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ANAEROBIC DIGESTION OF WASTE FRUITS AND VEGETABLES
(A REVIEW)

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Abstract. Every day large quantities of fruits and vegetables from markets and shops are converted into wastes. A conventional method for their removal is the deposition into landfills. The high organic content is a reason to develop different methods for their utilisation. Anaerobic digestion is a suitable method resulting in biogas production as well as a solid phase enriched in nutrients. A literature survey on this problem has been done. The experimental conditions, the content of the fruit and vegetable wastes used and the biogas yield have been compared.

Keywords: anaerobic digestion, fruit wastes, vegetable wastes, biogas

1. INTRODUCTION

One of the main trends of today's waste management policies is to reduce the stream of waste going to landfills and to recycle the organic materials and the plant nutrients back to the soil. Anaerobic digestion has the opportunity to be a part of the solution to these problems and in addition it can be net energy producer. Through this process, organics are decomposed by specialized bacteria in an oxygen-depleted environment to produce biogas and a stable solid. Each of these products can be used for beneficial purposes to close the loop in organic waste management. The anaerobic digestion is widely used for the treatment of cattle manures [1], wasted activated sludge and various mixtures of organic wastes [2].

Large part of organic wastes produced in the markets is the fruit and the vegetable waste. There have been a number of reports on the utilization of fruit and vegetable waste (FVW), individual or mixed as feedstock for biogas production.

The aim of this paper is the reviewing of the results obtained by the scientists all over the world in their investigations of the wasted fruits and vegetables anaerobic digestion.

2. ANAEROBIC DIGESTION OF WASTED INDIVIDUAL FRUITS AND VEGETABLES

Sarada and Joseph [3] compared the performance of single and two stage anaerobic digestion of tomato processing waste. They reported on 80 % of carbon conversion to total gas (65 % methane) of 0.8 m^3 kg^{-1} volatile solids (VS). The two stage process yielded a 40-50 % increase in the rate and yields of methane over the single stage under similar conditions. The authors used two-phase system consisted of 1 dm^3 reactor for acidogenic process and 5.5 dm^3 digester for methanogenic process. Acidogenesis was carried out at 4 and 8 days hydraulic retention time (HRT) and 20 days for methanogenesis.

Lane [4] observed the anaerobic digestion of orange peels. The aim was to establish the opportunity to reduce the peel oil content and to use the peels as feedstock for biogas production. He obtained yield of 0.5 m^3 kg^{-1} of total solids (TS), the concentration of methane is 50-55 %. The conversion of solids to gas at loading rate 3.5 kg TS m^{-3} d^{-1} is approximately 98 %. He used 10 dm^3 microbiological reactor initiated with activated digesting sludge from a municipal sewage digester. Digestion was stable at concentration of oil not more than 0.25 % (w/v). The temperature was maintained at 37±1°C. The digestion failed if pH decreased fewer than 6.4.

Biomethanation of bananas wastes was examined by Clarke et al. [5] in order to estimate the ultimate methane yield and the degradation kinetics of microbial consortia in a fed batch operation. They showed that the conversion of acetate to methane was the rate limiting step. The digestion was carried out in 200 dm^3 anaerobic reactors at temperature

38îC. The methane yield obtained during the process was 380 dm^3 CH_4 kg^{-1} TS. They considered that the solid residue could be used as a compost. It contained no human pathogens, it is free of plastics, glass and heavy metals.

Bardiya et al. [6] studied the process of anaerobic digestion of banana peels and pineapple wastes at various HRT. The results showed that the gas production is highest at lower retention time. The yield of the biogas for the banana peels at 25 days HRT was 0.76 v $v^{-1}d^{-1}$ with 36 % substrate utilization and for the pineapple it was 0.93 v $v^{-1}d^{-1}$ at 10 days HRT with 50 % utilization. Aspirator bottles with volume of 2 dm^3 were used as reactor at temperature 37îC. The percentage solids of banana peel and pineapple wastes were 10 and 7 % (w/v), respectively. They also observed that the degradation hemicellulose was higher than that of cellulose.

