APPLICATION OF TRIGENERATION WITH DIRECT CO-COMBUSTION OF POULTRY WASTE AND COAL
A Case Study in the Poultry Industry from Turkey

by

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This study implies the significance of a trigeneration (TG) system, which converts a single fuel source into three useful energy products (i. e. power, heating, and cooling), and focuses on the simulation of a TG system with direct co-combustion of poultry wastes. The methodology is applied to a case study in northwest of Turkey to investigate how local poultry manure and environmental conditions can be effective in the production of energy. In addition, thermodynamic assessment of the system is performed, and the performance of the TG system is assessed by using energy, exergy, and parametric analysis methods. Poultry litter to coal ratio was 50% at the beginning, then poultry litter ratio in the mixture was increased to 90%, and this has led to less CO_2 emissions from the TG and combined heat and power systems co-firing with poultry litter. With rice husk however the consumptions of TG and combined heat and power increased from 6533-6624 tonne per year, and 6549-6640 tonne per year, respectively. As a result, co-combustion of poultry waste can be considered as the best environmentally-friendly remedy to dispose chicken farm wastes, while catering the energy demand of the facility.

Key words: *clean energy, power plant, combined heat and power, trigeneration system, CO_2 emissions, exergy*

Introduction

In recent years, there has been a growing need for renewable resources along with increased environmental requirements to minimize the environmental impact and supply cost. Poultry waste (PW), which is one of the richest biomass, is also the main source of pollution obtained from poultry farming. However, PW that is being used as fertilizer in agriculture could be utilized as a RES in energy conversion systems. Using PW as fuel or secondary fuel in the chicken farms' combustion systems can be a noteworthy method in order to solve waste disposal problems, and reduce fossil fuel consumption and subsequent emissions. Zhu and Lee [1] indicated that the poultry industry generates a huge amount of waste as a by-product in confined areas. The PW mixture consists of the manure resulting from poultry production, bedding litter used for poultry housing (*e. g.* sawdust or rice husk), waste feed, dead birds, broken eggs, and removed feathers. Kelleher *et al*. [2] studied these byproduct components (*i. e.* litter and manure) that have a high nutritional value can be used as organic fertilizer. Therefore, they

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have traditionally been utilized as amendment by spreading on soil. However, Henihan *et al.* [3] researched that over-application can result in enrichment of water-soluble nutrients, and in eutrophication of water sources. There are some other alternative disposal routes for poultry waste such as: composting, anaerobic digestion, and gasification combustion. Billen *et al.* [4] have worked on electricity production from poultry litter manure and its environmentally friendly combustion technologies. In this study, the ash, which was produced by the fluidized bed combustor of BMC in the Netherlands, was used as a PK fertilizer. In other words, zero ash was produced in this system. Evaluation of poultry litter as a feasible fuel was studied by Davalos *et al.* [5]. In this study, wet and dry poultry litter fuel was examined according to calorific values, and the effects of their water contents on combustion energy. Palma [6] studied characterization, kinetics and modelling of gasification of poultry manure and litter as an overview. The interest of using poultry litter as fuel is increasing in relevant industries, therefore turkey litter is being used as fuel to generate electricity instead of using litter as fertilizer. Hence, Williams *et al.* [7] searched that the ammonia emissions were reduced by using turkey litter, and primary fossil fuels were saved in generating electric from biomass as well. Nevertheless, all around the world there is still a huge amount of fossil fuel been used as fuel in generating electricity. Emission modeling of fluidized bed, in which co-combustion of poultry litter and peat was studied by Henihan *et al.* [3]. In this study, chicken litter and peat were monitored in fluidized bed and recorded as gaseous emissions. These data were used in a dispersion model that was near site on a poultry farm in Ireland. Variables influenced both combustion and emission levels of pollutants such as SO_2, NO_x, and CO [3].

