Energy consumption and sustainability in wastewater treatment plants
- Criteria for choosing the appropriate technology -

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ABSTRACT

There are continuously growing objections against compact technical systems for wastewater treatment due to their following negative characteristics: lack of sustainability, high external energy budget, and continuously growing functional costs.

Emphasis has been given to: wastewater treatment target, purification efficiency of compact technical systems, residual loadings, ecological consequences caused by effluents into the natural recipients and “alternative technologies” using methods “closer to nature”.

In addition a critical report concerning the “activated sludge process” is presented. The budgeting of carbon turnover by those plants shows a conversion to CO_2 of about 38 % only, which represents the “real degradation efficiency”. The rest of 62 % consists of sludge (55 %) and residual organic matter (7 %) (persistent and sometimes ecotoxic) discharged into the recipient (natural water body). This may cause serious environmental problems, which cannot be solved by any technology until now.

1. INTRODUCTION

In the wastewater treatment practice the methods, which work by forced oxygenation, became more and more predominant. Methods most used are the “activated sludge process” and aerated lagoons. They are supposed to meet the technical standards and are therefore regarded as “State of the Art”.

These standards however, represent a rather narrow technical way of viewing and understanding biological processes. They concentrate on the target to accomplish a “clean effluent” from the treatment plant –under whatever conditions. Although this seems to be the most reasonable and so to speak “natural” aim of a purification plant, it is rather far away from nature and has actually nothing to do with ecology and ecological management of wastewater and natural water bodies. We will try to contribute to clarity of this subject by the following article.

2. THE TARGET OF THE WASTEWATER TREATMENT

Wastewater treatment aims at the degradation of the organic matter and its recycling into the natural recirculation of substances. Different from solid wastes, wastewater can neither be deposited in landfill nor can be burnt. It also cannot be transported over long distances for irrigation purposes due to the high costs in comparison to the low benefit to arable land. Therefore the only remaining way to handle the problem is, to get it clean very close at the location of its production. There is no way around. All technologies as installed there have the same target: the dissimilation of the organic matter dissolved or suspended in the wastewater.

This organic matter originates from the photosynthesis products, which have been transformed via intermediates by man, animal and microbes into wastes finally, which have to be treated in order to achieve the "terminal" oxidation (which in natural systems is the job of the soil microorganisms). Therefore the treatment target must be the transformation of organic residues to simple inorganic substances like CO_2 and H_2O respectively. Organic loads in wastewater are expressed as their "Biological Oxygen Demand" (BOD) and/or "Chemical Oxygen Demand" (COD) consequently.

2.1 Assimilation and dissimilation of organic matter

During photosynthesis and plant assimilation oxygen is produced. For the dissimilation (degradation) of the organic matter produced (e.g. sugar) -which is the opposite process- an equivalent of oxygen must be provided from outside.

As an example the photosynthesis of a sugar molecule (Hexose) is given as a summary process:
Equation I $6\ CO_2 + 6\ H_2O \rightarrow C_6H_{12}O_6 + 6\ O_2 - 2880$ kJ/Mol

The opposite reaction (dissimilation) consequently is as following:
Equation II $C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O + 2880$ kJ/Mol

It may be regarded as a "burning" process, by which energy is produced. This can be utilized by heterortophic organisms like animals (including man) and many microorganisms. Finally the energy therefore originates from the sun. In wastewater treatment this is just the energy, which maintains the life and degradation capacity of the microbes dealing with the organic load. Again taking the hexose as a representative structure of organic loads (which is not too wrong), an amount of 180 g (1 Mol) of such compounds gives rise of 2880 kJ.

We conclude therefore: the target of the wastewater treatment is the **full** degradation (mineralization) of the organic load, energy is released by such degradation and an oxygen input is needed to achieve this.

3. WHICH IS THE PURIFICATION EFFICIENCY OF COMPACT TECHNICAL SYSTEMS?

In all wastewater treatment plants the degradation of organic loads is accomplished by microorganisms, which need oxygen according to the equation II. In compact technical systems this supply is provided by compressors in order to accelerate the process (the "price" for compaction) by fast development and reproduction rates of the microorganisms involved. One regards the short residential times and the small reactor volumes resulting as the **most desirable** target and consequence of such technology.

