ANALYSIS OF WASTE TRANSPORT RELATED BIOGAS UTILIZATION

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1. INTRODUCTION

In the last few thousand years, nature has provided a stable base of living and almost infinite supply to reserve the biosphere to humanity. In the early ages, humanity made changes to the environment with limited technology, but the rate was infinitesimal compared to the size of the natural environment. Global changes were not detected. In the last two or three hundred years, there has been an explosion in the development of the industrial and technical sector that supplied people with a multiplied set of tools to encroach on natural environment. The motorization has been developed so dynamically that the air, soil, water pollution is considerable to the amounts of those found on the Earth. Sustainable development is a kind of development where the pace of technical development, the satiation of increasing supply and the raw materials and resources of the Earth are poised so that the rate of living and the opportunities of the future generations should not decline. This paper is focusing on the analysis of combustion properties of biogases from the aspect of waste transport related utilization. The utilization of renewable alternative energy sources like liquid bio-fuels [7, 10] or gaseous fuels will have a major role in mitigating the climate change while the increasing energy and mobility demand of the humanity need to be fulfilled and the sustainable development should be maintained [3]. Renewable gaseous fuels like biogases utilized in gas engines can be an alternative and effective way to fulfill remarkable part of these demands [3, 6, 13]. The waste transport related energetic utilization of biogases is not fully worked out yet because the combustion characteristics of biogas – due to its CO_2 content – differs from those of conventional fuels like natural gas or PB gas, which are already used in the transport sector.

2. THEORETICAL INVESTIGATION

Approximately a quarter of the total industrial emission of CO_2 caused by humanity is produced by road transportation that contributes to climate change. Within the transport sector, the road transport market share is the largest and is increasing due to its superior service in terms of greater flexibility, reliability, speed and a lower probability of damage [2]. Therefore every attempt that decrease the contribution of road transport sector is worth of consideration. In this paper the analysis of waste transport related waste based biogas utilisation has been investigated. The CO_2 content of biogases has adverse impact on the combustion properties because CO_2 is an incombustible component like the N_2 content of air. With increasing CO_2 content the two significant combustion parameters: the adiabatic flame temperature and the laminar flame velocity decrease (Fig. 1.) that can cause burning instability and stretched combustion [4]. The decreasing flame temperature can lower thermal efficiency. That is why the incombustible content of waste based biogas needs to be considered.

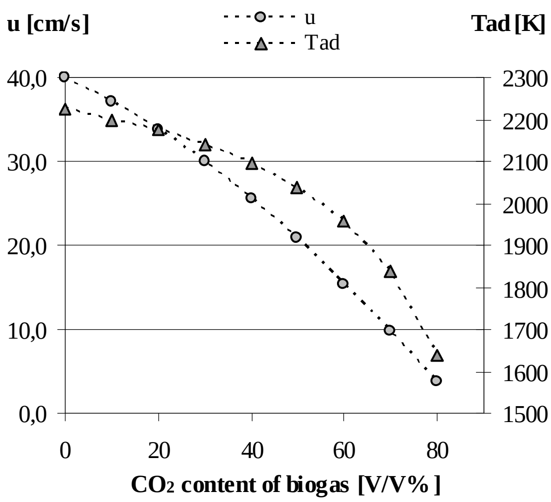

Fig. 1. Adiabatic flame temperature and laminar flame velocity of biogases with various CO_2 content, calculated at $\lambda = 1$, 273 K, 101325 Pa
(*source: own calculations*)

The values of these two parameters (adiabatic flame temperature [K], laminar flame velocity [cm/s]) are affected partly by the composition of the gaseous fuel and are influenced by the LHV (*Lower Heating Value*) of biogas, which is relatively low. In case of 40% CO_2 content the LHV is around 20 MJ/m^3 (Fig. 2.). From the point of view of operating the biogas fuelled combustion machine, apart from the biogas LHV, the Wobbe number is also important parameter. The Wobbe number expresses the heat load of the combustion machine, and can be calculated from:

$$Wo = \frac{HHV}{\sqrt{n}} \tag{1}$$

Where: the HHV is the higher heating value [MJ/m3], n - is the relative density, which can be calculated from the densities of fuel and air:

$$n = \frac{r_{fuel}}{r_{air}} \tag{2}$$

The Wobbe number of a gaseous fuel with similar HHV can vary if the composition of this fuel varies and changes the relative density. As far as the stable engine run is considered the variation of these two parameters should be kept in the range of ±5%. Thus, it is obvious that neither the LHV nor the Wobbe number can be held in the required range due to unstable biogas composition, in which the CO_2 content can vary in the limits of from 30 to 40% by volume (Fig. 2.) [11].

