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Design and Economic Analysis of a Heating/Absorption Cooling System Operating with Municipal Solid Waste Digester: A Case Study of Gazi University

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Abstract **– Recovering energy from municipal solid waste (MSW) is one of the most important issues of energy management in developed countries. This raises even more interest as world fossil fuel reserves diminish and fuel prices rise. Being one of main processes of waste disposal, anaerobic digestion can be used as a means to reduce fossil fuel and electricity consumption as well as reducing emissions. With growing demand for cooling in Turkey, especially during warm seasons and considering the energy costs, utilizing heat-driven absorption cooling systems coupled with an anaerobic digester for local cooling purposes is a potentially interesting alternative for electricity driven compression cooling. The aim of this article is to study the viability of utilizing biogas obtained from MSW anaerobic digestion as the main fuel for heating facilities of Gazi University, Turkey and also the energy source for an absorption cooling system designed for the central library of the aforementioned campus. The results prove that the suggested system is sustainably and financially appealing and has the potential to replace the conventional electricity driven cooling systems with a reasonable net present worth; moreover, it can notably reduce carbon dioxide emissions.**

Keywords **– MSW, absorption cooling system, anaerobic digestion, economic analysis, greenhouse gas reduction.**

I. INTRODUCTION

Unavoidable population growth and modern lifestyle has resulted in a more rapid depletion of natural resources and an increasing rate of environmental issues. In addition, changing consumption patterns has led to rising numbers of solid waste produced per person. Consequently, in line with global sustainable development, in order to convert wastes from being a threat to the environment and human health into a source of income for the economy, employing waste management strategies is inevitable. Integrated waste management generally starts with waste reduction at its source, recycling and recovery and ends with the disposal of gathered waste. Municipal solid waste subjected to anaerobic digestion demonstrates a promising potential to produce biogas [1, 2]. During the process of anaerobic digestion, organic materials are converted to their oxidized and reduced form to yield methane, carbon dioxide and trace gases in absence of air [3, 4]. Igoni et al. [2] have discussed the key points and characteristics for designing an optimized anaerobic digester. They have noted that MSW size reduction and providing the appropriate digestion environment i.e. temperature, moisture, hydrogen-ion amount and some other factors are necessary in order to obtain an optimal design for anaerobic digester. They have also concluded that batch digestion system is a feasible means by which to convert MSW into useful energy forms.

Several other technologies are also employed in waste management strategies, especially with the aim to produce energy via biogas. Murphy and Mckeogh [5] have studied four main methods for energy recovery from MSW: thermal technologies including incineration and gasification; and biogas technologies for CHP and transportation fuel production. They have deduced that in almost all cases despite having its own shortfalls, producing fuel for transportation is the most feasible solution both from the economic (gate fee) and environmental (greenhouse gas emissions) point of view. Also, various investigations have been carried out to assess the application of biogas for cogeneration and trigeneration. Mikael Lantz [6] has investigated the feasibility of different technologies for CHP production using manure-based biogas. Bruno et al. [7] studied different integrated arrangements of absorption chillers and biogas-fired micro gas turbine CHP systems. They carried out a case study for a sewage treatment plant and concluded that the most appropriate configurations are the ones that trigeneration plant, using biogas and supplementary natural gas, which totally replaces the available system.

On the other hand, during recent decades there has been an immense increase in cooling demand globally. In warmer regions electricity demand peaks are in part due to electrical cooling devices which lead to higher peak load power generation and subsequently higher costs and carbon dioxide emissions [8-10]. Aside from climate conditions, population growth combined with a modern lifestyle and an expanding use of electric devices like lighting and computers also escalate cooling demand [8]. About 40% of Europe's buildings are equipped with cooling systems, a number that rises to 80% in the United States and Japan [11]. Therefore, a major part of the world energy consumption is used for cooling purposes. Almost 40% of the electric consumption in warm regions is spent on cooling while in Turkey 7% of the produced electric energy is used in air conditioning industries [12]. Replacing the conventional electricity-driven compression cooling (CC) chillers with heat-driven absorption cooling (AC), particularly in areas where industrial excess heat or recovered energy from MSW are available, is a promising option to reduce the power used for cooling and to decrease the rate of carbon dioxide emissions.