This procedure, of course, seems to be therefore a very plausible and reasonable one. The truth is, that indeed this is a rather technical and very limited view on a complex problem. Admittedly from those installations a seemingly clean and transparent effluent is released to the recipient, and the analytical data show, that at least the bulk of impurities has been removed. This, of course, has to be acknowledged, and an effluent having lost about 90 % of the dissolved organic loads is a most welcome contribution to the quality of natural waters. But the exclusive emphasis, which is given at present to those data, is a bit ambiguous and needs some complementary considerations.

Since 1967 DIETRICH [1] has shown, that by increasing the "grade of compactness" of the bioreactors and by reduction of the residential time, the dissimilation of the organic loads steps back in comparison to the incorporation of the carbon into microbial biomass, resulting in excessive sludge production. As DIETRICH [1] reports: "in classical plants working with the method of activated sludge only 20 - 25 % of BOD is degraded, whereas the other 50 - 70 % is used for the formation of the activated sludge itself".

Other researchers in later years, for instance AIVASIDIS and WANDREY [2] had proven, that only 50 % of organic matter dissolved in wastewater can be degraded to CO_2 and H_2O (figure 1). These results show how low the real yield of degradation is. This cannot be satisfactory in consideration of the main target of the wastewater treatment.

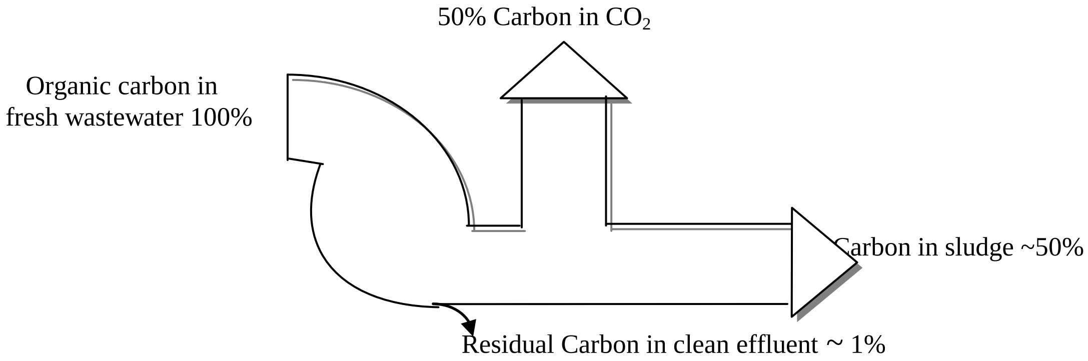

FIGURE 1. Remains of organic matter expressed as COD loading during the wastewater treatment working with the method of activated sludge or aerated lagoons (AIVASIDIS and WANDREY [2]).

As KICKUTH and VOLLMER [3] have shown, these results are even poorer considering the fact, that some 30 % of the organic load is already removed by the mechanical pretreatment through settlement of the solid parts in the wastewater, before the biological process takes place. Therefore this part of the organic loads doesn't participate at all in the biological dissimilation process.

