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Analysis on Life Cycle Energy Consumption and Emission of Vehicle Gas Produced by Kitchen Waste

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Abstract. Based on the life cycle analysis method, the life cycle analysis model of the energy consumption and emission of the vehicle gas which was produced by kitchen waste's anaerobic fermentation was established. By calculating each phase of the life cycle energy consumption and emission of biomass vehicle gas, by contrastive analysis between the research result and the conventional diesel oil, this research concludes that using biomass vehicle gas produced by kitchen waste instead of using conventional diesel fuel in urban buses has a better energy conservation and emission reduction effect.

1. Introduction

In the wake of the rapid development of China's social economy, the energy demand is burgeoning. The degree of dependence on import of oil resources surpasses 60% [1]. Following the rapid development of urbanization, car ownership continues to increase at the same time. The air quality in the city environment keeps worsening day after day. Energy conservation and emission reduction has become a main problem the human beings are facing nowadays. Carrying out the diversification of the urban buses fuel is an effective way of dealing with this challenge [2, 3]. As a renewable biological energy source, methane not only can take full advantage of deserted kitchen waste to change the disposal way of the kitchen waste in the productive process, but also can reduce environmental pollution at the same time. At present, to replace the conventional vehicle fuel by vehicle gas that is produced by methane has become more and more promotable [4, 5].

Referring to living examples of kitchen waste's dealing project of Nanning City, this research, with Life Cycle Assessment(LCA), analyzes energy consumption and emission of vehicle gas produced by kitchen waste's anaerobic fermentation, makes a comparison between such technical route and the traditional burning diesel fuel, thus providing theoretical basis for the comprehensive utilization of kitchen waste in the development of the technology of biomass vehicle gas.

2. Analysis model of biomass vehicle gas

2.1. Brief introduction of life cycle theory

Starting with raw material production, followed by raw material processing, product manufacturing, product packaging, transporting, selling, to be used, recycled and repaired by customers, eventually to be recycled, dealt with or disposed as a waste, this process which seems to be "from birth to death"of a product is called a product's life cycle. Energy consumption and the emission of the environmental pollution can be happened in every phase. As a result, pollution prevention and effective utilization of the resources should be existing in every phase of the product life cycle. LCA is an evaluation methodology that is used to evaluate a product or a producing activity from raw material extraction, processing and the final disposal [6].

2.2. System boundary

The starting point of the life cycle range of the biomass vehicle fuel gas produced by kitchen waste anaerobic fermentation is the kitchen waste produced by restaurants, hotels, dining rooms and other locations. This kitchen waste will be collected, transported and pre-dealt, it will go through anaerobic fermentation, biogas treatment and then it will be used in vehicles until it is entirely used up, as shown in the figure 1. Non-biomass (plastics, papers, metals, woods, etc.) that is produced in the pre-processing stage of the waste will be used in landfill or be in classification collection. This type of non-biomass is not the same system as vehicle fuel gas, so it is not included in this research. Residue (biogas residue and biogas slurry) of anaerobic digestion will be used to produce organic fertilizer, it is also not included in this research, neither. This research does not contain energy consumption or pollutant emission caused by equipment or building projects, neither.
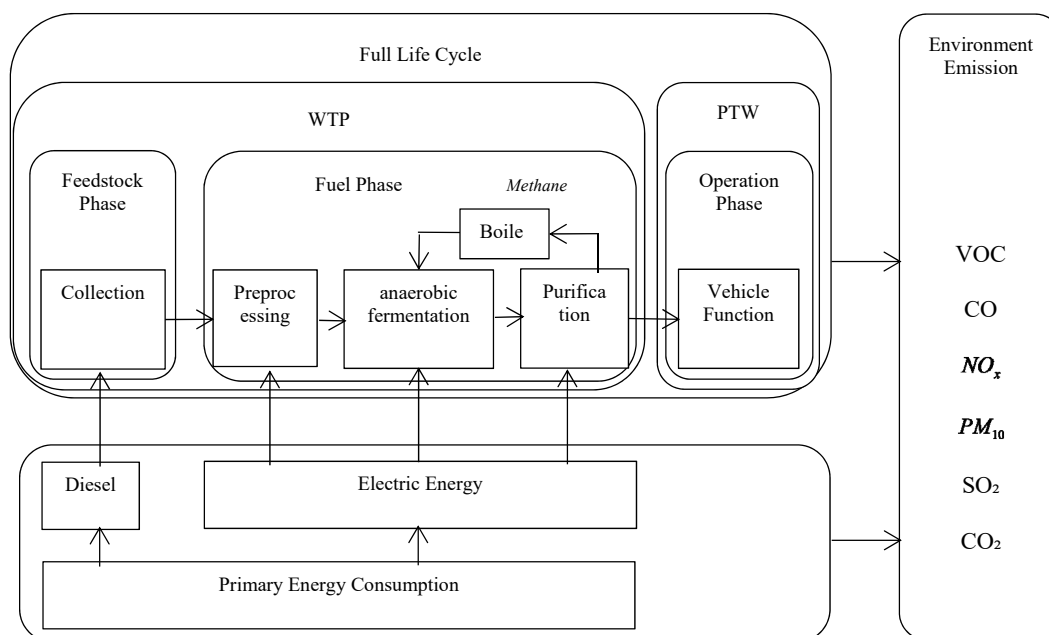

