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A Theoretical Calculation of Electrical Energy Production from the Incineration of Baghdad Municipal Solid Wastes

Ahmed H. Hadi[1]*, Basim A. Hussain[2], Ahmed A. Khalaf[3], Abdullah F. Abdurazak[4]

[1]Directorate of Treatment and Disposal of Hazardous Wastes, Baghdad, Iraq
[2]Directorate of Environment, Water and Sustainable Energy, Baghdad, Iraq
[3]Ministry of Electricity, Baghdad, Iraq
[4]Energy Engineer, Baghdad, Iraq
Ahmed_nu9@yahoo.com[1], Basimsaidi@hotmail.com[2], Eng.jubouri@gmail.com[3], Abdullah.clash12082000@gmail.com[4]

ABSTRACT

A theoretical investigation study was carried out to determine the requirements of establishing a steam power plant by incinerating municipal solid wastes generated from the city of Baghdad. Survey data the generated quantities of municipal solid wastes from both Al-Karth and Al-Rusafa sectors of the city were utilized to predict the theoretical possible energy production that can be obtained from the incineration of this waste under controlled parameters. Results reviled that the high heating value of Baghdad's municipal solid wastes is of about (12.789 MJ/kg) and the possible electrical energy production in the steam power plants in Al-Karth and Al-Rusafa are (119.287 MW, 203.917 MW) respectively using a steam turbine of efficiency (25%). Resulted emissions of CO_2 gases are estimated to be 4209.995 ton/day. So the emission of CO_2 is the main problem of this method because of its effect on global warming but it is less effect on environment from Methane, Sulphur Oxides and Nitrogen Oxides. The quantity of plastic wastes in Municipal Solid Wastes is important in increasing their average high heating value.

Keywords: Waste to energy, Incineration, Baghdad city, Municipal solid wastes, Steam cycle.

*Corresponding author
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حساب نظري لانتاج الطاقة الكهربائية من حرق النفايات الصلبة لبلدية بغداد

أحمد حسن هادي[1]*, باسم عبد الستار حسين[2], أحمد عبد الله خلف[3], عبد الله فاضل عبد الرزاق[4]

[1] دائرة معالجة واتلاف المخلفات الخطرة, بغداد, العراق.

[2] دائرة البيئة والمياه والطاقات المتجددة, بغداد, العراق.

[3] وزارة الكهرباء, بغداد, العراق.

[4]مهندس طاقة, بغداد, العراق.

الخلاصة

تم إجراء دراسة استقصائية نظرية لتحديد متطلبات إنشاء محطة كهرباء بخارية عن طريق حرق النفايات البلدية الصلبة المتولدة من مدينة بغداد. تم استخدام بيانات المسح المتعلقة بالكميات المتولدة من النفايات الصلبة البلدية من قطاعي الكرخ والرصافة في المدينة للتنبؤ بإنتاج الطاقة النظرية الممكنة التي يمكن الحصول عليها من حرق هذه النفايات تحت تدابير محددة . أظهرت النتائج أن القيمة الحرارية العليا للنفايات الصلبة البلدية في بغداد تبلغ حوالي (12.789 ميجا جول / كغ) وأن الطاقة الكهربائية المحتملة لإنتاج الطاقة البخارية في محطتي للكرخ والرصافة هي (119.287 ميغاواط ، 203.9175 ميغاواط) على التوالي باستخدام كفاءة التوربينات البخارية (25٪). تقدر انبعاثات غازات ثاني أكسيد الكربون الناتجة بحوالي 4209.995 طن / يوم. أن انبعاث غاز ثاني اوكسيد الكاربون هو المشكلة الرئيسية لهذه الطريقة بسبب تاثيره على الاحتباس الحراري العالمي ولكنه اقل تاثيرا على البيئة من غاز الميثان او اكاسيد الكبريت او اكاسيد النتيتروجين. ان كمية المخلفات البلاستيكية في المخلفات البلدية الصلبة لها اهمية في زيادة قيمتها الحرارية العليا.

