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Research paper

Effectiveness of Microwave Drying for Shrimp Aquaculture Sludge

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A B S T R A C T

The disposal of the shrimp aquaculture sludge requires large area and high amount of disposal cost. The improper treatment and disposal can cause soil and water pollution. Sludge drying is an effective solution to reduce the weight of sludge and eventually reduces the disposal cost. This study was aimed to assess the effectiveness of thermal treatment on drying shrimp sludge at different power and time of 270W, 450 W 630W and 60s to 390s, respectively. Heavy metals concentrations and chemical compounds were also determined. Results reveal that the best drying rate recorded were at power and time of 630 W and 240s, respectively. Fourier transform infrared spectroscopy spectrum (FTIR) shows that the main groups presence are aliphatic chains with double bonds, as well as carbonyl, hydroxyl and N–H groups in organic compounds. Sludge drying has proven to be effective in reducing moisture content and organic matters for shrimp aquaculture sludge. It could be considered as one of the alternative methods to handle sludge.

Introduction

In shrimp farming, accumulation of sludge at the bottom of the pond induces the deterioration of the aquatic environment and also greatly affects the growth and survival of shrimps.To prevent sludge accumulation, it needs to be constantly removed from the pond, but effective treatment or utilization method is yet to be established. Aquaculture effluents are recognized to be a source of organic pollution for the receiving watershed (Gowen *et al., 1990)*. Solids produced in trout facilities are mainly due touneaten food and faeces. Cumulative build-up of nutrients results in deteriorating water quality, which can trigger stress and diseases in cultured fish, reducing farm productivity (Ankaet *et al.,2013)*. Regular removal of pond sediments is therefore an optimal management practice, but manual excavation after draining and drying ponds is labor intensive (Haqu *et al., 2013)*. Cripps and Bergheim, 2000 reported that many technologies have been developed to remove solids produced during fish farming such as micro-screens, filter beds, Cornell-type circular tanks and settling tanks. However, these systems are rarely used in small production facilities as they are relatively expensive and labor intensive. Accordingly, in small fish production facilities thermal treatment technology for sludge drying could be a suitable strategy to properly manage sludge generated during fish production.

The development of microwave technology has gained an increasing amount of attention as an alternative non-conventional heating source that can be applied for the processing of biomass and wastes (Anastas and Warner, 1998, Richel, 2015*)*. .Previously, heavy metals have been classified into volatile (Pb and Cd), semi-volatile (Zn, Sb, and Se), and non-volatile (Cr, Cu, Ni, As, Mn, and Co) heavy metals (Yang *et al.,1994)*. The mobility of heavy metals, their bioavailability and related eco-toxicity to plants, depend strongly on their specific chemical forms or binding ways (Jinet *et al., 2005*0). The evaluation of sludge toxicity by chemical speciation and biological testing is therefore very important (Chen *et al., 2008)*.

Shrimp and fish are an essential food source and the ever-increasing population typically has a strong influence on fish demand. Moreover, aquaculture is often presented as a potential alternative to respond to this challenge caused by the stagnation in the fish catch (FAO, *2007)*. Managed fish and shrimp ponds are a rearing system commonly used in Asia and Europe. The main objective of the present work was to assess the effectiveness of thermal treatment on drying aquaculture sludge using microwave technology. Heavy metals concentrations and chemical compounds were also determined.

Material and Method

1. Shrimp aquaculture sludge sample

The shrimp aquaculture sludge was collected from shrimp hatchery pond in Johor Bahru. The samples were collected from the bottom of the shrimp breeding ponds. The sludge was stored at 4 °C and retrieved to room temperature prior to the experiments. Fluctuation of sample mass was controlled within ± 0.5 g. The drying rate was calculated by using the following equation (Chen, Afzal and Salema, 2014*)*:

$$Drying\ rate = \frac{M_{t+dt} - M_t}{dt} \quad (1)$$

where the drying is (kg/kg), Mt + dt (kg/kg) is the moisture content at t + dt, and t(s) is drying time and Mt (kg/kg) is the moisture content at a specific time. The moisture content of raw materials was measured by drying the samples at 105 °C for 24 h in a drying oven. The volatile solid content of raw materials was quantified by combusting the samples at 550 °C for 3 hours in a muffle furnace.

