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Study of energy recovery and power generation from alternative energy source

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ABSTRACT

The energy requirement pattern of world is growing up and developing technology. The available sources, while exhausting and not friendly to the environment, are highly used. Looking at partial supply and different options of environment problems associated with usage, renewable energy sources are getting attention. MSW (Municipal solid waste) composition data had been collected from 1997 to 2009, in Benghazi Libya, to evaluate the waste enthalpy. An incinerator with capacity of 47,250 kg/h was confirmed to burn all the quantity of waste generated by the city through the next 15 years. Initial study was performed to investigate energy flow and resource availability to insure sustainable MSW required by the incinerator to work at its maximum capacity during the designated period. The primary purpose of the paper is to discuss the design of Rankin steam cycle for the generation of both power (PG) and combined heat power (CHP). In the power generation case, the system was found to be able to generate electrical power of 13.1 MW. Including the combined heat power case, the results showed that the system was able to produce 6.8 million m^3/year of desalinated water and generate 11.33 MW of electricity. In conclusion, the CHP designed system has the greatest potential to maximize energy saving, due to the optimal combination of heat production and electricity generation.
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1. Introduction

MSW (Municipal solid waste) contain methane is considered a potential source of clean renewable energy. Studies of energy and waste management are, deserve special attention, due to the constraints arising from limited availability of land, resources and pollution [1,2].

Today, the world's population generates enormous amount of waste. Whether we live in industrialized countries or developing countries, in big or in small cities, or whether we are rich or poor, we all produce waste, for decades, industrial countries (ICs) have lived beyond these resources. Yesterday's belief that all resources were eternal has now changed. Waste minimization is a key concept in ICs. The amount of waste produced is dependent on the country, type of urban district, population, city size, culture, style of life and of course income. Selective sorting from MSW (municipal solid waste) or recycling and recovering materials is generally a difficult task in small isolated systems. Moreover, the alternative energy sources and the price of primary energy transportation are very expansive due to limited markets there. Consequently, the

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policies are recommended to use of local energy sources, to be exact incineration of MSW with energy recovery and carbon dioxide emission mitigation [3].

Thermal technology has been applied for a long time to shrink the volume of MSW. in addition, to recovery the incineration of energy, to generate heat and/or electricity [4]. The main objective of an incineration plant is decreasing of MSW. The energy recovery is working out for sustainability of energy with the optimum costs as fundamentals on it. Therefore, it should not compare with the energy generation from fossil fuels.

The air pollution is one of the significant sides to the MSW incineration project. In fact, we can reduce the methane emission from landfills and fossil fuels as a result of using energy recovery [5]. The amount of energy recovery as achieved depended on MSW ratio of biogenic to fossil carbon and on the energy transformation efficiency. The MSW has relationship with a human activity and renewable resource, it is a potential source of significant materials and energy [6]. As an importance, the waste characteristics for generation rate and composition have been researched to assist the decision maker's design environmental model for waste policies to give more appropriate technological solutions [7].

This study aimed to discuss the benefits of MSW incineration with energy recovery possibly will bring to big city, Benghazi, Libya. This study determines the MSW incineration as an alternative source of energy for power generation. First of all, the waste components were estimated and its low heat value determined, to evaluate the total heat potential. Second, the analysis of the incineration process was carried out, to appraise the potential of the energy recovered for thermal water treatment and electricity generation. Technologies to convert biomass to energy come under two categories [7]:

1. Biological process:
   [a] Anaerobic digestion
   [b] Fermentation
2. Thermo chemical process:
   [a] Combustion
   [b] Pyrolysis
   [c] Gasification
   [d] Liquefaction.

2. Case study background

The MSW is management problems that are made worse by its specific distinctiveness. In contrast, those same extreme characteristics put together Benghazi for the most part interesting case study. In nature, Benghazi is located in the north-eastern of Libya at coordinates (32°07′N 20°04′E) with an area of 314 km^2, it is on the Mediterranean Sea at Gulf of Sidra in the north of Africa. Benghazi is the second largest city in Libya, dominating the eastern Cyrenaica region, and is the capital of the district of Benghazi. (Fig. 1a and b). Mild winters (5–18 °C) and dry, hot summers (23–36 °C), typical of the Mediterranean climate, define the weather in Benghazi-Libya [8].