Microbiological pretreatment of mango peels was studied by Sumithra and Nand [7]. The trials were carried out in 1.5 dm^3 glass aspirator bottles with working volume of 1.0 dm^3. The feed slurry contained 6 % TS (w/v), and the temperature was maintained at 30îC. The biogas contained 58 % methane and its yield was 0.36 m^3 kg^{-1} VS. The process was carried out under semi-continuous fermentation conditions. The results suggested that the microbiological pretreatment of mango peel would have a significant influence on the economics of the process.

Lane [8] examined the anaerobic digestion of apples, apricots, corn cobs, apple press cake, extracted sugar beet pulp and pineapple pressings. He used 10 dm^3 microbiological reactors, maintained at 36 ± 1îC. The loading rate ranged from 3.5-4.25 kg m^{-3} d^{-1}. The conversion of organic solids was 88-96 %. The processes were stable excepting the digestion of apricot waste, which decline after 63 days. The author suggested low cost final treatment including stabilization lagoons, oxidation ditches and anaerobic ponds or tanks. The residues can be used also like fertilizers.

Gunaseelan [9] determined ultimate methane yields using the biochemical methane potential assay. Several fractions of fruit and vegetable solid wastes, sorghum and napiergrass were used as substrate. Serum bottles of volume 135 ml were used for the digestion at mesophilic regime (35îC). The ultimate methane yield ranged from 0.241-0.523 dm^3 g^{-1}VS added.

The work of Hills and Nakano [10] has highlighted the importance of particle size on methane gas production. They used digesters with operating volumes of 4 dm^3 fed at 3 g VS per dm^3 of digester with retention time of 18 days. The tomato solid waste was chopped to particle sizes of 1.3; 2.4; 3.2; 12.7 and 20 mm. The results showed that biggest gas production occurred with the smallest particle size 1.3 mm. VS reduction was also greatest in that trial and the gas yield was 0,8 dm^3 dm^{-3} d^{-1}.

Sarada and Joseph [11] studied the anaerobic degradation of tomato processing waste and focused on the biochemical changes during the process. They compared the performance of batch and semi-continuous modes of digestion. A set of 1 dm^3 Buchner flasks for batch process and aspirator bottles of 5.5 dm^3 capacity for the semi-continuous process was used. In both types of reactors the temperature was maintained at 33±2îC. Presented results demonstrated that the hemicellulose and cellulose are easily degradable in both processes. The proteins were degraded to greater extent (70 %) in batch reactors, and the digestion of lipids was better in semi-continuous process.

In another study Sarada and Joseph [12] examined the factors influencing methane production from tomato processing waste. Bottles of 5.5 dm^3 capacity were used as digesters. The authors estimated the influence of loading rate, hydraulic retention time and temperature on the yield of total gas during the digestion. The values of loading rate were 3.0, 4.5, 6.6, 7.5 kg $m^{-3}d^{-1}$ at constant temperature and HRT. The effect of HRT was studied at 4, 8, 16, 24 and 32 days, keeping solids loading at 4.5 kg TS m^{-3} and temperature at 33±2îC. The temperature was maintained at mesophilic range at 25, 30, 35, 40 and 45îC, keeping the HRT and loading rate constant. At 24 days HRT, 4.5 kg m^{-3} loading rate and 35îC the greatest yield of total gas 0.7 m^3 kg VS^{-1} was obtained.

A start-up of anaerobic degradation of tomato processing wastes was observed by Sarada and Nand [13]. The digestion was carried out in 5.5 dm^3 laboratory reactors at 30ÎC and operated in semi-continuous mode. Initially the digesters were charged with a cowdung slurry and an active starter culture was used as inoculum. The process was stable with gas yield of 0.597 m^3 kg^{-1} VS and methane content of 72 %. The results showed a rapid and stable process achieved by stepped increasing of the wastes.

Knol et al. [14] carried out anaerobic digestion using waste of apples, carrots, green peas, spinach, French beans and strawberries. 1 dm^3 reactors were used for the processes and the temperature was maintained at 33ÎC. The retention time was 20 days with loading rate varied between 0.8 and 1.60 kg VS m^{-3} d^{-1} and biogas yield was between 0.3-0.58 m^3 kg^{-1}VS d^{-1}. The residual solids could be completely removed by flocculation.