However, despite this increasing demand and raising energy costs, there is a dearth of literature about the application of biogas produced from municipal solid waste for heating and cooling purposes. The general objective of this research is to assess the feasibility of utilizing MSW to meet the heating/cooling demands of Gazi University. Calculations have been carried out to specify both the heating and cooling loads. Absorption cooling chillers are proposed as a sustainable and economically advantageous solution. Net Present Worth and payback period for the system are computed and compared to the existing system.

II. MUNICIPAL SOLID WASTE

Differing with respect to the urban and rural population characteristics, social and economic structure, consumption patterns and geographical location, Turkey produces 1,14 kilograms of waste per person each day [kg/person-day]. During the warm seasons of the year, this number rises to 1.15 [kg/person-day] while during cold seasons it is 1.10 [kg/person-day]. Considering the current population of 73 million, the amount of waste produced across Turkey can be estimated at 69.252 tons per day (25.277 million tons per year). The statistical data obtained on waste across Turkey is presented in Table I [13]. Also, Table 2 presents the physical characteristics of sample MSW of Ankara in the year 2005 [14].

Physical characteristics, ultimate and approximate analyses results of the MSW used in this study is presented in Table III [15].

III. SYSTEM DESCRIPTION

Regarding the energy consumption patterns and costs, replacing the currently used natural gas driven heating and electrical cooling with a MSW driven heating/cooling system is a promising alternative. This research plans to planned to assess the technical and economical possibility of replacing the currently used natural gas driven heating and electrical cooling with a thermal system driven by biogas and an AC system, respectively in order to provide 26.3 MW of heating and 1.1 MW of cooling demands of Gazi University main campus (Figure 1).

Figure 2 shows a three dimensional diagram of the simulated biogas production, heating and cooling system. As it can be seen, gathered waste is brought to the facility and stored in the balancing ponds, after which it is sent to the biogas production unit. The produced biogas is led to the boilers and AC generator in order to provide the energy demands of the heating and cooling systems.

The system used in this study mainly consists of an anaerobic digester, heating facilities and an absorption cooling system. Each system is described briefly below:

TABLE I

STATISTICAL DATA OBTAINED ON WASTE ACROSS TURKEY (TÜİK)

Data	*Amount*
Number of cities providing waste management services	2879
Ratio of waste service offered population to total population (%)	83
Total gathered waste amount (1000 ton/year)	25277
Average waste amount per person per day (kg/person-day)	1.14
Average waste amount during warm seasons (kg/person-day)	1.15
Average waste amount during cold seasons (kg/person-day)	1.10
Number of landfill of wastes facilities in Turkey	52
Capacity of landfill of wastes facilities 1000 ton)	432142
Disposed waste amount (1000 ton/year)	14309
Number of compost facilities	5
Capacity of compost facilities (1000 ton/year)	556
Amount of waste received at compost facilities (1000 ton/year)	216
Number of thermal recovery facilities	2
Capacity of thermal recovery facilities (1000 ton/year)	44
Amount of burnt medical waste (1000 ton/year)	6
Ratio of population receiving disposal and recovery services to total population (%)	47