الكلمات المفتاحية: تحويل المخلفات الى طاقة, الحرق, مدينة بغداد, المخلفات البلدية الصلبة, دورة البخار.

1. INTRODUCTION

Municipal solid wastes (MSW) are considered to be one of the most renewable sources of energy. Millions of tons of (MSW) are generated daily around the world and the quantity is continuously increasing because of human population and activities **(Pluskal et al., 2022; Lozada et al., 2023)**. Waste to Energy (WTE) main principal technology is incineration which can reduce waste volume to less than 10 % and produce electricity and thermal energy **(Gupta and Mishra, 2015; Saha and Singh, 2020)**. Many countries around the world have reached to advanced levels in recycling, reuse and converting wastes to energy such as Sweden, U.S.A., China, Brazil, Turkey, India and many others while Iraq is still too late in WTE technologies **(Ghani and Faleh, 2023)**. There are hundreds of researches that have been conducted around the world to investigate (WTE) possibilities and efficiency. The minimum economic quantity of (MSW) required for steam power plant is estimated to be 240 tons/day **(Luna et al., 2010)**. In research conducted in Brazil, a production of 15.6 MW was obtained from the utilization of 500-ton MSW/day. **(Zaman, 2010)** analyzed using SimaPro software three different treatment technologies which were sanitary landfill, incineration and gasification-pyrolysis using life assessment tool. **(Kapitler et al., 2011)** studied the characteristics of combustion of municipal solid waste as a fuel in waste to energy plant using computational fluid dynamics. **(Yadav and Samadder, 2015)** studied the options of management for municipal solid wastes using life cycle assessment. **(Gupta and Mishra, 2015)** in their study produced 7 MW from 250-ton MSW/day of Indian, Roorkee city solid waste. In another study **(Moora et al., 2017)** determined the biomass content in combusted (MSW) which was 52% and the associated the annual average CO_2 emissions by 429 kg/ ton of combusted MSW in Estonia. The average value for H.H.V. was (9.64 MJ/kg). **(Kim and Jeong, 2017)** studied and analyzed the incineration of flammable industrial wastes according to economic and environmental cost analysis in cement furnace. **(Amountzias et al., 2017)** studied and assessed the findings of U.K. energy markets about waste to energy according to competition and market authority during the period between June 2014 and June 2016. **(Goswami, 2020)** studied the effectiveness of many waste to energy technologies like incineration, landfill, pyrolysis and gasification on municipal solid wastes in India. **(Saha and Singh, 2020)** studied many of WTE technologies as incineration, anaerobic digestion, pyrolysis, gasification and plasma gasification according to the efficiency of conversion and by products materials but they didn't give the cost of electricity production of each technology. **(Kappler et al., 2022)** gave a review of the pyrolysis technology in WTE in Brazil. **(Andreenko et al., 2022)** studied the effects of using grain agricultural waste (straw) as a source of energy in Russia. **(Pluskal et al., 2022)** studied how to choose the optimal location and operation of waste to energy plants. **(Thanh, 2022)** studied the best strategy of WTE for sustainable MSW management in Vietnam. Recently, **(Lozada et al., 2023)** decided that the best WTE technology for food wastes was anaerobic digestion among other WTE technologies.

