

EDWARD S. KEMPA*

AEROBIC SLUDGE DIGESTION STUDIES

The paper deals with characteristics of sewage sludges stabilized aerobically. Temperature, initial composition of the sludge and the method of operation, have a great influence on the course of the process. The new term "stabilization quotient" is introduced. The term allows an easy determination of the technical limit of aerobic digestion and, by utilizing vectorial calculus, makes it possible to evaluate the rate and correctness of the reaction course.

1. INTRODUCTION

Aerobic sludge digestion has been known for more than 40 years [12] and is now being increasingly applied in biological waste treatment through processes of extended aeration.

It is possible to treat in this way all kinds of sludges containing organic matter available to microorganisms. The method can be also used for municipal sludges. In each case, however, the course of stabilization may be different. The sludge mineralization occurs in the extended aeration chamber when the sludge age is long and when the food supply is insufficient. The sludge is often stabilized in a separate reactor in a batch, semicontinuous or continuous process.

Up to recent times the technical limit of stabilization has been difficult to determine, but now this problem seems to be solved by different methods proposed by various authors [1], [5], [9], [13].

*) E. S. KEMPA — Associate professor, Institute of Environment Protection Engineering, Wrocław Technical University, Wrocław, Poland.

2. DETERMINATION OF THE STABILIZATION LIMITS

The most popular definition for stabilized sludge: "the sludge could not be further decomposed and would not create offence" (emission of offensive odors) is not precise, therefore it ought to be based on an analysis of sludge composition.

The author suggested [5] that the technical limit of stabilization should be taken as the point where a definite change occurred in the rate of the decomposition reaction. This rate changes during the whole degra-

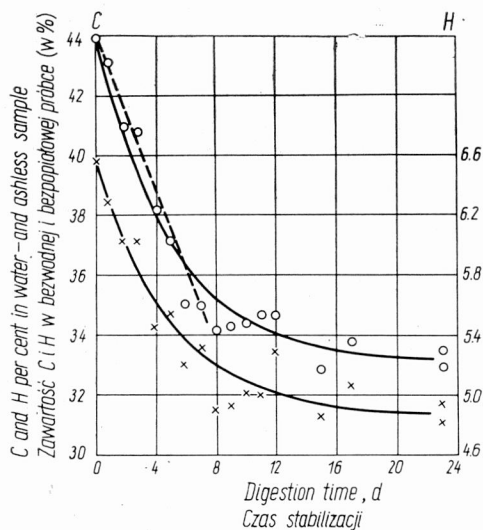


Fig. 1

ation period of the organic matter. It is possible to measure the rate using several parameters, but the decrease in carbon and hydrogen contents in the stabilized matter would appear the best one. The corresponding curves obtained during the author's experiments are shown in Fig. 1. C and H contents have been analysed by the shortened method published in [11].

It has been confirmed that the C and H decrease in waste activated sludge follows the formula:

$$y = ae^{-bx} + c,$$

where y is C or H percentage in the dry organic matter of the sample after x days of stabilization.

In the experiments of Wawrzyniak [15]

$$y_C = 10.9^{-0.201x} + 33.10$$

and

$$y_H = 1.68^{-0.205x} + 4.87.$$

From the above equations it is evident that the degradation rates of C and H in organic compounds are practically identical. Since the ash amount in the sample increases, a more correct value is obtained using the stabilization quotient, as product of C and H divided by the ash content:

$$\frac{C \times H}{\text{ash content}}$$

In this way from three groups of values and three curves (two of them are shown in Fig. 1), one obtains a single point representation which, when expressed graphically, gives a curve with a definite inflec-

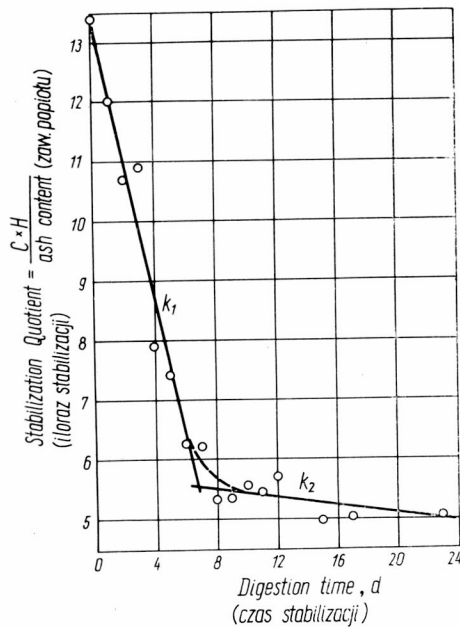


Fig. 2

tion* (Fig. 2). By the mathematical equalization of collection points, one can draw two straight lines; the differences from the theoretical values are in both cases practically the same.

