Advanced Materials Research *Online: 2012-05-14*
ISSN: 1662-8985, Vols. 518-523, pp 2991-2995
doi:10.4028/www.scientific.net/AMR.518-523.2991
© 2012 Trans Tech Publications, Switzerland

Comparative Analysis of the Measurement Methods of Bound Water Content in Municipal Sewage Sludge

Weijun Zhang [1, a], Kechun Sun[1,b]

[1] the Department of Civil Engineering, Luoyang Institute of Science and Technology, Luoyang, China

[a]jgzwj@126.com, [b]skchun@163.com

Keywords: Bound Water Content, Sludge, Measurement Methods.

Abstract. The dewatering of municipal sewage sludge is a current problem due to the huge production of this waste. The bound water content in sludge is closely related to the sludge dewatering performance. By comparative analysis of the measurement methods of the bound water content in sludge, this article points out their respective advantages and disadvantages, as well as the respects which should be noted in practice.

Introduction

With the increasing of urban sewage volume and treatment rate, resulting in a large number of activated sludge. Environmental and economic considerations, reduction and reuse of municipal sewage sludge is an urgent thing that need to be solved today. The difficulty of urban sewage sludge treatment lies in the high moisture content of sludge. In various types of sludge, biological sludge dewatering is the most difficult. The composition of the sludge is very complex. There are many factors that can affect the dewatering performance, such as particle size, extracellular polymeric substances, metal ions, organic matter, filamentous bacteria, a variety of conditioning agents. In addition, water distribution in the sludge is[1] considered as an important effect on the sludge dewatering and drying performance. The sludge treatment of Shidongkou Shanghai municipal sewage treatment plant and the study by Songxian Jiang et al[2], to evaluate the effect of sludge regulate reagents on dewatering performance, have confirmed that regulate reagents has an important effect on the bound water content in sludge. In the sludge thermal drying process, the bound water in the sludge needs more consumption of heat to evaporate than the free water. Therefore, the bound water content of the sludge determination is of great significance to improve sludge dewatering performance and reduce sludge dewatering and drying energy consumption.

In this article, the characteristic of every existing form of water in the sludge and their common determination methods are described, compared and analyzed in order to afford lessons that merit attention to related researchers.

Existence form of water in the sludge

Due to the influence of the sludge solid particles, in the following aspects: water evaporation, enthalpy, entropy, viscosity and density, there are some differences of water in the sludge and ordinary water. In drying dehydration process, the behaviors of water molecules are closely related with the degree of them which are close to the solid particles.

In accordance with the solid particles, water in the sludge is usually divided into two forms: free water and bound water. Free water is present in the sludge surface and the gap, independent of the impact of a variety of solid particles. Its properties are generally the same as ordinary water. Bound water is the part of water which properties is changed due to the impact of the sludge particles, including capillary water, sludge particle surface adsorbed water.

However, water in the sludge is only divided into two forms: free water and bound water, is far from enough to gain a better insight into the mechanism of dehydration and pretreatment. The water in the sludge is broken down into the following four forms by Vesiline[3]

All rights reserved. No part of contents of this paper may be reproduced or transmitted in any form or by any means without the written permission of Trans Tech Publications, www.ttp.net. (#69777602, Pennsylvania State University, University Park, USA-15/09/16,23:16:27)

Free Water: Water is not affected by the sludge particles, including the pore water not be affected by capillary phenomenon.

Interstitial Water: Water of in the capillaries and in the intercellular spaces.

Surface water: The water be adsorbed to the sludge particle surface.

Bound water: Water be combined by chemical force, including the part of water which belongs to the cell structure.

According to literature[4], free water accounts for about 65% -85%, capillary bound water of 15% -25%, the internal bound water for about 10%. Bound water content in different sources sludge are quite different, even in the same city sewage treatment plants when using different conditioning agents.

Comparative analysis of the measurement methods of bound water

The quantity of free water and bound water are generally estimates. Taking into account the feasibility of the test and different water properties change, corresponding to different test methods, the following several test methods are commonly used.

Thermal drying test method: the method is based on the difference of free water and bound water evaporation rate.

Dilatometer test method: The method is based on the property change of bound water to freeze.

Differential scanning calorimetric method

Centrifugal sedimentation method

Thermal drying test method. This method is based on the following assumptions: the water evaporation rate depends on its combination of solid particles. Bound water content is measured according to the thermal drying curve analysis in the method. The curve reflects the evolution of the relationship between evaporation rate and the average water content. Fig.1.shows that this evolution process typically includes the following three different stages[5].

(1) Warm-up stage: The district is generally shorter.

(2) Constant speed dry stage: This stage is the evaporation of free water at the surface of the sludge drying.

(3) The drying deceleration stage: With the change of internal drying boundaries in the sludge, above the drying boundary, only bound water and steam are transferred and below the drying boundaries, the migration of free water occurs while the heat and mass transfer resistance increase, which lead to a decline in the rate of drying.