In Iraq, several studies were conducted in different cities to evaluate MSW generation and possibility for power production, **(Al-Rawi and Al-Tayyar, 2013)** in their study of Mosul MSW found that 1033.6 tons MSW/day were generated from the city with an average generation rate (0.68 kg/ (capita. day)). Meanwhile **(Abbas et al., 2017)** studied the MSW and WTE in Basrah city, and found that 2885.592 tons MSW/day with average generation rate (1.05 kg/ (capita. day)) with high heating value (H.H.V.) 20.25 MJ/kg. The computed electrical energy generated from MSW was 158 MW. Similar to that **(Al-Ameen and Al-Hamdany, 2018)** studied the MSW in Babylon governorate, a value for the average daily rate of MSW generation by this province was estimated to be of 0.802 kg/ (capita. day). In another study (**Musheb, 2018)** the economics of waste recycling in Iraq was investigated and the wasted resources and lost opportunities were evaluated. Also **(Anssari et al., 2020)** research for the WTE in Najaf city was conducted using Homer pro simulation software, the study showed that 1127 tons MSW/day of generated wastes can gave 42.7 MW of net electrical energy. This study was supported by other researchers whom looked into the ways of development for solid waste management in Iraq (**Al-Mohammed et al., 2021**). **(Janna et al., 2021)** computed the high heating value (H.H.V.) for MSW in Al-Diwaniyah city by physical composition; they gave values of (8.655 MJ/kg and 6.44 MJ/kg) for dry and wet H.H.V. respectively. **(Al-Flaiyeh, 2022)** gave a general review about electrical generation from MSW, research findings found that the WTE was still in beginning in Iraq and there were many factories for recycling and sorting wastes in Kurdistan region in Iraq. **(Altai et al., 2022)** studied the problems of electricity in Iraq; they found that 70% of the generated electricity in Iraq was lost in 2013 in commercial, technical and administrative losses. Recently **(Noori and Rasheed, 2023)** studied and evaluated the procurement management of power plants construction projects in Iraq. **(Ghani and Faleh, 2023)** designed an experimental rig for sorting municipal solid wastes depending on the principle of gravity and difference in density between types of wastes and they designed another experimental rig

for anaerobic digestion for food waste to produce methane as a source of thermal energy from wastes at average ambient temperature of (32.55˚C).
Many researchers studied the biomedical solid wastes in Iraq, **(Al-Hashimi and Al-Mandalawi, 2007)** studied the management and treatment of solid wastes (medical and general wastes) for seven of Baghdad hospitals in AL-Rusafa during the period between December 2003 and June 2004. The wastes rate generation varied from (0.3 to 1.6 kg/ (bed. day)). This generation value was based upon several factors such as the hospital specialty, number of beds, number of patients in a day, number of operations in a day and number of employees in hospital. Their results also showed that the moisture content and density for medical wastes was (21%, 219.56 kg/m^3) respectively, yet for general wastes (48%, 298 kg/m^3) respectively. In another waste management study **(Nada, 2019)** presented a case study (using checklist) of development of methods of treatment of medical wastes in the hospitals, so managers can use it to improve the surrounding environment. Moreover **(Al-Nakkash et al., 2019)** defined and assessed the health care waste management (HCWM) system in public and private hospitals and public health centers (PHC) all over Iraq (except three Kurdish provinces). The hazardous solid wastes were found to be (10-25) % from the total medical wastes; they also found that public hospitals generate 500 kg/month; and about 167 kg/month from private hospitals. The study also showed that public health centers generated 83.3 kg/month of solid hazardous wastes. There are 145 public hospitals (with a total of 36347 beds), 73 private hospitals and 1717 public health center. The mean health care solid wastes generating rate per bed was calculated and found ranging from (1.4 to 1.7) kg /(bed. day). **(Mensoor, 2020)** studied the management of medical wastes in ten of Baghdad public hospitals with a total bed capacity of (5241 bed). The results showed that the average generation rate of medical waste in the ten hospitals was 0.5 kg/(bed. day).
The study of (**Khudair et al., 2018**) whom investigated MSW quantity generation in the capital city of Baghdad showed that the city generates over 9813.509 tons /day of waste with an average 3621.95288 tons / day in Al-Karth and 6191.5831 tons/day in Al-Rusafa. The average generation rate per capital was estimated to be of (1.1865 kg/(capita. day)). Those values were adopted in the current research to compute WTE requirements for the city.
The objectives of the current research are to compute (H.H.V.) of MSW for Baghdad city and determine the value of the net electrical energy that can be produced from MSW of Baghdad city for both Al-Karth and Al-Rusafa if steam power plants will be established in Al-Karth and Al-Rusafa. The determination of the quantity of CO_2 emissions from burning the MSW of Baghdad city is important objective of the current research.

