazardous wastes and the treatment of wastewaters generated by refinery operations.

No matter today waste management is difficult and costly by the increasing volumes of waste produced, by the need to control potential serious environmental and health effects of disposal still it is the prime objective of industry for its sustainable operations. Many mathematical models have been developed to resolve the rising hazardous waste treatment problem by physical, chemical, thermal and biological processes. Additionally, mathematical programming techniques such as linear programming, dynamic programming and network models have been introduced to aid in managing the logistical aspects, such as finding the optimal location and size of facilities, of hazardous and non-hazardous wastes. In managing and planning the logistical aspects of hazardous waste systems, multiple goals, such as community and environmental control goals, those have different priorities have not to be ignored and have to be properly addressed.

In the late sixties in California, USA, an economic optimization for the system planning of solid waste management was first applied[1]. The issue of increasing environmental concerns and the emphasis on material recycling have gradually changed the focus of solid waste management in the following two decades. Recent research programs into solid waste management system planning frequently emphasize that both socioeconomic and environmental considerations have to be evaluated simultaneously to provide a set of total solutions regarding waste recycling, facilities sitting and systems operation.

The integrated models are based on simplified descriptions of the system and are subject to many limiting assumptions: weak disaggregation of material flows, a processing option of each type, sites dedicated to a particular processing or land filling technology, only one time period, recyclables/organics collections rarely taken into account, poor (or no) description of markets for recyclables, a single waste generating

source, insufficient user's control on the accuracy of the investment cost functions. Gottinger[2] proposed a dynamic network flow model with nonlinear costs for waste management and facility-sitting decisions. Shekdar et al.[3] described a dynamic goal programming model for the management of existing facilities in a waste system. A multi-objective mixed integer programming approach was proposed by Caruso et al.[4] for the study of a regional system over a single time period. An interesting dynamic mixed integer programming model incorporating a large set of technologies and dealing with financial and air pollution constraints was presented by Chang et al.[5]. The preceding model has been transformed into a multi-objective one by Chang and Wang[6]. It takes four different criteria into account, three of them being environmental functions. Revenues from sales to markets are taken into account in the dynamic mixed integer programming model of Baetz and Neebe[7]. The model has a limited choice of technologies and only one new land filling site may be developed. A multi-period and multi-regional model developed by Everett and Modak[8] has some interesting distinguishing features. Amongst them, there is the consideration of aggregated and disaggregated flows of materials and of a number of collection options for the components of the waste stream. The model does not deal with capacity addition. A very detailed static nonlinear programming model, MIMES/WASTE, has been proposed by Sundberg et al.[9] to address municipal and regional waste problems. The main objective of the model is cost minimization but emission control is integrated in the model via explicit restrictions and fees. Recycling and energy production goals may also be imposed. The model of Ljunggren[10] is an extension of MIMES/WASTE to national problems.

The approach of optimal waste minimization in a petroleum refinery was addressed by Takama et al.[11]. Their approach was to reuse and make use of regeneration opportunities. Wang and Smith[12] discussed the minimization of wastewater in the process industries. They pointed out that there are three possibilities for reducing wastewater, reuse, regeneration and regeneration recycling. Fletcher and Johnston[13] and Harries[14] described a waste auditing approach that involves a detailed analysis of a company's processes and wastes aimed at minimizing, a meliorating or even eliminating discharges from unit processes to establish waste management. Duke[15] indicated that waste minimization played a key role in US planning for hazardous waste management. He examined the effectiveness of waste minimization policies and regulations. Extensive pollution prevention

programs in the industrial sectors have been adapted to minimize solid wastes generation[16-20].

Waste minimization can be achieved by elimination of solid and hazardous waste generation through changes in product design and manufacturing technology[21]. Keen[22] addressed new regulations that require a waste minimization program to be in place.

Petroleum waste: The present research is focused on the development and testing of a multi-objective planning model based on the goal programming approach for the proper treatment and disposal of solid wastes generated by Kuwaiti oil and petrochemical industries. All of the oil and petrochemical industries are located at the Shuaiba Industrial Area (SIA) in Kuwait. The SIA is located about 50 km south of Kuwait City. It accommodates most of the large-scale industries in Kuwait. The total area of the SIA (both eastern and western sectors) is about 23 km^2. Fifteen plants are located in the eastern sector and 23 in the western sector, including two petrochemical companies, three refineries, two power plants, a melamine company, an industrial gas corporation, a paper products company and, two steam electricity generating stations, in addition to several other industries. Currently, approximately 70% of the total land area in the SIA's eastern sector is occupied by industrial facilities. Approximately 30% of the total land in the SIA's western sector is also occupied by industrial facilities.