Figure 1. Life cycle of biomass vehicle gas

2.3. Establishment of analysis model

The system of vehicle fuel gas produced by kitchen waste can be divided into three stages, which are feedstock phase (collection and transportation of raw materials), fuel phase (waste's preprocessing, anaerobic fermentation and biogas purification) and operation phase. For convenience of the comparison and analysis between the biomass vehicle fuel gas and the conventional diesel, this research will see the phase of feedstock and fuel as the upstream phase (WTP, Wells-to-Pump) meanwhile regard operation phase as its downstream phase (PTW, Pump-to-Wheels) of fuel.

2.3.1. The algorithm analysis of the upstream phase(WTP)
In this research, suppose there are X links (s suggests phase s) in the upstream phase of the life cycle of the biomass vehicle fuel gas, in this way, the quantity of certain analysis index can be obtained through the guidance of the corresponding data of each link.

Primary energy consumption of stage S is E_S:

$$E_S = e_{1s} + e_{2s} + e_{3s} \tag{1}$$

Where: e_{1s}, e_{2s} and e_{3s} separately suggest the consumption of coal, crude oil and natural gas in stage S.

Primary energy consumption of WTP is E_{WTP}:

$$E_{WTP} = \sum_{s=1}^{X} E_S \tag{2}$$

The quantity of emissions of type I in stage S is ep_{si}:

$$ep_{si} = ep_{osi} + ep_{1si} + ep_{2si} + ep_{3si} \tag{3}$$

Where: ep_{osi} is the quantity of emission of type i produced in stage S; ep_{1si}, ep_{2si} and ep_{3si} refer to the i-kind emission quantity of coal, oil and natural gas consumed in their upstream phases (exploiting, producing and transportation) during the S-link respectively.

Then, the total emission quantity of type i in WTP is EP_{WTP}^i:

$$EP_{WTP}^i = \sum_{s=1}^{x} ep_{si} \tag{4}$$

(1) The feedstock phase is the stage when the kitchen waste produced by restaurants, hotels and dining rooms, transported by garbage truck to the processing center. In this phase, the involving energy consumption is the diesel consumed by the garbage truck. The primary energy consumption in this phase is caused by the upstream phase of the diesel. The emission load in feedstock phase during transportation is the garbage truck's self-emission and the consumed diesel emission in its upstream phase.