According to the Libya National Statistics Office 2009 projections, the Benghazi has 631,555 inhabitants, leading to the highest population density in the other Libyan cities, 2000 inhabitants per square kilometer. Electric energy is generated by two power plants, fueled by imported fossil fuels and natural gas. As a significant, the power plant stations have a high effect in the global carbon dioxide emissions and in the economy. Economy raise electricity consumption, mainly through the use of air conditioning systems and electrical heating appliances, while there is no central heating system; it is most important key for the grid overload. At this time, the government plans to enhance the renewable sources part of the energy

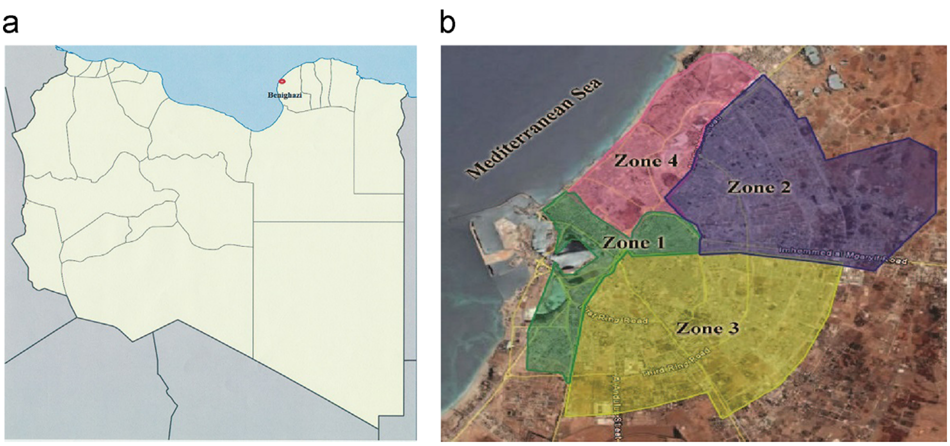

Fig. 1. (a) Geographical location of Benghazi-Libya [8]. (b) Zone location of Benghazi Libya [9].
Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels.

combination, but it is highly restricted by a number of factors. On the other hand, even the off-shore projects face environmental restriction problems.

Water supply in Benghazi-Libya is strongly dependent on south of Libya, as rainfall is rather low, approximately 400 mm/year [9]. Due to that the government spent a lot of money to transfer water from south to north of Libya. This makes the power plants the largest energy users in the country. Furthermore, the MSW management should be having a well-organized collection process, the system is limited by the high quantity of waste generated per capita. The average amount of MSW generated in Benghazi was between the ranges 0.95 kg/person/day, which is almost equal to the national average (1.1 kg per person per day) [9].Indeed, Benghazi has close the same amount of waste collected per capita/day as the some Libyan cities and some of world cities instances; Bani Walid City (Libya), Tripoli City (Libya), Penang State (Malaysia), Tehran (Iran), Santiago de Cuba (Cuba), Beijing & Shenzhen (China), Gümüşhane (Turkey) the amount of waste collected per capita/day for mentioned cities are 0.89, 1, 0.9–1.1, 0.88, 0.86, 1.21, and 1 respectively[10]. There are many cities in other countries produce lower amounts of MSW per capita than Benghazi. The facts mentioned above and up to date Benghazi Libya government projects to make an incineration plant forced this study, based on current MSW data as well as thermodynamic and combustion idea on incineration with energy recovery.

3. Analysis procedure

The flow chart shown in Fig. 2 illustrates the procedure of MSW generation and management chain of a city waste. Also, the flow chart showed the procedure from the MSW analysis to the energy analysis. It is clear from the scheme that it is necessary to know the average Benghazi-Libya MSW components one by one to distinction the efficiency of waste separation as a group. In addition, those components are required to study the incineration process, for the reason that it is used as an input in the heat recovery calculation.