Al-Shammari *et al.*[23] have given a detailed account of total solid waste generated from SIA in year 2006. There are three main categories; thermal, chemical and physical treatment for treatment of solid wastes from the petroleum refining industry. Each of these technologies has some advantages over the others while there are disadvantages associated with all of them. In any industry, to achieve the required criteria for disposal, all wastes must be treated to minimize the impact on the surrounding in order.

Thermal treatment unit operate at very high temperatures, usually 400-2000°C, to breakdown hazardous chemicals. These units are designed to handle specific type(s) of waste to be treated. The final stream could be a less toxic waste aqueous stream which could be further processed to separate the liquid phase from the solid phase. Thermal treatment units usually consist of two sections, the incinerator and the adsorber. The incinerator provides the thermal energy while the absorber removes the contaminants from the flue gas.

There are also non incineration alternatives for thermally treating hazardous wastes. These processes involve oxidation, reduction and/or pyrolysis environments to destroy the organic component of the waste matrix, but generate significantly less flue gases than incineration. Some of the industrially available technologies include: Rotary kiln oxidation, fluidized bed incarnation and Liquid injection incarnation.

Most widely used chemical treatment technology today is Stabilization. Stabilization is generally used to extract leachable metals prior to landfilling. In the refinery solid waste environment, streams that may require stabilization include: contaminated soils and incinerator ash.

Physical treatment technologies employ gravity separation techniques in order to separate the liquid phase from the solid phase in aqueous environments. Some of these processes are capable of capturing some of the fine solid that are in the mixtures.

Solidification can be accomplished by a chemical reaction between the waste and solidifying reagents or by mechanical processes. Contaminant migration is often restricted by decreasing the surface area exposed to leaching and/or by coating the wastes with low-permeability materials. The technologies are not regarded as destructive techniques; rather, they eliminate or impede the mobility of contaminants.

General model: The model is based upon a general hierarchy of waste flowing a source to a thermal treatment plant or a chemical treatment plant or a third party. If a thermal unit is chosen, then the next tier is a chemical unit. Following a chemical unit is a physical processing unit. The hierarchy ends at a landfill which follows a physical treatment unit. This hierarchy is shown in the following Fig. 1.
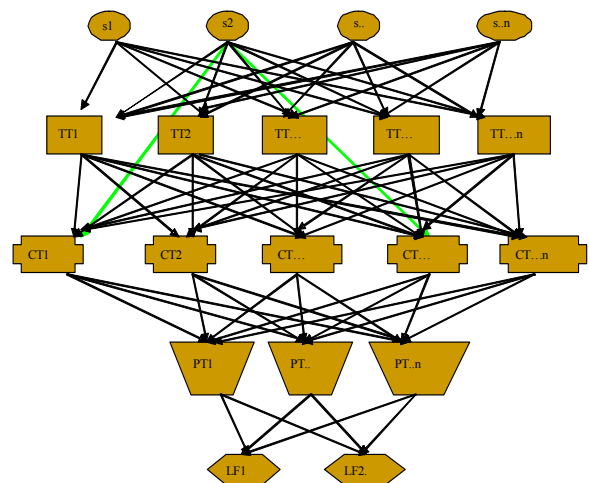

Fig. 1: General model hierarchy

Based on available refinery data a model is developed and tested to minimize the transportation, processing, disposal and capital costs for the management of solid wastes produced from various facilities and having many processing and disposal routes. The objective function that must be minimized is composed of mainly four different sections. The first section is the transportation cost. The cost of transporting waste is given as dollars per mass unit of waste. This cost rate is multiplied by the total amount of waste that is transported would give the cost of transporting the waste. Transportation costs are incurred anytime there is a transfer of waste from one node to the other node. The second section of the objective function is the processing costs. Each facility

that is operating will incur a processing cost. This cost is based upon utilities, man power and other operating costs. Disposal costs are the third section to the objective function. These costs are imposed when one is disposing of waste in a landfill. Third party costs are incurred when a decision is made to exercise a contractual agreement with a third party.