Combustion behavior of different kinds of torrefied biomass and their compositions with lignite was investigated by Toptas *et al.* [8] in Turkey. In this study, the combustion behavior of different kinds of torrefied biomass (lignocellulosic and animal wastes), and their compositions with lignite were investigated via non-isothermal thermogravimetric method under air atmosphere. Utilisation of poultry litter as an energy feedstock was studied by Lynch *et al.* [9]. In this study, they examined how the application in a small-scale fluidized bed could solve both energy and waste problems, by using poultry litter as fuel. In another study, Kwiatkowski *et al.* [10] investigated generating electricity in fixed bed gasification reactor by using poultry litter as fuel in a real industry-scale plant, which was located in city of Olsztyn, Poland. They analyzed the data, which was taken from this system and searched the profitability of gasification process in terms of technical parameters regarding emission standards. As it is known, waste management is a main job concerning industrial cycles with respect to EU Directives. Producing energy from wastes could be possible using different types of technology. Cotana *et al.* [11] studied energetic evaluation of poultry litter in a gasification thermal power plant. This research has been conducted by the University of Perugia. In these experiments, physical and chemical characterization of the manure were given, and the monitoring of the performances of the plant was shown by means of exhaust gases at the chimney. The PW combustion (or co-combustion) which provides a sustainable and environmentally friendly disposal technology, can get both space heating (or/and cooling), and power generation of the facility. Zhu and Lee [1], and Sweetena *et al.* [12] gave the advantages of the co-combustion of PW with coal: minimizing the poultry farming wastes, reducing the fossil fuel consumption, minimizing the system emissions, decreasing the anaerobic release of CH_4, NH_3, H_2S, and volatile organic acids due to the reduced storage time. The TG (also called combined cooling, heating and power, CCHP) which are based on combined heat and power (CHP) systems coupled to an absorption chiller can be recognized as one of the best technologies for recovering biomass effectively, and for purposes of heating, cooling and generating power. Previous studies have shown that the TG system is able to generate three useful energy forms with only a single fuel source [13-21]. However, for decades, TG systems have only utilized in a small number of food manufacturing and retail facilities with limited fuel sources as Suamir and Tassou [22] performed evaluation of integrated TG and CO_2 refrigeration systems. Nevertheless, Wang *et al*. [21] studied on type of renewable fuel such as jatropha oil and Eicker [23] worked renewable fuel such as wood, Bruno *et al*. [24] studied renewable fuel such as biogas from sewage and Huang *et al*. [25] researched renewable fuel such as willow, rice husk and miscanthus that these renewable fuels are potential fuels for TG systems. By considering these facts, a TG system based on a thermal boiler is co-fired with poultry waste and coal. This application would solve the waste disposal problems in chicken farms, and allow utility production at lower fossil fuel consumption, less air and water pollutants and reduced overall facility cost as Lai and Hui [26] has posed in their study. The primary objective of this study is to investigate the effect and the performance of the co-combustion of poultry waste and coal in a TG system. The objectives are: designing and simulating a TG system based on a steam boiler, a steam turbine and a single-effect absorption chiller, examining the performance of the system in CHP and TG mode, performing exergy and environmental analyses of the system including a determination of the exergy efficiency of the system for both configurations, investigation of the variation of fuel consumption rate, energy efficiency, exergy efficiency and CO_2 emissions of the system with different compositions of Tuncbilek coal and PW.

In this regard, at the first step, a TG system firing with Tuncbilek coal has been simulated in the THERMOFLEX simulation software, and then modified for co-firing with two types of PW. This work to the world literature has contributed that using poultry and coal as fuel to run a TG system was to be technically feasible as well as efficient and economical. Beside, this system is more environmental friendly than other classical systems. Moreover, this study can bring contributions to science, it can encourage the enhancement of other similar systems.

Methodology of the system

The methodology backward the modeling process of the CHP system was maintained the steady-state analysis for the producing energy. The energy system consists of two main modules: CHP and absorption chiller module. When system is in TG mode, the exhaust steam from the steam turbine is used to produce cooling energy via the absorption chiller. In addition, part of the remaining exhaust steam of waste heat is recovered by a heat exchanger to produce hot water at a temperature level sufficient for domestic hot water or heating (~85 °C). When there is no need for chilled water (coincides with winter months), the system can operate in CHP mode. The net electric output of the simulated system is around 253 kW at full capacity. This steam boiler worked by coal and biomass with air. Boiler was a circulating fluidized bed type boiler that produced energy and heat with the steam turbine.

In this study, Tuncbilek coal and two types of PW (chicken manure with sawdust and chicken manure with rice husk) are investigated. Both sawdust and rice husk are the raw materials for poultry litter and manure properties of PW particularly then moisture content, fractions of fixed volatiles and calorific values are important in combustion processes.

The TG can be recognized as one of the best technologies for the efficient improvement of biomass and for its heating, cooling and producing power, because CCHP based on CHP systems connected to absorption chillers are known. The TG, the electricity generated at the same time, is one step ahead of the cogeneration by finding useful heating and cooling from a single source of fuel. According to CHP, the otherwise lost heat is captured and used to create a cold effect in addition to power and heat. Second, the thermally driven system can be produced by heat pumps or dehumidifiers [27].

