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RESEARCH ARTICLE

BIOGAS PRODUCTION FROM WASTE BY-PRODUCTS OF ETHANOL PRODUCTION: 2. EFFECT OF BATCH CO-DIGESTION WITH SOME ANIMAL AND PLANT WASTES ON BIOGAS PRODUCTION

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ABSTRACT

The effect of batch co-digestion of the wastes emanating from ethanol production process with some animal and plant wastes on the biogas yield was studied. The wastes from the processing of some starch feedstock and from their fermentation wort were utilized for the biogas production studies. The wastes constituted: (i) process wastes from starch extraction (ET) and (ii) fermentation wort (ETP). They were studied alone (ET-A) and (ETP-A) and in combination with some animal wastes (cow dung (CD) and swine dung (SD) and plant wastes (field grass (FG) and glycerol (GL). The biogas production capabilities of the wastes were in terms of (i) biogas yields (ii) onset of gas flammability and (iii) effective retention time. This was carried out for a retention period of 45 days under ambient mesophilic temperature range of 23°C – 38°C and slurry temperature of 38°C to 48°C using 1 liter micro-digesters under anaerobic digestion. Data analysis was carried out using one way analysis of variance (ANOVA). The results of the biogas production showed that the ET-SD had the highest cumulative biogas yield of 3,800.01 ml/kg slurry and average gas yield of 84.4447± 58.6707 ml/kg slurry while the ETP–A had the least cumulative biogas yield of 677.70 ml/kg slurry and average biogas yield of 15.0602± 6.7644 ml/kg slurry. The onset of gas flammability for the ET-SD and ET-CD were on the 6th day (lag period of 5 days), ETP–FG-GL (13 days) while the ETP–A and ETP-FG did not combust throughout the retention period. By the 45th day, all the other variants were still producing gas whereas the ETP-A and ETP–FG had minimal gas production. General results for the biogas indicate that the processing wastes from the bioethanol are better utilized in combination with animal wastes and with glycerol. These are expected to provide effective waste management system.

INTRODUCTION

Rising energy prices and concerns about long term sustainability have once again brought renewable energy sources to the forefront. The use of biofuels is increasing in many regions throughout the world. Biogas production from biogenic wastes is currently being viewed as an alternative source of fuel in most developing and developed countries of the world (Isei and Demirer, 2007). Biogas typically refers to a gas produced by the biological breakdown of organic matter in the absence of oxygen (anaerobic digestion). The organic waste materials include animal wastes, agricultural wastes, municipal wastes, industrial wastes, domestic wastes, human wastes, solid organic wastes etc (Abubakar, 1990). The gas is composed of mainly methane (50 – 70%), carbondioxide (20 – 40%) and traces of other gases such as nitrogen, hydrogen, ammonia, hydrogen sulphide, and water vapour etc. (Edelmann *et al*., 1999). The gas is odourless and flammable and yields about 1,000 British thermal units (BTU) (252 kilocalories) of heat energy per cubic foot (0.028 cubic meters) when burned (De Bruyn and Hilborn, 2007). Biogas (for cooking and lighting) being one of the renewable fuels has been adopted as one of the best alternatives for fossil fuels after the 1970's world energy crisis. The Chemistry of the digestion process leading to biogas involving hydrolysis, acidogenesis/acetogenesis and methanogenesis has been well documented (Kalia *et al*., 2000; Agunwamba, 2001; Ofoefule *et al*., 2009a). The production of biogas via anaerobic digestion of large quantities of various agricultural residues, municipal wastes and industrial wastes would go a long way in solving the problem of indiscriminate waste disposal and hence environmental pollution. Biogas technology amongst other processes (including thermal, pyrolysis, combustion and gasification) has in recent times also been viewed as a very good source of sustainable waste treatment / management, as disposal of wastes has become a major problem especially to the third world countries (Arvanitoyannis *et al*., 2007). The effluent of this process is a residue rich in essential inorganic elements like nitrogen and phosphorus needed for healthy plant growth known as biofertilizer which when applied to the soil enriches it with no detrimental effects on the environment (Bhat *et al*., 2001). Many findings have been reported on the