2. THEORETICAL ANALYSIS

2.1 High Heating Value (H.H.V.)

The determination of (H.H.V.) for (MSW) is important to compute the net electrical power that can be generated from (MSW). There are two methods to determine (H.H.V.) as in Eq. (1.a) and Eq. (1.b) below **(Abbas et al., 2017; Al-Rawi and Al-Tayyar, 2013),** respectively:

$$H.H.V.\left(\frac{KJ}{Kg}\right) = 337C + 1428\left(H - \frac{O}{8}\right) + 9\,S \tag{1.a}$$

$$H.H.V.\left(\frac{KJ}{Kg}\right) = \left(\frac{\Sigma\, H.H.V.(i)\; m(i)}{\Sigma m(i)}\right) \tag{1.b}$$

In Eq.(1.a), it is required to specify the organic content weight percentage for (C, H, O, and S) **(Gupta and Mishra, 2015; Moora et al., 2017; Janna et al., 2021)**, this method is more accurate but there is no published article to determine (H.H.V.) for MSW for Baghdad city for the best of the author's knowledge. Therefore, in the current research, the computation of (H.H.V.) was computed using Eq. (1.b) depending on data in **Table 1**. It is an approximate method because the component (Food waste) with H.H.V. of (5800 MJ/kg) can be differ from one city to another. In Eq. (1.b), the term of (m(i)/ $\Sigma m(i)$) represents the weight percentage of a certain type of MSW.

Table 1. Solid wastes types and corresponding H.H.V. **(Al-Rawi and Al-Tayyar, 2013; Luna et al., 2010)**

Number	Component	H.H.V. (kJ/kg)
1	Food waste	5800
2	Paper	16300
3	Glass	140
4	Plastic	32800
5	Metal	700
6	Tin cans	-
7	Textiles	17500
8	Wood	18600
9	Rubber	17500
10	Trimmings	6500

Table 2 shows the weight percentage of MSW for Baghdad city see (**JICA, 2022)**, depending on the data of **Table 2** and using Eq. (1.b), the H.H.V. for Baghdad city can be computed (ignoring the mixed term in **Table 2**) and is equal to (12.789 MJ/kg).

Table 2. Solid waste constituents in Baghdad city (**JICA, 2022)**

Number	Component	Weight percent (%)
1	Organic (Food)	42
2	Plastic	21
3	Paper	21
4	Metals	5
5	Glass	5
6	Mixed	6

2.2 The quantity of MSW in Baghdad city

Table 3 illustrates the MSW quantity is listed depending on the results of **(Khudair et al., 2018)**. From this data it can be observed that Al-Rusafa has more MSW than Al-Karth. This is probably because Al-Rusafa district in Baghdad has more population than Al-Karth and there are a many bigger markets in it such as the Shorja and Jamela stck markets. For this reason the average generation rate of MSW for each capita in Al-Rusafa was found to be more than Al-Karth as seen in **Table 3.**

Table 3. Solid wastes quantity in Baghdad city **(Khudair et al., 2018)**

	Average Population	MSW (kg/ (capita. year))	MSW (kg/(capita. day))	MSW (tons/day)
Al-Karth	3483987	379.457	1.0396	3621.925
Al-Rusafa	4774877	473.303	1.2967	6191.58314
Baghdad city	8258864	433.083	1.1865	9813.509029

Table 4. H.H.V. for selected fuel types

Number	Fuel name	H.H.V. (MJ/kg)
1	Gasoline	47
2	Diesel	44.8
3	Coal	32.5
4	Wood	21.7
5	CH_4 (Methane)	55.5
6	Crude oil	42-47

2.3 Computation of Net Electric Power Generation from Wastes (WTE)

The complete combustion of MSW generates thermal energy which can be used to produce pressurized steam at (40 bars that can be used to operate thermal turbine of efficiency (25% is considered in the current research) to produce electrical power based upon the following equations **(Abbas et al., 2017)**:

$$Steam\ energy\ available\ \left(\frac{MJ}{Kg}\right) = \eta\ \ H.H.V. \tag{2}$$

$$Electric\ power\ generation\left(\frac{KWh}{Kg}\right) = \frac{Steam\ energy}{3600} \tag{3}$$

$$Total\ electric\ power\ generation (MW) = Electric\ power\ generation\left(\frac{KWh}{Kg}\right)\ \ M(\frac{Kg}{day}) \left(\frac{1\ day}{24\ h}\right)\ (\frac{1}{1000}) \tag{4}$$

