COST MINIMISATION BY DISINTEGRATION - A FULL-SCALE COMPARISON

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ABSTRACT

To optimize anaerobic digestion, different methods of disintegration were investigated at a full-scale plant. Two stirred ball mills, a plant for oxidation with ozone, a lysate centrifuge and an ultrasonic homogenizer were applied.

A positive influence of disintegration on the anaerobic biodegradability could be established with all aggregates. The enhancement of the degree of degradation varied between 7.4 to 26 %. Beside this, laboratory investigations proved that disintegration increases the polymer demand and leads to a lower solid content after dewatering. Higher ammonia concentrations in the process water after dewatering corroborated the results of the anaerobic degradation.

Capital costs for the aggregates, costs for energy, manpower and maintenance can be covered, if specific costs for disposal are high. If the development of sludge treatment costs in future and the current discussion about sludge disposal are taken into account, sewage sludge disintegration can be a suitable technique to minimize costs on waste water treatment plants.

KEYWORDS

Disintegration, economic efficiency, full-scale investigations, improvement of stabilization, lysate centrifugal technique, ozone treatment, stirred ball mills, ultrasonic homogenizer

INTRODUCTION

The main part of costs at waste water treatment plants consists of costs for disposal and energy. Applying disintegration, the reduced sludge quantities will lead to a minimization of disposal costs. Also a minimization of the energy costs by increasing the biogas production and by optimizing biogas utilization is intended.

Sewage sludge disintegration is a stressing of sewage sludge by external forces using mechanical, thermal, chemical or biological methods. With low energy input this treatment changes the floc structure. A higher energy input needed for the disruption of the cell wall results in a solubilization of the organic matter in the sludge. Due to that, disintegration enables an accelerated and an enhanced degradation of organic matter. Extensive research work in half-scale and lab-scale plants has already shown that disintegration is a suitable method to make organic material from excess sludge available for the degradation in an anaerobic process. Especially at short retention times (< 15 days) an enhanced degradation of organic matter can be achieved. An increase in the degree of degradation of about 10 to 30 % [1] can be attained. The second effect is a change in dewaterability. In most cases a higher polymer demand for an optimal dewatering could be observed [2]. The increased degree of degradation also effects the process water after dewatering, which shows a high concentration of ammonia-nitrogen.

In order to verify the above mentioned results full-scale investigations are necessary. This paper will show results of investigations at a municipal WWTP located in Schermbeck (Lippeverband, Germany) comparing different disintegration aggregates and methods. The application of two different stirred ball mills (disk mill system, annular chamber mill system), a chemical disintegration by partial oxidation with ozone, a lysate centrifuge and an ultrasonic homogeniser were investigated.

METHODS

Disintegration at Schermbeck WWTP

Investigations took place at Schermbeck WWTP which is an activated sludge plant with a capacity of 17,000 PE. The wastewater treatment consists of primary settling followed by biological nitrogen and phosphorous removal. The excess sludge is thickened in a gravity thickener to 25 g/l suspended solids (volatile suspended solids: 17 g/l) before being digested together with the primary sludge in two mesophilic digesters with a retention time of 17-18 days. Daily flow of excess sludge varies from 12 to 30 m^3/d. Flow of primary sludge is about 6 to 10 m^3/d with an average concentration of suspended solids of 27 g/l (volatile suspended solids: 20 g/l). Disintegration of excess sludge takes place in the influent of one digester. Up to now, there have not been enough long-term experiences about the disintegration of sewage sludge. Due to that fact, the disintegration aggregates with the exception of the ultrasonic homogenizer only worked for five days a week. To ensure a continuous effluent from the gravity thickener as well as a continuous influent in the digester, two storage tanks were installed prior to and after the disintegration aggregate. Hydraulic retention times in the storage tank after the disintegration aggregate varied between 1.8 to 4.5 days.

Methods of Sludge Disintegration

Stirred Ball Mills consist of a cylindrical grinding chamber which is almost completely filled with grinding beads. A rotor forces the beads into a rotational movement. The micro-organisms are disintegrated between the beads by shear and pressure forces. For a continuous operation the beads are held back by centrifugal forces and an additional sieve. This kind of mill is called disk mill system and was investigated in Schermbeck (Type LME 50 K, Netzsch Feinmahltechnik GmbH). The motor rating was 37 kW. Circumferential speed of the rotor was set at 15 m/sec. The grinding chamber kept a volume of 52.8 l. About 85 % of the grinding chamber were filled with grinding beads, which were of a different material and diameter (SAZ-balls/600-800 μm and zirkon-sand/150-250 μm).