The schematic diagram proposed for the TG system integrated with a steam boiler is illustrated in fig. 1. Fluid circulation bed boiler works with coal biomass fuel. Energy is obtained from turbine steam and transferred to generators. In addition, the process is completed using heat exchanger, pump, and absorption chiller in the system.

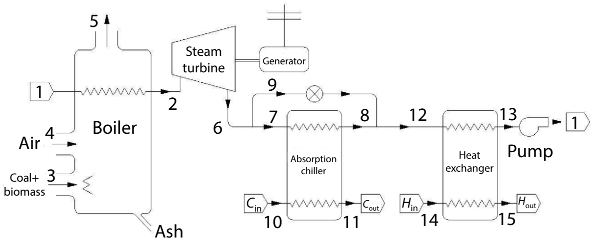

Figure 1. Schematic diagram of the proposed TG

Table 1. The characteristics of Tuncbilek coal, poultry litter with sawdust (PWS) and poultry litter with rice husk (PWR)

	PWS	PWR	Tuncbilek coal
Proximate analysis (as received %)			
Moisture	18.16	32.57	7.50
Volatile matter	56.17	48.39	27.50
Ash	16.64	10.85	23.70
Fix carbon	9.04	8.20	41.30
Total sulphur	0.60	0.00	–
Ultimate analysis (as dry basis %)			
Carbon	37.31	39.90	59.29
Hydrogen	4.41	4.79	4.61
Nitrogen	9.96	8.70	2.10
Sulphur	0.73	–	1.81
Thermal analysis [kcalkg^{-1}]			
Higher heating value	2992	2701	5553
Lover heating value	2688	2343	5273
Temperature sensitivity analysis [°C]			
Deformation temperature	1258	1360	–
Softening temperature	1417	>1500	–
Hemisphere temperature	>1500	>1500	–
Fusion temperature	>1500	>1500	–

Proximate, ultimate and temperature sensitivity analyses and calorific values corresponding to both PW types and Tuncbilek coal are presented in tab. 1. As can be seen from this table, high levels of moisture and ash are recorded for both PW types, which result in heating values approximately 50% that of the coal. Regarding the proximate analysis, coal has a higher carbon and sulfur content than poultry wastes, but on the contrary, nitrogen content is higher in waste samples. The hydrogen content is almost equal for all investigated samples. Due to the high mineral content, the ash composition of PWS is also analyzed and the results are presented in tab. 2. The exergy of a system is defined as the maximum available work that can be done by the system-environment combination. A higher value of exergy means a higher potential of obtainable work. The exergy analysis is the composite of the First- and Second- Laws of thermodynamics. In this analysis, heat does not have the same value as work, and exergy loss represents real loss of work. This analysis provides a quantitative measure of the quality of

Table 2. The analyses of ash of PWS

Parameters	PWS
K_2O	10.86
Na_2O	1.68
MgO	3.28
Al_2O_3	2.28
P_2O_5	10.19
S	6.0
Cao	15.82
Fe_2O_3	7.42

energy in terms of its ability to perform work, and leads to a more rational use of energy that Oktay [28] investigated similar study as a case of coal-fired power plant. Thus, in this study, the exergy analysis, which is applicable to any thermal system, has been applied to both CHP and TG cycle for CCHP combined production.

Exergy analysis of CHP and TG cycle

In the absence of nuclear, magnetic, electrical, and surface tension effects, the total exergy of a systemcan be divided into four components:

$$\dot{E}x = \dot{E}x_{PH} + \dot{E}x_{CH} + \dot{E}x_{PT} + \dot{E}x_{KT} \tag{1}$$

By neglecting potential, $\dot{E}x_{PT}$, and kinetic, $\dot{E}x_{KT}$ exergies eq. (1) can be rewritten:

$$\dot{E}x = \dot{E}x_{PH} + \dot{E}x_{CH} \tag{2}$$

The specific physical exergy, $\overline{ex}_{PH}$, can be expressed:

$$\overline{ex}_{PH} = h - h_0 - T_0(s - s_0) \tag{3}$$

where h, T, s, and subscript 0 indicate enthalpy, entropy temperature, and reference conditions, respectively.