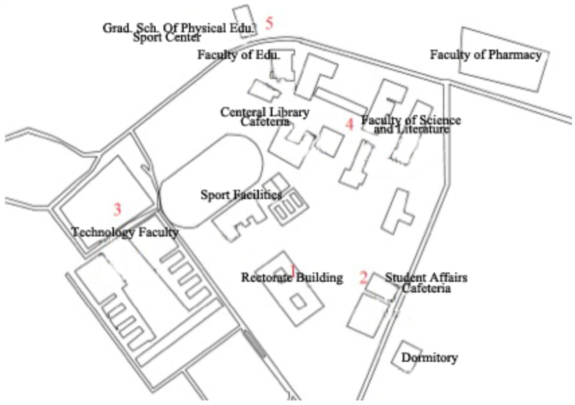

Fig.1. Gazi University main campus map

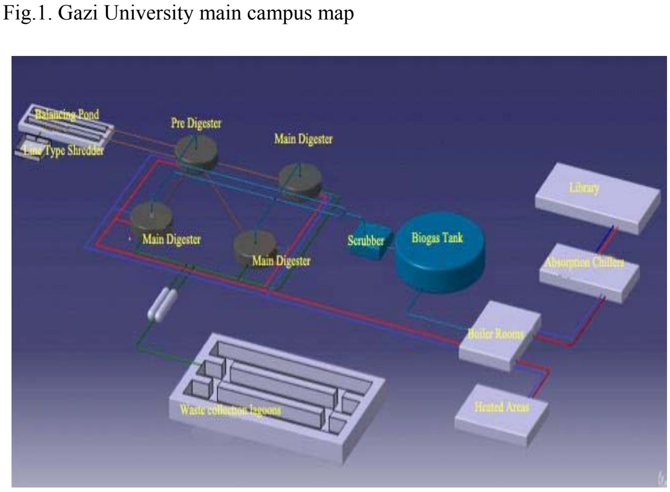

Fig.2. 3D flow diagram of the simulated biogas-cooling facility

TABLE II

PHYSICAL CHARACTERISTICS OF MSW FOR ANKARA

Ingredients	*Paper*	*Plastic*	*Metal*	*Textile*	*Glass*	*Ruble stone*	*Organic material*	*Ash*
Percentage (%)	8.4	7.7	1.1	1.3	1.6	1.6	47.8	30.5
Weight (kg)	89	81	12	14	18	18	508	324
Density (kg/m3)	0.27	34.1	240.3	84.1	193.8	104.1	288.3	480
Volume (m3)	1.35	0.33	0.05	0.22	0.07	0.17	1.76	0.68
Compression ratio	0185	0.1	0.225	0.15	0.4	0.2	0.33	0.75
Compressed volume (m3)	0.225	0.038	0.009	0.033	0.028	0.034	0.58	0.810

TABLE III

PHYSICAL CHARACTERISTIC, ULTIMATE AND APPROXIMATE ANALYSES RESULTS OF THE USED MSW

Physical characteristics	
Density of organic waste (kg/m^3)	288.6
Sludge density (kg/m^3)	758.26
Ultimate analysis (%)	
Moisture	25.2
Ash	21
Volatile matter	25
Fix carbon	28.8
Calorific value (kJ/kg)	10113
Approximate analysis (%)	
C	28.1
H	3.9
N	0.4
S	0.3
O_2	0.5
Cl	20.6

TABLE IV

DETAILED INFORMATION ON THE BOILERS

Boiler Room	Capacity(kW)	Quantity	Location
Boiler room 1	1,162	3	Rectorate building, Kindergarten and Museum
	400	1	
Boiler room 2	697	1	Medical center and cafeteria
Boiler room 3	3,021	3	Technology Faculty and Cultural Center
	651	1	
Boiler room 4	2,556	2	Education Faculty and Faculty of Science and Literature
	1,162	2	
Boiler room 5	1,220	2	Sport Center and Graduate School of Physical Education
	2,092	1	

A. Heating facility

The current heating facilities of Gazi University consists of five natural gas-fired boiler rooms, each with total capacities of 3877 kW, 700 kW, 9700 kW, 7440 kW and 4500 kW, respectively. The detailed information of the boilers is presented in Table IV. By modifying the current burners, boilers are capable of operating with biogas instead of natural gas, without any major changes in the system.

B. Absorption Cooler

An AC system operates similar to vapor-compression cooling systems. The difference is that it uses thermal compressors instead of electrically driven compressors. Depending on the number of pressure stages, AC systems can be divided into two main categories: single-effect and double-effect. A fundamental AC system consists of four main components: a generator, an absorber, a condenser and an evaporator, and it operates with absorption-refrigerant pair rather than a pure refrigerant used in electrically driven cooling systems [16].