For the annular chamber mill the grinding chamber is made up of two double cylinders. Separation of the grinding beads is achieved by centrifugal forces alone. A stirred ball mill from the company Draiswerke (Type Cosmo 25), also investigated in Schermbeck, makes use of this method. The motor rating was 30 kW. The grinding chamber was smaller and kept a volume of about 8.5 l. Circumferential speed of the rotor was set at 22 m/sec.

Chemical Disintegration with Ozone: Due to ozone treatment cell walls of micro-organisms are disintegrated and inner cell products can be released. In addition ozone reacts with organic compounds that are less biodegradable, oxidizing them to smaller compounds which are bio-available. In Schermbeck a plant for ozone treatment was made available from the company Wedeco. It consisted of a storage tank for oxygen, an ozone generator (maximum power rating 7.5 kW), and a reaction tank of 6 m^3 volume. A maximum ozone load of 1 kg

O_3/h could be generated. Ozone was inserted by an injector in the reaction tank bypass.

The Lysate-Centrifugal-Technique uses a thickening centrifuge equipped with a disintegration device located at the discharge of the thickened sludge. Tools on the rotor and the stator stress the sludge by shear-forces. Additional energy needed for the disintegration is low. But this results in a very low degree of disintegration. A lysate centrifuge from the company Hiller (Type DECATHICK DT31-422) was investigated for four months. Motor rating was 15 kW. The number of revolutions of the drum was 8500 per minute with a maximum flow of 10 m^3/h. During the research project only the effect of disintegration and not the effect of thickening sludge were to be investigated. For this reason the thickened sludge was diluted again with centrate water. This was the only possibility for comparing the two digesters with similar hydraulic retention times.

Ultrasonic homogenizers consist of three major components. A generator supplies a high-frequent voltage. A ceramic-crystal of piezo-electrical material transforms electrical into mechanical impulses, which are transmitted by a sonotrode into the fluid. Cavitation bubbles are created by alternating overpressure and underpressure. The following implosion of the gas and vapor-filled bubbles leads to high mechanical shear-forces which are apt to disintegrate bacterial cell material [3]. During this research project an ultrasonic homogenizer from the company Sonotronic was applied. It consisted of five sonotrodes (frequency 25 kHz) with a total power rating of 5 kW. Volume of the loop-reactor was about 30 l. Only a partial flow (30 %) of the excess sludge was treated by ultrasound. It was assumed in earlier investigations [4] that even with a low energy input an activation of the bacteria could be achieved. These results were to be verified during this research project.

Program of Investigation

To find optimal operating conditions for the stirred ball mills, pre-investigations were carried out. Different parameters were varied such as sludge flow (450 – 1300 l/h), concentration of suspended solids (5 – 25 g/l SS) and bead diameter (150-250 μm, 600-800μm). The plant for ozone treatment initially ran in batch operation with an increasing ozone dose up to 0.06 g O_3/g SS. The sludge flow of the lysate centrifuge varied between 2.4 and 4.3 m^3/h when the centrifuge was in continuous operation. Investigating the ultrasonic homogenizer, sludge flow was varied between 50 and 450 l/h. The results of the disintegration were quantified by the degree of disintegration. This parameter is determined by the rate of oxygen demand (DD_O) and the COD release (DD_{COD}). Both methods are described elsewhere. [5] [6]

After this period of pre-investigation, each aggregate ran for 2-4 months. To quantify the influence of disintegration on anaerobic digestion the specific gas production related to the input of organic matter and the degree of degradation of the organic matter were determined. For that reason the influent flow of raw sludge was recorded as well as the flow of biogas. The concentration of volatile suspended solids VSS was analyzed daily in the influent and effluent of both digesters.

To quantify influence of disintegration on conditioning and dewatering characteristics which can be observed after digestion, specific resistance to filtration, capillary suction time and polymer demand for an optimum dewatering were estimated in lab-scale investigations. Furthermore a prediction of full-scale dewatering results by thermo-gravimetric determination of the water distribution of sludge was possible. The applied method is described elsewhere [7]. In addition the sludge was dewatered in a pilot filter press. To quantify the pollution level of process water after dewatering, concentrations of COD and ammonia-nitrogen were analyzed.