(2) The main energy consumption in fuel phase is: the electric energy consumption of mechanical equipment and methane consumption of heating anaerobic fermentation tank in the produce process of the vehicle fuel gas. Because methane is not primary energy, so the primary energy consumption in this phase is caused by the upstream phase of the electric energy. The quantity of emission in fuel phase is: emission quantity of methane when burning in the boiler; emission quantity of electric energy expended in the produce process; and emission quantity produced because of consumption of technology fuel to produce electric energy.

2.3.2. The algorithm analysis of the downstream phase(PTW)
PTW, the operate phase of the vehicle, is not involved in the consumption of primary energy. Emission quantity of PTW is the emission quantity of the biomass vehicle fuel gas in function. This data refers to document [7]. In the document, Huang Wei of BJTU and some others did a research by using electric control gas (model NO: WD615.00Q) engine of China National Heavy Duty Truck Group Company Limited as experimental prototype and vehicle fuel gas got from biogas purification as fuel. This kind of engine accounts for more than 40% of the large domestic gas engine market share. It is widely used in heavy trucks and city buses of 16~40t of the STYER series.

3. Inventory Analysis

3.1. Data Sources
The technology fuel related to the model established in this research are mainly diesel and electric energy. To get applicable data coped with our national situation, after consulting lots of former documents, this research gets the following data.

(1) Primary energy consumption and emission data of diesel in WTP refers to document [8]. This document calculates stages of raw material extraction, raw material transportation, fuel processing, fuel production transportation and other stages. Specific data refers to table 1.

Table 1. Primary energy consumption and environment emission of diesel in WTP.

Project	Energy Consumption (GJ/GJ)	VOC (g/GJ)	CO (g/GJ)	NOx (g/GJ)	PM_{10} (g/GJ)	SO_2 (g/GJ)	CO_2 (g/GJ)
WTP	1.395	8.51	6.37	77.7	7.33	1413	31359

(2) Electrical energy structure of our country refers to table 2 [9]. Assume that hydropower, wind power and nuclear power will not consume fossil fuels. Primary energy consumption and emission of fuel and gas power are ignored because they make up only 2.3% of the total power generation. The electric energy's average primary energy consumption and emission of our country can be calculated according to data of coal-fired power generation [8]. Refer to table 3.

Table 2. Power structure ratio of China in 2013.

Type	Coal power generation	Fuel power generation	Gas power generation	Hydropower generation	Wind power generation	Nuclear power generation	Others
Percentage,%	74.41	0.11	2.19	17.16	2.07	1.97	2.09

Table 3. Primary energy consumption and emission of China electric power production.

Project	Energy Consumption (GJ/GJ)	VOC (g/GJ)	CO (g/GJ)	NOx (g/GJ)	PM_{10} (g/GJ)	SO_2 (g/GJ)	CO_2 (g/GJ)
Coal power generation[8]	3.26	26.45	41.48	880.91	51.57	10505	341483
Average	2.43	19.68	30.87	655.49	38.37	7816.77	254097

(3) The environment emission of biogas combustion is concerned because in the fuel phase of the biomass vehicle gas, part of methane automatically produced by the system will be used to heat anaerobic fermentation tank through the boiler burning. Environment emission data of biogas combustion refers to document [10], see table 4 for details.

Table 4. Emission quantity of biogas combustion.

Pollutants	VOC(g/m^3)	CO(g/m^3)	NOx(g/m^3)	CO_2(g/m^3)
Emission factor	0.4048	0.5238	0.4048	213.9

(4) Energy consumption and emission data of the function stage of vehicles refers to table 5.

Table 5. Energy consumption and emission of the function stage of vehicles.

Project	Energy Consumption (MJ/km)	VOC (g/km)	CO (g/km)	NOx (g/km)	PM_{10} (g/km)	SO_2 (g/km)	CO_2 (g/km)
Diesel[a]	14.82	1.85	3.95	6.84	1.03	0.29	932.06
Biomass gas[b]	13.58	1.21	3.48	6.23	0	0.13	861.84

[a] Data in operation phase of diesel refers to document [11].
[b] Data in operation phase of biomass vehicle gas refers to document [7].