3.1. MSW analysis

The Benghazi-Libya MSW analysis includes data from household, hotels and restaurants waste, as well as commercial and industrial waste. The data was collected from Libyan Authority Statistics Office (LASO) 2006 surveys. The waste from the commercial and industrial streams was determined using literature data on the composition of the same streams in similar countries, like Bani Walid City (Libya), Tripoli City (Libya), Penang State (Malaysia), Tehran (Iran), Santiago de Cuba (Cuba), Beijing & Shenzhen (China) and Gumuşhane (Turkey) [10]. Fig. 3a illustrates the Benghazi-Libya MSW. Moreover, the final MSW composition determinant about 85% of the total waste generated between 2003 and 2006 from household solid waste [9]. The largest MSW fraction in the survey discovered is organic waste (food) as illustrated in Fig. 3a [9].

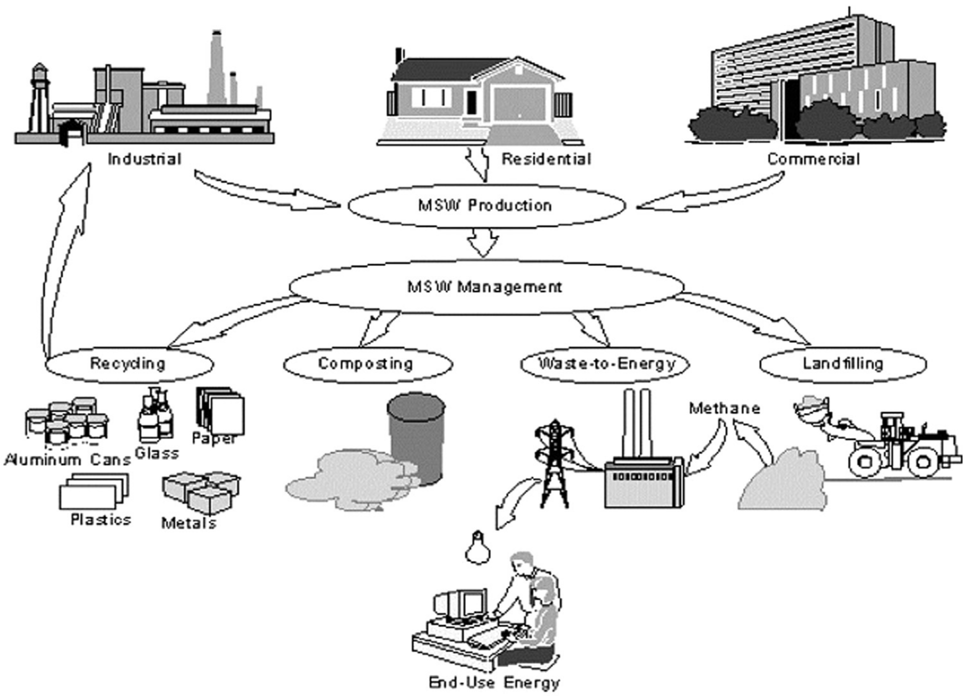

Fig. 2. MSW generation and management chain [7].

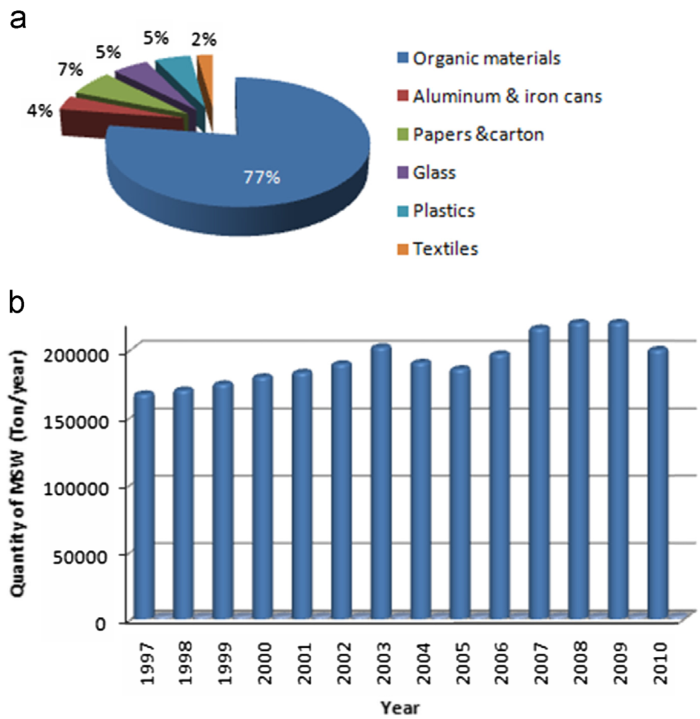

Fig. 3. (a) Physical compositions and quantities in tones of MSW collected in Benghazi City. (b) Historical Benghazi-Libya MSW generation [12].