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enhancement of gas production through processes such as co-digestion or blending of organic wastes (Parawira *et al*., 2004; Uzodinma *et al*., 2007; Mshandete and Parawira, 2009), reduction of size of organic wastes, addition of chemicals, etc. (Ofoefule and Uzodinma, 2008). Co-production of bioethanol and biogas would allow all the components of both plant biomass and animal manure to be used. An earlier study on the pure wastes alone from bioethanol process which constituted the waste from starch processing and that from fermentation wort showed that their biogas production profile needed optimization, even though the biogas production of the variant from starch processing was better in terms of cumulative and average yield, onset of gas flammability and microbial load (Ofoefule *et al*., 2012). The study was therefore undertaken to; determine the effect of co-digesting the pure wastes from bioethanol process with some animal and plant wastes on the biogas production. The wastes constituted: (i) process wastes from starch extraction (ET) and (ii) fermentation worth (ETP). They were studied alone (ET-A) and (ETP-A) and in combination with some animal wastes (cow dung (CD) and swine dung (SD) and plant wastes (field grass (FG) and glycerol (GL). The combinations were done in a 1:1 ratio thus giving ET–CD, ET–SD, ETP–FG, and ETP– FG-GL. The biogas production capabilities of the wastes were in terms of (i) biogas yields (ii) onset of gas flammability and (iii) effective retention time.

MATERIALS AND METHODS

Other materials

Other materials used for the digestion studies include; 1 liter Buckner flask which formed the micro-digesters. These were fitted with metal beehive at the bottom and connected to 2 liter measuring cylinders for measurement of the daily biogas production. The micro-digesters were fitted at the top with corks, slightly perforated for the insertion of thermometers to measure the influx temperature. Additional materials used were hose pipes, water trough, clamps and stands to hold the measuring cylinders in place, biogas burner fabricated locally for checking gas flammability.

Fig. 1: Digester set-up for biogas production of the wastes.

Digestion Studies

Waste sample preparations

The ET-A was allowed to degrade for two months. After that, it was soaked in water for four (4) days to allow for partial decomposition of the waste by aerobic microbes, which has been reported to aid faster digestion of the waste by anaerobic microbes (Fulford, 1998). It was then strained from the water using large size mesh screens while the water was also used for the charging of the wastes. The ETP – A was also allowed to degrade for the same period as the ET-A. This was done to also allow for partial decomposition of the waste by aerobic microbes. As a result of the sterility the substrate was subjected to before and during fermentation, this was necessary to aid faster digestion of the wastes by aerobic microorganisms. The field grass (FG) was cut from the surrounding environment and allowed to degrade for a period of one month. It was then chopped into small sizes of 2″ (two inches) to reduce the particles sizes. This was expected to aid intimate contact between the waste and microorganisms and also to aid ease of stirring. After chopping the grass, it was soaked in a small bowl for one week, to allow for partial decomposition of the wastes by aerobic microorganisms and reduction of acidity (Ofoefule and Uzodinma, 2008). At the end of 7 days, the waste was strained using large mesh screens while the water was kept and utilized for the charging of the waste. The cow dung, swine dung and crude glycerol were used as obtained without modification of their structure.