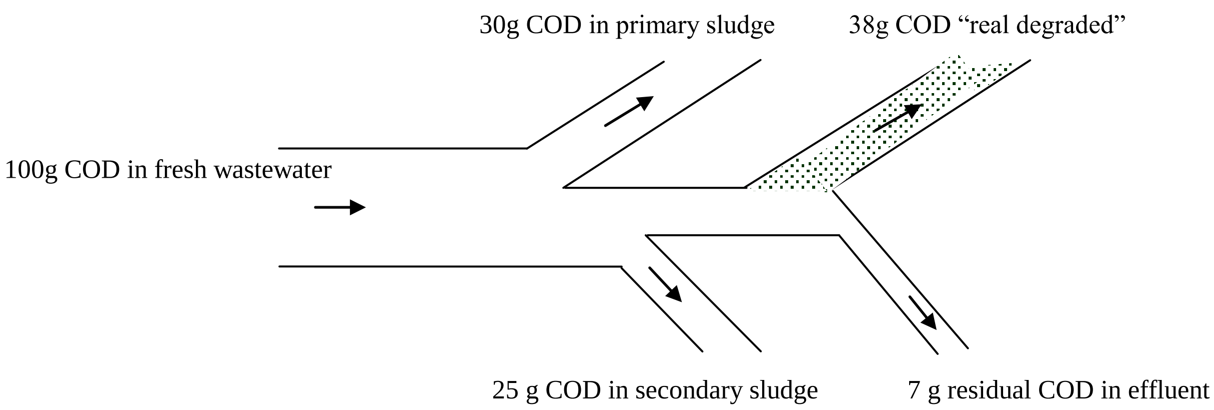

FIGURE 2. Whereabouts of the organic matter expressed as COD load during wastewater treatment in an activated sludge installation (after KICKUTH [3]).

Figure 2 shows what happens with the organic carbon during the treatment of domestic sewage by a conventional treatment system. The COD has been chosen as parameter because accidentally the COD load per P.E. and day is 100 g and the figures therefore represent the masses and the percentages of the organic whereabouts likewise.

Apparently the real degradation by dissimilation is about 38 % only, whereas the rest of 62 % is made up by sludge (55 %) and residual organic matter (7 %) (persistent and sometimes ecotoxic) discharged into the recipient (natural water body).

55 % of the total carbon remains untreated therefore and has to look for other subsequent technologies "to get rid of it". Incineration or deposition on landfill sites (after drying procedures) are the most employed secondary technologies. Application to agricultural crops –as practiced in the past- is not longer accepted by the farmers themselves or by the authorities. Anyway whether for deposition or for land application, considerable costs and area requirements are resulting finally from the attempts to reduce the time for wastewater treatment and the size of the bioreactors in modern compact treatment plants. This is a real "homemade" problem created by compact technical treatment systems and falsifies partially the philosophy of compaction. And finally, of course, the oxygen consumption is the same whether the sludge is incinerated of deposited on landfill or arable land –but it is purposeful provided **not during but after** the wastewater treatment in a compact treatment plant. The "sludge problem" indeed is a more problematic topic at present than the wastewater treatment itself.

The above-mentioned rest of about 7 % is released directly into the recipients (lakes, rivers, creeks or the sea). This part of organic matter needs longer residential times and more complex biocenoses to be degraded than compact systems (residential time ca. 6 hrs) can provide. It consists chiefly of so named xenobiotics, which have been synthesized by industry and are widely used as tensides, disinfectants, drugs and organic intermediates for industrial and domestic use. They are ecotoxic partially and can cause serious damages in the recipient. But their ecological role in the recipients is widely unknown so far.

As conclusion we would like to underline, that the benefits of using compact treatment plants is to protect natural waters from easily degradable organic matter and therefore to achieve a very low BOD level which prevents the natural waters from a high oxygen demand and its consequences. This is the achievement everybody can be happy about. But it might happen on the other hand, that ecotoxic effects of the residual COD - unknown so far- will prove in future much more alarming than the lack of oxygen due to higher BOD levels.

No doubt, that poor purification result of 38 % itself and the production of great quantities of sludge cannot give rise to excessive satisfaction but making wastewater purification by compact technical systems a rather questionable "technical progress".

4. THE REAL, TANGIBLE ECOLOGICAL CONSEQUENCES OF WASTEWATER TREATMENT IN COMPACT TECHNICAL PLANTS

4.1 The carbon budget in compact technical systems

At this point we want to demonstrate a unique and especially impressive "collateral harm" coming from compact technical purification plants and give emphasis to it because almost nobody speaks about it.

As it is obvious from the dissimilation equation II, the organic matter in wastewater represents an "energy source" -that means a fuel. Its oxidative transformation to CO_2 and H_2O is an exergonic process. Based on a daily production of ca. 100 g COD per citizen, which equals ca. 1,500 kJ, this adds up to ca. 547,500 kJ per year.