The effect of the feeding of various fruit and vegetable wastes was studied by Gunaseelan [15]. The aim of the trails was to compare extents and rates of conversion to methane. The ultimate yields of fruits and vegetables varied from 0.18 to 0.732 dm^3 g^{-1} VS and 0.19 to 0.4 dm^3 g^{-1} VS, respectively. It was also found that the conversion kinetics were higher at 35ÎC than at 28ÎC.

Traverso et al. [16] studied acidogenic fermentation of fruit and vegetable wastes in a pilot scale anaerobic acidogenic reactor. The HRT ranged between 1 to 12 days in mesophilic range (37±1ÎC). When the HRT is bigger than 6 days, the organic matter in the liquid phase is completely due to volatile fatty acids (VFA), lactate and ethyl alcohol.

The effect of trace elements on biogas production was observed by Raju et al. [17]. Mango processing waste was used as a substrate for the process. The salts of trace elements used in the experiment were $CoCl_2.6H_2O$, $NiCl_2.6H_2O$ and $FeCl_3$ (anhydrous). The results showed that the biogas production increases with the increasing of Co^{2+} and Ni^{2+} concentration up to 125 mg dm^{-3}. The gas production was highest when $FeCl_3$ was added at concentration 4000 mg dm^{-3}. The methane content was not influenced by the addition of cobalt and nickel.

Lane [18] studied the digestion of fruit and vegetables processing wastes in small-scale and pilot-scale experiments. The laboratory digesters with volumes of 100 ml, 2 dm^3 and 15 dm^3 were operated at 37ÎC and apple pomace, pelletised dried citrus peel and bean as well as pea wastes were used as a substrate. The biogas yield was 374-436 dm^3 kg^{-1} solids fed (60 % CH_4). The volume of pilot reactor was 3700 dm^3 and the gas yield obtained with the pilot-scale system was 450 dm^3 kg^{-1} of feed.

The comparison of single and two-phase anaerobic digestion of vegetable solid wastes under mesophilic and termophilic conditions was made by Verrier et al. [19]. Two 16 dm^3 completely mixed reactors were used for the one-stage process at 35ÎC and 55ÎC. The two-phase system consisted of 7 dm^3 CSTR and 3.8 dm^3 useful volume up-flow anaerobic filter packed with PVC rings. The results suggested that the two-phase system was highly stable and flexible to overloading. In addition the two-phase process permitted high conversion efficiencies. 90 % of VS was removed.

The yields of hydrogen and methane from potato waste during anaerobic digestion were determined by Zhu et al. [20]. The acidogenic stage was operated in continuous flow with HRT of 6 h and pH of 5.5 and the hydrogen production was 30 dm^3 kg^{-1} TS. The methanogenic stage was operated in continuous and semi-continuous flow with HRT of 30 h and 90 h, respectively, and pH was maintained at 7. The energy yield was 2.14 kWh kg^{-1} TS.

Linke et al. [21] studied the performance of completely mixed tank reactor using potato processing waste as a substrate. The temperature was maintained at 55ÎC (termophilic range) and the influence of organic loading rate (OLR) on the biogas production was estimated. The results showed that the biogas yield decreased with the increase in OLR. The biogas and methane production obtained were 0.85 dm^3 g^{-1}-0.65 dm^3 g^{-1} and 58 %-50 %, respectively at OLR in the range of 0.8 g $dm^{-3}d^{-1}$ - 3.4 g dm^{-3} d^{-1}.

Anaerobic digestion of potato waste leachate was carried out by Parawira et al. [22]. They compared the performance of laboratory scale up-flow anaerobic sludge blanket (UASB) reactor and anaerobic packed bed (APB) reactor. The OLR and HRT ranged from 1.5 to 7.0 g COD dm^{-3} d^{-1} and from 13.2 to 2.8 days, respectively. With increase of OLR the methane yield increased up to 0.23 dm^3CH_4 g^{-1} COD $_{degraded}$ in the UASB reactor and 0.16 dm^3 CH_4 g^{-1} COD $_{degraded}$ in the APB reactor. Overall 90 % of total COD was removed. The comparison showed that the UASB could better work at higher OLR than the APB reactor.

