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Investigation of Electricity Production Feasibility in Tabriz using Biomass Resources

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ABSTRACT

In this research, the feasibility of biogas production using biomass in collected wastes is studied. In this paper, first the different methods of recycling energy and for most used algorithms are studied. Second, by analyzing daily collected wastes and considering the realistic obtained data from leachate of Tabriz waste landfills, the average amount of Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD) are obtained. Then, an appropriate scenario is presented to get the maximum reachable biogas. Also, an economic model taking into account the effect of main variables of preparations such as the cost of waste transport vehicles, capacity of the purchased devices, special costs of biomass and distributed density are considered and the best and most economical method is utilized based on generated gas volume in biomass power plants. Finally, the short-term and long-term models are presented for power generation and investment using biogas. The proposed method is applied for the wastes of Tabriz City, as one of the largest industrial metropolitan in Iran, with a daily waste more than 1200 tons.

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1. INTRODUCTION

Increasing oil and gas prices and the growth of cancer diseases as well as global temperatures increase due to the pollution and carbon dioxide emissions has caused more attentions toward energy production by the use of renewable energy resources. One of the renewable energy sources known as clean sources of energy is biomass. For long time, Iran has been involved in environmental issues, and the large volume of wastes and industrial and urban wastewaters anticipated dangerous future in terms of health [1]. In Iran, the facilities of gas extraction from bio-waste landfills have been installed in three large cities, and two 380 kW biogas generators each are operating in 24h period [2], [3]. According to the data obtained from International Energy Agency (IEA), the share of renewable energies in global energy supply was about 19.3% in 2009 of which 10% is attributed to biomass energy [4]. In 2011, more than 9000 MW biomass power plants are installed in U.S and now there are more than 2000 waste-burnt systems in Japan in which more than 80% of wastes are utilized [5]. In 2008, in Turkey, biomass has a 5% share of total energy and a number of researches have been conducted for the production of biogas from different sources such as solid waste, sewage and agricultural products [6], [8]. The heating value of gathered gas is about 15 - 25 MJ/m3 which can generate 1.5-2.2 kWh/m3 energy using biogas combustion generators [3]. In Thailand, based on the developmental and supplying energy programs by the end of 2011, generation capacity of 2800 MW is expected for biomass energy [9]. There are several methods for producing biogas from biomass such as pyrolysis, gas-making and fermentation [10], [14]. In this paper, by presenting the different methods of recycling energy from wastes and biogas production, the leachate of Tabriz waste landfills are analyzed. By taking into account the effect of main variables of preparations such as the cost of waste transport vehicles, capacity of the purchased devices, special costs of biomass and distributed density are considered and the best and most economical method is utilized based on generated gas volume in biomass power plants.

Wastes are the solid, liquid and gas substances (expect for sewage) which are directly and/or indirectly resulted from the human activities and considered to be useless by the producers. The wastes fall into five categories; ordinary wastes, medical wastes, poisonous wastes, agricultural wastes, and industrial wastes. Considering the abovementioned descriptions, Table 1 shows the average analysis of urban wastes throughout the country.

Table 1. The average analysis of urban wastes throughout the country

Element	Percent
Decaying organic materials	62.64
Paper, cardboard, carton	10.92
Plastic and rubber	10.28
Ironware	3.24
glass	4.24
textile	4.08
Wood and sifting	5.52

According to the conducted studies, the daily home wastes, hospital wastes and industrial wastes are 800 gr, 20 gr, and 30 gr per capita, respectively. In Tabriz metropolitan, daily collected wastes consist of 1200 tons home wastes, 15 tons hospital wastes and 80 tons industrial wastes and etc. Figure 1 illustrates the average analysis of urban wastes in Tabriz City.

As shown in Figure 1, urban wastes of Tabriz City consisting of 70% putrescible organic materials have good potential to generate leachate, and in turn biogas production [15].

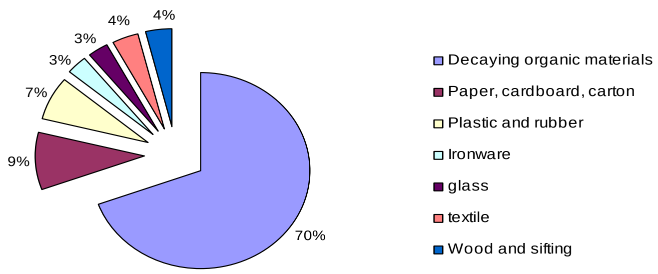

Figure 1. The average analysis of urban wastes in Tabriz City

The reminder of the paper is as follows: section 2 provides the proposed method for biogas production from wastes. The third section presents the evaluation of heat energy and economic model. Section 4 presents the case study and its results, and section 5 concludes the paper.