RESULTS AND DISCUSSION

Energy Consumption

During the operation of both stirred ball mills, the degree of disintegration was estimated by measuring the oxygen demand DD_O. When applying chemical oxidation with ozone and lysate centrifugal technique, calculation of the degree of disintegration by measuring the COD (DD_{COD}) was the only possible method. Using ozone inhibited the bacteria and overlaid the disintegration and inactivation of the bacteria. In case of applying lysate centrifuge, very low and often negative values were determined when measuring the DD_O. This could be an indication for an activation of the bacteria.

The different disintegration methods can be compared using the degree of disintegration in relation to the specific energy which is shown in the figure below. The specific energy is defined as the energy input related to the treated solid mass.

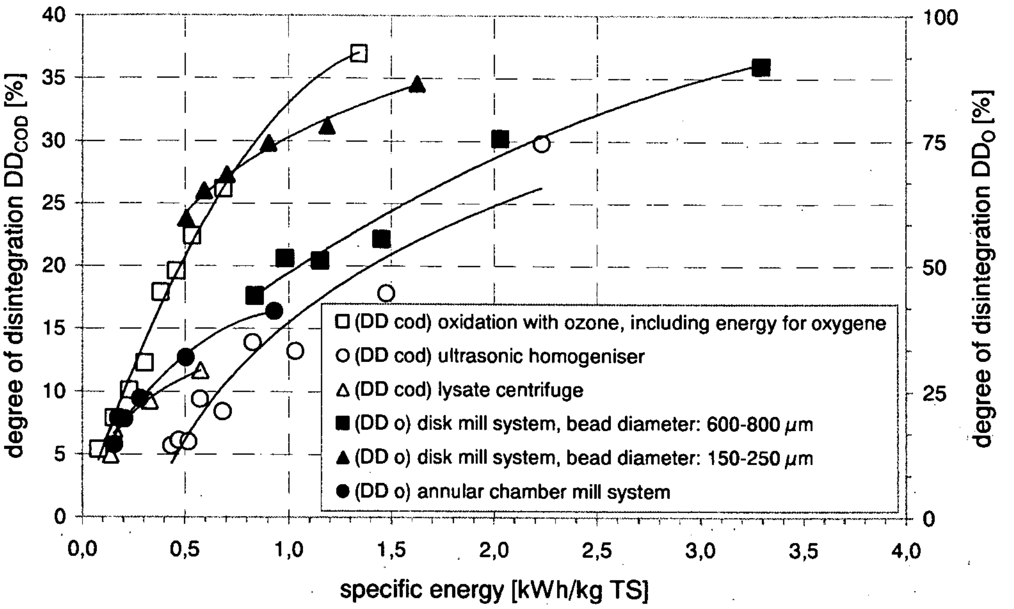

Figure 1: Comparison of different disintegration methods in regard to energy consumption

The annular chamber mill reaches a medium degree of disintegration at a relatively low energy demand. The disk mill uses a higher energy input, due to that, a higher degree of disintegration can be achieved. Using grinding beads with smaller diameters improves efficiency. With chemical oxidation a high degree of disintegration can be achieved, but additional energy for the production of pure oxygen, necessary for generating the ozone, is needed. This has already been considered in the figure above. Energy input of an ultrasonic homogenizer is less effective than the other aggregates. With lysate centrifugal technique an average degree of disintegration of 10 % DD_{COD} could be achieved. During long-term investigations with the stirred ball mills an average degree of disintegration of about 25 % DD_O (annular chamber mill) and 60 % DD_O (disk mill) was obtained. Treatment with ozone resulted in 30 % DD_{COD} mean value. Mean value 17 % DD_{COD} was achieved with the ultrasonic homogenizer.

Operational Behavior

A mechanical pre-treatment was not necessary. Clogging by coarse or fibrous particles was not a problem for any of the aggregates. No abnormal wear at the aggregates was observed. Only a high loss of grinding beads because of wear (disk mill) and the sudden shutdown of the mill (annular chamber mill) occurred. The ozone plant was more difficult to handle because of foaming problems and had several breakdowns. The ultrasonic homogenizer had at first problems with heat. The sludge flow was not high enough for cooling the sonotrodes. This resulted in several break downs of the sonotrodes. Since an extern cooling system was installed no further problems occurred.

