# INFLUENCES ON THE ANAEROBIC SLUDGE TREATMENT BY CO-DIGESTION OF ORGANIC WASTES

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## ABSTRACT

Due to high organic loads and high water contents organic wastes especially residues from food processing industries and food waste from households are generally more suitable for anaerobic than for aerobic treatment. As a consequence of changes within waste water treatment processes sludge compositions have changed and sludge ages have increased continuously in the past. Therefore many municipal digesters in Germany offer free capacities which can be used for the digestion of organic wastes.

The transport of organic wastes to the waste water treatment plant (WWTP) can be realised by different devices. For industrial wastes the transport via truck connected with a central or peripherally waste preparation is most suitable (direct co-digestion) while for food wastes from households the cutting by food waste disposers (FWD) and transport via sewerage system seems useful for cities with a separated sewerage system (indirect co-digestion).

Basing on a representative investigation among German WWTP this paper describes the spreading and the main facts about direct co-digestion of industrial organic waste in municipal digesters. Moreover the influences of FWD-application on waste water and sludge treatment are estimated, going out from a expanded literature study and own batch-tests.

## KEYWORDS

co-digestion; biogas; food processing; food waste; food waste disposer; industrial organic residues;

## INTRODUCTION

Since the 1960ies many things have changed in Germany regarding waste and waste water treatment. Nutrient removal has been prescribed by limit values. Basic condition for the appropriate biological Nitrogen and Phosphorous removal is a sufficient supply with easily degradable substrate. Connected with the introduction of these treatment processes higher sludge ages occurred, which partially led to free capacities within the systems of anaerobic sludge treatment. The application of instrumentation (measuring, controlling, regulating, MCR) enabled an optimization of the treatment processes. Likewise this meant partial free capacities in the aeration tanks. Beyond that biogas is nowadays seen as a regenerative energy source. The collection and treatment of wastes is practised over whole Germany and the problems of the waste management economy like high costs, increasing "garbage mountains", air pollution (odour emissions) and leachate treatment are well-known.

Concerning energy supply and usage expressions like “Green house effect” and “Global warming” led to an increasing pressure on politicians which - regarding Germany – among others resulted in a financial support for energy produced from regenerative energy resources. A new law guarantees that for electrical energy, gained from solar power 0,46 US$/kWh will be paid concerning a power plant with less than 0,5 MW. For energy from wind power it will be 0,08 US$/kWh and for energy from biodegradable waste between 0,08 and 0,09 US$/kWh. Biogas from municipal digesters and landfills will be sold for prices from 0,06 to 0,07 US$/kWh.

The described effects and processes make it useful to investigate about the possibilities of using free capacities of municipal digesters for the anaerobic treatment of easily biodegradable waste (co-digestion). In order to make co-digestion an economical interesting process, large amounts of co-substrate which do not imply the installation of expensive pretreatment devices must be available. Organic residues from food processing industries which often require no or just simple pretreatment as well as food waste from households, ground by food waste disposers and reaching the digester via the path sewerage – primary sludge, seem to be most suitable as co-substrates.

## CO-DIGESTION OF INDUSTRIAL ORGANIC WASTES (DIRECT CO-DIGESTION)

Despite of the efforts of in-plant treatment, like avoidance and internal recycling, etc. still great amounts of residues occur within the different branches of food processing. Residues from food processing industries traditionally have been used for nourishment of animals. Basing on a continuous decrease of meat consumption, especially in western Europe, a reduction concerning this way of utilisation has been observed during the last years. As a consequence of BSE (Bovine Spongiforme Encephalopathie) and other diseases among cattle and pigs this effect will strengthen in the future.

As the organic fraction of the residues generally dominates, landfilling cannot be considered a long-lasting means of treatment. From the year 2005 on German laws prohibit the dumping of residues with an organic content (VSS) higher than 5 %. The disadvantages of composting are the great demand for area needed for the process, as well as the odours that arise from it. The great oxygen demand of this process only makes it suitable for waste that has a low water content and sufficient fibrous structure.

### Results

During the years 1997 and 1998 the Institute for Water Quality and Waste Management, University of Hanover (ISAH) executed an inquiry around German waste water treatment plants with anaerobic sludge digestion (about 1.250 plants). The analysis showed that about 10 % of all plants practice a co-digestion of waste water sludge and industrial residues and thus use free capacities which manifested themselves in retention times up to 60 days whereby 75 % of all digesters had a retention time of more than 20 d (recommendation: 15-20 d) (Austermann-Haun et al., 2000).