2. THE PROPOSED METHOD FOR BIOGAS PRODUCTION IN WASTE LANDFILL OF TABRIZ CITY

The wastes have leachate. In general, the wastes have about 70% - 80% humidity and leachate. There is an index of BOD in waste, the amount of this index is 300 mg/l in swage, and however this quantity in waste leachate is 36000 mg/l. The amount of produced leachate in waste landfill depends on factors such as weather conditions (rain, and evaporation). If the rate of raining is more than evaporation, the raining will have positive effect on leachate production. The other factor is how damp the waste is which in dry and hot weather conditions the dampness of waste plays more important role in leachate production. In addition, other factors having impacts on quality of leachate are the waste landfill site, the type and chemical compound of wastes, recycling and separating the wastes, the rate of compacting and other aspects of dumping process, temperature, PH, the condition of chemical oxidation and reduction in dumping site, presence (or lack) of sludge and industrial waste, the thinness of layers of dumping, the permeability, and thinness and the daily compacting soil for convening the wastes [16], [17]. Table 2 shows the components of fresh leachate in Tabriz City's waste landfill site obtained by various samples of waste transport vehicles. There are three different steps for waste decomposition in biological processes:

2.1. First stage

Hydrolysis of complex and insoluble organic substances into soluble forms.

2.2. Second stage

The obtained organic components in the first step are broken down by acid-forming bacteria; consequently the organic acid is produced. Usually the five-carbon and six-carbon hydrocarbons dissolved in water are consumed by acid-forming bacteria and converted into compounds such as hydrogen, format, acetate, and carbon dioxide.

2.3. Third stage

All organic compounds and acids produced in acid-forming stage are converted into biogas using methane-forming bacteria. Anaerobic digestion is performed in a relatively wide range of temperature, 10 – 60 °C. Optimum temperature for the biogas production in terms of technical and economic aspects is about 37 °C [18], [19]. As shown in Table 2, a high value of BOD_5 indicates a high content of organic substances in leachate which is influenced by the high content of organic compounds in the waste. High concentration ratio of COD and COD/BOD_5 in leachate in a newly established landfill sites reveal that an anaerobic process should be used prior to aerobic one. In addition to anaerobic and aerobic processes, since the high concentration of organic compounds remain in the leachate which are resistant to biological degradation then it is required to use advanced oxidation processes such as ozoneation for the elimination of these compounds or strengthen their ability to use biological degradation. By performing the abovementioned stages, the maximum biogas can be obtained from the leachate [20], [22].

Table 2. The components of in fresh leachate in waste landfill of Tabriz City

Parameter	Unit	Amount
PH	_	6.5
BOD_5	g/m^3	8000
BOD	g/m^3	18000
COD	g/m^3	42000
COD/BOD_5	g/m^3	1.5

3. RESEARCH METHODOLOGY

3.1. Evaluation of Heat Energy and Impure Energy of Urban Wastes

In order to compute heat value of the waste, Equation (1) known as Dyvlang equation is used as follows:

$$HHV = 337.8C + 1440.7(H - \tfrac{1}{8}O) + 95.2S \quad (1)$$

Where,
HHV : Heat value in terms of Kj/Kg in dry condition
C : The percentage of carbon amount
H : The percentage of hydrogen amount
O : The percentage of oxygen amount
S : The percentage of Sulfur amount
The heat value of moist substance is calculated using Equation (2).

$$HHV_{wet} = HHV_{dry} \times (1 - W/100) \quad (2)$$

W: The percentage of moisture amount

In Iran, the heat value of waste is calculated using Equation (3).

$$E_{gMSW} = \sum_{i=1}^{n} HHV_i \times P_i \times (1 - W_i/100) \tag{3}$$

E_{gMSW}: The heat value of unprocessed waste

HHV_i : Heat value of the *i*th element is calculated using Eq. (3) (such as paper and cardboard)

P_i: The percentage of the *i*th element in the total waste

The heat value of biogas usually depends on the percentage of methane. The heat value of biogas with 60% of methane is equal to 5.96 kWh/m^3 while the heat value of natural gas is 7.52 kWh/m^3. Heat value of produced biogas from the waste and its equivalent natural gas volume in urban wastes are shows in Table 3.