Anaerobic Treatment

When applying the different disintegration aggregates, an increase of the anaerobic biodegradability could be observed in all cases. This effect varied depending on the degree of disintegration. The following table shows the degree of degradation of both digesters, one fed with disintegrated excess sludge and one fed with untreated sludge.

An evident increase of the degree of degradation could be achieved using a stirred ball mill and chemical disintegration with ozone. A lesser effect was observed with lysate centrifuge and ultrasonic homogenizer. Both aggregates achieved a lower degree of disintegration and hence a low increase in the degree of degradation.

Table 1: Influence of disintegration on the degree of degradation

disintegration aggregate / method	degree of degradation with untreated sludge [%]	degree of degradation with disintegrated sludge [%]	relative increase [%]
stirred ball mill (total flow disintegration)	44.0	55.8	26
chemical disintegration with ozone (total flow disintegration)	46.6	55.5	19
lysate centrifugal technique (total flow disintegration)	44.0	47.9	8.8
ultrasonic homogeniser (partial flow disintegration)	48.8	52.4	7.4

In all cases a pre-degradation of the organic dry mass was observed during storage periods in the tank after the disintegration aggregate. The results shown in the table above include this pre-degradation. In this case the biogas produced during this pre-degradation was lost. To achieve an optimum benefit from the application of disintegration, the sludge should not be stored after disintegration.

Dewatering and Conditioning

As a consequence of disintegration the fraction of small particles increases. Due to that, capillary suction time and specific resistance to filtration deteriorate. Parameters, such as the polymer demand and the solid content in the sludge cake after dewatering, which directly influence costs for dewatering and disposal, are of a greater interest.

Table 2: Influence of disintegration on the polymer demand and the solid content after dewatering

disintegration aggregate / method	relative change of polymer demand [%]	change of dewatering result [% TS] thermo-gravimetric measurement	change of dewatering result [% TS] pilot chamber filter press
stirred ball mill (total flow disintegration)	+7.4	+0.2	-2.9
chemical disintegration with ozone (total flow disintegration)	+31	-1.4	-2.7
lysate centrifugal technique (total flow disintegration)	+5.2	-0.7	-2.3
ultrasonic homogeniser (partial flow disintegration)	+8.7	+0.6	-0.7

Table 2 shows that the polymer demand increased slightly due to disintegration. Only disintegration with ozone leads to an evident increase of polymer demand of about 31 %. With thermo-gravimetric measurements hardly any difference in the full dewatering results was predicted, while dewatering with a pilot chamber filter press resulted in a lower solid content in the sludge cake. Only disintegration with the ultrasonic homogenizer did not influence the dewatering result.

The pollution level of process water after dewatering corroborated the results of the anaerobic degradation. TKN in the process water consisted mainly of ammonia-nitrogen, which is, among other substances, a product of protein degradation. Because of disintegration the concentration of ammonia-nitrogen increased, corresponding to the improved degradation of organic matter. During the period of investigation, ammonia concentration increased by about 10 % (stirred ball mill), 17 % (oxidation with ozone), 10 % (lysate centrifuge) and 5 % (ultrasonic homogenizer). Furthermore COD increased about 2 % (ultrasonic homogenizer), 5 % (lysate centrifuge), 17 % (stirred ball mill) and 52 % (oxidation with ozone) due to the solubilization by disintegration and only partial degradation in the digester.

Economic Efficiency

Costs for disintegration were estimated for a model wastewater treatment plant of 100.000 PE [8]. On one hand capital costs for the aggregates including storage tanks, pumps, measurement and control systems have to be covered as well as energy costs for disintegration. This makes up the main part of costs, furthermore costs for manpower, maintenance. Costs for the higher polymer demand and cost for additional aeration resulted from the higher pollution level of sludge process water are negligible.

On the other hand profit of thermal and electrical energy is possible due to the higher gas production resulting from disintegration. But the main part of profit is made by minimizing disposal costs because of a decreased amount of sludge resulting from the higher degree of degradation. Costs for disposal include transport and dewatering. Figure 2 shows the different annual costs as well as the profit due to disintegration.