From the equation II can be seen, that 137.5 g of carbon dioxide (CO_2) will be produced if 100 g oxygen is consumed (COD) by the dissimilation (burning) process. If the dissimilation would occur at 100 %, the whole amount of sun energy, which has been accumulated by photosynthesis, would be liberated and the CO_2 as well into the atmosphere. This, of course, is the real target of the wastewater treatment as outlined before. Again we wish to underline, that this turnover is taking place in compact technical systems at 38 % only. From such poor yield only 52.28 g of CO_2 are released (instead of 137.5 g as shown above) per P.E. and day. However, whether the yields are poor or good, the process itself is most welcome.

By the following figure 3 a complete picture of the whereabouts of organic carbon compounds from wastewater of a small city with 5,000 P.E. in compact technical purification plants is given.

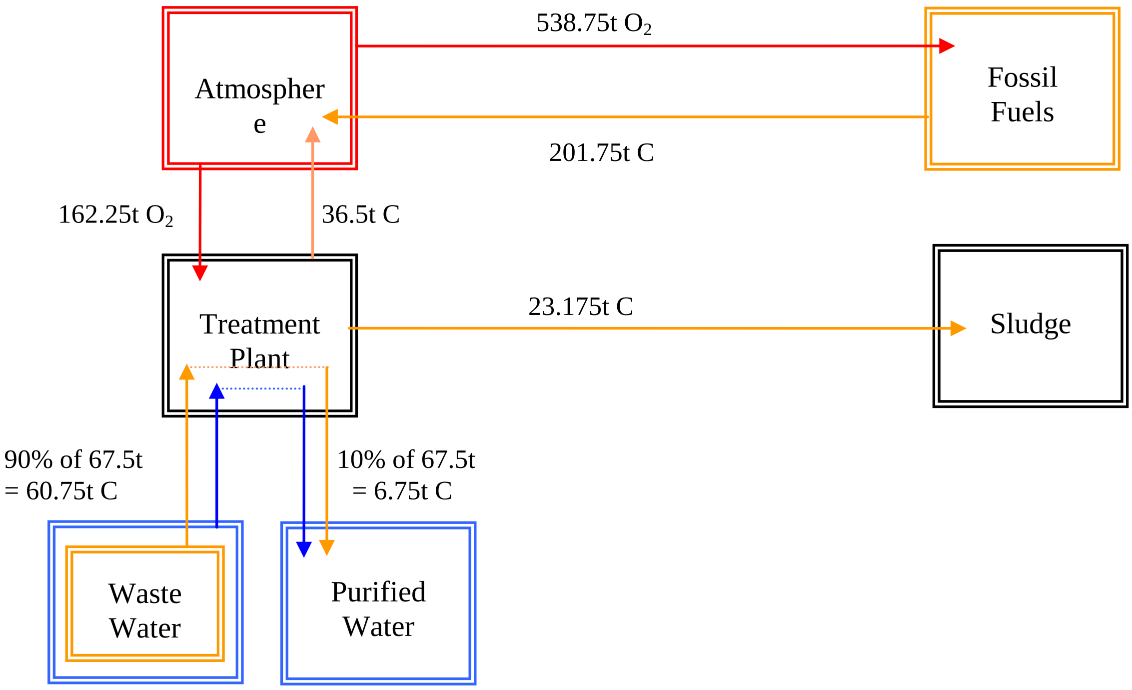

FIGURE 3. Carbon turnover in the activated sludge process (ARDERN & LOCKETT since 1914) after KICKUTH [4] for wastewater of a small city with 5,000 P.E.

The following figure 4 shows the budgeting of the carbon turnover, when wastewater is treated by a process "closer" to nature, as for example by the Root-Zone Method (KICKUTH since 1965), according to KICKUTH [4].