Yet there are many losses in the generated electrical power. Those losses can be evaluated using the following equations **(Abbas et al., 2017)**:

$$Station\ service\ allowance\ (MW) = \ 0.06\ total\ electric\ power\ generation \tag{5}$$

$$Unaccounted\ heat\ loss\ (MW) = \ 0.05\ total\ electric\ power\ generation \tag{6}$$

The net electrical power that can be generated and the contribution of (WTE) in the national electrical demand are given in the following equations:

$$Net\ electric\ power\ generation\ (MW) = \ 0.89\ total\ electric\ power\ generation \tag{7}$$

$$WTE\ ratio\ (\%) = \frac{Net\ electric\ power\ generation\ from\ MSW}{City\ demand\ from\ electricity} \tag{8}$$

The quantity of CO_2 emissions can be given as **(Moora et al., 2017)**:

$$CO2\ emissions\ (\frac{Ton}{day}) = 0.429\left((\frac{Ton\ CO2}{Ton\ MSW})\right)\ M(\frac{Ton\ MSW}{day}) \quad (9)$$

3. RESULTS AND DISCUSSIONS

Calculations and research findings of this study are presented in **Table 5**. The table also holds comparisons with previous works and results for various different cities around the world. It is noted that the average generation rate of MSW for capita per day is different from one city to another. This is due city population, economical level, and social habits differences from one city to another.

Table 5. Current research results and comparison with previous works

	Researcher's name	City and Country	MSW (kg/(capita.day))	MSW (tons/day)	H.H.V. (MJ/kg)	Steam turbine efficiency(%)	Net electrical power(MW)	WTE ratio (%)
1	**(Luna et al., 2010)**	Sao Paulo Brazil	1	500	10.6068	25.4	15.6	-
2	**(Gupta and Mishra, 2015)**	Roorkee India	-	250	12.26069	31.6	7	16
3	**(Moora et al., 2017)**	Estonia	-	-	9.64	-	-	-
4	**(Al-Rawi and Al-Tayyar, 2013)**	Mosul Iraq	0.68	1033.6	90.812	-	-	-
5	**(Abbas et al., 2017)**	Basra Iraq	1.05	2885.592	20.25	25	158	21
6	**(Anssari et al., 2020)**	Najaf Iraq	-	1127	-	-	42.7	-
7	**(Janna et al., 2021)**	Diwaniya Iraq	-	-	8.655 dry 6.44 wet	-	-	-
Current research		Al-Karth	1.0396	3621.925	12.789	25	119.2876977	-
		Al-Rusafa	1.2967	6191.583	12.789	25	203.9175333	-
		Baghdad city	1.1865	9813.509	12.789	25	323.2	4

It can be seen that Baghdad had the highest generation rate of MSW per capita per day among the listed Iraqi cities in **Table 5**. This may be related to the fact that it is the capital of the country and there are millions of people from other Iraqi governments whom visit the city on daily basis. Also, there are large commercial central markets in the city whom distribute goods and products to the rest of the Iraqi governments such as (Shorja and Jamila markets). This will sure increase the quantity of MSW generated in the city.

It can also be seen in **Table 5**, that the computed high heating value from this research is (12.789 MJ/kg), This result comes compatible with other values obtained from other studies to different cities **(Moora et al., 2017; Gupta and Mishra, 2017)**.