Charging of micro -digesters and set up

For ET-A, 300 g of ET waste was weighed out into the micro-digester. 600 g of water was weighed and added to it and stirred thoroughly. This gave water to waste ratio of 2:1. It was stoppered with the cork and kept. The moisture content of the waste determined the water to waste ratio. For ETP-A, 400 g of ETP waste was weighed into the micro-digester; 500 g of water was weighed and added to it. This gave water to waste ratio of 1:1.25. Again, the constitution of the ETP determined the water to waste ratio. The mixture was stirred thoroughly and stoppered with the cork. For ET–CD, ET–SD and ETP–FG, 150 g of ET (for CD and SD) and ETP (for FG) wastes and 150 g of CD, SD and FG wastes were weighed separately, mixed thoroughly and put into the micro- digester. 600 g of water was weighed and added to them and mixed thoroughly. These gave water to waste ratio of 2:1. Again the moisture content of the wastes determined the water to waste ratio. The mixtures were stirred to ensure homogeneity and stoppered with the cork. For the ETP–FG–GL variant, 150 g of the FG waste, 147 g of the ETP waste and 3 g of the crude glycerol (GL) were weighed into the micro- digester. 600 g of water was weighed and added to the mixture giving water to waste ratio of 2:1. The constitution of the ETP waste again determined the water to waste ratio. The mixture was stirred thoroughly and stoppered with the cork. They were all charged up to ¾ of the micro-digester while leaving ¼ headspace for gas collection. All the micro- digesters were stirred thoroughly on a daily basis to ensure intimate contact of the wastes with microorganisms responsible for converting the wastes to biogas. Daily biogas production was measured by downward displacement of the water in the trough by the gas produced and recorded as the difference between the initial reading at the beginning of each day and the final reading at the end of that same day. pH of the waste slurries were monitored daily for a period of five days to ensure stability of the waste slurries. Gas flammability was monitored daily from 24 h of charging the micro-digesters till the onset of gas flammability. Microbial load of the waste slurries were carried out four times during the retention period; at the point of charging the micro-digesters, at the onset of gas flamsmability,

Table 1: Lag period, cumulative and mean volume of gas production

Parameters	ET-A	ET-CD	ET-SD	ETP-A	ETP-FG	ETP-FG-GL
Lag period (days)	8	5	5	Nil	Nil	13
Average vol. (ml/kg. slurry)	52.34±24.23	63.70±56.67	84.44±58.67	15.06±6.76	16.05±9.34	48.89±19.59
Cumulative vol. (ml/kg. slurry)	2,355.49	2,866.62	3800.01	677.71	722.15	2199.94

Table 2: Physicochemical properties of the wastes

Parameters	ET-A	ET-CD	ET-SD	ETP-A	ETP-FG	ETP-FG-GL
Moisture (%)	21.50	45.90	55.15	83.30	58.70	74.90
Ash (%)	1.60	7.00	8.25	0.25	6.30	1.65
Crude fibre (%)	3.90	3.28	2.86	1.90	2.15	2.13
Crude fat (%)	0.43	0.27	0.44	0.25	0.24	0.49
Crude protein (%)	4.20	2.98	3.30	2.01	3.06	2.54
Crude nitrogen (%)	0.67	0.48	0.53	0.32	0.49	0.41
Total solids (%)	78.50	54.10	44.85	16.70	41.30	25.10
Volatile solids (%)	36.60	47.10	56.90	16.45	23.45	35.00
Carbon (%)	16.35	9.81	14.23	3.92	15.86	11.12
C/N ratio	24.40	20.44	26.84	12.26	32.37	27.12
Carbohydrate (%)	68.37	40.58	27.00	12.29	27.42	18.29
Calorific value(kcal/g)	125.20	176.65	294.14	59.47	87.70	125.26
Initial pH	7.59	8.09	8.11	7.98	6.14	6.29
pH at charging	7.51	7.80	7.85	7.42	6.97	7.21

Table 3: Microbial total viable count (TVC)

Parameters	ET-A	ET-CD	ET-SD	ETP-A	ETP-FG	ETP-FG-GL
At charging	$2.89x10^7$	$4.51x10^7$	$5.08x10^7$	$1.72x10^7$	$1.41x10^7$	$5.00x10^5$
At flammability	$2.21x10^7$	$3.05x10^7$	$4.52x10^7$	-	-	$9.01x10^6$
At peak of production	$3.21x10^7$	$5.28x10^7$	$5.52x10^7$	$3.82x10^6$	$6.31x10^6$	$9.01x10^6$
At end of digestion	$9.50x10^6$	$2.71x10^7$	$3.23x10^7$	$2.92x10^6$	$5.00x10^6$	$6.43x10^6$

at the peak of gas production and at the end of the retention period. Ambient and slurry temperatures were monitored daily throughout the retention period. Figure 1 shows the experimental set up of the micro digesters for the biogas production.