At the intersection of the straight lines, or in the "compression point" of the curve, the technical stabilization time limit is obtained. The slope of the second straight line designates the small value of the reaction rate. For the quoted examples of waste activated sludge stabilization, the y values at the intersection amounted to 0.4–0.6 of the initial value of the quotient: C.H/ash content.

In a stabilized sewage sludge the slopes k_1 and k_2 of the straight lines had the following values:

$$\begin{aligned} k_1 = x/y = 1.15 & \quad \text{for} \quad 0 < x \leq 7 \text{ days,} \\ k_2 = x/y = 0.033 & \quad \text{for} \quad 7 < x \leq 23 \text{ days.} \end{aligned}$$

For lightly-loaded waste activated sludge from the treatment of textile wastes (the sludge was partially stabilized before reaching the stabilization chamber), the following results were obtained:

$$\begin{aligned} k_1 = 0.23 & \quad \text{for} \quad 0 < x \leq 3 \text{ days,} \\ k_2 = 0.031 & \quad \text{for} \quad 5 < x \leq 28 \text{ days,} \end{aligned}$$

and the quotient C.H/ash after 3 days of aerobic digestion amounted to 0.57 of the initial value.

These values confirm that in the first phase of stabilization of municipal waste activated sludge, the reaction rate is very high.

However, in the second phase, it approaches zero because of the different sludge composition and presence of organic matter resistant to microorganisms.

Besides the proposed quotient for measuring the reaction rate, it is also necessary to try to determine its correctness. At the beginning of stabilization we have some organic substrates with a general formula $C_{c_0} H_{h_0} O_{q_0} N_{n_0}$. After following biochemical oxidation with m moles of oxygen we get a new formula $C_{c_1} H_{h_1} O_{q_1} N_{n_1}$ plus reaction products, where

$$c_0 \geq c_1, \quad h_0 \geq h_1, \quad \text{and} \quad n_0 \geq n_1 \quad \text{but} \quad q_0 < q_1.$$

*) The curve may be compared with sludge thickening curve in which both sections form straight lines and the curvature is the biggest in the compression point C_2 (vide e.g.: L. G. Rich, *Unit Operations of Sanitary Engineering*, John Wiley, New York 1961, p. 98).

In an orthogonal system where $x = O/C$ and $y = H/C$ we should get — a vector, which is the resultant of all reactions. The direction and sense of the resultant will more or less approximate the direction and sense of one the basic vectors proposed among others in the classification of solid fuels [6, 7] (Fig. 3) or in the systematic representation of all organic compounds given by Jurkiewicz [3].

The reaction rate is characterized by the length of the resultant divided by digestion time.