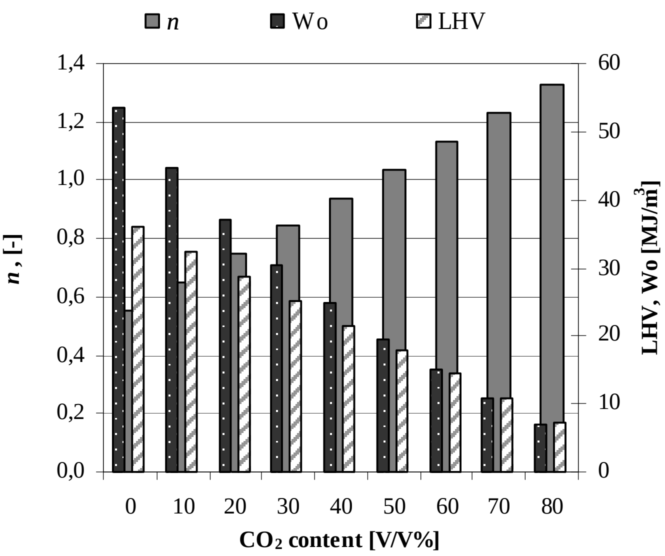

Fig. 2. LHV, Wobbe number and relative density of different biogases against CO_2 content, * calculated at 273 K and 101325 Pa
(*source: own calculations*)

The CO_2 emission is an important issue with respect to climate change, because CO_2 can contribute to global warming, so, it is necessary to consider the fact that the CO_2 as product of biogas combustion will remain in the atmosphere after combustion. Fig. 3. presents the maximum CO_2 proportion of the exhaust gas (CO_2max%) and the exhaust gas volume (Vfg) of different biogases calculated at stoichiometric combustion terms.

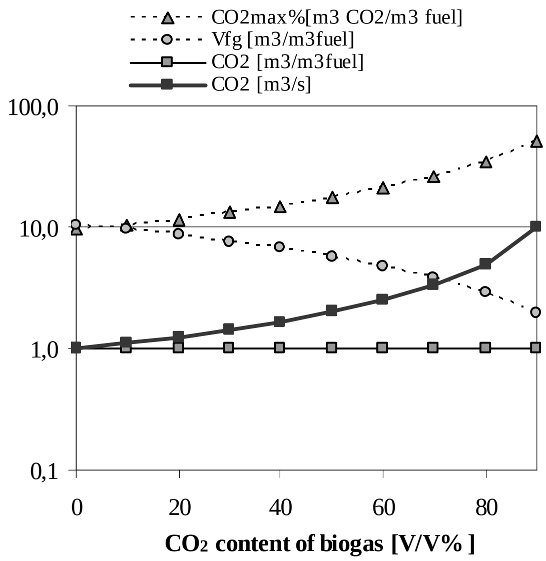

Fig. 3. The values of CO_{2max}, V_{fg} and CO_2 emission of different biogases against CO_2 (inert) content
(*source: own calculations*)

With increasing the CO_2 content in the biogas its emission (CO_2 [m3/m3fuel]) is constant although CO_2max% increases, while the exhaust gas amount (Vfg) decreases. As the LHV of biogases decreases with their inert content, to keep constant heat input the biogas consumption need to be increased. Therefore the consumption weighted specific CO_2 emission of biogas (CO_2 [m3/s]) need to be determined as well, that is higher than the CO_2 emission of natural gas, but presently this CO_2 emission does not have to be taken into account as the global warming issue because it was not produced from fossil fuel and the time scale of CO_2 capture for biogas production and CO_2 emission from biogas combustion are the same, therefore there is no additional emission of CO_2.

3. MEASUREMENTS

To determine the IC engine usefulness for biogas combustion laboratory tests were made on the gas engine unit at the Department of Energy Engineering – BUTE. The measurements were performed at both constant speed and the air excess ratio. From the energetic point of view of the engine operation: to keep the constant heat input the consumption need to be increased with the CO_2 content of biogas because increase in CO_2 content causes LHV decrement. But due to the high incombustible content improper combustion might take place, therefore, even with increased fuel consumption the power of the engine may decrease. The potential power drop is not really significant under 30V/V% CO_2 content but, it is significant above this limit. (Fig. 4.). Additionally, the figure. 4 depicts the measured CO_2 content of the exhaust gas which is extra enriched with the CO_2 content from biogas. The increment is non linear, but it is in good correlation with the results from the theoretical calculations [5, 8, 9[.