The forecast of the waste to be generated in future years is important to establish the capacity of any incineration plant. Since, no studies did forecasting to progression of the Benghazi-Libya MSW. In other hand, the quantity of waste generated in 2010 it was 200×10^6 kg. Therefore, the future MSW generation could be predicted by using that data. The yearly operation time of the incinerator based on values supplied by the energy plant agency was projected to be 8000 h. In view of the 2010 MSW data, this leads to a 25,000 kg/h capacity. For an unexpected variety of capacity add 5% from the amount of capacity for safety coverage [11], the amount of MSW burned become 26,250 kg/h. Fig. 3b shows the historical MSW data generation between 1997 and 2009.

The last idea was established using the MSW generated per capita, an indicator normally applied to support expectations estimations. These data were taken from the Benghazi-Libya population (growth rate 4.85%) [12], the expected population peak at 1,091,011 inhabitants in 2025. The yearly MSW generation estimated gets to a in the 15 years is 378×10^6 kg or 47,250 kg/h, for 8000 h of operation/year. However, we can conclude that the 47,250 kg/h capacity got to use till 2025. The maximum amount of MSW generated up to 2025 will be used for next calculation.

3.2. Incineration and energy saving

This analysis conceder to the incineration process, estimating the chimney gas and the air supplies temperature required to achieve complete burning. All data from the literature were used on the cumulative burden imposed by the EU Directives. The mass burn technology was consider, that is the firing technology, useful for the solids till completely burnout. Low level processing of MSW is required for this technology.

The principles of energy and mass conservation applied to the MSW characteristics were utilized to find the output volume of chimney gas generated, the heat generated, and the input air. The MSW incineration analysis considers the complete combustion of the three basic elements—sulfur (S), carbon (C) and hydrogen (H) [13]. Therefore, with elemental compositions and typical physical from the literature [14] the calculations begin by estimating the stoichiometric oxygen that feeds the combustion chamber.

In addition, the European Incineration Directive [15] in subsequent requirements measured the temperature of the chimney gas to be retained in the range of (850–1050) °C to keep away from dioxins formation [6,14,16]. Moreover, the flue gas and oxygen volumetric ratio must be $\geq$ 6% [13]. Now, by using Eq. (1) [13] are easy to evaluate the chimney gas volume (V_{fg}) and excess air (e). The MSW and air are not oxidized the nitrogen as a result released in the molecular form

$$V_{fg} = V_{CO_2} + V_{H_2O} + V_{SO_2} + V_{N_2,MSW} + [0.79V_{air,theo}(1+e) + 0.21eV_{air,theo}] \quad (1)$$

where V_{CO_2}, V_{H_2O}, V_{SO_2}, $V_{N_2,MSW}$ $V_{air,theo}$, and $V_{air,theo}$ are volume of carbon dioxide (m^3), volume of water (m^3), volume of sulfur dioxide (m^3), nitrogen content in the MSW (m^3), and theoretical volume of air (m^3) respectively. The heat released in the combustion LHV is caused by the variation of the chimney gas enthalpy ($\sum \Delta H_{fg}$) which can be represented by Eq. (2)

Table 1
The chimney gas temperature process analysis.