In this study, considering the heat source and site conditions, a single effect AC system working with Li-Br pair is selected to provide the required cooling demand. Related technical characteristics of the AC system are presented in Table V.

TABLE V

TECHNICAL CHARACTERISTICS OF THE DESIGNED SYSTEM

Parameter	*Unit*	*Value*
Outlet Temperature of the evaporator	°C	10
Cooling capacity	kW	1163
Thermal energy demand of the generator	kW	1738
Condenser capacity	kW	1224
Absorber capacity	kW	1677
COP	-	0.669

C. Anaerobic digester

Categorization of anaerobic digester systems mainly depends on the process type, total solid content of the MSW, temperature level and complexity. There are two most widespread kinds of anaerobic digesters which are defined in regard to complexity: single stage and multi stage. To be able to choose an appropriate digester type, all biological, technical, economical and environmental conditions should be taken into consideration. Furthermore, there are several factors which affect the performance of anaerobic digesters. Reactors' temperature, waiting time, organic loading rate, ratio of the total solid amount to loading ratio, PH and buffering capacity, Carbon/Nitrogen ratio and toxicity are the main factors affecting the performance of the digesters.

Considering the aforementioned parameters and requirements of the designed system, a double-stage digester is used. In double-stage digesters, two separate reactors are used for different steps. Generally, acid hydrolysis is produced in the pre-digester (first reactor) and then it is sent to the main digester (second reactor) in order to produce biogas. It should be stated that according to previous literature and experimental studies, calorific value of the produced biogas varies between 19,950-23,830 kJ/Nm^3 [5 and 17]. Normally wastes do not display stable performance in single-stage digesters. Subsequently, aside from higher reactor speed, the main advantage of double-stage digesters is higher reliability of the waste. Waiting time may or may not be included in the design of the digester, where in the first case the system will be more reliable against production of nitrogen gas and toxins.

In designing the digester, it was decided to use 10% solid content, double-staged, continuous feed and completely mixed digester type and 15 days of waiting time with a mesophilic working condition which are the most proper design parameters for the system's application location in Ankara. Also, 50% of volatile solid devolatilization, 0.0975 m^3 of specific gas production per 1 kg of MSW and the produced biogas with calorific value of 20,900 kJ/m^3 were assumed for the digester. Further technical data of the used digesters are presented in Table VI. A simple flow diagram of the used double-stage anaerobic digester is presented in Figure 2.

TABLE VI

MAIN TECHNICAL DATA OF THE ANAEROBIC DIGESTER

Parameters	*Unit*	*Value*
Digester volume (one pre-digester and three main digester)	m^3	9382.5×4=37530
Digester diameter	m	38.6
Digester height	m	9
System thermal energy demand	MW	64.34
System electrical energy demand	MW	13.6
Daily liquid fertilize	t/day	2160

IV. ECONOMIC ANALYSES

Economic evaluation model provides a means to assess the costs and benefits of investments on anaerobic digestion utilization for heating and cooling purposes.

In order to perform an economic assessment of the studied project, the payback method and net present value method are employed.

In the payback period method, the period of time needed for return on an investment in order to refund the initial investment is calculated while the net present value method yields the difference between the present value of the future cash flows and the amount of initial investment.

Present worth of the expected cash flows can be calculated by discounting them at the required rate of return. As Quoilin and Lemort [18] have expressed, the net present worth can be calculated using the equation below:

$$NPW = PW_{benefits} - PW_{costs} \quad (1)$$

Equation (2) can be used to calculate the net present value of benefits or costs.

$$\Pr = F(1+i)^{-n} \quad (2)$$

Series present worth of benefits and costs can be obtained using equation (3).

$$\Pr = A\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right] \quad (3)$$

In Equation (2), "Pr" is the present sum of money, "F" is the future sum of money, "I" is the interest rate per interest period and "n" shows the related year. Also, "A" in the equation (3), symbolizes an end-of-period cash receipt.

After carrying out these computations, if the present worth of benefits is higher than present worth of costs, the project can be interpreted as acceptable.