Lastly, capital costs are incurred when a new facility is opened. These costs are incurred only in the case of a new facility. Capital costs are based upon the facility type and capacity of the facility. The overall objective equation is given as follows.

Objective function:

$$\text{Minimize} = z = \underbrace{\sum_{j \in stp \cup s6 \cup s7} \sum_{i \in A} f_{ij} t_{ij} + \sum_{k \in scp} \sum_{i \in q} f_{ik} t_{ik} + \sum_{j \in stp} \sum_{k \in scp} f_{jk} t_{jk} + \sum_{k \in scp} \sum_{m \in spp} f_{km} t_{km} + \sum_{m \in spp} \sum_{l \in sl} f_{ml} t_{ml} + \sum_{l \in sl} \sum_{j \in s7} f_{jl} t_{jl}}_{\text{Transportation costs}}$$

$$+ \underbrace{\sum_{j \in stp} P_j(\sum_{i \in B} f_{ij}) + \sum_{j \in s7} P_j(\sum_{i \in B} f_{ij}) + \sum_{k \in scp} P_k(\sum_{j \in stp} f_{jk} + \sum_{i \in q} f_{ik}) + \sum_{m \in spp} P_m(\sum_{k \in scp} f_{km})}_{\text{Processing costs}}$$

$$+ \underbrace{\sum_{j \in s6} P_j(\sum_{i \in B} f_{ij})}_{\text{Third party treatment costs}}$$

$$+ \underbrace{\sum_{l \in sl} d_l(\sum_{m \in spp} f_{ml} + \sum_{j \in s7} f_{jl}) + \sum_{l \in sl} d_l(\sum_{m \in spp} f_{ml} + \sum_{j \in s7} f_{jl})}_{\text{Disposal costs}}$$

$$\underbrace{\sum_{j \in stp^p \cup s7^p} A_j Y_j + \sum_{k \in scp^p} A_k Y_k + \sum_{m \in spp^p} A_m Y_m + \sum_{l \in slp^p} A_l Y_l}_{\text{Capital costs}} \tag{1}$$

Constraints: The design model is constrained on several parameters. Firstly, each node must satisfy a mass balance equation. This states that all the mass going into a node must equal an efficiency value multiplied by the output.

Material balance on thermal units

$$\sum_{j \in stp \cup s6} f_{ij} t_{ij} = F_i \tag{2}$$

$$\sum_{i \in B} f_{ij} = a_j \sum_{k \in scp} f_{jk} \tag{3}$$

Mass balance on chemical units

$$\sum_{i \in q} f_{ik} + \sum_{j \in stp} f_{jk} = a_k \sum_{m \in spp} f_{km} \tag{4}$$

Mass balance on physical units

$$\sum_{k \in scp} f_{km} = a_m \sum_{l \in sl} f_{ml} \qquad (5)$$

There is also capacity limitation at each of the facilities which must be satisfied. Logic states that once the capacity of a facility is reached, then a decision must be made. First option is to open a new facility to handle the rest of the waste. The second decision is whether to neglect the first facility and just consider another facility.

Landfill capacity constraint

$$\sum_{m \in sl} f_{ml} + \sum_{j \in ss7} f_{jl} \le C_l Y_l \qquad (6)$$

Thermal unit capacity constraint

$$\sum_{i \in B} f_{ij} \le C_j Y_j \qquad (7)$$

Chemical unit capacity constraint

$$\sum_{i \in B} f_{ik} \sum_{j \in stp} f_{jk} \le C_k Y_k \qquad (8)$$

Physical unit capacity constraint

$$\sum_{k \in scp} f_{km} \le C_m Y_m \qquad (9)$$

As an extra limitation, there can only one type of each facility. This constraint was set to in order to achieve a non complex solution. The mathematical formulations of these constraints are as flows:

At most build one thermal treatment unit, $\sum_{j \in stp^p} Y_j \le 1$, one chemical treatment unit, $\sum_{j \in scp^p} Y_k \le 1$, one physical unit, $\sum_{m \in spp^p} Y_m \le 1$ and one landfill unit, $\sum_{l \in sl^p} Y_l \le 1$.