Excess of air (e), (%)	Oxygen in the chimney gas, (V_{CO_2}/V_{fg}) (%)	Temperature, T (°C)	Enthalpy variation, $-\Delta H$ (kJ/kg)
51.2	6.0	1045.2	8432.5
58.4	6.5	1021.8	8432.5
65.7	7.0	1000.4	8432.5
72.9	7.5	9986.7	8432.5

and the energy balance in the incinerator [13]

$$\sum \Delta H_{fg} = \Delta H_{O_2} + \Delta H_{N_2} + \Delta H_{H_2O} + \Delta H_{CO_2} + \Delta H_{SO_2}$$
$$= \text{LHV} \times \dot{m}_{\text{MSW}} - \xi \text{LHV} \times \dot{m}_{\text{MSW}}$$
$$= \text{LHV} \times \dot{m}_{\text{MSW}}(1-\xi) \quad (2)$$

where ΔH_{O_2}, ΔH_{N_2}, ΔH_{H_2O}, ΔH_{CO_2}, ΔH_{SO_2}, LHV, $\dot{m}_{\text{MSW}}$, ξ, and LHV are enthalpy of O_2 in chimney gas (kJ/s), enthalpy of N_2 in chimney gas (kJ/s), enthalpy of H_2O in chimney gas (kJ/s), enthalpy of CO_2 in chimney gas (kJ/s), enthalpy of SO_2 in chimney gas (kJ/s), energy lost as a function of the total released, and MSW low heat value (kJ/kg), respectively. Then, the relationship between C_p and temperature is a third degree polynomial [6], which is used to calculate the final the chimney gas temperature, by using the EXCEL Solver to solve Equation (2) [17]. There are many try and error iterations to find the water energy gained to cooling (boiler). If take the average annual temperature is18 °C in Benghazi-Libya and an incinerator mass of MSW flow capacity is 47.25 × 103 kg/h, it is doable to calculate the quantity of raw material or information processed of mass and number of moles/h for every main elements, the amount of Throughput Mass, Total moisture (H_2O), Total carbon (C), Total hydrogen (H_2), Total oxygen (O_2), Total nitrogen (N_2), Total sulfur (S), and the Ash are 118 kg/h, 15.10, 9.25, 1.81, 6.38, 0.37, 0.06, and 6.73 respectively.

The chimney gas temperature process analysis determined for four different values of excess air (e) as illustrated in Table 1. Also, estimated the total energy released from the combustion for the enthalpy variant in the calculations that 90%, the10% left behind is heat losses [6,16]. Moreover, the excess of theoretical air satisfies all earlier mention criteria, it can be get 52.78% even if still maximize the potential for energy recovery.

The heat generated by burning of the MSW must be used in a steam cycle with the option power generation, heat or make both for a combination system. However, to prevent problems with wet steam in power or combined heat and power (CHP) plants usually use the Rankine cycle. Then, by applying second law thermodynamic and the isentropic efficiency for determine the real electrical and thermal power. Furthermore, the pressure drops in the boiler and in the condenser suppose negligible and possibly will be ignored in the computations. The conditions for inlet and outlet are (4.0 MPa; 440 °C), (0.01 MPa; 45.8 °C) respectively of the steam condensing turbine to determine the potential for power generation. By estimate the steam mass flow rate as the first step; after that, determine the shaft work. The converter efficiency is computed when transfer mechanical energy to electrical and electric consumption power on site by using the developed formulas Zsigraiova [6] and Mastro [13].

4. Results and discussion

the result of the Steam flow rate, electrical power generation, turbo-alternator efficiency, Electric power consumed in site, Overall plant efficiency, net electrical power, and Mechanical energy are 67.32 × 103 kg/h, 15.72 MW, 95%, 2.97 MW, 23.47%, 13.10 MW, and 15.98 MW respectively. The overall plant efficiency is calculated in order to emphasize the remaining thermal energy that is eliminated in the condenser.

The energy generated by incineration can lead to decrease the quantity of oil consumed in power plants at Benghazi-Libya. On the other hand, the heat recovered could be used for thermal desalinate seawater, by way of multi-effect distillation (MED) and decrease capital cost. MED, lesser electrical consumption and lower operation temperature compare with the multi stage flash (MSF) technology.

The thermal gain output ratio (GOR) calculation has a typical consumed rate of 12 kg of distillate per kilogram of steam was used [18]. This study regard as the minimum steam needed and the resting on GOR rate for the process of the plant, according to the quantity of water is treated if all thermal energy generated was used in a low temperature MED plant. A simple steam condensing cycle operating at 0.035 MPa and 72.68 °C was considered, to get the requirements.