Table 6. Percentage weight of solid wastes types and corresponding H.H.V. from Eq. (1.b)

	Component	H.H.V. (kJ/kg)	Basra 1 %W	Basra 2 %W	Mosul %W	Najaf %W	Diwaniyah %W	Sao Paulo %W
1	Food waste	5800	54.8	60.5	68.173	68.17	60	49.5
2	Paper	16300	7	7.2	9.602	9.6	6	12
3	Glass	140	2.92	2.8	2.61	2.3	-	1.5
4	Plastic	32800	25.2	14.5	6.29	5.29	10	22.9
5	Metal	700	3.04	2.7	0.88	0.98	-	1.9
6	Tin cans	-	-	-	2.27	1.4	-	-
7	Textiles	17500	3.5	4.1	6.59	5.09	3	2.4
8	Wood	18600	2.6	5	0.47	0.85	3	1.3
9	Rubber	17500	-	0.6	1	1	-	0.3
10	Trimmings	6500	-	-	1.13	-	-	-
11	Mise.	-	-	2.5	0.59	-	-	-
H.H.V. from Eq.(1.b)			13.7064	11.2139	9.08121	9.16685	8.821	13.0679
H.H.V. from previous works			20.25	20.25	90.812	-	8.655(dry) 6.44(wet)	10.6068
Name of reference for previous works			**(Abbas et al., 2017)**		**(Al-Rawi and Al-Tyyar, 2013)**	**(Anssari et al., 2020)**	**(Janna et al., 2021)**	**(Luna et al., 2010)**

The only exception that can be identified is the value obtained for Basra city which is relatively high compared with other cities from different studies, **(Moora et al., 2017)** gave an average value of (9.64 MJ/kg) in Estonia . The high heating value is important to determine the value of the net electrical power generated from MSW as in Eq. (2) and Eq. (7). Another important factor in determining the net electrical power is the efficiency of steam turbine that is used in steam power plant which is between (20-32) % as in **Table 5.**, it is better to buy the highest steam turbine efficiency in establishing the steam power plant for MSW projects in WTE projects, the current research depends a value of (25%) as in **(Luna et al., 2010; Abbas et al., 2017)**.

In **Table 6.** the H.H.V. for many cities are computed using Eq. (1.b) and the results were compared with the previous specific works of each city, for Basra city, two weight percentage data are considered which are (Barsa 1) represents data from **(JICA, 2022)** and (Basra 2) represents data from **(Abbas et al., 2017)** who gave a value for H.H.V. of (20.25 MJ/kg) where the computed values for H.H.V. using Eq. (1.b) are (13.706468 MJ/kg and 11.21392 MJ/kg) respectively. The (20.25 MJ/kg) value means that the complete combustion of (1kg) of MSW of Basra city gives thermal energy nearly equal to the resulting thermal energy from the complete burning of (1 kg) of wood (**Table 4.**). The computed values of H.H.V. were found to be nearer the values calculated of other cities that were investigated in this current work where the result of **(Moora et al., 2017)** gave an average value for H.H.V. of (9.64 MJ/kg). Meanwhile Mosul city, computed value of H.H.V. was (9.08104 MJ/kg) which is comparable to the corrected value from **(Al-Rawi and Al-Tyyar, 2013)**. This result can be obtained by dividing the total energy from MSW (90.812 MJ) to their mass (99.62 kg) as seen in **Table 7 (Al-Rawi and Al-Tyyar, 2013)**. The column of total energy in (kJ) not in (kJ/kg) and the corrected value is (9.11585 MJ/kg) and their given result for H.H.V. of (90.812 MJ/kg) is inacceptable because it means that the resulted thermal energy from the complete burning of (1 kg) of MSW of Mosul city is equal to the resulted thermal energy from the complete