2. Experimental setup

Isolated A domestic microwave oven, Sharp (AX-1100V) was used in this study. The unit operates at a frequency of 2450 MHz with a power output ranging from 0 to 1000 W.The sludge drying experiment was carried out in a batch mode. The microwave power was maintained at 270 W, 450 W, and 630 W and the exposure time was set at 60 s with 30s intervalto the maximum of390s.Samples of sludge were prepared in triplicates by placing 100 g samples (height approximately 5mm, surface area approximately 144 cm2) in Pyrex bowl as shown in Fig. 1. The effectiveness of the microwave treatment was evaluated mainly based on the changes in the weight reduction measured before and after exposure to microwave. The initial weight was measured as the samples were transferred into the Pyrex glassware, while the final was measured once the samples were cooled to room temperature after the microwave treatment.

Figure 1. Raw shrimp aquaculture sludge.

Based on the maximum temperature attained during microwave treatment, the weight reduction could only be attributed to the water evaporating from the heated sludge. Hence, considering the density of water, the weight reduction was deemed to be equivalent to the sludge volume reduction.

3. Analytical Analysis

The digested samples were filtered through 0.45 μm and sent for ICP-MS analysis (Agilent 7700 instrument) at Malaysia-Japan Institute Technology at UniversitiTeknologi Malaysia. ICP-MS was employed to analyse for the trace elements which are found at very low concentrations. The Agilent 7700 instrument reported the trace element concentrations in parts per billion (ppb). The treated sludge sample was tested for thermal analysis at Institute of Advanced Technology (ITMA), *Universiti Putra Malaysia.* The proximate analysis of sample was carried out using thermogravimetric analyzer (Perkin Elmer) to characterize thermal stability of the sample. Sample was heated from 30oC to 1000oC at constant heating rate of 10oC/min in nitrogen atmosphere with flow rate of 100 ml.min-1 using a sample of approximately 10-15 mg. The curves of thermogravimetric mass loss (TG) and differential thermogravimetric (DTG) are recorded and produced online by using bundled software with the analyzer.

Result and Discussion

1. Sludge Drying Rate

The chemical composition used in this study is showed in Table 1. Low moisture content and low volatile matter content in raw aquaculture sludge indicating that the sludge to be relatively rich in organic matter and making microwave heating as a suitable option for drying. The basic principle of microwave heating is that the polar molecules contained in the dielectric materials will move quickly and collide intensely with each other in high frequency microwave electromagnetic field.

As a result, heat is created and the temperature of microwave absorbers (biomass) will increase. After heating, the content of volatile matter decreased at relevant heating time. Significant reduction in aquaculture sludge volume might bring economic benefit for its further treatment and processing. It is assumed that microwave is able to remove the capillary moisture as well as the particles surface moisture (Manara and Zabaniotou, *2012)*. Microwave drying of sludge at constant microwave power follows the typical drying curves. As expected, the temperature increment rate increased as the microwave power input rose, with 630 W inducing the highest rate. Fig. 2 shows the moisture content reduction over time at different microwave power levels. It was noted that the highest removal of moisture content observed from 56.25 kg/kg to 4.78 kg/kg in 390s. This is equivalent to 91.5% of moisture content removal after microwave treatment. Water has a high thermal capacity, thus by virtue of its higher water content with bigger sample size of 100g has a higher capacity to absorb a bigger fraction of the initial microwave energy. Similar observations were made by Tang *et al., (1990)* when excess sewage sludge was heated with different water contents.

The trendline observed in Fig. 2 also agreed with those from previous studies involving microwave heating of different kinds of sewage sludge (Menedez *et al.,2002,*Hong et al., 2002, Yu *et al., 2010*, Lin *et al, 2012)*. This can be explained the resulting microwave energy which is a function of power input. Fig. 3(i) and 3(ii) show the TG and DTG curves obtained in the pyrolysis process of the treated aquaculture sludge. As illustrated in Fig. 3(i), the slight reduction in weight around 100oC is due to the removal of residual water left after the drying process. Starting at 200ºC, some compounds start to volatize with major loss happened between around 370ºC and 600ºC.

The mass loss happened in three stages between 200 and slightly above 800ºC indicating three different types of materials being volatilized (accumulation of nutrients and organic matter). Cultured aquatic animals accumulated between 5% to 40% of nutrients in the feed (carbon, nitrogen, phosphorus). The mass loss is caused mainly by the decomposition of carbohydrate and lipids originated from the shrimp feces and food waste.

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Table 1. Characteristics of treated aquaculture sludge.