In addition, the current RO plants is consumed 4.77 kWh/m^3 as the actual average energy for each cubic meter of water desalinated and it is become 2 kWh/m^3 in this MED plant. Subsequently, the efficiency of the Benghazi electrical power plants (32%), it is achievable to determine this technology decrease oil consumption to roughly 0.75 L/m^3 of treated water [19]. Furthermore, By using this system we can save amount of fuel oil as 3.86 barrels per hour, for roughly 6.5 million m^3 of water desalinated per year treated in a thermal plant. On the other hand, the steam is mainly used for power generation by high quality of energy to produce shaft work in the combined system, and the residual thermal energy is useful in heating processes like MED desalination. However, the steam extraction feeds the MED system and the sub-cooled steam remaining

Table 2

Property	(4 MPa)	Units
(a) Backpressure turbine and MED.		
Volume of water desalinated	6885.8	10^3 m^3/yr
Gain output ratio	12.0	kg_{dist}/kg_{steam}
Thermal energy available	43.1	MW
Mechanical energy	14.14	MW
Turbo-alternator efficiency	95.0	%
Electric power consumed in the plant	2.97	MW
Electric power produced	14.3	MW
Primary energy savings	23.6	%
Net electric power	11.33	MW
(b) Steam extraction turbine and MED.		
Property	$\dot{m}_{ST,ext} = 75\% \times \dot{m}_{ST}$ (4 MPa)	Units
Volume of water desalinated	4489.4	10^3 m^3/yr
Thermal energy available	31.2	MW
Mechanical energy	14.3	MW
Turbo-alternator efficiency	95	%
Electric power consumed	2.97	MW
Electric power produced	14.6	MW
Primary energy savings	15.4	%
Net electric power	11.63	MW

in the turbine is condensed, in the case of a condensing turbine. In the earlier case, the estimation of the flow rate of water treated and the electrical power go behind the same procedure refer to earlier than for the steam condensing turbine [6,13].

The quantity of energy savings supplied by cogeneration was estimated using the so-called primary energy savings (PES) [20]. The fuel energy saved by using a CHP plant compared to the energy required running one by one the heating plant and the power plant with the aim of the cogeneration facility replaces [6]. Sum up the results achieved for both the backpressure and the condensing turbine plant configurations in the Table 2a and b.

The validation for combination of the backpressure turbine and MED system can save about 22.1 barrels of fuel oil per hour if 6.8 million m^3 of water were treated per year by the MED system as an alternative of the RO system. For the condensing turbine with steam extraction, these numbers will be 22.8 barrels per hour and about 4.4 million m^3 per year, respectively. The MSW generated in Benghazi-Libya could provide a significant involvement to mitigate with energy problem for three scenarios in this study. To raise the electrical supply or to power the installed RO plants contribute to important principal energy savings use condensing turbine for electrical power generation [21].

Benghazi-Libya consumed about 19.7 × 106 m^3/year, so if used in a MED plant then about 34% of the total potable water could be generated. Furthermore, this result can express limitation to installed RO system to desalinate seawater. Generate electrical power and to desalinate seawater at the same time by CHP plants represent the best model. The potable water created by the thermal method can assist to get together the water demand, without raising the electrical using up, and the plant improve the Benghazi-Libya electrical energy provide. Moreover, the installation of the condensing turbine with steam extraction is ensuring a higher electrical power production.

5. Conclusion

This article discusses to propose an alternative energy for Benghazi-Libya city by using local resources of MSW. The MSW incineration system will be built in Benghazi-Libya with an electrical power plant, and seawater desalination system. On the other hand, the CHP plant provides the energy necessary to desalinate all the water usage in that year or electricity to power the city. Energy savings analysis was conducted to evaluate the effect of the CHP system on energy consumption. Consequently, the generated of the energy by the MSW burning can be a decrease of the fuel oil energy, even if the fuel oil consumption is too small. The CHP plant is the best method to save fuel. The MED plant can satisfy the increased water demand that occurs in Benghazi-Libya in future. To sum up, the incineration plant give Benghazi-Libya opportunity to save fossil fuel usage, raise the energy provided, and GHG emissions mitigation. CHP with back-pressure steam turbines can desalinate 18,865 m^3/d of sea water with MED with an additional power production of 11.33 MW, and for the case, potential electric power of 13.10 MW (PG).