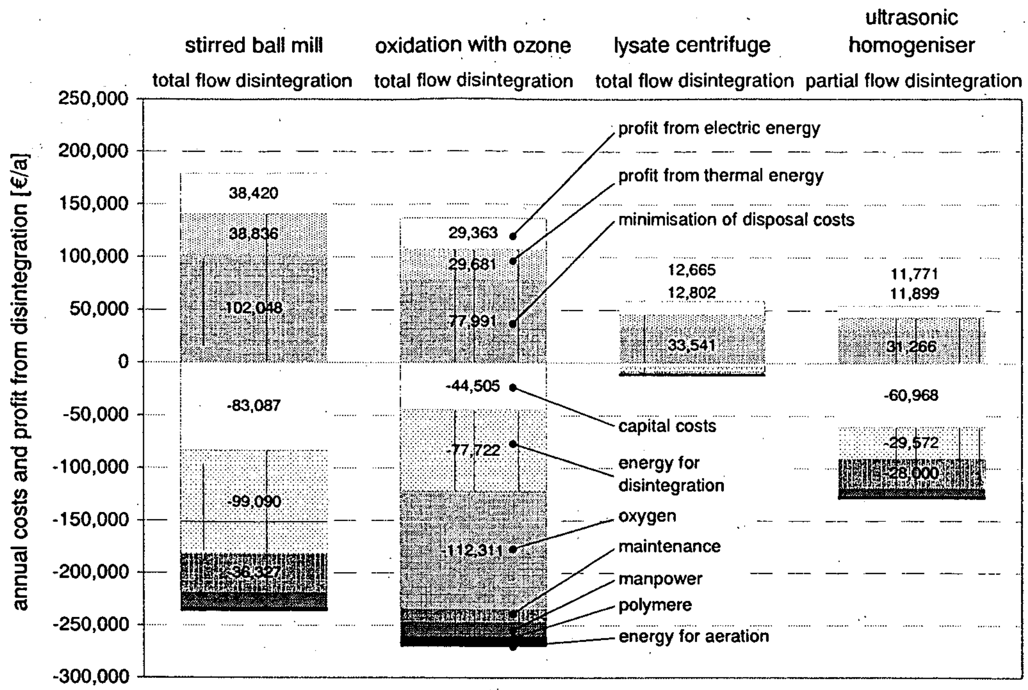

Figure 2: Comparison of costs and profit due to disintegration with specific disposal costs about 400 Euro per Mg digested sludge

Annual costs for disintegration are high, especially for the stirred ball mill and oxidation with ozone. In case of applying chemical oxidation with ozone, additional costs for the oxygen necessary for generating the ozone had to be taken into account. When only a partial flow of the excess sludge is disintegrated, costs decrease . This is evident for the application of the ultrasonic homogenizer. In case of the application of a lysate centrifuge, capital costs are low when a conventional centrifuge is already installed. Due to this, costs result only from upgrading with the lysate equipment. Additional energy resulting from the use of the lysate equipment depends on the dimension of the centrifuge and makes up at maximum 30 % of the energy needed for the operation of a conventional centrifuge.

Most profit can be achieved applying a stirred ball mill and oxidation with ozone. In dependence of the enhancement of the anaerobic biodegradability profit becomes lower when applying an ultrasonic homogenizer or a lysate centrifuge. When calculating the profit from disintegration, it has to be taken into account that profit made from the minimization of disposal costs is influenced by the specific costs for disposal depending on the way of disposal. In this case specific costs of about 400 Euro per Mg dry mass of digested sludge were calculated. Under this circumstances profit is lower than costs for the stirred ball mill, oxidation with ozone and ultrasonic homogenizers. A break-even-point can be achieved if specific costs for disposal are about 625 Euro (stirred ball mill), 1,087 Euro (oxidation with ozone) or 1,350 Euro per Mg dry mass of digested sludge.

The economic efficiency of a disintegration prior to anaerobic digestion is mainly influenced by three factors:

- The achieved improvement of the anaerobic degradation, because this determines the additional gas production and the reduction of the amount of sludge to be disposed of
- The specific disposal costs of the sludge, because they determine most of the cost savings.
- The size of the WWTP, because the specific capital costs for the disintegration devices are reduced with increasing size of the WWTP.