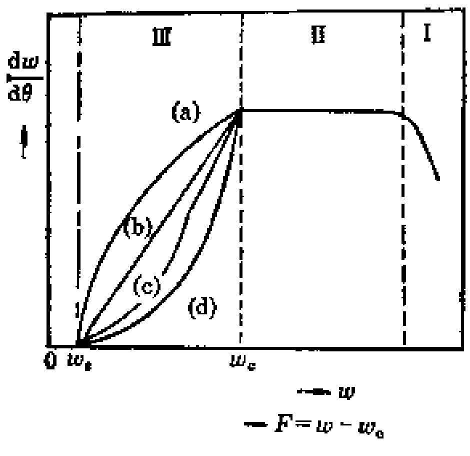

Fig.1. Drying characteristics curve

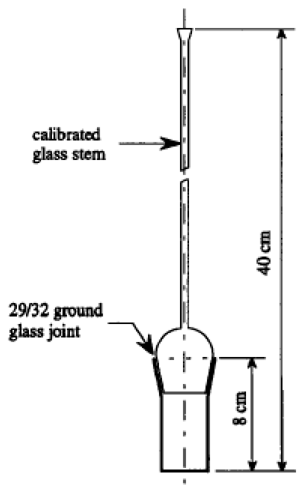

Fig.2. Dilatometer diagram

W_c is the critical point of the water content which alter from the constant drying area to the deceleration drying zone. It is called the critical water content.

This indicates that a conversion from mainly under the control of the external conditions (temperature, relative humidity and air flow rate) to mainly under the control of the sludge internal properties (specific heat of sludge, the heat transfer coefficient ,heat and mass transfer resistance etc.) exists in sludge drying process. Thierry Ruiz, et al[6] measure the bound water content by the transition point from the constant rate drying period to the deceleration drying period. However, the water content of the conversion point not only with sludge itself, but also closely related to the operating conditions of the sludge thermal drying. The same sludge samples under different operating conditions, such as different drying temperature, different sample size, thermal drying curve has also changed. To a larger size sample, due to the existence of the moisture content gradient in drying process, using the average water content instead of the sludge sample moisture content have a larger impact on the results. In addition, in the drying process, the sludge samples come into being a larger deformation, and is accompanied by cracks, which will also affect the thermal drying curve analysis. Studies have shown[4] that the type of flocculants used also affects the sludge drying curve. Dewatered sludge added the polymer flocculants hasn't apparent constant rate drying zone. In the whole drying process, drying rate is reduced with the decline of the moisture content, which indicates internal moisture diffusion is the controlling factors of the drying process. In this case, the bound water content will not be able to be measured by the dry test method. The constant drying area and the deceleration drying area are both present in the drying process of dewatered sludge which contains inorganic flocculants.

In summary, Thermal drying test method is of simple and intuitive, but there are also shortcomings and deficiencies with the test conditions influence and other factors influence. Therefore, it is recommended that the thickness of the sample choose 1cm or so and maximize low-temperature drying to reduce the influence of experimental conditions.

Expanded test method. The method is based on the different of the freezing point for bound water and free water. The free water in the sludge is calculated by determining the expansion of the sludge samples in selected cryogenic temperature, and then the bound water content will be calculated by the total water content. Test equipment shown in Figure 2[7].

Put Sludge samples into the lower container of the dilatometer, in which filled with the indicator liquid, then the volume change can be measured by the thin tube in top of the dilatometer. The test temperature of the method choose -20℃ in the most of literature, the selection criteria of the indicator liquid[3] as follows: (1) liquid and water is not miscible; (2) liquid specific gravity less than 1.0; (3) with linear expansion or contraction in the selected temperature range; (4) not be frozen in the selected low temperature.

The expansion coefficient of water is an important parameter in the processing of test data, Chin Chao Wu et al[8] found that the distilled water and the filtrate have different expansion coefficient. The test temperature choosing is also a problem, generally using the -20°C, but there are also using other values. Smith and Vesilind recommends to careful consider the factors which can affect the results, and confirms the dissolved gases in the sludge is one of the influencing factors. In the freezing process, these gases out from the liquid come into being air bubbles which change the size of ice, making the determination of the volume of ice is larger. In addition, the number of unfrozen water in the sludge have some controversy due to the influencing factors, such as the trapping water between the floc particles, the ice formation of intracellular water and the quantity of the particle adsorbed water etc, and the test fail to distinguish all these factors. However, by the method the measuring is fast and test data easy to analyze, so it still has certain advantages.