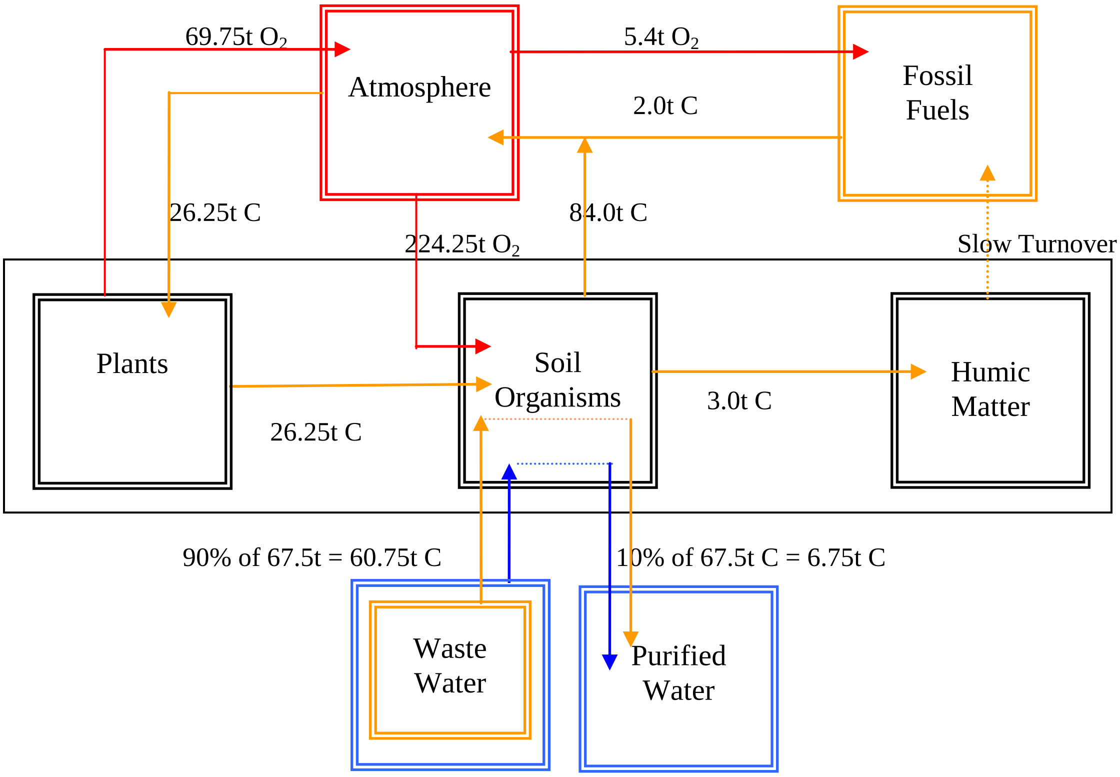

FIGURE 4. Carbon turnover in the Root-Zone Method (KICKUTH since 1965), after KICKUTH [4] for wastewater of a small city with 5,000 P.E.

For the planning civil engineer, on the other hand, a poor yield of 38 % can never be a satisfactory result of an exergonic process, whereas almost the rest of the carbon is converted to sludge. It cannot be overseen, that the microbial masses, of which the sludge consists after the treatment procedure preferentially, cause serious problems because they are slimy and will not settle readily – as well known and most troublesome implication in conventional treatment installations.

It must be kept in mind, that degradation of organic substances can occur without any trace of sludge left behind, as can be shown by agricultural practice, when huge masses of organics are applied to ploughed land as a fertilizer year per year. This means a 100 % turnover of COD actually.

4.2 The energy input and its costs in compact technical systems

Even more shocking is the fact, that an exergonic process, which must proceed by itself, needs a huge external energy input in compact technical purification plants. Indeed, the energy needed per P.E. and year sums up to 35 - 40 kWh (and even more). Chiefly this energy is consumed for feeding the compressors, which provide the oxygen for dissimilation (38 %!).

For a small city of 5,000 inhabitants and a given price of electricity of 0.1 € per kWh e.g. an amount of ca. 20,000 € annually has to be risen by the citizens for energy costs. This is one of the economical “collateral harms” mentioned above.
Apparently it is taken as an inevitable fate and the technical world doesn’t regard it as a problem at all.