burning of nearly (2 kg) of diesel fuel (**Table 4.**) and the corrected value of (9.11585 MJ/kg) and the computed current value of (9.08104 MJ/kg) are nearer to the values of H.H.V. which are listed in the previous international works like **(Moora et al., 2017; Luna et al., 2010)**. Also, Najaf city, **(Anssari et al., 2020)** data gave the weight percentage of MSW without computing their H.H.V. The computed value of the H.H.V. was found to be (9.16685 MJ/kg) which is comparable to the previous international works **(Moora et al., 2017; Luna et al., 2010)**. Similar to that the Iraqi city of Diwaniyah calculations obtained a value of H.H.V. (8.821 MJ/kg) which is close to the value of the dry H.H.V. of (8.655 MJ/kg) of (**Janna et al., 2021**). This gives a good convergence between the accurate and approximate methods which are used to compute H.H.V. of MSW. The municipal solid wastes types and percentage weight are taken from (**Janna et al., 2021**).
Still yet when computed results are compared with other studies such as the one carried on in Sao Paulo city in Brazil, **(Luna et al., 2010)**, it is observed that the (10.6068 MJ/kg) value for H.H.V. is much lower than the (13.0679 MJ/kg) calculated in this study with a nearly 30% between the two values . This means that the approximate method of Eq. (1.b) is not always accurate method and it is best to use the analytical method to determine H.H.V. of MSW as in **(Janna et al., 2021)**. **Table 6** shows the plastic wastes type had the highest value of H.H.V. of (32800 MJ/kg). This is due to of its hydrocarbon origin. Meaning that the weight percentage of plastic wastes is very important for increasing the value of H.H.V. of MSW of a certain city in order to increase the net electrical produced power from MSW (see Eq. (2) and Eq. (7)) for mixed wastes. It is better for the environment to recycle wastes than burning them because of greenhouse gases emissions such as CO_2, but still the process of sorting out and recycling wastes is still not much developed in many third countries one of them is Iraq **(Ghani and Faleh, 2023)** recently in Iraq designed an experimental rig to sort MSW. The recyclable wastes are plastic, glass, metal, textile and paper so if these wastes types are recycled completely, the H.H.V. may be reduce nearly to the half because the compostable wastes will become only food and wood wastes, this point is important for future planning of WTE projects where all previous works showed the economic feasibility of WTE projects for MSW quantity larger than (240 ton /day) for mixed wastes. The quantity of CO_2 emissions from burning MSW of Baghdad city of (9813.509 ton/day) is 4209.995 ton CO_2/ day) using Eq. (9).

4. CONCLUSIONS

The MSW of Baghdad city can be used to produce electrical energy by establishing two steam power plants in both Al-Karth and Al-Rusafa and the present results can be concluded as:

1- Baghdad city municipal wastes were found to have an average high heating value of (12.789 MJ/kg) for its mixed wastes.
2- The waste composition and weight percentage of the plastic content in the waste mix is very important for increasing the value of the high heating value of municipal solid wastes.
3- The net produced electrical power from municipal solid wastes is (119.287 MW, 203.917 MW and 323.2 MW) for Al-Karth, Al-Rusafa and Baghdad city respectively which can be well used and utilized for the national power production.
4- The incineration of (9813.509-ton MSW/day) of Baghdad city has the potential to produce (4209.995-ton CO_2/day) which increases the global warming.
5- Depending on Eq. (1.b), the average high heating value of many cities like Basra (1 and 2), Mosul, Najaf, Diwaniyah and Sao Paulo are 13.706468, 11.21392, 9.081214, 9.16685, 8.821 and 13.0679 respectively.

NOMENCLATURE

Symbol	Description	Symbol	Description
C	Weight fraction percentage of Carbon, %.	MSW	Municipal solid wastes.
H	Weight fraction percentage of Hydrogen, %.	O	Weight fraction percentage of Oxygen, %.
H.H.V.	High heating value, $\frac{KJ}{Kg}$.	S	Weight fraction percentage of Sulfur, %.
H.H.V.(i)	High heating value of MSW constitution like food, paper, etc…, $\frac{KJ}{Kg}$.	WTE	Waste to energy.
M	Mass of MSW, $\frac{kg}{day}$.	η	Efficiency of steam turbine, %.
M(i)	Weight fraction percentage of MSW constitution like food, paper, etc…, %.		

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Credit Authorship Contribution Statement

Ahmed H. Hadi: Writing – review & editing, Writing – original draft, Validation, Software, Methodology. Basim A. Hussain: Writing – review & editing, Software. Ahmed A. Khalaf: Writing – review & editing. Abdullah F. Abdurazak: Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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