Typical case study: This study deals with refinery waste data where all available technologies and their processing and transportation costs and capital investment are considered. However, this model has an option to analyze fluctuating data that could occur in day to day operation.

The objective in this exercise is to determine the best method of treating these wastes in the most economical fashion. The model explores many possible combination of treatment technologies in order to achieve the required pacification to dispose of these materials.

The effectiveness of each treatment is a factor of the inherent capability of the treatment technology, the size and cost of the equipment. In the treatment hierarchy, twelve possible thermal treatment units have been defined. In addition, the model was asked to consider the possibility of allowing a third party to dispose of some of the waste. The model considered the following technologies:

- Liquid injection (LJ1)
- Fluidized bed process (FB1, FB2, FB3 & FB4)
- Molten glass process (MG1)
- Wet oxidation process (WO1, WO2, WO3 & WO4)
- Rotary kiln (RK1 & RK2)
- Third party treatment (CON)
- Catalyst recovery by high thermal treatment (HTT)

Continuing with the hierarchy, the model explored the best chemical treatment unit from a list that was provided. Similar to the thermal treatment units, the effectiveness of each treatment is a factor of the inherent capability of the treatment technology, the size and cost of the equipment. The following is the list of the considered chemical treatment technologies:

- Organic extraction (OE1)
- Solvent extraction (SE1)

Physical treatment units were the following item on the hierarchy. The following are the list of the considered physical treatment units:

- Encapsulation unit (EN1)
- Stabilization unit (ST1)

Lastly, the model was requested to consider a list of possible landfills and land treatment facilities. There were specific criteria for sending waste to either a landfill or a land treatment. This criterion was a factor of the waste stream and the amount of treatment it has received. The following are the list of the landfills and land treatment available facilities:

- Landfill (LF1 & LF2)
- Land Treatment (LT1)

The model was asked to determine the optimized route from the waste streams to the landfills/land treatment. The model was run using GAMS. The

following figure gives a flow diagram of all possible combination considered.

Solid waste data

F037 (Off-spec Sulfur) = 3,351 t year^{-1}
F038 (Refinery Sludge) = 9,486 t year^{-1}
K048 (Extraction Clay) = 1,900 t year^{-1}
K049 (Alkylation Clay) = 3,540 t year^{-1}
K051 (Lube Oil Processing Clay) = 733 t year^{-1}
K052 (Clay Filtering) = 900 t year^{-1}
Cat (Spent Catalyst) = 3,956.5 t year^{-1}

Capacities and Efficiencies of various units

Thermal units

Units	LJ1	FB1	FB2	FB3	FB4	MG1
Capacity (t year^{-1})	196	795	179	295	45,000	256
Efficiency	75%	94%	94%	94%	94%	92%
Units	WO1	WO2	WO3	WO4	RK1	RK2
Capacity (t year^{-1})	600	100	900	5,400	100	4,820
Efficiency	68%	80%	68%	75%	62%	71%

Contracts

Units	CON
Capacity (t year^{-1})	1,000,000
Efficiency	100%

Chemical units

Units	SE1	OE1
Capacity (t year^{-1})	60,000	1,250
Efficiency	70%	75%

Physical separation units

Units	EN1	ST1
Capacity (t year^{-1})	35,000	50,000
Efficiency	90%	90%

Landfills

Units	LF1	LF2	LT1
Capacity (t year^{-1})	10,000	15,000	100,000

Waste to thermal transportation cost ($/ton)

	LJ1	FB1	FB2	FB3	FB4	MG1
F037	70	71	72	74	197	76
F038	76	79	77	84	177	78
K048	79	73	77	78	95	78
K049	72	75	79	74	79	76
K051	74	72	79	73	90	78
K052	72	77	70	80	81	71
K062	70	79	77	76	70	70

	WO1	WO2	WO3	WO4	RK1	RK2
F037	78	79	87	92	197	182
F038	72	78	66	96	177	72
K048	77	69	86	62	87	69
K049	78	89	87	82	167	174
K051	71	68	81	61	188	181
K052	79	70	61	96	177	62
K062	73	81	86	80	182	64

Waste to high temperature treatment unit transportation cost ($/ton)

	HTT
CAT	88

Waste to chemical transportation cost ($/ton)

	SE1	OE1
K049	89	88
K051	81	82
K052	88	87
K062	87	88

Thermal to chemical transportation cost ($/ton)

