# INFLUENCE OF KITCHEN BIOWASTE ADDITION ON THE EFFECTIVENESS OF ANIMAL MANURE DIGESTION IN CONTINUOUS CONDITION

**M. Kuglarz*, B. Mrowiec*, J. Bohdziewicz****

*University of Bielsko-Biala, Willowa 2 Street, Bielsko-Biala 43-309, Poland,
(E-mail: mkuglarz@ath.bielsko.pl; bmrowiec@ath.bielsko.pl)

**Institute of Water and Wastewater Engineering, Silesian University of Technology,
Konarskiego 18, 44-100 Gliwice (Poland), (E-mail: jolanta.bohdziewicz@polsl.pl)

**ABSTRACT**
The aim of the research was to establish the influence of kitchen biowaste as a co-substrate on the effectiveness and stability of animal faeces (pig manure) anaerobic digestion for biogas production, conducted in mesophilic conditions. Digestion process was conducted for manure as well as mixtures containing 10% of kitchen biowaste and 90% of manure. The proportion of substrates in the co-digestion mixture was established as optimal, on the basis of tests conducted in static conditions. The digesters were maintained at a mesophilic temperature of 36˚C and the process was carried out at the hydraulic retention times (HRT) ranging from 25 to 50 days. Anaerobic digestion of manure for the HRT value of 30÷35 days ensured the highest amounts of biogas produced (0,77-0,85 $dm^3/dm^3 \times d$) as well as degree of organic matter reduction (52-54%). Whilst The highest biogas production rate (1,25 $dm^3/dm^3 \times d$) as well as degree of organic matter reduction (66%) were achieved for the HRT value of 35 days. Co-digestion of kitchen biowaste and munure allowed to achieve between 10 and 60% higher biogas production rates. The co-digestion process conducted for the shortest value of HRT (25-30 days) turned out to unstable and exhibited a relatively low effectiveness.

**KEYWORDS**
co-digestion, biogas, animal manure, kitchen biowaste

## INTRODUCTION

One of the main by-products of animal breeding are animal faeces, which are usually used as natural fertilizers. However, farmers must comply with permissible application periods and doses. What is more, liquid faeces should be stored in leak-proof containers with the capacity sufficient to keep the manure generated over a period of at least 4 months. During the period (winter), manure agricultural usage is not permissible and the manure stored undergoes natural decomposition which leads to the release of gases into the atmosphere, mainly $CO_2$, $CH_4$, $NO_x$, $NH_3$ [Pawełczyk and Auraviev, 2003; Szymańska, 2006].

In areas with high – intensity animal production, about 70-80% of ammonia emission is generated by farming-related sources [Pawełczyk and Auraviev, 2003; Romaniuk, 2004]. Apart from causing atmospheric pollution, manure leakages, may cause soil as well as surface and ground waters contamination [Pawełczyk and Auraviev, 2003; Mroczek and Kostecka, 2008; Macias-Corral M et al., 2008]. In Poland, farms rearing animals on a massive scale (> 2000 animal standings for pigs weighted more than 30 kg or 750 standings for sows) are obliged to use at least 70% of the manure generated as natural fertilizers in their own land. The remaining part can be donated or sold on condition that it will be also used as natural fertilizers. Significant congestion of stock-raising farms as well as their dense distribution, make difficult to utilize the generated manure for their own purposes. Besides, transportation of liquid manures to the areas suffering from their deficiency, is relatively expensive [Kutera, 1994; Romaniuk, 2004].

According to the binding regulations, the manure which is not directly used as natural fertilizers is considered as waste and has to be treated with appropriate methods to reduce its negative influence on the environment. One of the method constitutes the process of controlled anaerobic digestion. It permits to stabilize the raw faeces and generate renewable energy. Besides, the process eliminates odorous nuisance and has a positive impact on separation of digested faeces into solid and liquid phase. [Møller et al., 2000; Magrel, 2004]. However, anaerobic digestion of liquid manures, which are rich in water is not effective from a technological point of view. Increasing the proportion of organic matter in the digestion feedstock allows to increase the effectiveness of manure digestion. It can be realized through addition of co-substrates, such as: municipal biowastes, flotation sludges, fat remains, food processing wastes etc. [Jędrczak, 2007; Deublein and Steinhauser, 2008].