Table 3. Heat value of producible biogas from waste

City	Heat value of biogas (PJ)	Equivalent million m3 of natural gas
Tabriz	2.434	89.908
Urmieh	1.69	62.46
Ardebil	0.65	24.01
Esfahan	1.86	68.67
Tehran	8.398	310.21

3.2. Economic model

From the view point of system, the economical operation of biomass power plants is determined by the efficiency of energy conversion regarding the amount of biomass, conversion technology and the size of the plant. In order to achieve this goal, the power plant in considered as a simple fashion shown in Figure 2 which is a transfer function between input as biomass ton/year designated by M and power output energy MW designated by W_{NE} .

In Figure 2, M is the amount of input biomass ton/year, *LHV* is the final amount of biomass heat energy kJ/kg, η effective energy conversion efficiency and *OH* is operating hours of power plant. As mentioned earlier, the value of η depends on the type of technology and the size of power plant.

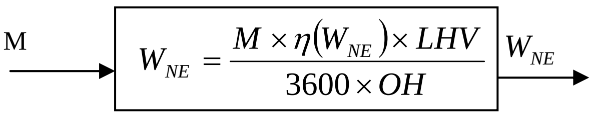

Figure 2. Biomass power plant model

Economic evaluation of the biomass power plant is obtained based on the total cost of investment TCI (IRR), total operation cost TOC $/year, revenue from electricity power sales $/kWh. TCI is obtained by the sum of direct and indirect costs. Direct cost includes plumbing cost, electric cost, construction cost, installation cost, services cost, equipment cost and site preparation cost. While indirect cost includes engineering and operation costs. TOC consists of labor costs, purchased biomass cost and biomass transferring cost, maintenance cost, insurance and ordinary costs. Purchase of biomass cost, PB, is calculated based on annual biomass input rate, M, and its purchasing cost are calculated based on Equation (4).

$$PB = C_B \times M \tag{4}$$

Transportation of biomass cost, TB, is calculated by adding transportation cost *V* $/year and transportation personnel cost, *TP*, according to Equation (5).

$$TB = V + TP \tag{5}$$

Vehicle cost V is a function of annual transportation d_T and vehicles cost C_{VT} as in Equation (6):

$$V = d_T + C_{VT} \tag{6}$$

d_T is the number of trips needed for providing necessary amount of biomass with the rate of M using the vehicles with the capacity of *VC* tons/vehicle. The average number of transportation can be calculated considering that biomass is obtained in 2 / 3 of the radius of a Circle area for providing the *M*-amount of needed biomass with the same density of biomass D_B as in Equation (7):

$$d_T = \frac{4}{3}\left(\frac{M}{D_B \pi}\right)^{0.5} \times \left(\frac{M}{VC}\right) \tag{7}$$

In Equation (7), M/VC is considered as the number of trips needed. Regarding *TP* as transportation cost, C_{TP} as transportation personnel cost, and n_T as the number of operators TP, according to Equation (8):

$$TP = C_{TP} \times n_T \tag{8}$$

Finally, maintenance cost, insurance and ordinary costs are calculated as a percentage of total cost in the form of coefficients. The revenue obtained from electric energy sales is calculated as Equation (9):

$$R = W_{ANE} \times OH \times EP \tag{9}$$

Where, *OH* is hours of power plant operation, *EP* is the current price of electric energy (disregarding government subsides), and *WANE* is a percentage of output pure electric energy, *WEN* is deliverable energy regarding 90% of *WEN* and needed energy from accessible parts of devices, finally *NPV* is obtained using Equation (10):

$$NPV = \sum_{k=1}^{N} \frac{F_k}{(1+i)^k} - TCI \tag{10}$$

Where, *N* is power plant working lifetime, *i* is interest rate, *Fk* is financial turn over in k*th* year in Equation (11):

$$F_K = R - TOC - T - FC \tag{11}$$

Where, *T* and *Fk* are the tax and current balance, respectively. Practically, the price considered for electric energy is directly related to retail price of electricity and consistent with competitive production cost in biomass technology [23], [24].

4. RESULTS AND DISSCUSSION

During the past years, without a targeted program for organizing, recycling and energy recovery, great deal of wastes are buried in Tabriz City. After many years and by accumulation of wastes, the gas-making process was started naturally and even a number of gas explosions are seen in wastes. In this paper, after considering the mentioned cases and practical experiences in electric power generation using biogas in two other cities in Iran, also in order to reduce investment risk and successful execution, the energy production project in Tabriz City wastes can be started by small capacity units. For this, it is suggested that this project to be employed in two executive stages.