Analyses of Wastes

Physicochemical analyses

Ash, moisture and fibre contents were determined using AOAC (2010) method. Fat, crude nitrogen and protein contents were determined using Soxhlet extraction and micro-Kjedhal methods described in Pearson (1976). Carbon content was determined using Walkey and Black (1934) method. Energy content determination was carried out using AOAC (2010) method, while Total and Volatile solids (TS) and (VS) were determined using Bhatia (2009) method.

Microbial analysis

Total viable counts (TVC) of the microbes for the treated wastes slurries were carried out to determine the microbial load of the blends using the modified Miles and Misra method described in Okore (2004). This was carried out at four different periods during the digestion; at the point of charging the micro-digesters, at the point of flammability, at the peak of production and at the end of the retention period.

Data Analysis

Statistical analysis was carried out on the data generated using "Completely Randomized design (CRD)"; a one way analysis of variance (ANOVA). It was carried out using a combination of SPSS 17.0 version and Genstat 3.

RESULTS AND DISCUSSION

The result of the daily biogas production for all the variants (ET-A, ET-CD, ET-SD, ETP-A, ETP-FG and ETP–FG-GL) are graphically presented in Figure 2. Gas production for ET-A, ET-CD, ET-SD and ETP-A commenced within 24 h of charging the micro-digesters. However, ETP-FG-GL started biogas production from 48 h while ETP–FG commenced gas production from the 7^{th} day. The experiment was carried out under ambient temperature range of 23^oC–36^oC and slurry temperature range of 28^oC–48^oC (All within the mesophilic temperature range). Onset of gas flammability for the different variants took place at different periods as shown in Table 1. However, the ETP– A and ETP– FG did not combust throughout the retention period and both systems had the least biogas yields. The ET–SD had the highest cumulative biogas yield followed by the ET–CD, while the ETP– A had the least biogas yield followed by the ETP–FG. There was significant difference ($P < 0.05\%$) between the biogas yields of ET-SD and the rest. There was no significant difference ($P > 0.05\%$) between the biogas yield of ET-A, ET-CD and ETP-FG – GL and there was also no significant difference between the biogas yield of ETP–A and ETP–FG.

The lag periods for the production of flammable biogas (which is from the time of charging the digesters to the onset of gas flammability) was the longest in the ETP–FG–GL, while the ET–SD and ET–CD had the same lag periods. Biogas that will serve the basic need of cooking and lighting must be flammable. If it burns, it means that the methane content is at least 45%. If it does not burn, it means that the methane content is less than 45% and contains mainly CO_2 and other gases (Anonymous, 2003). Some biogas feedstock have been