Despite the fact that there is not any exact information about the investment costs of establishing an anaerobic digester system in Turkey, it can be estimated that the average investment cost for producing one m^3 of biogas is approximately 150 € [19]. Moreover, with reference to previously established similar AC systems in Turkey, it is assumed that the total cost per 1 MW of cooling load is about 115,000 € [20].

Further assumed information for economic analysis of the system is presented in Table VII.

TABLE VII

ASSUMPTIONS MADE IN ECONOMIC ANALYSIS OF THE SYSTEM

Parameters	*Unit*	*Value*
Value of disposal of MSW (paid from municipality)	€/t	5
Value of compost	€/t	10
Value of liquid fertilizer	€/m^3	6
Natural gas price	€/m^3	0.4
Electric price	€/kWh	0.07
Lifetime of the system	Year	20
Interest rate (i)	%	8
Salvage value	%	5% of primary investment cost
O&M (including electric cost, water consumption cost, etc.)	%	15% of total investment cost

V. RESULTS AND DISCUSSION

A. *Technical results*

Table VIII illustrates the obtained technical results for applying MSW digestion technology for heating/cooling purposes in a case study of Gazi University, Ankara. Total annual energy demand of the system is determined by adding up the total heat demand of the University during the cold season, cooling demand of the Central library during the warm season and anaerobic digester system's internal energy consumption which is found to be around 126 MW. Moreover, for providing 126 MW of energy demand, approximately 23,923 m^3 of biogas with calorific value of 20,900 kJ/m^3 should be provided daily. On the other hand, for providing this amount of biogas, 245.4 tons of MSW equivalent to 850 m^3

must be gathered from municipality and campus area and supplied to the system continuously every day.

Some of the main byproducts of anaerobic digestion systems are compost and liquid fertilizer which have considerable economic value (related economic data is presented in Table VII). In this regard, daily compost and liquid fertilizer production of the system is determined. As it is shown in Table VIII, the compost and liquid fertilizer obtained amounts to approximately 21 t/day and 2,160 m^3/day, respectively.

In addition, in order to provide 1.1 MW of cooling demand of central library of Gazi University, the generator of the AC must be fed with 216 m^3/h of biogas.

TABLE VIII

ECONOMIC ANALYSES RESULTS

Parameters	*Unit*	*Value*
Energy demand	MW	126.2
Calorific value of produced biogas	kJ/m^3	20,900
Daily demand of biogas	m^3/day	23,923
MSW consumption rate	t/day	245.4
MSW consumption volumetric rate	m^3/day	850.2
Compost production rate	t/day	21
Liquid fertilizer production rate	m^3/day	2,160
Cooling load of central library	kW	1,163
Biogas consumption rate for cooling	m^3/h	216

B. Economic analyses results

The economic evaluation of the MSW driven heating/cooling system is applied using equations and assumptions given in Section IV. The results are summarized in Tables IX and X.

Table IX presents the total outcome, computed income and salvage value of system's first year of operation. The total outcome can be obtained considering the operation and maintenance costs of the system and it is found to be 1,496,720 € for the first year. On the other hand, total income can be calculated by summing up the incomes due to produced compost and liquid fertilizer, waste disposal and natural gas and electric cost savings. Adding up the incomes, a total amount of 2,904,586 € is obtained for the first year. Also, the salvage value is calculated as 498,906 € over the mentioned period.

Table X illustrates the annual present worth of benefits and costs over 20 years of system's lifetime in order to determine the payback period and net present worth of the project. Also, net annual income and its cumulative sum, used in the calculations, are given in this Table.

The present worth of the benefits (which include present sum of income and present sum of salvage value) and present worth of the costs (which includes present sum of outcome and initial investment cost) at the end of economical lifetime of project are calculated as 28,624,690 € and 24,673,132 €, respectively. By using Eq.1, NPW of the project is calculated about 4,605,911 €, which is a positive value and as it was mentioned in the Section IV, the project can be considered economically feasible. Moreover, as it can be seen from Table X, after approximately 11 years of operation, the cumulative sum of net annual income exceeds the initial investment cost; therefore, it can be stated that the payback period of the project is about 11 years.