The main advantages of the co-digestion process are [Jędrczak, 2007, Braun, 2002]:

- increased biogas production;
- higher organic matter bioconversion;
- better balance of nutrients in feedstock;
- greater fertilizer amounts (digested biomass);
- gate fees for waste treatment
- reduction of odour nuisance
- improved biomass dewatering properties

Kitchen biowastes which constitutes main ingredient of municipal biowastes are considered as valuable co-substrates of anaerobic digestion. Such biowastes are relatively easily-accessible and include a large proportion of biodegradable organic matter (approx. 90% of total solids). Moreover, in accordance with the European Council Directive on the landfill of waste [European Council Directive, 1999], the member states are obliged to reduce gradually the amount of biodegradable waste deposited at municipal dump sites. A promising solution of municipal biowastes utilization may be their co-digestion with animal faeces.

The aim of the research was to establish the influence of kitchen biowaste as a co-substrate on the effectiveness and stability of animal faeces digestion for biogas production, conducted in mesophilic range of temperature. The scope of the research encompassed: anaerobic digestion of animal faeces (pig manure) as well as pig manure and kitchen biowaste co-digestion, both conducted in continuous conditions. The criteria taken into account while assessing particular values of substrates retention (HRT) in a bioreactor mainly included: biogas production rate; VS reduction; volatile fatty acids production (VFA) as well as total fatty acids production to total alkalinity (TA) ratio. Additionally, dewatering properties of the digested biomass were assessed.

## MATERIALS AND METHODS

### Digestion feedstock

Animal faeces in a form of pig manure from a non-straw bedded rearing farm and kitchen biowaste were used as digestion substrates. Manure samples were collected at the outlet of the pipe connecting animal standings with storage tanks. Whilst, the kitchen biowaste was collected selectively from households as well as institutions (restaurants, school canteens etc.) located in the vicinity of the farm. A domestic food blender was used to homogenize the various components of biowaste into granules smaller than 2 mm in diameter.

Digestion process was conducted for the animal faeces (pig manure) as well as mixtures containing 10% (ww.) of kitchen biowaste and 90% (ww.) of pig manure. The proportion of substrates in the co-digestion mixture was established as the most appropriate, on the basis of tests conducted in static conditions. Table 1 presents the characteristics of the substrates used as a digestion feedstock.

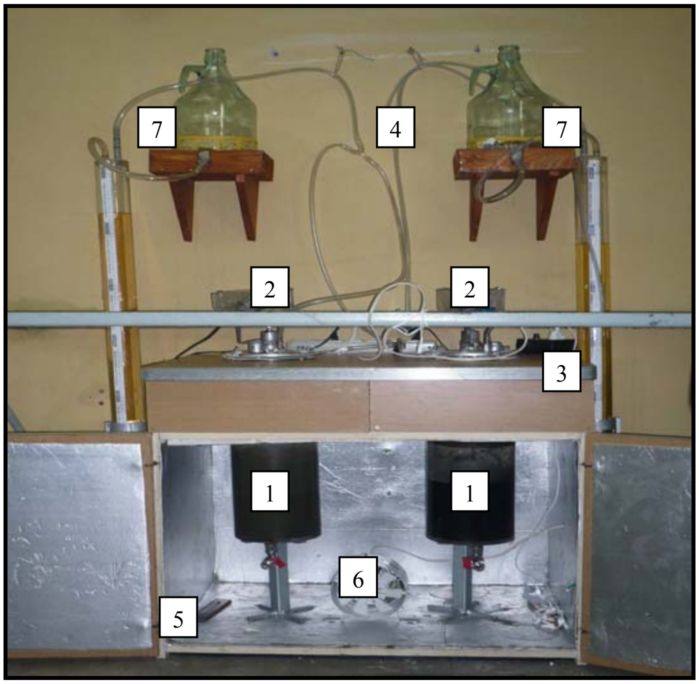
**Table 1.** Characteristics of the substrates and their mixture used as digestion feedstock.