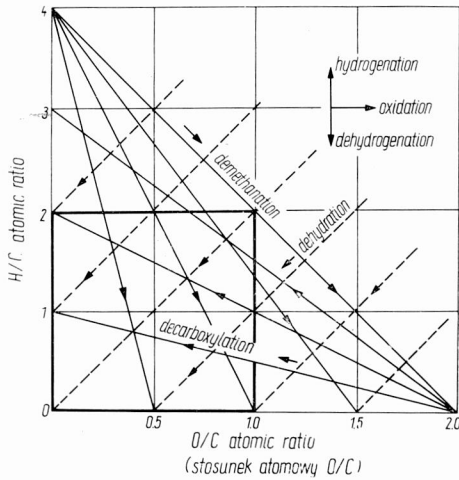


Fig. 3

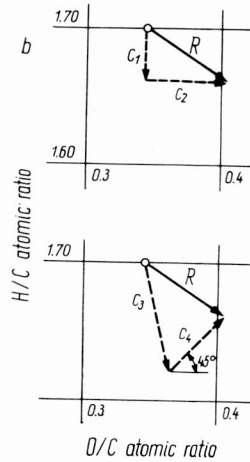
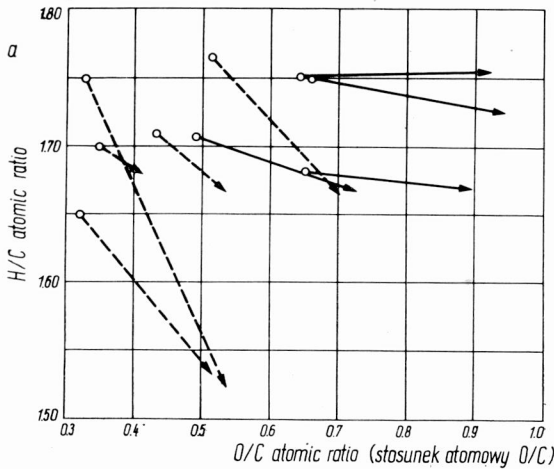


Fig. 4

In his experiments, Wawrzyniak [15] has stated that after aerobic digestion the resultant gets a clear oxidation direction with a small deviation toward dehydration. This phenomenon may be explained by the partial anaerobiosis occurring inside microorganism cells. In anaerobic digestion, the resultants were similar to the vector of demethanation [2] (Fig. 4a). This fact confirms, among others, the data of sludge composition before and after methane fermentation given by Owen [10].

The real oxidation vector obtained in the aerobic process can be drawn because the C and H decomposition rate of organic compounds was nearly the same. During the methane fermentation, CH_4 as a saturated hydrocarbon is formed. This means that the hydrogen is being released approximately four times faster than carbon.

The resultant of the methane fermentation can be decomposed into component vectors shown in Fig. 4b.

The systematic representation mentioned above is insufficient for this purpose mainly because nitrogen is not taken into consideration. In fossil fuels the nitrogen concentration is very low (in peat max. 3%) and therefore N may be neglected.

In sewage sludge the nitrogen concentration is comparatively large — e.g.:

crude, primary sludge	3 to 6.7%, av. 4.55%,
digested sludge	3.77 to 11.77% av. 4.46%,
activated sludge	4.68 to 12.32% av. 9.48%,

and it should be taken into account.

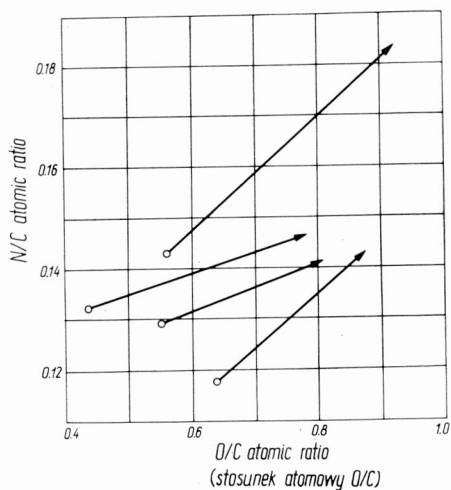


Fig. 5

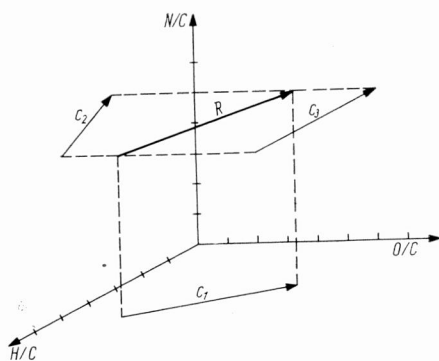


Fig. 6

The nitrogen compounds decompose slower than the carbon ones and therefore the percentage of N in the dry matter increases. Thus, we get one vectors similar to those shown in Fig. 5.

Finally a three-dimensional model (Fig. 6) is obtained. The amount of sulphur and phosphorus in the dry matter is negligible and therefore it was not taken into consideration.

3. SOME PROPERTIES OF THE STABILIZED SLUDGE

During the aerobic digestion, the amount of organic matter decreases. This change is related to the C and H decrease, as well as to the temperature. The stabilization of waste activated sludge under operating conditions begins immediately and, if there is no new substrate supplied, lasts 6 to 7 days. The stabilization of crude primary sludge proceeds normally via a biomass synthesis which occurs within several days. It can be measured by the increasing oxygen demand for synthesis and endogenous respiration, by the increase of dehydrogenase activity and by the presence of phosphates which appear after some days of aeration.