TABLE IX

ECONOMIC ANALYSES RESULTS

Parameters	*Value (€)*
Facility outcome	
Total Investment Cost (Anaerobic digester and Absorption cooling systems)	**9,323,772**
O&M	1,49637,20
Total outcome for the first year	1,49637,20
Facility income	
First year compost income	47,922
First year liquid fertilizer income	1,704,400
First year income for disposal of wastes (paid from municipality)	108,110
First year costs due to natural gas consumption before application of MSW anaerobic digester	968,477
First costs due to electric consumption for cooling before application of MSW anaerobic digester	75,680
Total income for the first year	**2,904,586**
Salvage Value (SV)	**498,910**

TABLE X

ECONOMICAL ANALYSES RESULTS

Year	*Annual income [€/Year]*	*Annual outcome [€/Year]*	*Net annual income [€/Year]*	*Sum [€/Year]*
1	2867504	1477611	1389893	1389893
2	2458423	1266813	1191609	2581503
3	2276317	1172975	1103342	3684845
4	2107701	1086088	1021613	4706458
5	1951575	1005637	945938	5652396
6	1807014	931146	875868	6528265
7	1673161	862172	810990	7339254
8	1549224	798307	750916	8090170
9	1434466	739173	695293	8785463
10	1328209	684420	643790	9429252
11	1229824	633722	596101	**1002535**
12	1138725	586780	551946	-
13	1054375	543315	511061	-
14	976273	503069	473205	-
15	903957	465805	438152	-
16	836997	431300	405697	-
17	774997	399352	376	-
18	717590	369771	348	-
19	664435	342380	322	-
20	615218	31702	298	-
Pr	28153580	14507403	-	-
Pr of SV	105673	-	-	-
PW	28259253	24358143	-	-

VI. Conclusion

In this study, using an aerobic digestion system operating with MSW and heating and cooling facilities located in Gazi University's main campus is investigated based on real data gathered from the University's authorities, and then an economic analysis is performed. Coupling an aerobic digestion unit with an existing heating/cooling facility provides economic and environmental-friendly solutions for MSW disposal problems, and provides a sustainable energy source for the University's energy demands. Some important results from this study are summarized as below:

i. To provide 126 MW of energy demand of the University, approximately 23,923 m^3 of biogas with calorific value of 20,900 kJ/$m^{3,}$ which can be obtained by digestion of 245.38 tons of MSW must be supplied to the system every day.

ii. 21 tons of compost and 2,160 m^3 of liquid fertilizer are obtained every day as the two most valuable by-products of the digestion facility.

iii. The economic analysis performed in this study shows that the Net Present Worth of the project is about 4,606,000 € which is a positive value and it means that the project can be considered as acceptable.

iv. Moreover, economic calculations reveal that the investment returns in approximately 11 years which is a considerably long period for an energy project to be economically feasible.

However, considering the benefits of sustainable and economical-friendly disposal of solid wastes of Gazi University's campus and a part of Ankara municipal, it can be said that such a long-term payback period can be acceptable.