3.2. Example analysis
This research takes the kitchen garbage disposal project in Nanning for example. This project is responsible to Guangxi Lande Renewable Energy Co. LTD. The total investment of this project is about 120 million yuan and is formally put into operation in February of 2015. At this stage, this project can deal with 220 tons of kitchen garbage per day, the output quantity of methane is 100m3/t and purification efficiency of methane is 55%. There are in total 44 diesel garbage trucks used to transport kitchen waste. The garbage truck is ISUZU (model No: QL11009KARY, model No of engine: 4HK1-TCG40), maximum total mass is 10t, emission standard is country V. See its energy consumption and emission data in details in table 6. According to statistics, the average fuel consumption of garbage trucks is 22L/100km, the total fuel consumption of garbage transportation is 26000L each month. In the fuel production stage, the entire process consumes 280,000 KW·h each month. Biogas used to heat the anaerobic fermentation accounts for 28.57% of the total gas production.

Table 6. Energy consumption and environment emission of garbage trucks.

Project	Energy Consumption (MJ/km)	VOC (g/km)	CO (g/km)	NOx (g/km)	PM_{10} (g/km)	SO_2 (g/km)	CO_2 (g/km)
Garbage truck	7.84[a]	0.98[c]	0.74[b]	0.28[b]	0.55[c]	0.15[b]	403.96[c]

[a] Garbage truck's energy consumption is calculated according to the actual statistical fuel consumption.
[b] These data refers to document [12].
[c] These data refers to document [11].

4. Result and Discussion
According to the model established, this research gets the primary energy consumption and emission data of the full life cycle of the biomass vehicle gas, makes a comparison to the conventional diesel. See table 7 for specific data in details.

Table 7. Primary energy consumption and emission data of the biomass vehicle fuel gas.

	Project	Energy Consumption (MJ/km)	VOC (g/km)	CO (g/km)	NOx (g/km)	PM_{10} (g/km)	SO_2 (g/km)	CO_2 (g/km)
Diesel	WTP	20.67	0.13	0.09	1.15	0.108	20.94	464.74
	PTW	0	1.85	3.95	6.84	1.03	0.29	932.06
	Full life cycle	20.67	1.98	4.04	7.99	1.138	21.23	1396.8
Biomass gas	WTP	5.49	0.28	0.26	1.19	0.16	13.53	521.85
	PTW	0	1.21	3.48	6.23	0	0.13	861.84
	Full life cycle	5.49	1.49	3.74	7.42	0.16	13.66	1383.69

Comparison of life cycle's primary energy consumption between biomass vehicle gas and conventional diesel can be seen in figure 2. In full life cycle, primary energy consumption quantity of biomass vehicle gas is 73.44% lower than conventional diesel. This is mainly because the raw material of traditional diesel is primary energy and the biomass vehicle gas is produced by disposed kitchen waste. Because it's raw material is not primary energy, the primary energy consumption of biomass vehicle gas is much lower than traditional diesel. It can be seen that the energy-saving effect of this technical route of making vehicle gas out of kitchen waste is preferable.
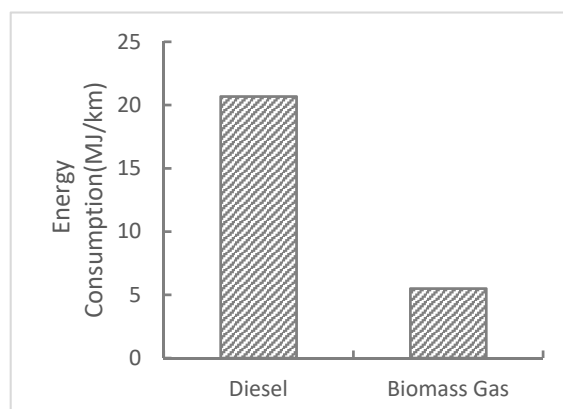
Figure 2. Life cycle's primary energy consumption comparison between biomass vehicle gas and conventional diesel