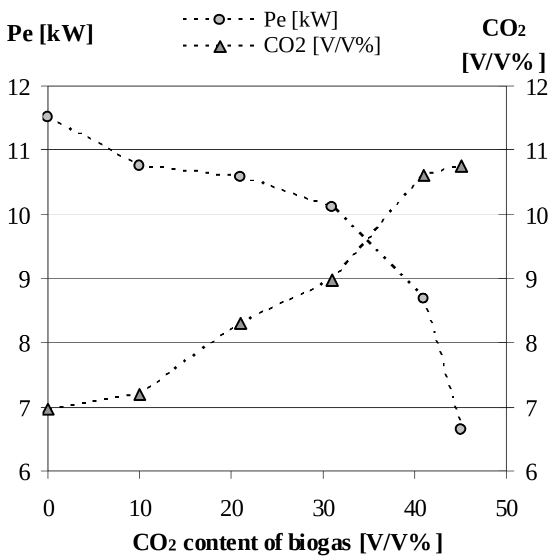

Fig. 4. CO_2 content of exhaust gas and effective power against the CO_2 content of biogas (*source: own measurements*)

4. BIOGAS UTILIZATION POSSIBILITIES IN WASTE TRANSPORT

On the basis of both theoretical analysis and tests of biogases someone can conclude that the waste transport related energetic utilization of biogases in gas engines is limited because the CO_2 content lengthen the combustion duration. Above a given CO_2 content the combustion does not even take place as the biogas consumption increases so does the CO_2 content in the exhaust gas. The negative impact of CO_2 on the combustion process and the effective power is noticed . Today it is already a well-known fact, that all over the world and here in the European Union passenger and freight traffic (including waste transportation) are continually growing from year to year. A correlation can be experienced between economic efficiency and the waste production. The logistic provider network has many participants; these are connected to each other dynamically. In this network the route of the stock, semi-finished product, the product, the workforce, and the waste can be distincted and the logistic tasks being attached to them. Nowadays, yield process' deliveries are much more organised, then those which generate and deliver raw materials from the waste. The waste logistic systems are logistical challenges, because waste materials' flows are not constant. The quantity and quality of the wastes of production, consumption and recycling are varying in time and space. Because of that the complexity of network control is going to increases, demands more resource to manage the dynamic transport demands at the total network [1]. One solution could be to use the waste based biogas in waste transportation. Biogas is a high methane containing gaseous substance that is produced primarily through biological breakdown of organic matter in the absence of oxygen. The process of anaerobic conversion occurs naturally at the bottom of ponds and gives rise to marsh gas (or methane). The main component of biogas is methane; it content is depending from the feedstock, technological process and typically is in the range between 55 and 80% [12]. For waste gas transport related utilisation the biogas should be cleaned. In that case the cleaned biogas can be used in the CNG (*Compressed Natural Gas*) fueled internal combustion engine. The authors have investigated the economic feasibility of changing combustion system. Due to the high cost of changing combustion system diesel oil to CNG and the higher price of a new CNG vehicles the economically feasible solution could be the operation with CNG-diesel oil mixture where the adaptation costs are lower. In this operation, the CNG added next to the diesel oil. In the next table, we calculate the profits in different cases with CNG mix operation. We used 800.000 HUF (approx. € 3200) as a rebuilt cost of vehicle, the net price of the gasoline is 229 HUF (approx. € 0.916) and the net price of the CNG is 178.8 HUF (approx € 0.71).

Table 1.
Profit of the year with CNG mix operation (rate of return: <2 year; <3 year; <4 year; >4 year)

Consumption (l/100 km)	Duration length / year (km)											
	15,000	20,000	25,000	30,000	35,000	40,000	45,000	50,000	55,000	60,000	65,000	70,000
5								100,305	110,335	120,366	130,396	140,427
6							108,329	120,366	132,402	144,439	156,475	168,512
7						112,341	126,384	140,427	154,469	168,512	182,555	196,597
8					112,341	128,390	144,439	160,488	176,536	192,585	208,634	224,683
9				108,329	126,384	144,439	162,494	180,549	198,604	216,658	234,713	252,768
10			100,305	120,366	140,427	160,488	180,549	200,610	220,671	240,732	260,792	280,853
11			110,335	132,402	154,469	176,536	198,604	220,671	242,738	264,805	286,872	308,939
12			120,366	144,439	168,512	192,585	216,658	240,732	264,805	288,878	312,951	337,024
13		104,317	130,396	156,475	182,555	208,634	234,713	260,792	286,872	312,951	339,030	365,109
14		112,341	140,427	168,512	196,597	224,683	252,768	280,853	308,939	337,024	365,109	393,195
15		120,366	150,457	180,549	210,640	240,732	270,823	300,914	331,006	361,097	391,189	421,280
16		128,390	160,488	192,585	224,683	256,780	288,878	320,975	353,073	385,170	417,268	449,366
17	102,311	136,415	170,518	204,622	238,725	272,829	306,933	341,036	375,140	409,244	443,347	477,451
18	108,329	144,439	180,549	216,658	252,768	288,878	324,988	361,097	397,207	433,317	469,426	505,536
19	114,347	152,463	190,579	228,695	266,811	304,927	343,042	381,158	419,274	457,390	495,506	533,622
20	120,366	160,488	200,610	240,732	280,853	320,975	361,097	401,219	441,341	481,463	521,585	561,707