	SE1	OE1
LJ1	127	89
FB1	95	122
FB2	121	125
FB3	147	111
FB4	151	114
MG1	120	111
WO1	121	122
WO2	118	114
WO3	98	99
WO4	101	122
RK1	121	134
RK2	99	97

Chemical to physical transportation cost ($/ton)

	EN1	ST1
SE1	121	144
OE1	144	159

Physical to land filling transportation cost ($/ton)

	LF1	LF2	LT1
EN1	100	100	1100
ST1	98	107	150

Catalyst to land filling transportation cost ($/ton)

	LF1	LF2	LT1
HTT	47	99	82

Capital cost for new thermal unit (million $)

Units	LJ1	FB1	FB2	FB3	FB4	MG1
Cost	167	735	106	73	200	75
Units	WO1	WO2	WO3	WO4	RK1	RK2
Cost	620	100	300	300	200	290

Capital cost for new chemical units (million $)

Units	SE1	OE1
Cost	103	100

Capital cost for new physical separation units (million $)

Units	EN1	ST1
Cost	290	125

Capital cost for new landfills (million $)

Units	LF1	LF2	LT1
Cost	125	125	100

Processing cost for thermal unit ($/ton)

Units	LJ1	FB1	FB2	FB3	FB4	MG1
Cost	443	59	718	112	271	972

Units	WO1	WO2	WO3	WO4	RK1	RK2
Cost	309	707	642	119	271	775

Processing cost for chemical units ($/ton)

Units	SE1	OE1
Cost	116	948

Processing cost for physical separation units ($/ton)

Units	EN1	ST1
Cost	320	358

Processing cost for land filling ($/ton)

Units	LF1	LF2	LT1
Cost	225	285	775

Third party processing and disposal cost ($/ton)

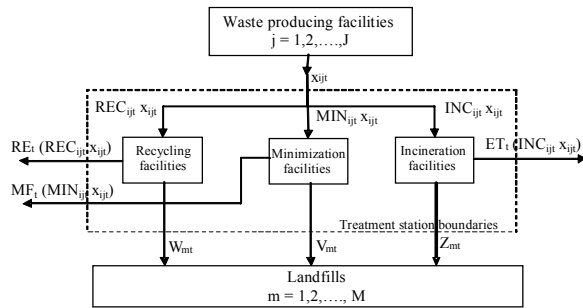| CON	1,000,000

Fig. 2: An integrated solid waste management system for the petroleum/petrochemical industries

The above data are used as input to the developed model and define the problem fully and clearly describe the structure of the refinery waste under study. The flow scheme for this integrated solid waste management system is shown schematically in Fig. 2.

The results of model solution provides the management with information about the extent of solid waste removal from the various sections. The model predicts the optimum route an provide a level of savings in financial resources allocated to run the transportation fleet and operates the solid waste treatment facilities, the extent of facilities utilization, energy production and level of recycling.

RESULTS AND DISCUSSION

In this case 23,866.5 t year^{-1} of various types of solid wastes have to be treated before it could be safely sent to landfill. The first step in treating all the solid wastes is the thermal treatment where various thermal treatment technologies are available to the model namely liquid injection, fluidized bed process, molten
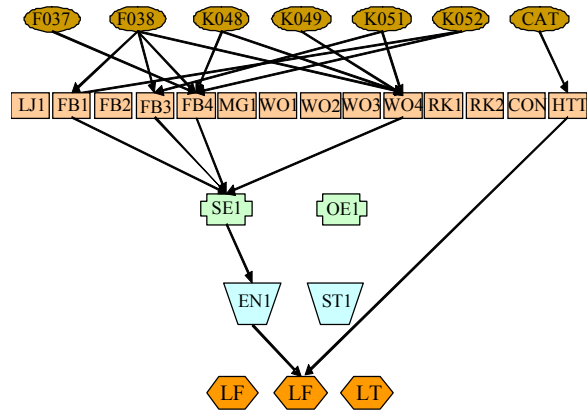
Fig. 3: Optimal Solution for case study

glass process, wet oxidation process and rotary kiln and an option to use third party treatment. However the spent catalyst can only be treated in high temperature treatment process.