The total exergy rate, $\dot{E}x$, can be written as a function of mass-flow rate, $\dot{m}$, and specific physical and chemical exergies:

$$\dot{E}x = \dot{m}[h - h_0 - T_0(s - s_0) - \overline{ex}_{CH}] \tag{4}$$

The molar specific chemical exergy, $\overline{ex}_{CH}$, of a substance can be obtained from standard chemical exergy tables relative to specification of the environment from Bejan *et al.* [29] that researched thermal design of power plant. The procedure for the determination of the chemical exergy based on stoichiometric combustion of coal has been developed by Bejan [30]. In this study, for the calculation of the specific chemical exergy of Tuncbilek coal, PWS and PWR, the same method was utilized.

Exergy efficiency of a thermodynamic system is the percentage of the exergy of the product (desired output) in terms of the fuel exergy provided to the system. Here, fuel exergy in general is defined as the whole source supplied to the system (for instance fuel, air, water, *etc.*). However, Second-law of thermodynamics which energy efficiency (exergy efficiency) is symbolized by, ε, and can be expressed:

$$\Sigma = \frac{\dot{E}x_P}{\dot{E}x_F} \tag{5}$$

Results and discussion

The proposed energy system of co-firing with Tuncbilek coal and biomass was successfully simulated using Thermoflex [31], and then it was operated in two modes (CHP and TG). Some technical and environmental data of the system firing with Tuncbilek coal is presented in tab. 3. For the technical performance of the system the energy and exergy efficiency for both CHP and TG configurations are shown. The CO_2, SO_2, and dust emissions are emitted, and their amounts are used for monitoring of the environmental impact of the systems. It can be seen that the process efficiency of TG (71.78%) is lower than that of the CHP (90.91%) configuration. Moreover, the TG system has a slight reduction in system emissions over the CHP option. However, it should not be ignored that the TG system offers cooling besides both heating and power generation.

Table 3. Technical and environmental data of the simulated system

Parameter / Fuel (coal and biomass)		
CHP mode	Unit	Value
Gross power	[kW]	258.6
Net power	[kW]	253.3
Net electric efficiency	[%]	10.2
CHP efficiency	[%]	90.1
Coal consumption rate	[t/h]	0.41
Hot water temperature	[°C]	84.2
Heat recovered from water-cooled condenser	[kW]	1992.8
Condensing pressure	[bar]	1.05
SO_2 emission	[t/year]	119.5
SO_2 emission	[kgGJ^{-1}]	1644.3
CO_2 emission	[t/year]	6657
CO_2 emission	[kgGJ^{-1}]	91413
Dust emission	[t/year]	625
Dust emission	[kgGJ^{-1}]	8602
TG mode	Unit	Value
Gross power	[kW]	251.8
Net power	[kW]	247.7
Net electric efficiency	[%]	10.0
TG efficiency	[%]	71.78
COP	–	0.67
Coal consumption rate	[t/h]	0.41
Cold water temperature	[°C]	5
Cooling load	[kW]	931.4
Hot water temperature	[°C]	84.2
Heat recovered from water-cooled condenser	[kW]	604.5
Condensing pressure	[bar]	1.05
SO_2 emission	[t/year]	119.2
SO_2 emission	[kgGJ^{-1}]	1644.3
CO_2 emission	[t/year]	6641
CO_2 emission	[kg/GJ^{-1}]	91633
Dust emission	[t/year]	623.5
Dust emission	[kgGJ^{-1}]	8602
General	Unit	Value
Ambient temperature	[°C]	25
Ambient pressure	[bar]	1.013

In order to investigate the feasibility of using poultry waste as a fuel or secondary fuel in the chicken farms, both options were modified and co-fired with two types of biomass, PWS and PWR.

The CHP mode results

Main purpose to utilize TG technology and biomass is not only financial, but also arranging some parameters like: amount of saved fuel, and reduction of emissions should also be taken into account by Kalhori *et al*. [32]. In this regard, beside the system efficiency, the variation of fuel consumption rate and CO_2 emission are investigated.