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References

[1] Udomsri S, Petrov MP, Martin AR, Fransson TH. Clean energy conversion from municipal solid waste and climate change mitigation in Thailand: waste management and thermodynamic evaluation. Energy Sustain Dev 2011;15:355–64.
[2] Chiemchaisri C, Juanga JP, Visvanathan C. Municipal solid waste management in Thailand and disposal emission inventory. Environ Monit Assess 2007;135(1–3):13–20.
[3] Kaosol T. Sustainable solutions for municipal solid waste management in Thailand. World Acad Sci Eng Technol 2009;60:534–9.
[4] Korobitsyn MA, Jellema P, Hirs GG. Possibilities for gas turbine and waste incinerator integration. Energy 1999;24(9):783–93.
[5] Otoma S, Mori Y, Terazono A, Aso T, Sameshima R. Estimation of energy recovery and reduction of CO_2 emissions in municipal solid waste power generation. Resour Conserv Recycl 1997;20(2):95–117.
[6] Zsigraiova Z, Tavares G, Semiao V, Carvalho MG. Integrated waste-to-energy conversion and waste transportation. Energy 2009;34:623e35.
[7] Jain S, Sharma M. Power generation from MSW of Haridwar city: a feasibility study. Renew Sustain Energy Rev 2011;15:69–90.
[8] 〈http://en.wikipedia.org/wiki/Benghazi〉, 2011.
[9] Gebril1 A, Omran A, Pakir A, Abdul Aziz H. Municipal solid waste management in Benghazi (Libya): current practices and challenges. Environ Eng Manag J 2010;9:1289–96.
[10] Abdelnaser O, Alsadey S, Gavrilescu M. Municipal solid waste management in Bani Walid City, Libya: practices and challenges. J Environ Manag Tour 2011;2(4):227–37.
[11] Rand T, Haukohl J, Marxen U. Municipal solid waste incineration. Requirements for successful projects. The international bank for reconstruction and development. Washington, U.S.A: Library of Congress Cataloging in Publication data; 2000. Technical Paper No. 462.0-8213-4668-7.
[12] EGA, (2008), Information on solid waste management issues in Benghazi city, Libya. Environmental General of Agency, On line at: 〈http://www.environment.org.ly/index_en.htm〉.
[13] Lo Mastro F, Mistretta M. Cogeneration from thermal treatment of selected municipal wastes. A stoichiometry model building for the case study of Palermo. Waste Manag 2004;24:309–17.
[14] Meraz L, Domínguez A, Kornhauser I, Rojas F. A thermochemical conceptbased equation to estimate waste combustion enthalpy from elemental composition. Fuel 2003;82:1449–507.
[15] Directive 2000/76/EC of the European Parliament and of the Council of 4 December 2000 on the incineration of waste.
[16] Budzianowski WM. Experimental and numerical study of recuperative heat recirculation. Heat Transf Eng 2012;33(8):712–21.
[17] Ferreira EC, Salcedo R. Can spreadsheet solvers solve demanding optimization problems? Comput Appl Eng Educ 2001;9:49–56.
[18] Rousseau RMF, Ronald W. Balance in reactive process.Elementary principles of chemical processes. 3rd ed. Danvers, MA, USA: John Wiley & Sons; 2005.
[19] Aqua Swiss. MED—Multi effect distillation. Economical and technological advantages over MSF and multi stage flash; 2010 [accessed May 2012], 〈http://www.aquaswiss.eu/images/solutions/whitepaper.pdf〉.
[20] Directive 2004/8/EC of the European Parliament and of the Council of 11 February 2004 on the promotion of cogeneration based on a useful heat demand in the internal energy market.
[21] Noor Z, Yusuf R, Abba A, Mohd Din M. Overview for energy recovery from municipal solid wastes (MSW) in Malaysia scenario. Renew Sustain Energy Rev 2013;20:378–84.