In another paper the authors presented the possible use of potato wastes as a substrate for two-stage mesophilic digesters [23]. Two systems were used. The first consisted of solid bed reactor for acidogenesis and UASB reactor for methanogenesis. The second consisted of solid bed reactor and digester packed with wheat straw biofilm carriers. The systems were estimated with regard to hydrolytic enzymes and methane production. The methane production was 0.3 m3 kg^{-1} VS and it was the same in both systems studied. The enzymes used by microorganisms were found to be amylase, carboxymethyl cellulase, filter paper cellulose, xylanase, pectinase and protease.

The inhibition of sodium humate on the hydrolysis of non-soluble potato protein during anaerobic degradation was investigated by Brons et al. [24]. Their results demonstrated an inhibition of the protein hydrolysis when 250 and 1000 mg of humate per dm^3 were added. They found that only this stage was influenced by humate and considered that the effect could be characterized mostly as an extended lag-phase of hydrolysis (extended 8 days by 1000 mg of humate per dm^3).

Sarada and Joseph [25] enumerated and monitored different groups of microorganisms during the digestion of tomato wastes. Batch and semi-continuous processes were compared. It was found that in batch digestion the numbers of cellulolytics, xylanolytics, pectinolytics, proteolytics and lipolytics increased up to 40 day. The numbers of cellulolytics, proteolytics and lipolytics increased fast at 24 and 32 days HRT than at 8 and 16 days HRT in the semi-continuous flow. The methanogens were more at higher HRT than at lower HRT.

Hills and Roberts [26] reported on biomethanation of tomato, peach and honeydew solid wastes. They presented the results from laboratory and pilot scale reactors. The laboratory digesters with volume of 4 dm^3 and maintained at 35îC were used. The tomato wastes were digested at 5 kg VS m^{-3} d^{-1} and 25 days HRT, honeydew - 3 kg VS m^{-3} d^{-1} and 20 days HRT and the peach residues - 1 kg VS m^{-3} d^{-1} and 15 days HRT. The VS reduction was 33, 83 and 86 % for tomato, honeydew and peach residues, respectively, and the gas yield was 0.43, 2.45 and 1.15 v v^{-1} d^{-1}, respectively. The data for tomatoes were confirmed by experiments with 22 m^3 pilot scale reactor.

Conversion of tomato solid wastes into methane gas was investigated by Hills and Dykstra [27]. Laboratory digesters with capacity of 4 dm^3 were operated for four months at mesophilic range. The effect of different loading rates (1.0, 3.0 and 5.0 kg VS m^{-3} d^{-1}) and retention times (15, 25 and 35 days) were studied. It was found that the methane yield increased at higher loading rates and longer retention times (maximum value 0.36 m^3 m^{-3} d^{-1} and minimum value 0.14 m^3 m^{-1} d^{-1}). The COD reduction was higher when the loading rate was decreased and/or the retention time was increased.

Kalia et al. [28] showed the comparison of anaerobic digestion of banana stem wastes under mesophilic (37-40îC) and termophilic conditions (50-55îC) in batch culture. The total solids concentration ranged in 2 -16 %. Biogas yields of 267-271 dm^3 kg^{-1} TS fed were obtained at mesophilic range with 2 – 4 % TS slurries. At 2 – 8 % TS slurries and termophilic conditions the gas yield was 212-229 dm^3 kg^{-1} TS fed. The termophilic digestion rates were 2.4 times faster than the mesophilic digestion. The results showed 45 - 50 % reduction in organic solids and 40 - 55 % reduction in COD.

Digestion under anaerobic conditions of banana wastes and coir pith was studied by Deivahai and KasturiBai [29]. During the process the reduction of TS and VS was 25.3

and 39.6 % in banana waste and 13.6 and 21.6 % in coir path, respectively. The biogas obtained from banana waste was 9.22 dm^3 kg^{-1} TS (72 % CH_4) and from coir path it was 1.69 dm^3 kg^{-1} TS (80 % CH_4).