Figure 2(a) shows the effect of the different compositions of Tuncbilek coal and PW on fuel consumption rate of the CHP system. For both PW types increase of the coal share results in the decrease of fuel consumption. However, in all five cases, the fuel consumption of the PWS are higher than the PWR. Figure 2(b) shows the variation of the energy efficiency of the CHP system with respect to the different compositions of fuel. As can be seen in the figure, by increasing the coal ratio in coal-PWR composition, energy efficiency decreases very slightly and remains nearly constant. On the other hand, by increasing the coal ratio in coal-PWS composition, the energy efficiency of the CHP system increases. Figure 2(c) displays the variation of exergy efficiency of the CHP system with different compositions of Tuncbilek coal and PW. Similar to the variation of the energy efficiency, by increasing the coal ratio in the fuel compositions, energy efficiency decreases for coal-PWR compositions from 82.45-80.04%, and increases for coal-PWS compositions from 78.37-79.48%. The effect of the different compositions of coal and PW types on CO_2 emissions of the CHP system is illustrated in fig. 2(d). As can be seen from this figure, the increase of coal ratio has different effects on CO_2 emissions. The increase of the coal share in the fuel compositions from 50-90% results inapproximately 91 tonne per year increase of the CO_2 emissions of the CHP system co-firing with PWR. On the other hand, due to the lower

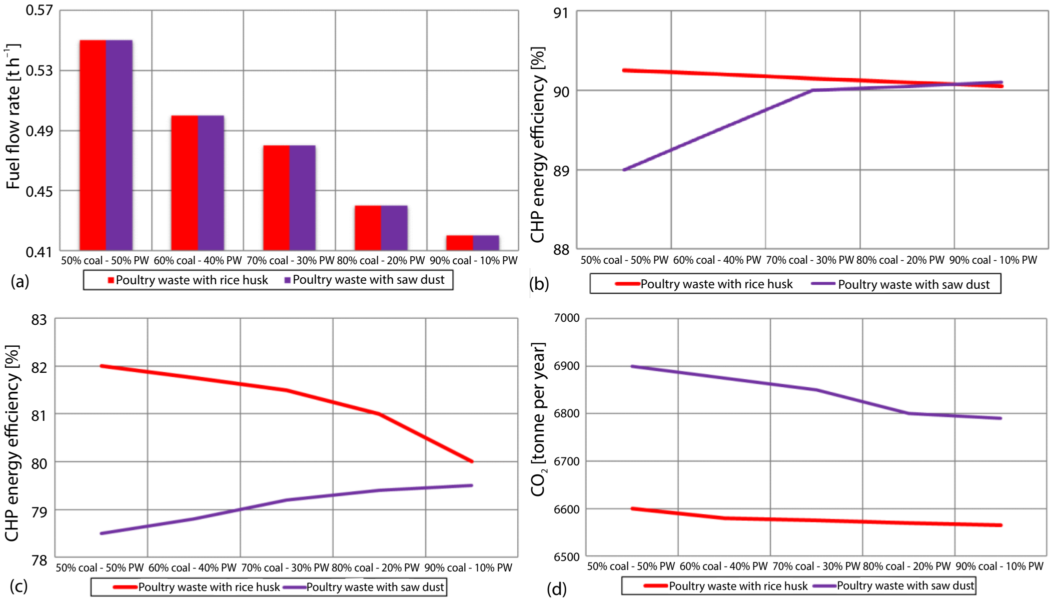

Figure 2. Variation of fuel consumption rate, energy efficiency, exergy efficiency, CO$_2$ emissions of CHP system with different compositions of Tuncbilek coal and PW (PW with rice husk and PW with sawdust); (a) variation of fuel consumption of the CHP system, (b) variation of energy efficiency of the CHP system, (c) variation of exergy efficiency of the CHP system, (d) variation of CO$_2$ emissions of the CHP system

coal-PWS consumption, it results in annually 183 tonne of CO$_2$ reduction for the CHP system co-firing with PWS. Comparing to previous study, overall CHP system thermal efficiency was found 65-85% by Pan *et al*. [33]. Eksi and Karaosmanoglu [34] indicated that CHP total system efficiencies could be from 60-85% for the generation of energy.

The TG mode results

In this part, the simulation results obtained through the variation of some essential parameters of the TG system for different compositions of Tuncbilek coal and PW are presented.