References

1. **Igoni, A. H., Eze, C. L., Ayotamuno, M. J., Abowei M. F. N.,** Potentials of biogas generation from municipal solid-waste in the port Harcourt metropolis. *Proceedings of the 1st annual conference of science and technology forum*, vol. 1(2). Uyo, Nigeria; 2005. P. 67–72.
2. **Igoni,a A. H., Ayotamunoa M.J., Ezeb C.L., Ogajic S.O.T., Probertc S.D.,** Designs of anaerobic digesters for producing biogas from municipal solid-waste, *Applied Energy*, vol. 85, Issue 6, 2008, P. 430-438
3. **Angelidaki, I., Ellegaard, L., Ahring, B. K.,** Applications of the anaerobic digestion process. *Advances in biochemical engineering/biotechnology biomethanation*, vol. 82. Berlin: Springer; 2003, P. 1–33.
4. **Sotirios, K., Ioannis, B., Georgios, K.,** Development of an investment decision tool for biogas production from agricultural waste, *Renewable and Sustainable Energy Reviews*, 11, 2010, P. 1273-1282
5. **Murphy, J.D., Mckeogh, E.,** Technical, economic and environmental analysis of energy production from municipal solid waste, *Applied Energy*, 77, 2004, P. 407–427
6. **Lantz, M.,** The economic performance of combined heat and power from biogas produced from manure in Sweden-a comparison of different chp technologies, *Applied Energy*, vol. 98, 2012, P. 502-511
7. **Bruno, J. C., Ortega-López, V., Coronas, A.,** Integration of absorption cooling systems into micro gas turbine trigeneration systems using biogas: Case study of a sewage treatment plant, *Applied Energy*, vol. 86, 2009, P. 837-847
8. **Fahlén, E., Trygg, L., Ahlgren, E.,** Assessment of absorption cooling as a district heating system strategy – a case study, *Energy Conversion and Management,* No. 60, 2012, P. 115–124.
9. Ecoheatcool, Work packages, Brussels: Euroheat and Power, 2006, [Accessed 10.09.2013] Available:http://www.euroheat.org.
10. District cooling, balancing the production and demand in CHP, IEA District Heating and Cooling Annex V, Report 1999, T2, published by November, http://www.iea-dhc.org/scanned_brochures/8DHCT99-02LR.pdf.
11. Ltd. EcoCooling [Accessed 10.09.2013] Available: http://www.ecocooling.org/
12. **Eroglu, V.,** Klima Sistemlerinde Enerjinin Iktisadi Kullanımı. *Termodinamik Dergisi*, Istanbul, No: 97, 2000, P. 66-68,
13. Turkish Statistical Institute [Accessed 10.09.2013] Available: http://www.turkstat.gov.tr
14. **Öner, M. A.,** Evaluation of strategies which are oriented towards the disposal and recycling of domestic and jobsite waste into the energy in the province of Ankara, M.Sc. thesis. Ankara, Gazi University, 2005.
15. **Yılmazoğlu, M. Z., Amirabedin, E., Kayacan, I.,** Kentsel Katı Atıkların GazlaǪtırılması ile Isı, Buhar ve Elektrik Üretiminin Ġncelenmesi ***In:*** *18. ULUSAL ISI BİLİMİ ve TEKNİĞİ KONGRESİ,* Zonguldak Karaelmas Üniversitesi. 2011.
16. **Horuz, I., Callander, T. M. S.,** Experimental investigation of a vapor absorption refrigeration system, *International Journal of Refrigeration*, 27, 2004, P. 10–16,
17. **Madu, C., Sodeinde, O. A.,** Relevance of biomass in sustainable energy-development in Nigeria., *Proceedings of the national engineering conference and annual general meeting of the nigerian society of engineers,* 2001.
18. **Quoilin, S., Lemort, V.,** Technological and economical survey of organic rankine cycle systems, *5TH EUROPEAN CONFERENCE ECONOMICS AND MANAGEMENT OF ENERGY INDUSTRY*, 2007, Portugal.
19. TARIM GRUP Makina Pazarlama ve Dış Ticaret Ltd. [Accessed 10.09.2013] Available: http://www.tosuntarim.com
20. **Sivrioğlu, M, Yurdakul, M., İlbilgi, L., İç, Y. T.,** A comparative economic analysis of an absorption cooling system using geothermal energy against steam compression cooling systems, *TÜBAV Bilim* vol. 2, 2009, P. 26-36.

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Topal H., Atimtay A.T., Durmaz A., Olive Cake Combustion in a Circulating Fluidized Bed, *Fuel*, Vol 82, 1-8, 2003,

Atimtay A.T.,Topal H., Co-combustion of olivecake with lignite coal in a circulating fluidized bed, *Fuel*, Vol 83, 7-8, 859-867, 2004,

Kaynak B., Topal H., Atimtay A, Peach and apricot stone combustion in a bubbling fluidized bed, *Fuel Processing Technology*, Vol 86, 1175-1193, 2005.

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