But our emphasis is directed to the ecological consequences of those technologies. The 40 kWh consumption per P.E. and year –as mentioned above-, which are needed to accomplish the biological wastewater treatment represents in fact a 80 kWh equivalent of primary production, because of an only 50% efficiency of the power plants (on average). By conversion into thermal units the annual need of energy per P.E. is about 288,000 kJ (1 kWh = 3600 kJ = 3.6 Mega joule MJ).

The amount of petrol to be burnt in order to achieve these thermal units is about 6.61 kg (1 kg of petrol has a thermal value of 43,576 kJ).

Actually the reaction, which takes place in a compact purification plant at the 38 % level of yield as described above, should result an **output** of 570 kJ per P.E. and day i.e. 208,050 kJ per year. Even if this output of caloric units may be consumed to maintain the degradation process and is not to our own direct disposition, it is a “technical joke”, when almost the same **external energy input** is needed to achieve to such poor yield. Literally this means that fuel has to be burnt by another fuel. For every process engineer this must be a nightmare –but apparently it is not.

It is not the target of wastewater treatment, of course, to “harvest” energy from this process but to get rid of the impurities i.e. the organic loads. But it must be expected at least, that the dissimilation reactions take place and maintain spontaneously. We discuss this matter here from the point of view of “sustainability”, energy saving and considerable thermal impact to the atmosphere resulting from such practice. Even more because alternative treatment methods exist since long, by which those economical and ecological problems can be avoided –even in large scale installations and with industrial effluents.

4.3 Air pollution coming out of compact technical systems

An ecologist cannot accept this situation from another, very important reason, too. Serious impacts on the atmosphere result as a consequence of the excessive external energetic input by burning fossil fuel. LORENTZEN [5] has shown that wastewater treatment by forced oxygenation –achieved by powerful compressors- results in massive atmospherical pollution. Whereas LORENTZEN [5] included construction and operation energy consumption and the NO_x and SO_2 emissions in addition to the CO_2-production, and whereas he based his calculations on carbon as fuel, the impact index was extremely high in comparison to KICKUTH [6] who took into consideration the operation of the compact treatment installation only and restricted to the emission of CO_2 **into** and consumption of oxygen **from** the atmosphere. Therefore the figures obtained by each of these authors are different, but both of them describe and deplore the same situation.

We have shown that the needed external energy input per P.E. and year is 288,000 kJ. Based on petrol as a fossil fuel this means a consumption of 6.61 kg as outlined above. The equation III is based on petrol consisting of the hydrocarbon $C_{12}H_{26}$ and shows the amount of oxygen needed and to be taken from the atmosphere for the complete oxidation (burning) of this hydrocarbon and the production (emission into the atmosphere) of CO_2 likewise.

Equation III $C_{12}H_{26} + 18.5\ O_2 = 12\ CO_2 + 13\ H_2O$
In molecular weight we calculate as following:

170g + 592 g = 528 g + 234 g

Therefore the annual turnover of petrol to meet the energy exigency per P.E. for wastewater treatment is:

6.61 Kg petrol ($C_{12}H_{26}$) + 23.017 Kg O_2 = 22.239 Kg CO_2 + 9.098 Kg H_2O

The gas volumes for CO_2 emitted into the atmosphere and for O_2 taken from the atmosphere are:

11.119 m^3 of CO_2 and **15.825 m^3 of O_2** respectively.

For the above-mentioned small city this means volumes of:

55.594 m^3 of CO_2 and **79.123 m^3 of O_2** respectively.

In metric tons it is:

111.195 t of CO_2 and **115.085 t of O_2** respectively.

This happens every year again and again as long as the compact purification plant is in operation.

The additional pollution by other gases as NO_x and SO_2 as outlined by LORENTZEN [5] show definitively, that this situation is unacceptable from an economical point of view and from ecological reasons as well. Even the annual payment of 20,000 €, which a small city of 5,000 inhabitants has to rise for energy, is not acceptable. It is also unnecessary because alternative systems exist, which have proven much more friendly for the citizens and the environment.

5. REFERENCES

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