Ensilage of pineapple processing waste before the anaerobic digestion was described by Rani and Nand [30]. Ensilaging of pineapple peels reduced BOD by 91 %. In this process 55 % of the carbohydrates were converted into VFA. The ensilaged pineapple peels, used as a substrate for anaerobic reactor resulted in biogas yield of 0.67 m^3 kg^{-1} VS (65 % CH_4) in comparison with the fresh and dried peels, which gave biogas yield of 0.55 m^3 kg^{-1} VS (51 % CH_4) and 0.41 m^3 kg^{-1} VS (41 % CH_4), respectively.

3. ANAEROBIC DIGESTION OF WASTED FRUITS AND VEGETABLES MIXTURES

Viswanath et al. [31] studied the anaerobic digestion of mixed fruit and vegetable wastes - mango, pineapple, tomato, jackfruit, banana and orange. They used a 60 dm^3 digester with working volume of 45 dm^3, operated under semi-continuous mode of feeding at a temperature of 30±2îC. During the experiment different loading rates and HRT were estimated. A maximum biogas yield of 0.6 m^3 kg^{-1} VS added was obtained at a 20 day HRT and 40 kg TS $m^{-3}d^{-1}$. The process was stable, with no nitrogen added and has been operated for 18 months.

The influence of the concentration of slurry, carbohydrates, proteins and fats on the biogas production rate and methane concentration in the gas was examined by Biswas et al. [32]. A digester with volume of 10 dm^3 and operated in batch mode was used at 40îC and pH of 6.8. Vegetable and food residues were used as substrate. It was found that biogas generation rate was not influenced by the proportion of fats. The rate increased with an increase in the concentration of slurry, carbohydrates and proteins.

Converty et al. [33] studied the factors limiting the biomethanation of the vegetable fraction of municipal wastes at mesophilic (37îC) and termophilic (55îC) conditions. The results demonstrated that the hydrolysis of the lignocellulosic fraction is the limiting step of the digestion. The process is inhibited by the lignin by-products. The termophilic digestion is more stable to overloading and needed shorter retention time.

The influence of HRT and feed concentration on the extent of biodegradation of FVW was examined by Bouallagui et al. [34]. The HRT was varied between 12 and 20 days with no effect on the process. An inhibition of methanogens was observed at HRT below 12 days. Good conversion efficiency (75 %) of the wastes was achieved at feed concentration of 6 % TS and HRT of 20 days. At feed concentration from 8 % to 10 % TS, the process was depressed. The same reactor was tested [35] at psychrophilic (20îC), mesophilic (35îC) and termophilic (55îC) conditions. The HRT and TS ranged from 10 to 20 days and 4, 6, 8 and 10 % TS, respectively. The biogas yields in the termophilic reactor were higher than those obtained in psychrophilic and mesophilic digesters by 144 % and 41 %, respectively. An improvement of the energy balance of the process was indicated.

In another investigation Bouallagui et al. [36] establish the performance of two coupled anaerobic sequencing batch reactors. FVWs were used as a substrate for the process. One of the digesters worked as hydrolizer and the other as methanizer at mesophilic temperature. It was found that the concentration of VFA increased with the increase in the loading rate during the first stage. The methane production obtained in the methanogenic stage was 320 dm^3 CH_4 kg^{-1} COD input. In the two systems the overall COD removal was 96 %. The same system was used [37] in order to establish the microbial consortia by a culture-independent approach based on single straw conformation polymorphism analysis of total 16 s rDNA showed the adaptation of the bacterial and archaeal communities to the process parameters.

Mitz.-Viturtia et al. [38] studied the two-phase anaerobic digestion of a mixture of FVW. A hybrid (up-flow anaerobic sludge bed anaerobic filter) reactor was used as a methanizer with volume of 0.5 dm^3. The hydrolizer was with volume of 1.3 dm^3. The both reactors were operated at mesophilic range (35îC) and discontinuous mode. The initial mixture contained oranges, cauliflowers, cucumbers, lettuce, tomatoes and water-melon with TS and VS concentration of 6.40 and 5.65 % (w/w), respectively. The average methane yield obtained was 0.521 m^3 CH_4 kg^{-1} VS and the biodegradation percentage was 96,7 %. In another study the authors [39] carried out degradation with the same composition of FVW exchanging only the water-melon with melon. The organic loading rates (OLRs) ranged from 3 to 12.5 kg VS m^{-3} d^{-1} and the gas yields were ranged from 0,2 to 0,63 m^3 CH_4 kg^{-1} VS. The lower production of biogas was due to the higher OLR. At an overall HRT of 18 days, the VS removal was 72 %. It was only 27 % at 4-5 days HRT. It was concluded that one-phase digestion was simpler and could achieved the same yields. Mtz.-Viturtia and Mata-Alvarez [40] also presented a simple method to fit the constants of first order, Monod and Chen and Hashimoto models. They used the system described earlier to test the method. The results showed that the model corresponded to the Chen and Hashimoto model. The two-phase system was used by Mata-Alvarez et al. [41] to carry out kinetic and performance studies of anaerobic digestion of FVW.