*Industrial co-substrates.* Industrial organic residues are generally characterised by high water contents (> 70 %) and high organic loads (COD: 10.000 – 200.000 mg/L) which makes that they are best suitable for anaerobic digestion. In 90 % of all cases the origin of the residues is the food processing industry. A remarkable fact of the inquiry was that almost all co-substrates that could be investigated where only named once. This shows the huge number of co-substrates which especially exists within the food processing industry. The following table names some co-substrates from the field of the agroindustrial food processing and even includes a short characterisation.

Table 1: Selection of some residues from food processing industries (KTBL, 1998)

| Substrate | Origin (Industry) | SS<br>% | VSS<br>% | C/N ratio |
|---|---|---|---|---|
| Distiller's wash from *apples* | Distillery of spirits | 2 - 3,7 | 94 - 95 | 6 |
| Distiller's wash from *rice* | Distillery of spirits | 12 - 15 | 90 | 3 - 9 |
| Distiller's wash from *wheat* | Distillery of spirits | 3 - 5 | 96 - 98 | - |
| Distiller's wash from *molasses* | Distillery of spirits | 10,5 | 71,2 | - |
| Rape from *apples* | Juice and wine fabrication | 25 | 86 | 30 |
| Rape from *mixed fruits* | Juice and wine fabrication | 40 - 50 | 30 - 93 | 30 - 50 |
| Rape from *grapes* | Juice and wine fabrication | 40 - 50 | 80 - 95 | 20 - 30 |
| Marc of spent malt | Brewery | 21 - 15 | 66 - 95 | 9 - 10 |
| Siliceous earth (beer filtration) | Brewery | 30 | 6,3 | 5 |
| Molasses | Sugar factory | 80 | 95 | 14 - 27 |
| Cheese whey | Dairy | 4,3 - 6,5 | 80 - 92 | 27 |
| Vegetable wastes | Tinnery, cannery | 5 – 20 | 76 - 90 | 15 |
| Cacao shells | Sweets fabrication | 95 | 91 | 20 - 22 |
| Pressed oil seeds | Fabrication of salad oil | 92 | 97 | 41 |

*Additional loads.* Usually only little amounts of co-substrates are treated thus the loads for the municipal digesters resulting from co-digestion are quite low. In 53 % of all cases the additional loads are below 0,05 kg SS/(m³*d), only 3 % with additional 1,1 to 1,8 kg SS/(m³*d).

Table 2: Additional digester loads due to co-digestion of different substrates (Austermann-Haun et al., 2000)

| Co-substrate, origin (number of WWTP) | Specific co-substrate loads | | Loading rate | | | | | |
|---|---|---|---|---|---|---|---|---|
| | L Co-S/(m³*d) | | kg SS/(m³*d) | | kg VSS/(m³*d) | | kg COD/(m³*d) | |
| | Ø | max. | Ø | max. | Ø | max. | Ø | max. |
| Residues and waste water from food processing (1) | 2,89 | 11,0 | 0,027 | 0,075 | 0,001 | - | 0,04 | 0,67 |
| Fatty substrates (56) | 1,5 | 14,3 | 0,12 | 1,14 | 0,11 | 1,03 | 7,42 | 19,5 |
| Distiller's wash (11) | 5,38 | 12,7 | 1,39 | 3,07 | 0,94 | 2,15 | 0,198 | 0,44 |
| Chemical industry (2) | 2,85 | 2,9 | -- | -- | -- | -- | 0,22 | 0,23 |
| Juice fabrication (4) | 1,2 | 2,2 | 0,24 | -- | 0,11 | -- | 0,045 | 0,13 |
| Slaughterhouse residues (4) | 7,9 | 13,9 | -- | 1,83 | 1,8 | -- | 0,43 | 1,04 |
| Straw granulates (1) | 0,12 (kg ...) | -- | 0,11 | -- | 0,09 | -- | -- | -- |
| Textile industry (1) | -- | -- | 0,02 | -- | -- | -- | 0,176 | -- |
| Sludge from septic tanks (2) | -- | -- | 0,41 | 0,65 | 0,28 | 0,45 | 0,36 | 0,57 |

In summary it can be said that the operators of WWTP only rarely practice co-digestion to the digesters limits. It can be assumed that co-digestion runs besides the actual WWTP-operation and therefore can be called an "opportunity business". Only little operators already have implemented co-digestion as a part of common operation. Cases which led to an overloading of digesters often resulted from campaign-depending co-substrates (e.g. distiller's wash, leachate from sour-kraut production). In all cases an increase of the biogas production was reported.