From various options the model calculates that fluidized bed process and wet oxidation process are most economical choices. In fluidized bed process FB1, FB3 and FB4 are available for use. The availability of FB2 is subjected to very high processing cost (718 $/ton) compared to other fluidized bed process. Among available four wet oxidation processes only WO4 is used as it has lowest processing cost of 119 $/ton compared to all other wet oxidation processes. However all the catalyst wastes are treated in high thermal treatment process (HTT) as the model has very restrictive option for treating the catalyst waste.

All the waste (3,351 t year^{-1}) from F037 is treated in FB4 where as waste from F038 used four different thermal treatment units. It uses FB1, FB3 and WO4 to its full capacity and the rest is sent to FB4. Therefore, the amounts of wastes from K038 treated in FB1 are 795 t year^{-1}, FB3 is 295 t year^{-1}, WO4 is 5,400 t year^{-1} and FB4 is 2,996 t year^{-1}.

Waste from K048 uses both fluidized bed process and wet oxidation process. Nearly 1,422 t year^{-1} of waste is treated in WO4 and the rest 478 t year^{-1} is treated in FB4. All the waste from K049 (3,540 t year^{-1}) is treated in WO4. For K052, it is more economical to use FB3 process compared to WO4, thus it uses FB3 to its full capacity (295 t year^{-1}) and the rest of the solid waste (438 t year^{-1}) is treated in WO4. Solid wastes from K052 is processed in FB1 and FB4. FB1 is used to its full capacity and processes 795 t year^{-1} of waste and the rest 105 t year^{-1} of waste is processed in FB4.

Total amount of waste fed to thermal processes was 23,866.5 t year^{-1} and is reduced to 17,040.3 t year^{-1} after thermal treatment. For further treatment the processed wastes are sent to chemical treatment section. The model has to choose between either solvent extraction or organic extraction process or both for processing 17,040.3 t year^{-1}. Processing cost of Solvent extraction process is 116 $/ton compared to the processing cost of 948 $/ton for organic extraction process. Although the capital cost and efficiency for organic extraction process is slightly favorable but processing cost plays a major role in deciding the usage of chemical treatment process and hence all the waste is processed in solvent extraction process. In this process 5,112.1 t year^{-1} of waste is rejected and hence 11,928.2 t year^{-1} of waste is send to physical treatment section.

Similar to chemical treatment process all the 11,928.2 t year^{-1} of waste is treated in encapsulation unit as it was found to be slightly more economical compared to stabilization unit. In this process 1,192.8 t year^{-1} of waste is rejected.

Finally the treated 10,735.4 t year^{-1} of waste coming from encapsulation unit and all the catalyst treated in high temperature thermal unit are send to landfill2 as its capacity is high enough to accommodate all the waste. The results of this model (Fig. 3) proves that it can be used to address many of the waste treatment and disposal problems and issues associated with the management of solid waste systems such as the need for solid waste removal from the various petrochemical plants, the efficient utilization of facilities, systems cost control and the control of environmental pollution.

The use of the model has been demonstrated, through this real problem, by showing how it can be utilized to assist in the management of solid waste generated by a petroleum industry. The results obtained show that the model is a viable tool and can be used to assist in making appropriate decisions regarding the management of solid waste.

CONCLUSION

The present model provides the most cost effective petroleum waste disposal details based on the choice of treatment processes, their capacities and appropriate routing of waste streams from a local oil refineries in Gulf State.

The multi-objective optimization model based on goal programming approach provides the efficient use of all available waste treatment units based on the control of environmental pollution and the most cost effective management strategies for the selected petroleum industrial complex.

The available data from typical petroleum refinery with all the accessible waste management facilities, the application of model provides the most efficient intermediate handling units, fluidized bed processes and wet oxidation process, which make the waste management highly cost effective. API separator waste can either be treated in solvent extraction unit or organic extraction unit but extraction unit is preferred based on space velocity/residence time. For a known waste quantity, the capacity and operation time is used to gauge the cost effectiveness for this chemical treatment process. In physical treatment process, the model provides the optimum use of the encapsulation unit with high cost stabilization unit to satisfy all the defined constraints in the industrial waste management exercise. The computed results are in concordance with other published refineries waste management results validating the application of the present model. This can be concluded that the present model is a viable tool and can be efficiently applied to solid waste from petroleum industries. The model output can be used to assist in making appropriate decisions regarding the petroleum industries solid waste management (minimization, processing, landfill etc.).