In two papers Mata-Alvarez et al. [42, 43] described the design of an anaerobic digestion plant to treat the organic fraction of the market wastes and the experiments which were carried out to obtain data for the preliminary design of the plant.

During the anaerobic digestion the most of the pathogens are destroyed. Termorshuizen et al. [44] studied the survival of human and plant pathogens in vegetable, fruit and garden wastes. *Fusarium oxysporum*, *Ralstonia solanacearum*, *Salmonella typhimurium*, *Plasmodiophora brassicae* and *Sclerotium cepivorum* were added to the substrate. The survival of the pathogenic microorganisms was below the detection levels.

An anaerobic co-digestion of solid potato waste and sugar beet leaves was studied by Parawira et al. [45]. The aim was to investigate the effect of concentration of potato waste and the initial inoculum-to-substrate ratio on methane production. At 40 % TS of potato waste and inoculum to substrate ratio (ISR) of 1.5, the methane yield was 0.32 dm^3 CH_4 g^{-1} VS depredated (maximum volume). The results of co-digestion showed an improvement of methane production with 31-62 %.

4. ANAEROBIC CO-DIGESTION OF WASTED FRUITS AND VEGETABLES WITH DIFFERENT ORGANIC WASTES

The potential of mesophilic co-digestion of primary sludge and fruit and vegetable fraction of the municipal solid wastes was investigated by Gomez et al. [46]. Different mixing conditions were examined with good result being found for reactors with limited mixing. The results showed better performance for the mixture than the pure substrates. The anaerobic digestion was also examined at different OLRs under low mixing condition. The process was stable even when the systems were overloaded.

Rizk et al. [47] examined the co-digestion of FVW and sewage sludge. They used 70 dm^3 stainless steel anaerobic reactor at temperature 25±5îC with no mixing. The inoculum was prepared from an anaerobic domestic sewage station of treatment. The biogas yield was around 331 dm^3 and most of it was produced during the first month of the experiment. Around 20 % of COD was removed and the pH, alkalinity and VFA were stabilized. The authors suggested that the low COD removal and the biogas generation almost only in the first month were due to the high organic load, the lack of mixing system and the difficulties in the degradation of these residues.

Anhuradha et al. [48] studied the co-digestion of vegetable market waste and sewage sludge. They compared the digestion of mixed wastes with the separate digestion of sewage sludge and vegetables. Three bench-scale reactors with working volume of 1.5 dm^3 were used. During the processes 63-65 % of VS were removed in the three digesters. The biogas production for the vegetable waste, sewage sludge and mixture were 0.75, 0.43 and 0.68 dm^3 g^{-1} VS, respectively. The higher biogas yield for vegetables was due to higher easily biodegradable organic matter content.

Alvarez et al. [49] presented the results obtained from the degradation of solid slaughterhouse waste, manure and FVW. Laboratory reactors with volume of 2 dm^3 were used at semi-continuous mode and the temperature was maintained at 35îC. Special attention was paid to the effect of increasing organic loading rate on the biogas yield. Co-digestion with OLRs in the range 0.3-1.3 kg VS m^{-3} d^{-1} resulted in methane yield of 0.3 m^3 kg^{-1} VS added. Both biogas yield and methane concentration in the biogas decreased with the increase in OLR. Another experiment was carried out using 10 different feed concentrations. The digestion in all cases was better than that of the pure substrate except the mixture of equal of FVW and solid cattle-swine slaughterhouse waste.