More details on the changes in the sludge composition have been given in former papers [4, 5].

A significant change in the bacteriological composition of the treated sludge was noted. Under these circumstances, the numbers of aerobic and anaerobic bacteria increase and decrease [14].

In the continuous process the influence of temperature is particularly noticeable at low temperatures. The previously established dosage of the supplied raw sludge may appear too large. Consequently, a partial denitrification, measured as the decrease in NO_3 content takes place. In such cases, it is necessary to reduce the daily dosage of the raw sludge supplied to the reactor. These experiments have indicated that the temperature of the liquid should not fall below 275 K (2 °C), since otherwise the process will fail. Therefore in winter it may be necessary to heat the aeration chamber or to supply warm air.

It has been stated [4] that the poor sedimentation properties of the stabilized sludge are caused by a high dispersion of the flocs due to comminution and intensive mixing of the medium.

The filterability of the sludge is also getting worse. The specific resistance (S.R.) of raw primary sludge measured on a Whatman paper No. 2. at a pressure of 500 mm Hg was $r = 6.5 \times 10^9 \text{ s}^2/\text{g}$. After 7 days

of aeration the S.R. of the same sample increased to the value $r = 2.7 \times 10^{11} \text{ s}^2/\text{g}$, but after 21 days of aeration it decreased to $r = 5.6 \times 10^9 \text{ s}^2/\text{g}$.

In spite of this undesirable feature of the sludge, an attempt was made to dewater and to dry digested sludge in Petri dishes and on laboratory-scale sand drying beds. For sludge samples in Petri dishes the rate of evaporation was faster than that of distilled water under the same conditions. This is due to a greater (inner) evaporation surface. For sludge samples poured into the dishes at temperatures 293–298 K (20–25 °C) and at a relative humidity $\varphi = 59$ to 72 % the rate of evaporation amounted to about 1,400 g H₂O/m²d. On the sand drying bed in the lab, within the period of 33 days (at the same air parameters as mentioned above), the water content of the sludge decreased to 4.7 %, which gives an evaporation intensity $I = 871 \text{ g H}_2\text{O/m}^2\text{d}$. The assumed air velocity was $v = 0.15 \text{ m/s}$.

Simultaneous dewatering of this sludge on a similar sand bed placed outside the laboratory yielded a final water content of 41.5 % H₂O [8].

4. DISPOSAL OF THE STABILIZED SLUDGE

In spite of the scarcity of mesophilic anaerobic bacteria, including pathogenic organisms, large numbers of them are still present in the aerobically stabilized sludge several authors also confirm the presence of helminth eggs in the treated sludge. The stabilized sludge therefore cannot be directly utilized for agricultural purposes without pasteurizing or thermal drying at a temperature higher than 373 K (100 °C). Otherwise some way must be found for its disposal according to local conditions.

BADANIA NAD TLENOWĄ STABILIZACJĄ OSADÓW

W artykule omówiono tlenową przeróbkę osadów ściekowych oraz scharakteryzowano skład fizykochemiczny i własności filtracyjne zmineralizowanego osadu. Stwierdzono, że na przebieg procesu wpływa głównie temperatura, sposób napowietrzania oraz początkowy skład osadu, a zwłaszcza zawartość związków azotowych, trudniej ulegających rozkładowi biochemicznemu niż substancje zawierające węgiel.

Zmiany zawartości węgla i wodoru w suchej masie osadu podczas stabilizacji są zgodne z przebiegiem krzywej wykładniczej, a stałe szybkości procesu — praktycznie identyczne dla obu wymienionych składników.

W celu wyznaczenia technicznej granicy stabilizacji, stosowanej w praktyce, autor wprowadza nowe pojęcie "ilorazu stabilizacji", będącego stosunkiem iloczynu zawartości węgla i wodoru w suchej masie próby do zawartego w niej popiołu:

$$IS = \frac{C \times H}{\text{zawartość popiołu}}.$$

Wektorowa interpretacja wyników pomiarów pozwala na precyzyjne określenie szybkości reakcji biochemicznego utleniania związków organicznych w stabilizowanym osadzie oraz ułatwia określenie stopnia zaawansowania procesu.