4.1. First stage

To start the project, two generating units, each with a capacity of 500 kW or together 1 MW, are used. In this stage, the produced gases in old landfill were collected sent into generator after refining. According to the data, the construction costs of 500 kW and 1 MW generating units are about 1.3 M$ and 2.47 M$, respectively. Considering the production of 150 m^3/h gas with the minimum 70% in landfill, selling price of 0.1 $/kWh and 8000 h with the power of 450 kW, the obtained revenue from selling will be 3.5 M$. Table 4 depicts the selling amount of one biomass generating unit with the power of 500 kW in seven years considering annual rise of 11%. Table 5 shows the total cost and revenue of power generation during 7 years. As indicated in Table 7, the payback period of the project is about 4.5 years.

Table 4. Sales amount of a unit 500 Kw power plant during 7 years

Year	Electricity price ($/MWh)	Total Income ($/Y)
1	100	360000
2	111	399600
3	123.21	443556
4	136.21	490356
5	151.8	546480
6	168.49	606564
7	187.0239	673286

4.2. Second stage

At this stage, the newly imported wastes into landfill site, the aerobic and anaerobic digestions are utilized. Here, by the construction of the waste storage tanks and by the use of advanced oxidation processes such as ozoneation, the removal of COD and enhanced capabilities such as biodegradation process are performed. It is required to remove 1 kg of COD to produce 300-350 m^3 of biogas. 2-3.5 kW electrical energy is produced by removing 1 kg of COD. Given that the average daily production rate of landfill leachate is about 400 kg, biogas production will be 1200 m^3/h. At this stage, two 1000 MW generators are installed and operated.

Table 5. Electricity production costs in first stage

Year	Investment cost($)	Maintenance cost($/Y)	Operation cost ($/Y)	Total cost ($/Y)	Total Income ($/Y)	Total Revenue ($/Y)
1	1300000	39000	72000	1411000	360000	-1051000
2	0	43290	79920	123210	399600	276390
3	0	48052	88711	136763	443556	306793
4	0	53338	98469	151807	490356	338549
5	0	59205	109301	168506	546480	377974
6	0	65717	121324	187041	606564	419523
7	0	72946	134670	207616	606564	398948

Considering the price of electricity sold at 0.1 $/kW and operated for 8000 h with the power of 900 kWh for each generator, the profits from the sale is 7.04 M$. Table 8 shows the revenue and expense amounts during six years in second stage. As it can be seen in Table 6, the initial cost of project is much more in first due to the cost of preparation and construction of pools, digesters and etc. Consequently, the payback period will be 7 years. Regarding that the overhaul period is considered to be after 8 years, therefore the abovementioned issue has not been applied in the calculations.

Table 6. Electricity production costs in second stage

Year	Investment cost ($)	Maintenance cost ($/Y)	Operation cost ($/Y)	Total cost ($/Y)	Total Income ($/Y)	Total Revenue ($/Y)
1	5000000	150000	90000	5240000	720000	-4520000
2	0	180000	92700	272700	799200	526500
3	0	216000	95481	311481	887112	575631
4	0	259200	98345	357545	984694	627149
5	0	311040	101296	412336	1093011	680675
6	0	373248	104335	477583	1213242	735659
7	0	447898	107465	555362	1346698	791336

5. CONCLUSION

In this paper, after a brief study on biomass history and describing the condition and definitions of biomass sources and biogas, the produced wastes, urban and industrial sewage in large and industrial cities are examined. Then the waste compounds in Tabriz City and Iran were analyzed. Considering that 70% of wastes components in Tabriz City are of organic and putrescible types, thus, by sampling of transported waste leachate into waste landfill and determining the amount of BOD and COD, the best and most appropriate way to generate electricity from the waste in Tabriz City was presented. The project was implemented in two stages. In the first stage, the produced biogas in the old part of landfill and collected waste gases were used for generating the electrical energy. For fresh collected wastes in the second stage, a combination of aerobic and anaerobic digestions and ozoneation were used to achieve maximum gas extraction. Finally, based on the volume of gas production and considering the input of biomass, the direct and indirect costs and average discharge of leachate production and the use of mentioned economic models in this paper, the revenue and expense of each kW power in each stage was performed and presented in seven year.

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