*Problems in operation.* Due to special characteristics of some co-substrates but often due to false operation co-digestion on some WWTP is accompanied by technical problems. The most heard problems during the inquiry among German WWTP are listed in the following table.

Table 3: Problems in operation due to co-digestion (Austermann-Haun et al., 2000)

| Problem | Frequency | |
|---|---|---|
| | absolutely [-] | relatively [%] |
| Foam in digester | 8 | 11,1 |
| Surface scum in digester | 3 | 4,2 |
| Heavy materials in digester | 2 | 2,8 |
| Blockage and sedimentation of/in pipes, pumps, etc. | 11 | 15,3 |
| Wear/abrasion of pumps, etc. | 5 | 6,9 |
| Odour emissions | 5 | 6,9 |
| Surface scum in storage tank | 1 | 1,4 |
| Increase of corrosion | 3 | 4,2 |
| Heavy metals in digested sludge | 6 | 8,3 |
| Degradation of gas quality | 3 | 4,2 |
| Degradation of dewatering characteristics | 9 | 12,5 |
| Degradation of digestion or overloading | 2 | 2,8 |

The problems foam, surface scum and blockage often were reported when fatty/greasy co-substrates were treated whereas corrosion and heavy metal problems can be connected with the co-digestion of distiller's wash from stone fruits like cherry and plum. The latter substrate is characterised by temperatures > 60°C and pH-values between 1,5 and 5,0. Reasons for the high Copper concentrations in the digested sludge are first cupreous substances for the separation of cyanide and second cupreous distilling apparatus.

## CO-DIGESTION OF FOOD WASTES FROM HOUSEHOLDS (INDIRECT CO-DIGESTION)

Within inner-city districts the collection of biodegradable waste, which in such areas mostly consists of food waste (vegetable waste, coffee ground, tea filters, remainder of prepared/cooked food) can be considered as being problematic. On the one hand odour and hygienic problems can occur and on the other hand the rate of source separated waste collection often is low in such areas. Consequently the biodegradable waste can be found in all other fractions of municipal household waste. Moreover home composting is not possible and composting on the balcony cannot be accepted for above named reasons.

Referring to the existing process chain of drain system sewerage system and waste water treatment plant including sludge digestion, food waste disposers generally offer alternative possibilities concerning the transportation and the treatment of biodegradable food waste. Free capacities in WWTP and sludge digesters, the support of energy gained from biogas and waste management problems caused by the organic fraction of municipal solid waste (MSW) support this idea.

For the transportation of food waste to the WWTP food waste disposers (FWD) can be used for cutting followed by transport via sewerage system. Most of the suspended solids will settle in the primary clarifier while screens and grit chambers will only be affected to a small extend. Thus the majority of food waste will find it's way into the system of sludge digestion and will cause a higher biogas production. The soluble organic fraction will lead to higher BOD respectively COD loads within the biological treatment steps.

### Food waste

In Germany the source separated collection and treatment of the organic, biodegradable fraction of household waste (bio-waste) is state of technology. The collection in special bins/containers ("Biotonne") followed by transportation via truck and connected with composting is the prevailing treatment. This however often leads to problems which especially occur in inner city districts and which in many cases are caused by food waste. Some of these problems are: odour emissions, increasing fraction of non-biodegradable waste, high water content of bio-waste, lack of space for bio-waste bins and an unsatisfying collection ration for bio-waste.

*Amount.* Food waste or kitchen waste occurs during the whole year. Its amount only depends on peoples particular life and nutrition habits. Compared to the whole organic fraction of household waste the particular fraction of food waste is characterised by the following items: highest moisture content, best biodegradability, highest density, lowest heating value (due to highest water content). Basing on a literature study the national (German) and international amount of food waste (moisty) can be estimated to about 55 kg/(capita*a) (45 – 65 kg/(capita*a)) for Western Europe. This means a daily amount between 123 and 178 g/(capita*d). Table 4 gives a more detailed insight into the single values.