UNTERSUCHUNGEN ÜBER DIE SAUERSTOFFSTABILISIERUNG VON SCHLÄMMEN

Die Artikel bespricht die charakteristischen Merkmale der Sauerstoffaufbereitung von Abwasserschlämmen. Temperatur, anfängliche Zusammensetzung des Schlammes, Art der Belüftung und andere Faktoren haben Einfluß auf den Verlauf des Verfahrens. Der Author führt den neuen Begriff "Stabilisierungsquotient" ein, mit dessen Hilfe man leicht die "technische", d.h. die normal angewendete Grenze der Stabilisierung bestimmen kann. Die vektorielle Fassung ermöglicht es, den eigentlichen Verlauf und die Geschwindigkeit der Reaktion zu bestimmen.

ИССЛЕДОВАНИЯ АЭРОБНОЙ СТАБИЛИЗАЦИИ ОСАДКОВ СТОЧНЫХ ВОД

Обсуждаются характерные черты аэробного метода переработки осадков сточных вод. Результат процесса зависит от множества параметров, таких как температура, первоначальный состав осадков, способ окисления и др. Автор вводит новое понятие "кратность стабилизации", при помощи которого можно легко определить степень „технической“ стабилизации (т. е. нормально применяемой). Векторный подход позволяет определить правильный ход реакции и её скорость.

REFERENCES

- [1] BENEDEK P., *Bestrebungen zur Vereinfachung der Technologie von Abwasserreinigungsanlagen*, Gas und Wass. Fach. **107**, 741, 1966.
- [2] CHARYDCZAK R., *Research on sludge mineralization by methane fermentation*, Master Thesis, Technical University of Wrocław 1967.
- [3] JURKIEWICZ J., and ROSIŃSKI S., *Karbochemia*, PWN, Warszawa 1968.
- [4] KEMPA E., *Beitrag zur Frage der aeroben Schlammstabilisierung*, Wiss. Z. Techn. Univers. Dresden, **16**, 1967, 1055-1060.
- [5] KEMPA E., *Zur Bestimmung der Stabilisierungsgrenze in aerob behandelten Klärschlämmen*, Wasser, Luft und Betrieb, **12**, 1968, 472-475.
- [6] VAN KREVELEN D. W., *Graphical-statistical method for the study of structure and reaction processes of coal*, Fuel, **29**, 1950, 296.

-
- [7] VAN KREVELEN D. W. and SCHUYER J., *Coal Science-Aspects of Coal Constitution*, Elsevier Publ. Corp., Amsterdam 1957.
- [8] MAJDANIUK-SIELCHANOWICZ L., *Research on the dewatering and drying properties of sludge digested aerobic*, Master Thesis, Technical University of Wrocław, Wrocław 1968.
- [9] MUDRACK K., *Die aerobe Schlammstabilisierung*, Münchner Beiträge **13**, 1966, 290-314.
- [10] OWEN N. B., *Sludge, Incineration*, Journ. San. Energ. Div., Proc. Amer. Soc. Civil Engrs. **83**, 1957, No SA 1, paper 1172.
- [11] RADMACHER W. and HOVERATH A., *Vereinfachte Verfahren zur Bestimmung des Kohlenstoffs und Wasserstoffs sowie des Schwefels fester und flüssiger Brennstoffe*, Brennstoff-Chemie, **41**, 1960, 304-308.
- [12] RUDOLFS W. and HEUKELEKIAN H., *Aerobic and anaerobic decomposition of sewage solids*, Ind. Engng Chem., **24**, 1932, 1312 and **25**, 1933, 1162.
- [13] RÜFFER H., *Untersuchungen zur Charakterisierung aerob-biologisch stabilisierten Schlämme*, Vom Wasser, **33**, 1966, 253-282.
- [14] STANKIEWICZ T. A., *Research on the biocoenosis of sludges stabilized aerobically*, Master Thesis, Technical University of Wrocław, Wrocław 1968.
- [15] WAWRZYNIAK Cz., *Change of the chemical composition of sludges stabilized*, Master Thesis, Technical University of Wrocław, Wrocław 1966.