| Parameter | Animal faeces - pig manure | Kitchen biowaste | Mixture of kitchen biowaste and pig manure |
|---|---|---|---|
| pH | 7,2 (0,2)* | 4,8 (0,4) | 7,0 (0,2) |
| ORP, mV | -356 (12) | -75 (10) | -325 (20) |
| Conductivity, mS/cm | 21,2 (2,6) | 9,5 (1,3) | 19,9 (1,3) |
| TS, % | 6,4 (0,5) | 24,8 (4,0) | 82,1 (1,8) |
| VS, % | 5,2 (0,5) | 23,1 (4,4) | 69,8 (2,1) |
| COD, $mgO_2/dm^3$ | 32 250 (1605) | 99 120 (11 934) | 39 650 (2540) |
| $NH_4^+$, $mg/dm^3$ | 5310 (753) | 625 (52) | 4738 (514) |

*( ) – standard deviation

### Digestion unit and procedure

The digestion process was conducted in bioreactors with a working volume of 3 $dm^3$, equipped with mechanical mixing devices. Their contents were mixed periodically – 5 minutes in every 3 hours. The digesters were maintained at a constant temperature of 36˚C (±0.5). Figure 1 depicts the digestion unit used in the experiment.




1. bioreactor
2. mechanical device
3. timer
4. pipes
5. thermometer
6. ventilator
7. biogas measurement unit

**Figure 1.** Anaerobic digestion unit

**Scope of the analyses**

The scope of the analyses encompassed: pH, ORP and conductivity measurement as well as determinations of total solids (TS), volatile solids (VS), ammonium-nitrogen ($NH_4^+$), total volatile fatty acids (VFA) and total alkalinity (TA). The susceptibility of the digested samples to dewatering was based on the capillarity suction time (CST). Both quantitative and qualitative analyses of the biogas produced were carried out during the experiment. The biogas was stored in a plexus tube containing 5% NaOH solution. The recorded amounts of biogas were adjusted to the volume at standard temperature (0˚C) and pressure (1 atm). Biogas samples were periodically analysed for $CH_4$, $CO_2$, $O_2$ and $H_2S$ [Eaton, 1995; Sawyer et al., 2003].

The process of anaerobic digestion of pig manure as well as co-digestion of kitchen biowaste and pig manure was carried out at the following hydraulic retention times (HRT): 25, 30, 35, 40 and 50 days. The particular values of substrates retention in a bioreactor were calculated according with the following formula [Jędrczak, 2007]:

$$HRT = \frac{V}{Q}, \quad \text{days}$$

where: HRT - hydraulic retention time of substrates in a bioreactor, d
V - active volume of the bioreactor, $dm^3$
Q – daily flow rate of substrates through the bioreactor (into and out), $dm^3/d$.

## RESULTS AND DISCUSSION

The anaerobic digestion for biogas production was conducted under high ammonia concentration (4952÷5930 mg $NH_4^+/dm^3$). The HRT value of animal faeces and its mixture with kitchen biowaste was successfully increasing from 25 to 50 days.

### Organic matter biodegradation

Anaerobic digestion leads to the reduction of organic matter through the biodegradation of macromolecular substances, mainly proteins, fats, carbohydrates as well as their derivative compounds. The HRT value of munure and its mixture with kitchen biowaste was successfully increasing from 25 to 50 days. The digestion was initially adopted by the application of the shortest HRT value, i.e. 25 days, which was tantamount to OLR of 2,08 and 2,79 kgVS/($m^3$×d) for manure and a mixture of manure and kitchen biowaste respectively. Under those conditions, the degree of organic matter reduction amounted to 45% (manure) and 53% (manure + kitchen biowaste). Furthermore, as the HRT values were subsequently extended, reduction degrees of VS increased. In case of manure, the maximum VS reduction, i.e. 52-54% was achieved when the HRT was extended to 30-35 days, which was associated with an OLR in the range of 1,49-1,73 kgVS/($m^3$×d). Whilst during the co-digestion process, the highest value amounted to 66% and was recorded for the HRT reaching 35 days. In those conditions, the OLR amounted to 1,99 kgVS/($m^3$×d). Further increases in HRT (40÷50 days) did not influence the parameter in a positive way. Figure 2 presents degree of bioconversion measured as volatile solids (VS) reduction.