Table 4: Amount of food waste in different Western countries

| **Author** | **Food waste** | | | |
|---|---|---|---|---|
| | **Amount (moisty)** | | **SS** | |
| | **kg/(capita·a)** | **g/(capita·d)** | **%** | **g/( capita·d)** |
| Nilsson et al. (1990), Sweden | 88 | 235 | - | - |
| Lagerkvist and Karlsson (1983), Sweden | 90 | 245 | 27<br>(25 - 30) | 67<br>(61 - 74) |
| De Koning and van der Graaf (1996), Netherlands | 44 | 120 | 40 | 48 |
| Hoffmann (1994), Germany | 100 | 274 | 30 | 82 |
| Karlberg and Norin (1999), Sweden | 100 | 274 | - | - |
| Diggelman and Ham (1998), USA | 48 | 132 | 30 | 40 |
| Strutz (1998), USA | 48 | 132 | - | - |
| Krogmann (1989), Germany | 52 | 142 | - | - |
| Schäfer (1995), Germany | 22,5<br>(20 – 25) | 82<br>(73 – 91) | - | - |
| Scheffold (1995), Germany | 50 | 137 | - | - |
| Doedens and Ketelsen (1992), Germany | 65<br>50 - 80 | 179<br>137 – 220 | - | - |

*Structure and composition of food waste.* Food waste mainly consist of less- or non-fibrous, mostly vegetable remainders which cooked or non-cooked are characterised by a high water content (70 % and more). The balanced C/N-ratio and the moisty consistency make that food waste is easily biodegradable whereby it is better suitable for anaerobic than for aerobic treatment.

Table 5: Chemical composition of different food waste fractions in percentage of dry solids (DS)

| | **Vegetable and food waste** | **Remainders of oranges and lemons** | **Meat remainders** | **Fat/grease** |
|---|---|---|---|---|
| **C** | 49,1 | 49,0 | 59,6 | 73,1 |
| **H** | 6,6 | 5,7 | 9,5 | 11,6 |
| **O** | 37,6 | 41,7 | 24,6 | 14,8 |
| **N** | 1,7 | 1,1 | 1,0 | 0,4 |
| **S** | 0,2 | 0,1 | 0,2 | 0,1 |
| **Summation of VSS (= % of SS)** | **95,2** | **97,6** | **94,9** | **100** |
| **FSS** | 4,8 | 3,4 | 5,1 | 0,0 |
| **Summation of SS** | 100 | 100 | 100 | 100 |
| **C/N** | **29,2** | **44,1** | **58,4** | **170,0** |

**Food waste disposers**

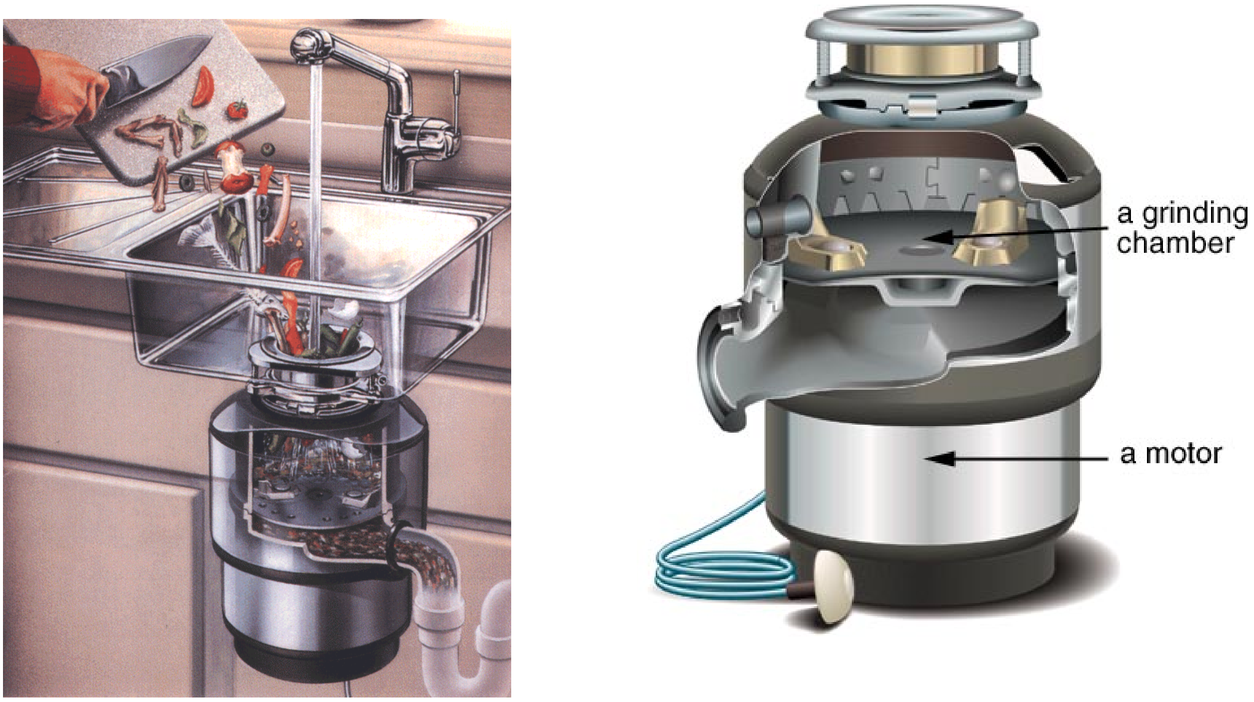
*History*. The food waste disposer (FWD) was invented in 1927 by the American architect John Hammes. Nowadays there are approx. 8 manufacturers of food waste disposers world-wide, market leader is the company In-Sink-Erator (ISE). FWD have been installed in the United States (US) since over 60 years and can be found in 45 % of all US-households. In some states and in over 100 cities their use is even mandated.