Figure 3(a) shows the fuel consumption rate against fuel types at different fuel compositions. It can be seen that, similar to the CHP mode, for both PW types, fuel consumption reduces approximately 110 kg/h. This is because of the lower calorific values of PWR and PWS than of that coal. Figure 3(b) illustrates the variation of energy efficiency of the TG system with different compositions of Tuncbilek coal, PW with rice husk, and PW with saw dust. It can be observed that increase of the coal ratio in the fuel compositions from 50-90% results in increase of the energy efficiency of TG system firing with PWS, from 71.52-71.72%. On the other hand, increase of the coal share in the fuel compositions has very low effect on TG system efficiency with PWR, and it remains almost constant around 71.77%. The effect of the different compositions of coal and PW on exergy efficiency of the TG system is shown in fig. 3(c) that the variations of the exergy efficiency follow almost similar trends to those of CHP system. For the coal-PWR composition, exergy efficiency decreases from 65.59-63.71%, while for the coal-PWS composition, it increases from 62.34-63.26%. Figure 3(d) displays the variation of CO$_2$ emissions of the TG system with different compositions of Tuncbilek coal and PW. It can be obviously seen in this figure that the increase of the coal share

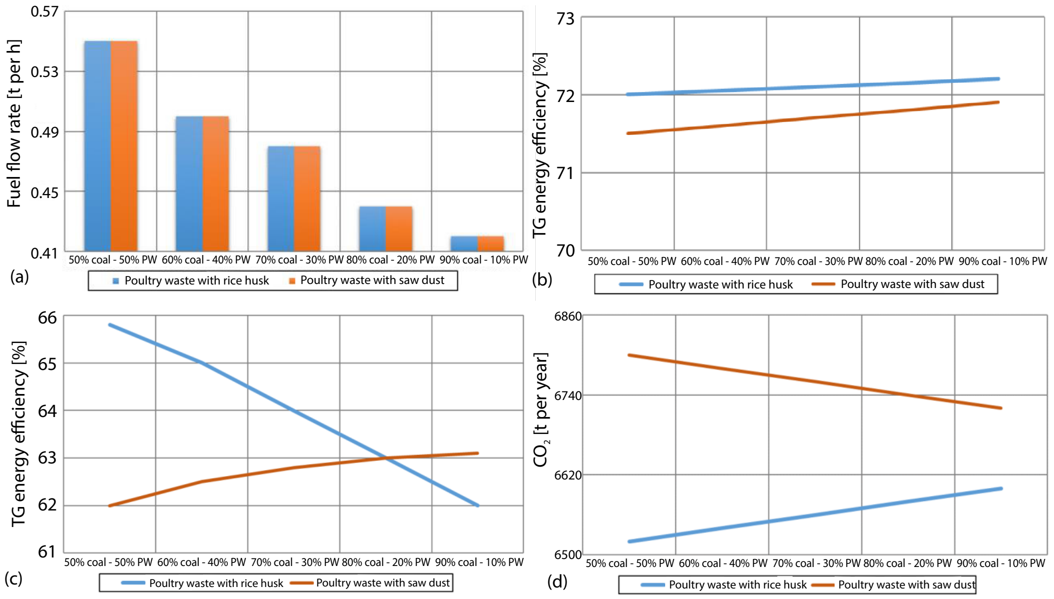

Figure 3. Variation of fuel consumption rate, energy efficiency, exergy efficiency, CO_2 emissions of TG system with different compositions of Tuncbilek coal and PW (PW with rice husk and PW with sawdust); (a) variation of fuel consumption of the TG system, (b) variation of energy efficiency of the TG system, (c) variation of exergy efficiency of the TG system, (d) variation of CO_2 emissions of the TG system

in fuel compositions from 50-90% results in the increase of the CO_2 emissions of the TG system co-firing with PWR from 6533-6624 tonne per year, but for the TG system co-firing with coal-PWS, it results in a reduction of CO_2 from 6857-6675 tone per year. Similar previous studies were investigated that Moussawa *et al*. [27] posed efficiency of combined cycle CHP and TG (CCHP) systems around 70-90%. Chitsaz *et al*. [35] found that the total energy efficiency of the TG system with anode gas recycle (Tri-SOFC-AR) was 82.5%.

Conclusion

The comprehensive simulation and thermodynamic analysis of a TG system for electricity generation, heating and cooling has provided some useful information. The following conclusions can be made from the theoretical study. Energy and exergy efficiencies of TG system are lower than that of the CHP only system. In addition, the TG system has slight reductions in system emissions compared to the CHP option. However, it should not be ignored that the TG system offers cooling besides heating and power generation. Decreasing of the coal share in the fuel compositions from 90-50% results in the fuel consumption of both systems. However, in all five-fuel compositions, the fuel consumption of the PWS is higher than of the PWR. For both CHP and TG systems, the increase of the coal share in the fuel composition mixture results in an increased energy and exergy efficiency of the system co-firing with PWS, but the same result cannot be mentioned about the system co-firing with PWR. The increase of the coal share in fuel composition mixture from 50-90% results in the increase of the CO_2 emissions for the TG and CHP systems co-firing with PWR from 6533-6624 tonne per year and 6549-6640 tonne per year, respectively. However, for the TG and CHP systems co-firing with PWS, it results in a reduction of CO_2 from 6857-6675 tonne per year and 6874-6691 tonne per year, respectively.