REFERENCES

1. Anderson, L.E., 1968. A mathematical model for the optimization of a waste management system. Sanitary Engineering Research Laboratory, SERL Report, No. 68-1. Berkeley: University of California.
2. Gottinger, H.W., 1991. Economic Models and Applications of Solid Waste Management, Gordon and Breach Science Publishers, New York.
3. Shekdar, A.V., K.N. Krishnaswamy, V.G. Tikekar and A.D. Bhide, 1992. Indian urban solid waste management systems-jaded systems in need of resource augmentation. Waste Manage., 12: 379-387.
4. Caruso, C., A. Colorni and M. Paruccini, 1993. The regional urban solid waste management system: A Modelling Approach. Eur. J. Operat. Res., 70 (1): 16-30.
5. Chang, N.B., R.E. Schuler and C.A. Shoemaker, 1993. Environmental and economic optimization of an integrated solid waste management system. J. Resource Manage. Technol., 21 (2): 87-100.

6. Chang, N.-B. and S.F. Wang, 1996. Solid waste management system analysis by multiobjective mixed integer programming model. J. Environ. Manage., 48 (1): 17-43.
7. Baetz, B.W. and A.W. Neebe, 1994. A planning model for the development of waste material recycling programmes. J. Operat. Res. Soc., 45 (12): 1374-1384.
8. Everett, J.W. and A.R. Modak, 1996. Optimal regional scheduling of solid waste systems. I: Model Development. J. Environ. Eng., 122 (9): 785-792.
9. Sundberg, J., P. Gipperth and C.O. Wene, 1994. A systems approach to municipal solid waste management: A Pilot Study of Göteborg. Waste Manage. Res., 12 (1): 73-91.
10. Ljunggren, M., 1997. A systems engineering approach to national solid waste management. Thesis for the Degree of Licentiate of Engineering, Energy Systems Technology Division, Chalmers University of Technology, Göteborg, Sweden.
11. Takama, N., Y. Kuriyam, K. Shiroko and T. Umeda, 1980. Optimal water allocation in a petroleum refinery. Comp. Chem. Eng., 4, 251-258.
12. Wang, Y.P. and R. Smith, 1994. Wastewater minimization. Chem. Eng. Sci., 1, 49 (7): 981-1006.
13. Fletcher, G.A. and Johnston, N. 1993. The Aire and Calder project: A regional waste minimization club. Institution of Chemical Engineers Symposium Series, 132: 67-79.
14. Harries, R.C. 1993. Waste auditing and minimization: Practical procedures and case studies. Institution of Chemical Engineers Symposium Series, 132: 41-54.
15. Duke, L.D. 1994. Hazardous waste minimization: Is taking root in U.S. industry. Waste Manage., 14 (l): 49-59.
16. Parr, J., 1994. Waste minimization opportunities for the electroplating industry: A case study. M. Sc. Thesis, University of Nebraska-Lincoln.
17. Dahab, M.F., 1995. The role of cooperative extension in industrial pollution prevention. Water Environment Federation Digest Series, Water Environment Federation, USA, 30-38.
18. Dahab, M.F. and D. Montag, 1993. Waste minimization in a metal finishing industry: A pilot project. Presented at the 3rd International Conference on Waste Management in the Chemical and Petrochemical Industries, Salvador-Bahia, Brazil, October 20-23.
19. Montag, D., 1993. Pollution Prevention in the Metal Finishing Industry. M. Sc. Thesis, University of Nebraska-Lincoln.
20. El-Nawawy, A., K. Puskas, A. Eliman, D. Al-Bakri and M. Allam, 1986. Solid waste management program for the enlarged Shuaiba Industrial Areas. Kuwait Institute for Scientific Research, Report No. KISR 2061, Kuwait.
21. Dickens, P.S., 1995. Waste elimination challenge of the 1990s, Water Environment Federation Digest Series, Water Environment Federation, USA, 92-103.
22. Keen, A.R., 1995. Total wastewater treatment and reuse by close looping. Water Environment Federation Digest Series, Water Federation, USA, 148-152.
23. Al-Shammari, J.S., F.K. Gad, A.A.M. Elgibaly and A.R. Khan, 2008. Solid Waste Management in Petroleum Refineries. Am. J. Environ. Sci. (In press).