More than 80 % of all new homes in the US have a FWD. The attitude towards FWD has always been negative in Central and Western Europe over the past decades. The main reasons for that have been the additional amount of fresh water and electricity for FWD-application as well as the additional loads for the WWTP which then often were overloaded. Nowadays the most common argument against FWD is that the device works against the idea of source separated waste collection.

However due to positive research results in the past and referring to a holistic point of view FWD gain more and more interest in Europe (e.g. UK, Sweden, Norway, Italy, the Netherlands). The biggest spreading concerning Western Europe can be find in the UK where about 5 % of all households (more than 1 Mio.) already have a disposer. For the rest of the western European countries the spreading of FWD can be estimated to 1 %. Concerning Germany no explicit prohibition of FWD exists on the federal level. However leading/mixing waste into waste water is prohibited and thus indirectly the application of FWD. Regarding the municipal level, the German waste water association (Abwassertechnische Vereinigung, ATV) recommends all communities not to allow FWD within their waste water directives.

*Function*. The FWD is installed under the kitchen sink whereby the outlet is attached to the siphon of the sink. Frequently even the outlet of a dishwasher can be connected to the FWD so that even larger particles from this stream will be cut up before entering the drains. The device is equipped with a waterproof electrical or pneumatics switch. The FWD can rather be described as a mill, than a cutter as the organic, moisty wastes are ground on the rough external wall of the grinding chamber. This works with the help of a rotary disk, on which two hammer-cheeks mobile in horizontal direction are fastened. The disk is provided with 5 mm large holes, by those the suspension of water and ground kitchen waste finally is led into the drain- and sewerage system.

Figure 1: Food waste disposer a) in operation b) cross section (ISE, 1999)




Against frequent heard prejudices FWD do not contain rotating knifes. Regarding a FWD the danger of injury is small, compared to other kitchen appliances like e.g. electrical hand mixers or a hot stove. The operation of a FWD can be divided into the following steps: 1. let cold water run, 2. switch on FWD, 3. add food waste and meal remainders by portion, 4. let water run another 20 to 30 seconds after the disposal is finished.

With the aid of a FWD all organic kitchen wastes such as vegetables, fruit rinds, coffee grounds, remainder of cooked meat and fish, small bones etc. can be ground. Non-organic materials like metal, glass, porcelain, leather, cotton, rubber, plastics and in addition hard organic material such as wood, fruit stones and large bones cannot be ground, since the mechanism of the device is not intended for such materials. The attempt to grind such materials will causes a resistance, which, if it becomes excessive, will cause a switch off of the engine (resistor). Additionally an intense noise is connected with the attempt of grinding hard materials which has an educational effect on the user.