Life cycle emissions of biomass vehicle gas and traditional diesel can be seen in figure 3. Throughout the life cycle, emission of biomass vehicle gas is lower than traditional diesel in varying degrees. In WTP, emissions of biomass vehicle gas with VOC, CO, NOx, PM_{10} and CO_2 are all higher than traditional diesel. This is because the main energy of biomass vehicle gas in the production process is electricity. However, most of the electricity production relies on coal, environment emissions of coal-fired power generation is serious in some degree in China, so the emission of biomass vehicle gas in WTP is higher than traditional diesel.

In figure 3(a), full life cycle's VOC emission of biomass vehicle gas is 24.75% lower than traditional diesel. Life cycle's VOC emission of these two types of fuel are all focus in stage WTP. Biomass vehicle gas is 81% and diesel is 93%. In figure 3(b), full life cycle's CO emission of biomass vehicle gas is 7.43% lower than traditional diesel. CO emissions of these two kinds of fuel focus in stage PTW as well. Biomass vehicle gas is 93% and diesel is 98%. In figure 3(c), full life cycle's NOx emission of biomass vehicle gas is 7.13% lower than traditional diesel. This is mainly because that vehicle gas is more easily to lean burn than traditional diesel, its ignition temperature is lower than traditional diesel as well. So, NOx emission of biomass vehicle gas is lower than diesel.

In figure 3(d), it is can be seen that PM_{10} particulate emission of biomass vehicle gas is 85.94% lower than traditional diesel in the whole life cycle. The reason is that it basically will not produce particles in the burning process of biomass vehicle gas. However, there is still particulate emission in the function stage of traditional diesel. As a result, particulate emission quantity of vehicle gas is far less than diesel.

In figure 3(e), full life cycle's SO_2 emission of biomass vehicle gas is 35.66% lower than traditional diesel. Life cycle's SO_2 emission of these two types of fuel are both focusing in stage WTP. Biomass vehicle gas is 99.0% and diesel is 98.6%. This is because most of the S element are cleaned up in desulfurizing tower in the technology of producing vehicle gas out of kitchen waste. As for diesel, the fifth stage standard of China(GB 18352.5-2013) greatly reduces the content of S in diesel as well, but it's content is still no more than 10mg/kg. As a result, SO_2 emission of these two fuels are little in the PTW stage.