Finally, it can be concluded that it is technically feasible to use PW and coal as the fuel to operate a TG system. This study to literature has been contributing to the use of poultry and coal as a TG system to be technically feasible as well as efficient and economical.

Nomenclature

$\dot{E}x$ – total exergy of a system (= $\dot{E}x_{PH} + \dot{E}x_{CH} + \dot{E}x_{PT} + \dot{E}x_{KT} =$ $= \dot{m}\,[h - h_0 - T_0\ (s - s_0) - \bar{e}x_{CH}]$), [kW]
$\dot{E}x_{CH}$ – exergy of chemical, [kW]
$\dot{E}x_{KT}$ – exergy of kinetic, [kW]
$\dot{E}x_{PH}$ – exergy of physical, [kW]
$\dot{E}x_{PT}$ – exergy of potential, [kW]
$\bar{e}x_{CH}$ – the specific physical exergy, [kJ/kg]
$\bar{e}x_{PH}$ – the specific physical exergy (= $h - h_0 - T_0\,(s - s_0)$), [kJ/kg]
h – entalphy, [kJ/kg]
s – entrophy, [kJ/kg K]
T – temperature, [℃]

Greek symbols

ε – exergy efficiency (= $\dot{E}x_p / \dot{E}x_F$), [%]

Subscript

0 – dead state (reference condition), [–]

Acronyms

CHP – combined heat and power
CCHP – combined cooling, heating and power
PW – poultry waste
PWR – poultry litter with rice husk
PWS – poultry litter with sawdust
TG – trigeneration

References

[1] Zhu, S., Lee, S. W., Co-Combustion Performance of Poultry Wastes and Natural Gas in the Advanced Swirling Fluidized Bed Combustor (SFBC), *Waste Management*, *25* (2005), 5, pp. 511-518
[2] Kelleher, B. P., *et al.,* Advances in Poultry Litter Disposal Technology – A Review, *Bioresource Technology, 83* (2002), 1, pp. 27-36
[3] Henihan, A. M., *et al.*, Emissions Modeling of Fluidised Bed Co-Combustion of Poultry Litter and Peat, *Bioresource Technology, 87* (2003), 3, pp. 289-294
[4] Billen, P. *et al.*, Electricity from Poultry Manure: A Cleaner Alternative to Direct Land Application, *Journal of Cleaner Production, 96* (2015), June, pp. 467-475
[5] Davalos, Z., *et al.*, Evaluation of Poultry Litter as a Feasible Fuel, *Thermochimica Acta, 394* (2002), 1-2, pp. 261-266
[6] Palma, C. F., Characterisation, Kinetics and Modelling of Gasification of Poultry Manure and Litter: An Overview, *Energy Conversion and Management, 53* (2012), 1, pp. 92-98
[7] Williams, A. G., *et al.*, Environmental Benefits of Using Turkey Litter as a Fuel Instead of a Fertiliser, *Journal of Cleaner Production, 113* (2016), Feb., pp. 167-175
[8] Toptas, A., *et al.*, Combustion Behavior of Different Kinds of Torrefied Biomass and Their Compositions with Lignite, *Bioresource Technology, 177* (2015), Feb., pp. 328-336
[9] Lynch, D., *et al.*, Utilisation of Poultry Litter as an Energy Feedstock, *Biomass and Bio Energy, 49* (2013), Feb., pp. 197-204
[10] Kwiatkowski, K., *et al.*, Bioenergy from Feathers Gasification-Efficiency and Performance Analysis, *Biomass and Bio Energy, 59* (2013), Dec., pp. 402-411
[11] Cotana, F., *et al.*, Energy Valorization of Poultry Manure in a Thermal Power Plant: Experimental Campaign, *Energy Procedia, 45* (2014), Jan., pp. 315-322
[12] Sweetena, J. M., *et al.*, Co-Firing of Coal and Cattle Feedlot Biomass (FB) Fuels – Part I: Feedlot Biomass (Cattle Manure) Fuel Quality and Characteristics, *Fuel, 83* (2003), 10, pp. 1167-1182
[13] Wang, Y. D., *et al.*, Characteristics of a Diffusion Absorption Refrigerator Driven by the Waste Heat from Engine Exhaust, *Proceedings of the Institution of Mechanical Engineers – Part E: Journal of Process Mechanical Engineering*, *220* (2006), 3, pp. 139-149
[14] Wang, Y. D. *et al.*, An Experimental Investigation of a Household Size Trigeneration, *Applied Thermal Engineering*, *27* (2007), 2-3, pp. 576-585
[15] Kong, X. Q., *et al.*, Energy Efficiency and Economic Feasibility of CCHP Driven by Sterling Engine, *Energy Conversion and Management, 45* (2004), 9-10, pp. 1433-1442
[16] Temir, G., Bilge, D., Thermoeconomic Analysis of a Trigeneration System, *Applied Thermal Engineering, 24* (2004), 17-18, pp. 2689-2699
[17] Calva, E. T., *et al.*, Thermal Integration of Trigeneration Systems, *Applied Thermal Engineering, 25* (2005), 7, pp. 973-984