(source: own calculation)

As it sawn on the table, by trucks it is easy to calculate the parameters of the CNG mix operation. Although the density of CNG station is low in case of waste transportation it does not seem to be a problem because the destination of every turn – the deposit of waste – is the refueling station. Reducing greenhouse gas emission will cost money, but the amounts required are clearly affordable. It is important to remember that climate policies can bring many win-win benefits. Reducing greenhouse gas emission might be one of the international community’s top priorities over the coming decades. There will be many difficulties and detour along the road to build climate friendly economies.

5. REFERENCES

[1] *A Kosztyo, Z Nagy, Á Török*: **The Effect of Waste Logistic on Environmental Impact of Road Transport**, Acta Technica Jaurinensis Series Logistica, Vol 1., No. 2., pp365-370, 2008

[2] *Á Török*: **Climate change and road transportation sector**, in Proceedings of the International Conference on Environmental Management, Engineering, Planning and Economics (CEMEPE) Skiathos, June 24-28 2007, 2569–2574.

[3] *Á Török*: **Theoretical estimation of the environmental impact of biofuel mixtures**, Transport

24(1): 26-29, 2009

[4] *Á. Bereczky, Gy. Gróf, V. B. Kovács, S. Könczöl, F. Lezsovits, A. Meggyes, A. Penninger, K. Sztankó:* **Utilization of Gas Mixtures Having High Inert Content Generated from Biomass in Gas-Engine and in Gasturbine**, Deutscher Flammentag - Verbrennung und Feuerungen Braunschweig, 267-272, 2005

[5] *A. Henham, M.K. Makkar*: **Combustion of simulated biogas in a dual-fuel diesel engine**, ENERGY CONVERSION AND MANAGEMENT Volume: 39, Issue: 16-18: p2001-2009, 1998

[6] *A. Meggyes, Á. Bereczky*: **Energetic analysis of combined gas engine systems**, Energetika, 2007/3: 18-22 (in Hungarian)

[7] *Bereczky Á,*: **Utilisation of biofuels in internal combustion engines**, Proceedings of Conference on Heat Engines and Environmental Protection, 43-47, 2008

[8] *J. D. Huang, R. J. Crookes:* **Assessment of simulated biogas as a fuel for the spark ignition engine**, FUEL Volume: 77, Issue: 15: p1793-1801, 1998

[9] *R. Uma, T. C. Kandpal, V. Kishore:* **Emission characteristics of an electricity generation system in diesel alone and dual fuel modes**, BIOMASS & BIOENERGY, Volume: 27, Issue: 2: p195-203, 2004

[10] *T. Laza, Á. Bereczky*: **Determination of the Evaporation Constant in Case of Pure and with Alcohol Mixed Rape Seed Oil,** Brassov, 16th International Conference in Mechanical Engineering, 232-237, 2008

[11] *V. B. Kovács, A. Meggyes, Á. Bereczky*: **Investigation of utilization of pirolysis gases in IC engine**, Proceeding of Sixth Conference on Mechanical Engineering, 153-157, 2008

[12] *Zöldy Máté*: **Potential future renewable fuel challanges for internal combustion engine**, JÁRMŰVEK ÉS MOBIL GÉPEK 4: 397-403 (2009),

[13] *S. Szwaja*: **Hydrogen rich gases combustion in the IC engine**, Journal of Kones – Powertrain and Transport, Warsaw 2009, Vol.16, No.4, 447-455 (2009),

ANALYSIS OF WASTE TRANSPORT RELATED BIOGAS UTILIZATION

Summary: Due to the increasing energy demand and mobility of the human population and in order to keep the sustainable development there is a major need to utilize alternative energy sources. The use of biogases as a source of renewable energy could provide an effective and alternative way to fulfil remarkable part of this energy demand. As biogases have a high inert content, their heating value is low. The energetic utilization of these low heating value renewable gaseous fuels is not fully worked out yet because their combustion characteristics significantly differ from the liquid fuels that are used nowadays in waste transportation, and this way they are not usable or their utilization is limited in devices with conventional equipment Thus theoretical and experimental analysis was made to investigate the usability of biogases in waste transportation vehicles. Further more economic investigation was made for determining the feasibility of changing combustion system.