**Results**

Main focus was laid on the determination of border conditions for an economical and ecological application of FWD. Moreover informations about the numerable influences of ground kitchen waste on WWTP and sludge digestion were collected. At last the main advantages and disadvantages of FWD-application are listed.

*Border conditions for useful FWD-application.* An introduction of FWD into existing waste (water) systems ought to fulfil some essential preconditions. Among others the use of FWD should be restricted to city districts with a separated sewerage system. The sewerage system ought to be in a good condition which means no fractures, no leakage, no sedimentations. The minimal gradient should not be below 2 ‰. Furthermore the concerned WWTP is to contain a primary clarifier and a sludge digestion and must offer free capacities regarding both waste water and sludge treatment. FWD should not be used in houses, connected to a dead end sewerage as this includes a higher risk of sedimentation.

*Additional loads.* Table 6 is a summary of all information gained from literature studies as well as from own batch-tests. In order to estimate the real (theoretically possible) impact of FWD on existing infrastructure the FWD-spreading is of great importance. Going out from the above named spreadings the annual spreading ratio can be estimated to about 1 %. The basic values of table 6 refer to the composition of German domestic waste water but will probably fit most of the Western European countries.

Table 6: Main influences of FWD-application on waste water and sludge treatment (partially summarised, calculated and/or evaluated, basing on literature studies and own batch-test)

| | **Domestic waste water loads*** | **Additional loads due to FWD-application** | |
|---|---|---|---|
| | **g/(capita*d)** | **g/(capita*d)** | **%** |
| **Flow** | 128 l/(capita*d) | 4,5 l/(capita*d) | 3,5 |
| **Screenings** | 0,016 | 0,17 | 5 |
| **Grit** | 0,04 | 0,042 | 5 |
| **$COD_{tot.}$** | 120 | 18 – 36 | 15 – 30 |
| **$BOD_{tot.}$** | 60 | 6 – 15 | 10 – 25 |
| **TKN** | 11 | 1,5 | 5 – 10 |
| **$P_{tot}$.** | 2,5 | 0,13 – 0,25 | 5 – 10 |
| **SS** | 70 | 28 – 40 | 40 – 60 |
| **C/N** | 2/1 – 5/1 | 25/1 | +++ |
| **Primary sludge** | 45 - 54 | 20 - 40 | 50 - 70 |
| **Surplus sludge** | 10 – 35 | 5 – 20 | 10 – 40 |
| **Raw sludge** | ca. 80 | ca. 50 | ca. 62 |
| **Digested sludge** | 48 - 60 (DS) | 15 –18 (DS) | 30 – 50 |
| **Biogas** | 6 - 9 $m^3$/(capita*a) | 6 - 9 $m^3$/(capita*a) | 90 - 100 |

* for Germany (after the German waste water associations working paper A 131 (ATV, 2000))

*Main advantages of FWD-application.* The main advantages of FWD-application are: Improvement of hygienic conditions regarding households and waste collection, utilisation of existing infrastructure, additional Carbon source for denitrification and biological Phosphorous removal, utilisation of energetic potential of organic wastes, higher rates of VSS-degradation.

*Main disadvantages of FWD- application.* Presupposed an observance of the border conditions named above the probability of problems like sedimentation, odour ($H_2S$) emissions, increase of rodents populations, additional loads for the aquatic system due to discharge events, soil and groundwater pollution due to leaky drains etc. can be classified as small and therefore are not listed in the following. The main disadvantages of FWD-application are: Higher amounts of digested sludge, additional sludge liquor, (high) initial costs for the user (not for the community), additional fresh water and energy requirement (FWD-application, aeration).

## CONCLUSIONS

The current waste, waste water and energy situation makes it useful, to use free capacities in municipal digesters for the co-digestion of easily biodegradable wastes and thus produce "green energy". Industrial organic residues especially from food processing industries and food waste as a fraction from households bio-waste are especially suitable as co-substrates. Regarding the direct co-digestion of industrial wastes choice, amount, composition and pretreatment are of great importance. Concerning the indirect co-digestion of food waste, ground by food waste disposers, the observance of border conditions (listed above) is essential. Despite of all positive aspects one always has to keep in mind, that the main purpose of a WWTP is to clean waste water and to treat the different kinds of sludge which occur during the single process steps of water treatment. This purpose must not be influenced in a negative way by co-digestion at any time. Therefore especially concerning direct co-digestion of industrial wastes monitoring plays an important role.

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