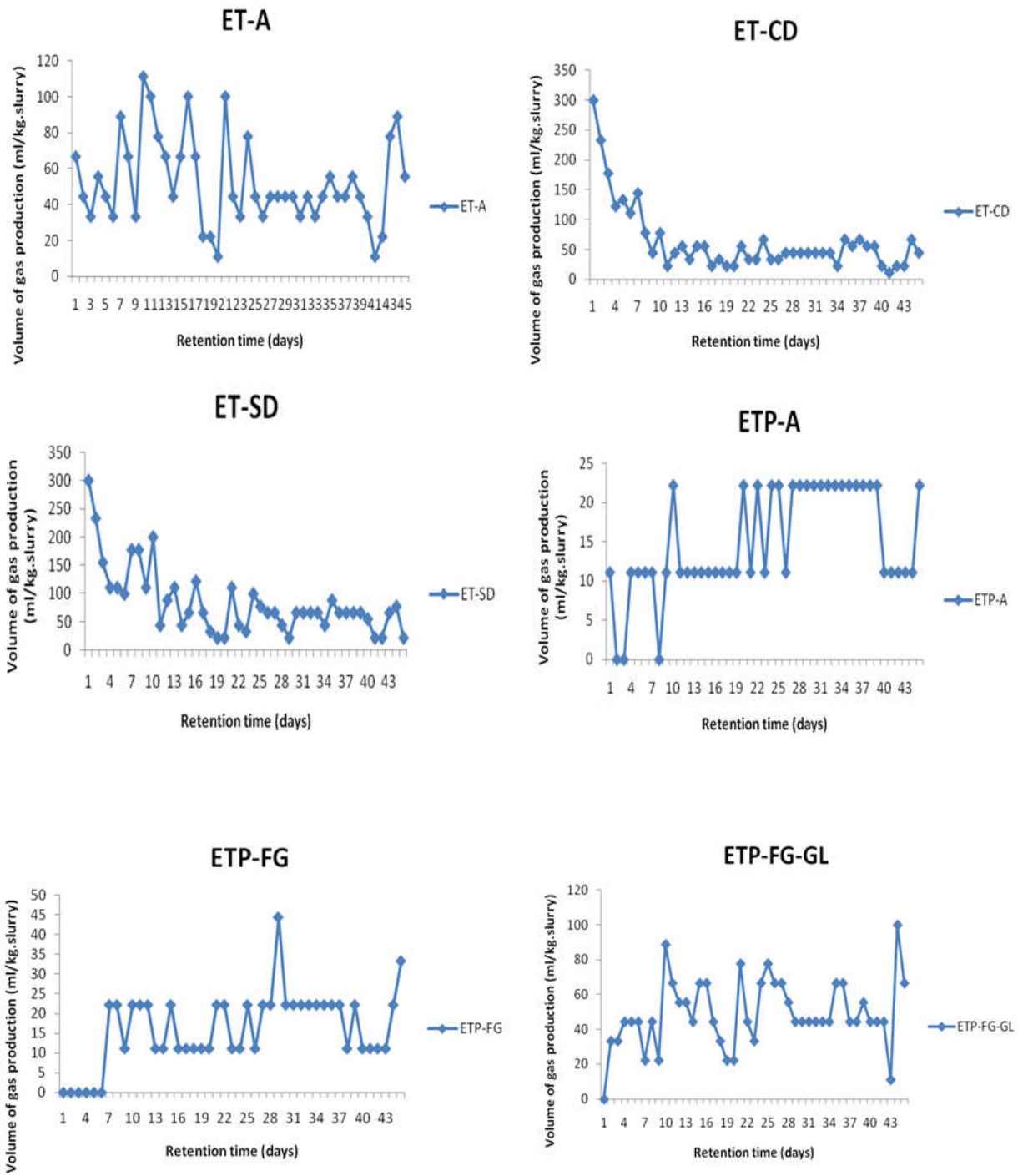

Fig. 2: Daily biogas production for all the variants

shown from previous reports not to combust until after 21 days and some 30 days (Ofoefule and Uzodinma, 2006; Ofoefule and Uzodinma, 2008). The need to reduce this lag phase to combustibility of biogas in order to enable the end users utilize the gas efficiently and effectively have been the subject of so many research efforts in recent times with regards to the utilization of the different wastes and feedstocks in the environment. The biogas production profile of ETP–A and ETP–FG in terms of biogas daily/cumulative yield and onset of gas flammability was very poor. Adequate physicochemical properties are known to promote biogas production. The nutrients (fat and protein) content, volatile solids (which is the biodegradable portion of the waste, carbohydrate content and calorific value of the ETP-A were lower than the that of the other variants. The carbon to nitrogen (C/N) ratio of the ETP-A, fell way below the optimum value which has been given to be in the range of 20 to 30:1 (Dennis and Burke, 2001). This is because the microbes that convert waste to biogas take up carbon 30 times faster than nitrogen. The moisture content of ETP-A was quite high showing that the waste was mainly watery with little nutrients. Most of the nutrients may have been taken up during the fermentation to ethanol production. According to Brigas *et al*., (1981), spent brewery waste is normally thrown out as a waste after the sparging operation in the brewery process. This gives rise to the death of most of the microbes that should be inherent in the waste after operation. As a result, spent wastes obtained in this way are normally attacked by moulds which inhibit the growth of the bacteria in