By varying these factors, it is possible to calculate the break-even-point for individual circumstances. In Figure 4 such a calculation based on the results obtained in this research work is shown. A volatile solids reduction of 45 % was assumed for the conventional anaerobic process and an energy consumption of 0.5 kWh/kg TS needed for disintegration. Because the capital costs for all disintegration methods are in the same order of magnitude Figure 3 is independent of the method that is used.

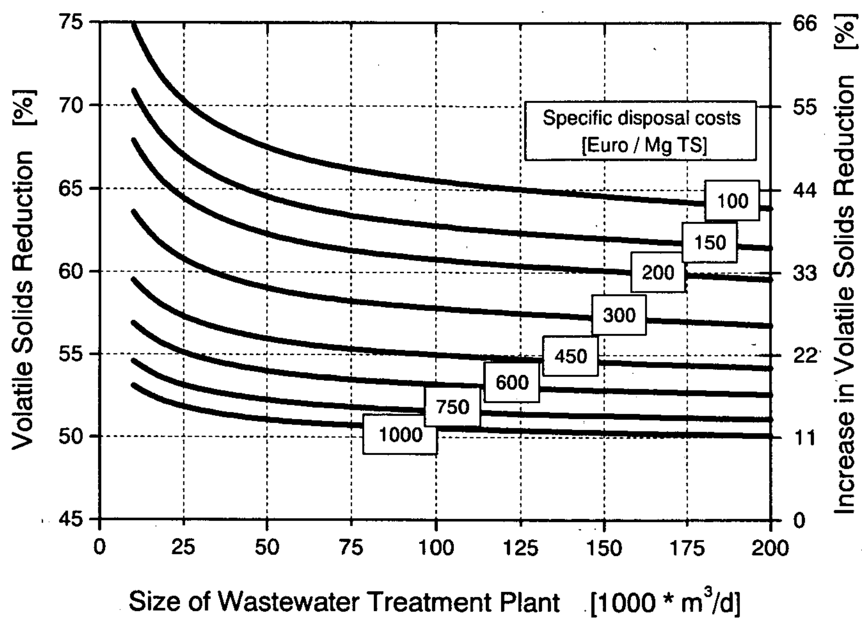

Figure 3: Break even point for the application of disintegration prior to anaerobic digestion [9]

Using these curves, the cost efficiency can be estimated. If for example a WWTP with an influent flow of 50,000 m^3/d and specific disposal costs of 300 Euro/Mg can achieve an increase in the volatile solids reduction of more than 30 % (from 45 to more than 58.5 %), the installation of a disintegration device on the plant will save costs.

In this investigation the best results were obtained using the stirred ball mill (see Figure 2), although cost efficiency was not achieved on the basis of the model WWTP of 100,000 PE (20,000 m^3/d). With an increase in volatile solids reduction of 26 % and specific disposal costs of 400 Euro/Mg TS it can be derived from Figure 3 that cost efficiency can be reached for WWTP of more than 50,000 m^3/d treatment capacity.

CONCLUSIONS

Disintegration of excess sludge is a possible pre-treatment to optimize anaerobic digestion. This has been shown already in various half-scale and lab-scale investigations. To validate these results two stirred ball mills, oxidation with ozone, a lysate centrifuge and an ultrasonic homogenizer were investigated at a full-scale plant in Schermbeck.

In continuous operation a constant quality of disintegrated sludge could be produced with all aggregates. A positive influence of disintegration on the anaerobic biodegradability could be established. The enhancement of the degree of degradation varied between 7.4 % and 26 %. Laboratory investigations validated that disintegration increases the polymer demand and leads to a lower solid content after dewatering. Higher ammonia concentrations in the process water after dewatering corroborated the results of the anaerobic degradation.

A balance of costs and profit from disintegration was estimated. The main part of profit is made up from the minimization of disposal costs because of a decreased amount of sludge resulting from the higher degree of degradation. The economic efficiency of a disintegration is mainly influenced by the achieved improvement of the anaerobic degradation, the specific disposal costs of the sludge and the size of the WWTP. If the development of costs and the current discussion about sludge disposal is taken into account, sewage sludge disintegration can be a suitable technique for minimizing costs at waste water treatment plants.

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