Co-digestion of FVW with a cattle slurry and a chicken manure was demonstrated by Callaghan et al. [50]. The process was carried out in continuous mode at mesophilic range (35îC). FVW and chicken manure were added to 18 dm^3 reactor, which was digesting cattle slurry. The loading rate was maintained in range of 3.19 - 5.01 kg VS m^{-3} d^{-1} at 21 days retention time. The authors found that when the proportion of FVW has increased from 20 % to 50 %, the methane yield has also increased from 0.23 to 0.45 m^3 CH_4 kg^{-1} VS added.

Kaparaju and Rintala [51] examined the co-digestion of potato tuber and its industrial by-products (potato silage and potato peels) with pig manure. A farm-scale continuously stirred tank reactor was used at 35îC. The process was carried out on semi-continuous mode. At loading rate of 2 kg VS m^{-3} d^{-1}, the methane yields were 0.13-0.15 m^3 kg^{-1} VS at 100:0 (VS % pig manure to VS % potato), 0.21 - 0.24 m^3 kg^{-1} VS at 85:15 and 0.30 - 0.33 m^3 kg^{-1} VS at 80:20 feed ratio. The results obtained by the authors shows that a good biogas production can be achieved with feed containing potato material up to 15-20 % of the feed VS.

Anaerobic digestion of tomato plant and rabbit wastes at mesophilic condition (37îC) and in continuous flow was demonstrate by Trujill et al. [52]. Different proportions of tomato plant and rabbit wastes in the feedstock at several HRTs were tested. The methane production was improved when the concentration of tomato plant wastes is higher than 40 % in the substrate.

Two-phase anaerobic co-digestion of fruit and vegetable mixture and wasted activated sludge was studied by Dinsdale et al. [53]. CSTRs were used for acidogenesis and inclined tubular digesters for methanogenesis both operated at 30îC, loading rate of 5.7 kg VS m^{-3} d^{-1}. The overall HRT was 13 days (3 day acidogenic HRT and 10 day methanogenic HRT). The volume of gas obtained was 0.37 m^3 kg VS^{-1} added, with 40 % VS destruction and methane content of 68 %. When the overall HRT was increased to 17 days, the VS destruction was 44 %.

5. CONCLUSIONS

The referred literature sources show that the anaerobic digestion can be a suitable process for the treatment of fruit and vegetable wastes. However, several aspects need further investigations:

- Because of the high organic loading it is difficult to maintain the process. More studies are required to determine better conditions for the anaerobic digestion both of single fruits and vegetables and of their compositions to obtain greater biogas production and solids reduction;
- Co-digestion of fruit and vegetable wastes with other organic wastes seems prospective topic for future investigation.

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Á. Êóìàíîâà, Ì. Ñúåâ

Ðåçþìå. Åæåäíåâíî ãîëåìè êîëè÷åñòâà ïëîäîâå è çåëåí÷óöè îò òúðæèùàòà, ïàçàðèòå è ìàãàçèíèòå ñå ïðåâðúùàò â îòïàäúê. Øèðîêî èçïîëçâàí ìåòîä çà òÿõíîòî îòñòðàíÿâàíå âñå îùå å äåïîíèðàíåòî èì â ñìåòèùà. Âèñîêîòî ñúäúðæàíèå íà îðãàíè÷íè âåùåñòâà â òÿõ å ïðè÷èíà çà ðàçðàáîòâàíå íà ìåòîäè çà òÿõíîòî îïîëçîòâîðÿâàíå. Ïîäõîäÿù ïðîöåñ å àíàåðîáíîòî èì ðàçãðàæäàíå, âîäåùî äî îáðàçóâàíå íà áèîãàç, êàêòî è íà îñòàòú÷íà òâúðäà ôàçà, áîãàòà íà õðàíèòåëíè âåùåñòâà. Íàïðàâåíî å ëèòåðàòóðíî ïðîó÷âàíå íà äîñòúïíàòà ñâåòîâíà ëèòåðàòóðà ïî òîçè ïðîáëåì, ðàçãëåäàíè ñà óñëîâèÿòà íà åêñïåðèìåíòèòå, ñúñòàâà íà èçïîëçâàíàòà ñóðîâèíà, êàêòî è ïîñòèãíàòèòå ðåçóëòàòè â äîáèâà íà áèîãàç.