[18] Rong, A., Lahdelma, R., An Efficient Linear Programming Model and Optimization Algorithm for Trigeneration, *Applied Energy, 82* (2005), 1, pp. 40-63
[19] Ziher, D., Poredos, A., Economics of a Trigeneration System in a Hospital, *Applied Thermal Engineering*, *26* (2006), 7, pp. 680-687
[20] Temir, G., *et al.,* An Application of Trigeneration and Its Economic Analysis, *Energy Sources, 26* (2004), 9, pp. 857-867
[21] Wang, Y., *et al.*, Trigeneration Running with Raw Jatropha Oil, *Fuel Processing Technology, 91* (2010), 3, pp. 348-353
[22] Suamir, I. N., Tassou, S. A., Performance Evaluation of Integrated Trigeneration and CO_2 Refrigeration Systems, *Applied Thermal Engineering, 11* (2012), 2, pp. 1-9
[23] Eicker, U., Biomass Trigeneration with Decentral Cooling by District Heating Networks, *Proceedings*, 2nd Polygeneration conference, Tarragona, Spain, 2011
[24] Bruno, J. C., *et al.*, Integration of Absorption Cooling Systems into Micro Gas Turbine Trigeneration Systems Using Biogas: Case Study of a Sewage Treatment Plant, *Applied Energy, 86* (2009), 6, pp. 837-847
[25] Huang, Y., *et al.,* Biomass Fuelled Trigeneration System in Selected Buildings, *Energy Conversion and Management, 52* (2011), 6, pp. 2448-2454
[26] Lai, S. M., Hui, C. W., Feasibility and Flexibility for a Trigeneration System, *Energy, 34* (2009), 10, pp. 1693-1704
[27] Moussawi, H. A. *et al.*, Selection Based on Differences between Cogeneration and Trigeneration in Various Prime Mover Technologies, *Renewable and Sustainable Energy Reviews, 74* (2017), July, pp. 491-511
[28] Oktay, Z., Investigation of Coal-Fired Power Plants in Turkey and a Case Study: Can Plant, *Applied Thermal Engineering, 29* (2009), 2-3, pp. 550-557
[29] Bejan, A., *et al.*, *Thermal Design and Optimization*, John Wiley and Sons, Inc., New York, USA, 1996
[30] Bejan, A., *Advanced Engineering Thermodynamics*, John Wiley and Sons, Inc., New York, USA, 1998
[31] ***, Thermoflow, *Thermoflex Version 18*, Thermoflow Inc., Sauthborough, Mass., USA, 2008
[32] Kalhori, S. B., *et al.,* Mashad Trigeneration Potential – An Opportunity for CO_2 Abatement in Iran, *Energy Conversion and Management, 60* (2012), Aug., pp. 106-114
[33] Pan, S. Y., *et al.*, Strategies on Implementation of Waste-to-Energy (WTE) Supply Chain for Circular Economy System: A Review, *Journal of Cleaner Production, 108* (2015), Dec., pp. 409-421
[34] Eksi, G., Karaosmanoglu, F., Combined Bioheat and Biopower: A Technology Review and an Assessment for Turkey, *Renewable and Sustainable Energy Reviews, 74* (2017), June, pp. 1313-1332
[35] Chitsaz A. *et al.,* Effect of Recycling on the Thermodynamic and Thermoeconomic Performances of SOFC Based on Trigeneration Systems, A Comparative Study, *Energy, 124* (2017), Apr., pp. 613-624

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