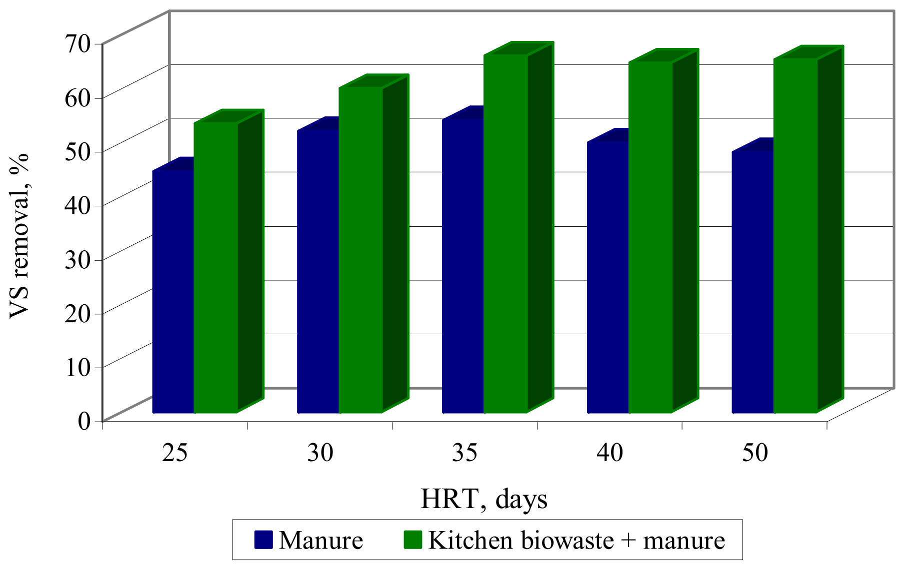



**Figure 2.** VS removal under different HRT's

### Biogas production

During the experiment, the biogas production as well as the chemical composition of the biogas generated, were analysed. Conducting the process for the lowest value of HRT, i.e. 25 days, daily biogas production amounted to 0,72 $dm^3/dm^3$×d (manure) and 0,80 $dm^3/dm^3$×d (manure + kitchen biowaste). In case of HRT amounting to 30 days, the manure produced the highest amount of biogas (0,88 $dm^3/dm^3$×d). Whilst the biogas production of co-digestion mixture reached the value of 0,97

$dm^3/dm^3 \times d$. When the HRT value was extended to 35, the highest value of biogas production, i.e. 1,25 $dm^3/dm^3 \times d$ was recorded for the feedstock comprising of manure and kitchen biowaste. The value was about 60% higher than the optimum biogas production rate noticed for feedstock containing manure exclusively. In those conditions (HRT = 35 days), the biogas production generated by manure decreased by about 12% (0,77 $m^3/m^3 \times d$). Similarly to the organic matter decomposition, the application of the longest HRT (40-50 days) did not play a positive influence on both biogas production rates. However, the amounts of biogas generated in the co-digestion process was higher by about 40%, as compared to the values recorded for manure digestion. Figure 2 shows the amount of biogas produced for various values of HRT, expressed in terms of daily production rates.