In figure 3(f), Compared with diesel, life cycle's CO_2 emission of biomass vehicle gas is not vary hugely, the proportion of both fuels is balanced in stage WTP and PTW. The proportion of vehicle gas is 33% in stage WTP and 67% in stage PTW. The proportion of diesel is 38% in stage WTP and 62% in stage PTW.
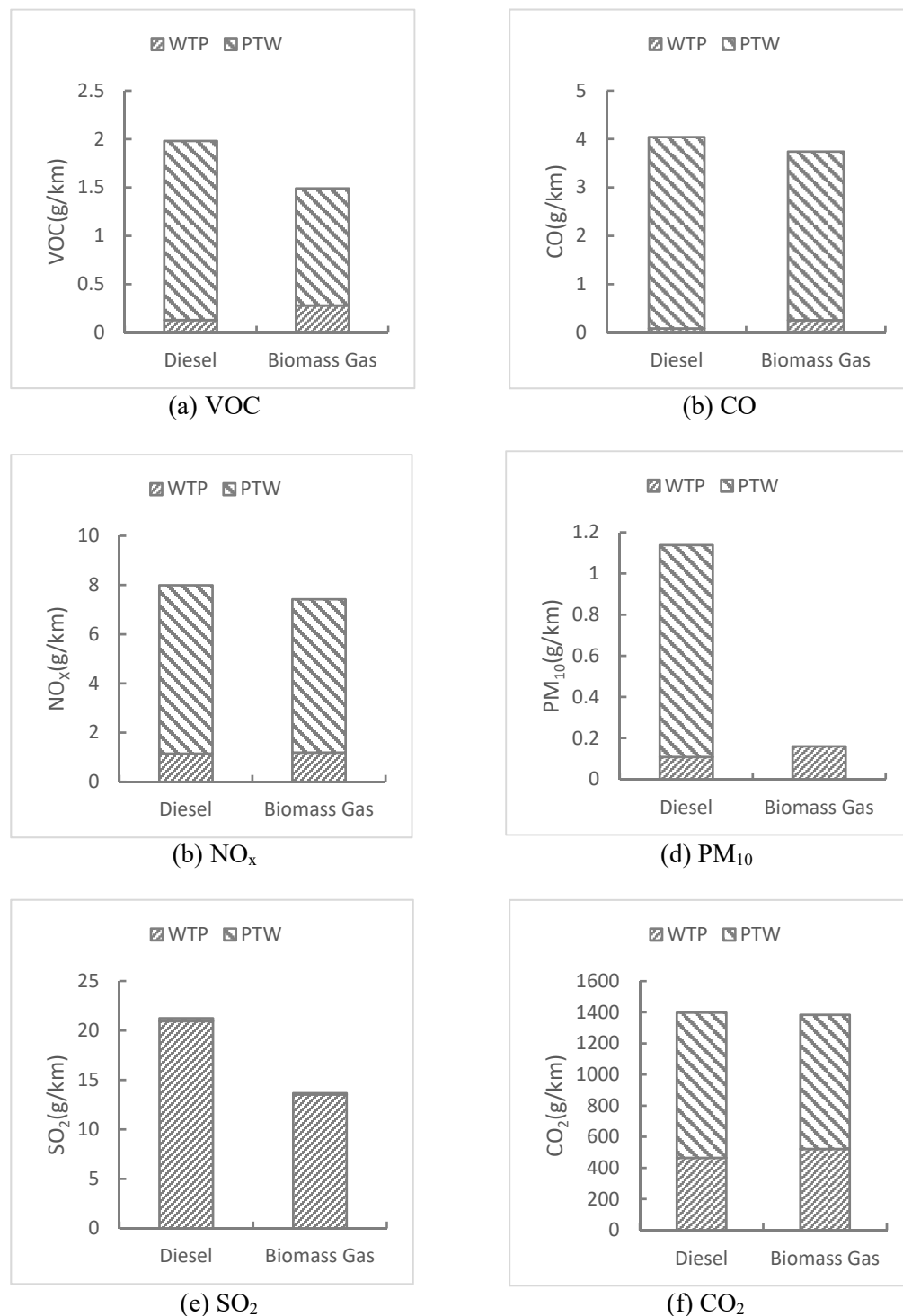
Figure 3. Emission comparison of life cycle

5. Conclusion

This research established the analysis model of life cycle's energy consumption and emission of vehicle gas made of kitchen waste's anaerobic fermentation. This research also made analysis aiming at this model by actual examples. It calculated energy consumption and emission of biomass vehicle gas's

life cycle in every stage. This research provided theoretical and practical basis for the resource utilization of kitchen waste.

In full life cycle, the primary energy consumption of biomass vehicle gas is 73.44% lower than traditional diesel, it can be seen that the energy-saving effect of this technology route of making vehicle gas out of kitchen waste is preferable.

In full life cycle, emission quantity of vehicle gas made out of kitchen waste's anaerobic fermentation is lower than the traditional diesel in different degrees. Compared to traditional diesel, life cycle's VOC, CO, NOx, PM_{10}, SO_2 and CO_2 emissions are lower by 24.75%, 7.43%, 7.13%, 85.94%, 35.66 and 0.94% separately. VOC, CO and NOx emission of biomass vehicle gas and diesel are both focusing in the stage of WTP.

Acknowledgments

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