DSC detection method (Differential scanning calorimeter). Based on the principle of not be frozen at a given threshold temperature (for example, -20° C). By scanning the release or absorb heat of sludge samples, any change, such as freezing (that is, Exothermic peak), can be observed in the process of change of the sludge sample from room temperature to the specified value, and then thermal analysis. Assume that the bound water does not freeze at a given threshold temperature, the release heat is proportional to free water content in the sludge samples during the test. Then you can determine the bound water content by the difference of the free water content and the amount of water content.

Katsiris and Kouzeli-Katsiri[9] believe that the method is fast and reliable for the determination of bound water in sludge. But taking into account the sludge heterogeneity, in fact, inside the sludge contains large floc particles, according to the instrument requirements, sample volume is generally relatively small (10-30mg), which is bound to affect its representation. In addition, the choice of the temperature threshold is also a problem

Centrifugal sedimentation test method. Centrifugal sedimentation method assumes that at the rotational speed $N \to \infty$, the height of sludge sample in the centrifugal sedimentation tube tends to a balanced value h_∞, and believe that only the dry solids and bound water in the sludge samples are left over. According to this assumption, bound water content per the unit mass of dry solid Φ_w can be calculated by the following mass balance Equations(Eq. 1) [10].

$$\Phi w=[(\rho_s-\rho_w h_\infty)/(\rho_{sl}-\rho_w h_0)-1]\ \rho_w/\rho_s \quad (1)$$

ρ_s Sludge sample density;
ρ_w The density of water;
ρ_{sl} Sludge solids particle density;
h_0 samples initial height;
h_∞ The height of the samples balance;

The key to this method is to determine h_∞. Matsuda, et al[10] believe the relationship between h/h_0 and $1/N$ linear. h_∞ can be attained by the intercept of the straight line on the vertical axis. However, PS YEN and the DJ LEE[11] believe that this activated sludge is not appropriate, because the nonlinear relationship between h/h_0 and $1/N$ when the rotating speed is high. In the case of high rotating speed, when the centrifuge is stopped, the height of the sludge sample in the centrifuge tube will has a rebound. Different types of sludge in the use of centrifugation may have different elastic response. Sludge elasticity is ignored will cause errors. Therefore, the centrifugal sedimentation method also needs to further improve in this regard

Conclusions

Bound water content is closely related to the sludge dewatering performance. In variety of bound water content measurement methods, drying test method due to the greater impact of dry conditions, while the bound water content is the intrinsic properties of the sludge, therefore, the credibility of the determination results is of the compromised. However, the method is simple and intuitive, as a rough estimate is feasible. Expansion test method there are also some aspects need further improvement, such as temperature thresholds determination, but the method is of fast, easy analysis for experimental data, therefore, the method is still the most recommended. To pay attention to the homogeneity of the sludge, DSC test method should do several parallel trials to attain the mean value so that reduce its impact. Centrifugal sedimentation method, at high rotating speed, has some limitations for a viscoelastic material, such as activated sludge.

Acknowledgements

This work was financially supported by Luoyang Institute of Science and Technology, Program of Science and Technology Department of Henan Province Commission (112102310661).

References

[1] Xiaofeng, P. and C. Jianbo, The specialties of sludge and associated thermal physcial issues. Bulletin of National Science Foundation of China, 2002(5): p. 284-286.（In Chinese）

[2] Xian-qiang, S., L. Heng-yi and Y. Guang-wei, Study on Application of New Composite Coagulant to Improvement of Sludge Dewaterability. China Water & Wastewater, (2007). 23(13): p. 87-90.(In Chinese)

[3] Smith, J.K. and P.A. Vesilind, Dilatometric measurement of bound water in wastewater sludge. Wat. Res, 1995. 29(12): p. 2621-2626.

[4] Qiang, X., sludge treatment and disposal technologies and devices. 1 ed. (2003): Chemical Industry Press. 312-319.(In Chinese)

[5] Masakatsu, H., Sludge Treatment Engineering, (1990).(In Chinese)

[6] Ruiz, T. and C. Wisniewski, Correlation between dewatering and hydro-textural characteristics of sewage sludge during drying. Separation and Purification Technology, (2008), 61: p. 204-210.

[7] COLIN, F. and S. GAZBAR, Distribution of water in sludges in relation to their mechanical dewatering. Wat. Res, (1995), 29(8): p. 2000-2005.

[8] WU, C.C., C. HUANG and D.J. LEE, Bound water content and water binding strength on sludge flocs. Wat. Res, (1998), 32(3): p. 900-904.

[9] Katsiris, N. and A. Kouzeli-Katsiri, Bound water content of biological sludges in relation to filtration and dewatering. Water Research, (1987, 21(11): p. 1319-1327.

[10] Matsuda, et al., Measurement of bound water in excess activated sludges and effect of freezing and thawing process on it. Journal of Chemical Engineering of Japan, (1992), 25(1): p. 100-103.

[11] YEN, P.S. and D.J. LEE, Errors in bound water measurements using centrifugal settling method. Wat. Res, (2001). 35(16): p. 4004-4009.