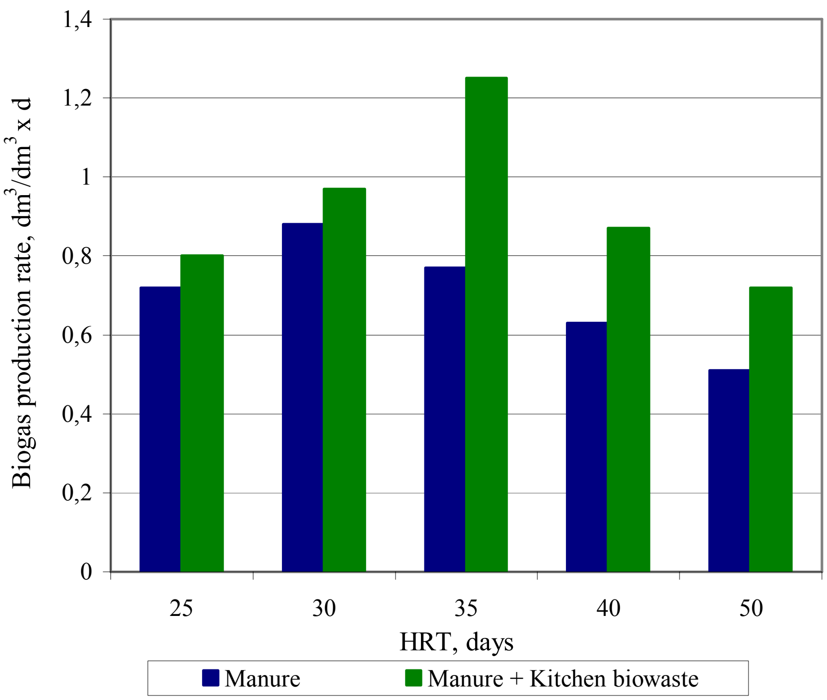



**Figure 3.** Specific daily biogas production rate

It was established that the length of manure retention in a bioreactor did not impact the content of methane in biogas produced. The average $CH_4$ concentration amounted to between 74 and 76% vol. For co-digestion of kitchen biowaste and manure carried out at the HRT value above 30 days, the $CH_4$ content in the biogas produced reached the similar level as in case of manure digestion (75-76% vol.). Conducting the co-digestion in the conditions of HRT < 30 days, a 10% decrease in $CH_4$ concentration was noticed. A high content of $CH_4$ in the biogas produced was ascribed to the feedstock rich in substances, such as fats and proteins which are believed to produce biogas of the high $CH_4$ proportion [Buraczewski,1989; Hartmann, 1996].

**Anaerobic digestion stability**

Discussing the overall stability of the anaerobic digestion, a primary indicator which influences the biological conversions is the pH value. Although range of acceptable pH values for bacteria consortia participating in the anaerobic digestion varies between 5.5 and 8.5, most methanogens prefer the pH value at the level of about 7. The use of pH as a process indicator is based on the fact that a pH drop is commonly related to the VFAs accumulation. However, if anaerobic digestion is conducted at a high concentration of ammonia, which is mainly generated in proteins mineralization, the $NH_4^+$ released counteracts partially the decrease of pH caused by VFAs accumulation. Moreover, a significant decrease in pH value usually occurs after the collapse of the process and when the acid phase dominates in a bioreactor. A more reliable stability indicator seems to be a volatile fatty acids to total alkalinity, i.e. VFA/TA ratio. If the latter exceeds the threshold of 0.3÷0.4, it is believed to have an inhibitive effect on the process stability [Dymaczewski and Sozański, 1995; Callaghan et al., 2002; Magrel, 2004].

Taking into account the achieved values of the VFA/TA ratio, it can be pointed out that the process of manure digestion exhibited stable properties for the whole analysed range of HRTs. Whilst the co-digestion of kitchen biowaste and manure showed stable condition for the HRT value exceeding 30 days. When the mixture of biowaste and manure was maintained in a bioreactor for a period shorter than 35 days, a significant concentration of VFA (9140-9450 mg $CH_3COOH/dm^3$) as well as increased values of VFA/TA ratio (0,82-0,86) occurred. Table 2 depicts factors impacting the stability of anaerobic digestion.

**Table 2.** Factors influencing the stability of anaerobic digestion

| HRT, days | pH | $NH_4^+$, mg/dm$^3$ | VFA, mg/dm$^3$ | Total alkalinity, mgCaCO$_3$/dm$^3$ | VFA/TA |
|---|---|---|---|---|---|
| **Digestion of pig manure** | | | | | |
| 25 | 7,7 | 5780 | 3290 | 12580 | 0,26 |
| 30 | 7,8 | 5805 | 3640 | 13850 | 0,26 |
| 35 | 7,9 | 5930 | 3459 | 13740 | 0,25 |
| 40 | 7,9 | 5895 | 3759 | 14500 | 0,26 |
| 50 | 7,9 | 5695 | 3625 | 14850 | 0,24 |
| **Co-digestion of kitchen biowaste and pig manure** | | | | | |
| 25 | 7,5 | 5750 | 9450 | 10980 | 0,86 |
| 30 | 7,6 | 5655 | 9140 | 11220 | 0,82 |
| 35 | 7,8 | 5447 | 4355 | 12360 | 0,35 |
| 40 | 7,8 | 5382 | 4170 | 12380 | 0,34 |
| 50 | 7,8 | 4952 | 4137 | 11897 | 0,35 |