the waste. Therefore, for the spent waste to produce flammable biogas, it has to be pre-decayed and co-digested with the good starter wastes in order to improve on the microbial load of the waste. A look at the microbial total variable count (Table 3) shows that the ETP–A had very low microbial load when compared with the other variants. This corroborates the report by Uzodinma *et al*., (2007) on the poor biogas production of brewery spent grain when used alone. Again, the process of fermentation wort preparation (sterilization, pH control with acids and bases etc), may have contributed to the poor production performance of ETP– A. Co-digestion of the ETP–A/FG with glycerol (ETP–FG–GL) improved most of the physicochemical properties important/necessary for enhanced biogas production such as fat content, volatile solids, calorific value and C/N ratio. This translated to an increased microbial load, onset of gas flammability and cumulative biogas production. Glycerol (a by-product of biodiesel production) has been reported by some researchers to improve biogas production once the level is below 3% (optimum level has been reported to be at 1%) (Fountoulakis *et al*., 2010).

The result of the present study confirms the report. When the glycerol for this experiment was used at 50% level, there was no biogas production at all. However, when it was reduced to 1%, the gas production was increased by 186%. Co-digestion of the ETP–A with field grass (FG) did not have any significant effect on the physicochemical properties of the gas production profile in terms of biogas yield and gas flammability. The ET-A (which is the waste from the processing of the feedstocks to obtain the starches), had better biogas production performance than the spent waste. This is obviously as a result of the fact that the waste was at the primary stage of utilization unlike the spent waste which had undergone a stage of usage and was at the secondary stage. Some of the nutrients had not been eroded at this stage. However, this waste had longer onset of gas flammability on the 9th day when compared with the variant of cow dung and swine dung with onset of gas flammability on the 6th day. Plant wastes contain a lot of cellulose, hemicelluloses, pectin, lignin and plant wax. These contents of plant wastes are very difficult to biodegrade and can be a major rate determining step in the anaerobic digestion process (Ishizuka *et al*., 1996).

This probably affected the onset of gas flammability for the ET–A. Co-digesting the ET–A with cow dung (CD) and swine dung (SD) improved the physicochemical properties and consequently the gas production profile of the waste. Animal wastes have been reported to be good biogas production enhancers and starters (Ofoefule *et al*., 2009b). The ET–SD had the highest cumulative biogas yield, energy content, volatile solids, C/N ratio and nutrient content. In previous reports, cow dung has been rated as the best biogas producer and hence, the best gas enhancer (Odeyemi, 1987), however, that did not apply in this study. Most often, the source of the animal waste and its feeding pattern contributes to the biogas production capability of a particular waste (Adeyemo, 2003). The swine waste used for this study was obtained from a domestic source unlike others normally obtained from farm settlements. This may have influenced the production pattern of the variant (ET-SD). Co-digestion of the ET–A with SD and CD increased the biogas yield by 61% and 22% respectively. This indicates that though using the waste alone can give reasonable yield of biogas, combining it with animal wastes, would increase the yield significantly. The results of the total viable count (TVC) in Table 3 indicate that the microbial load of ET-A was also increased by the combination with cow dung and swine dung.

Conclusion

The results of the study have shown that using the processed wastes alone would not give very high yield of biogas. Combining them or co-digesting the processed wastes with animal wastes would give better yields of biogas thereby supplementing the energy supply to the industry and providing an effective waste management system. The spent slurry emanating from the biogas system could also be dried, bagged and sold as biofertilizer, thereby providing cheep source of revenue to the industry. Use of the crude glycerol in biogas production has been shown from this study to be another outlet for its utilization since purification of glycerol is very expensive.

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