### Dewatering properties of the digested biomass

The process of anaerobic digestion usually enhances the digested biomass susceptibility to separation into solid and liquid fractions. The former can be more efficiently transported into areas suffering from natural fertilizer deficiency while the latter can be used as organic fertilizer within the farm generating it. Considering the above, the research encompassed the influence of biowaste addition as a co-substrate on the separation properties of the digested manure.

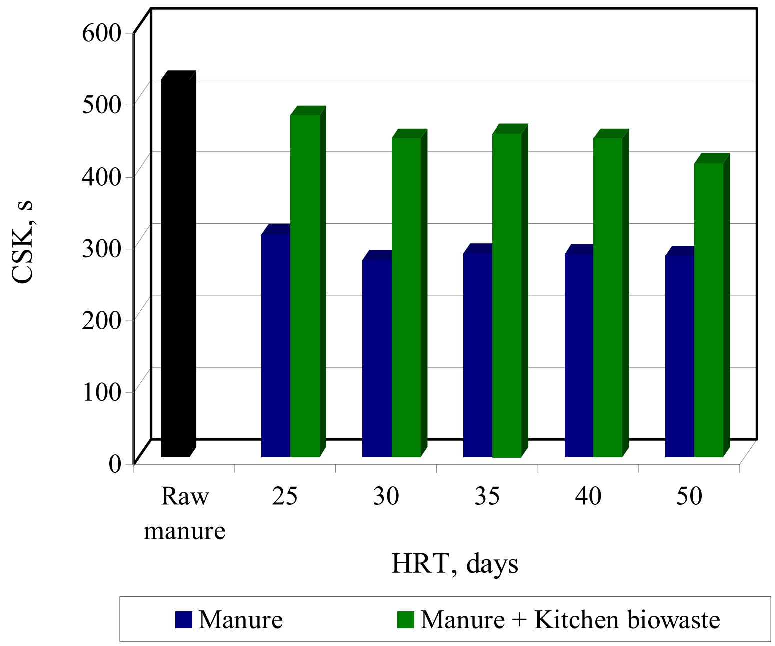



**Figure 4.** The influence of various HRT on filtration properties of digestion residues.

The anaerobic digestion affects the separation properties of the treated substrates in a positive way. As compared to the raw manure (520s), the digested manure as well as the residue after co-digestion process exhibited a better susceptibility to dewatering. However, introducing kitchen biowaste to the feedstock undergoing digestion deteriorated the dewatering properties of the digested materials. The capillary suction times (CST) increased by about 46-61%, comparing to equivalent values recorded for digested manure.

**SUMMARY**

The addition of a co-substrate in the form of source sorted kitchen biowaste to the anaerobic digestion of animal faeces (pig manure) had a positive impact on the amount of biogas produced and degree of organic matter biodegradation. The treatment of manure together with other biodegradable wastes, e.g. kitchen biowaste, constitutes an environmental-friendly solution, which enables renewable energy production and organic bio-waste utilization.

The process of anaerobic digestion of animal faeces (manure) conducted under high ammonia concentration ensured the highest amounts of biogas produced (0,77-0,85 $dm^3/dm^3 \times d$) and organic matter reduction (52-54%) for the HRT in the range of 30-35 days. The capillary suction time (CST) measurement showed that the digestion process impacted the dewatering properties of the raw manure in a positive way. In case of co-digestion, the highest biogas production rate (1,25 $dm^3/dm^3 \times d$) as well as degree of organic matter reduction (66%) were achieved for the HRT value of 35 days. Co-digestion of kitchen biowaste and manure allowed to achieve between 10 and 60% higher biogas production rates.

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