Proximate analysis	Wt %
Moisture	0.19 %
Volatile matter	3.26 %
Fixed carbon	1.38 %
Ash	95.2 %

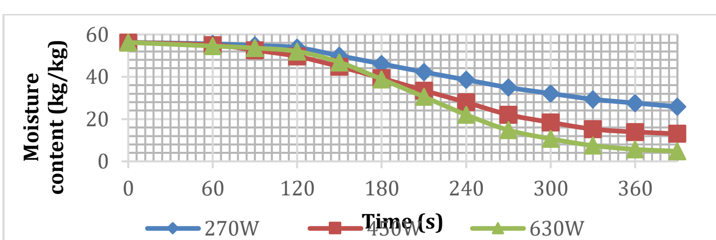
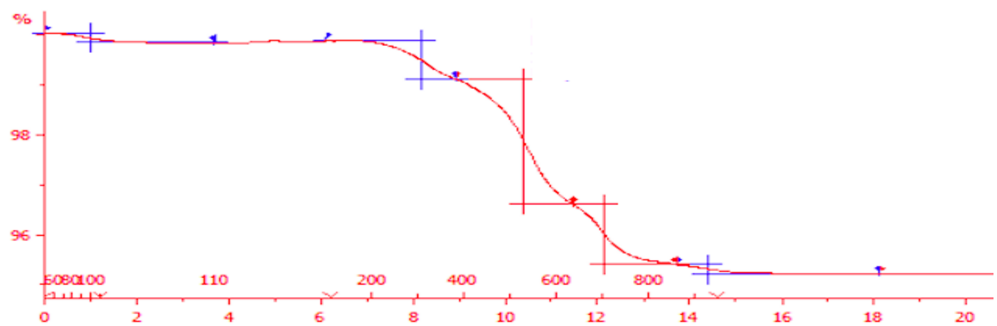
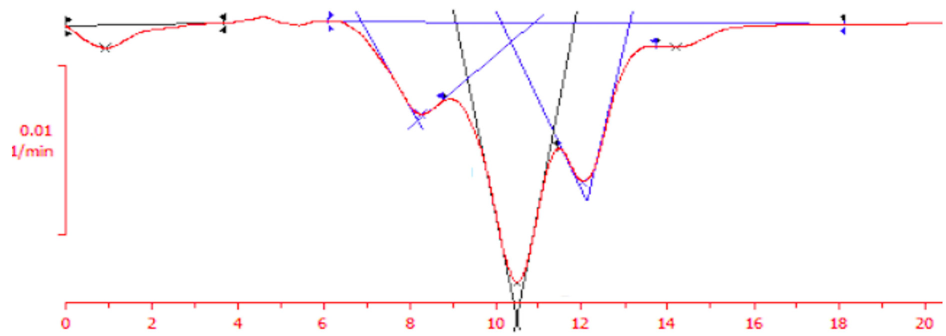


Figure 2: Moisture content reduction over time at different power level.



(i)



(ii)

Figure 3: Treated aquaculture sludge: (i) TG Curves (ii) DTG Curves

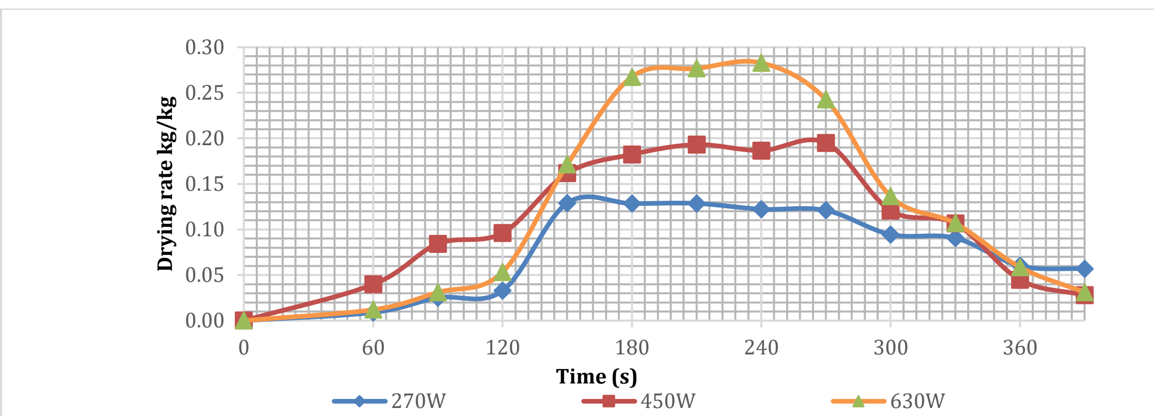


Figure 4: Sludge drying rate over time

The drying phase can be attributed to the interaction between the microwaves (i.e. high frequency electromagnetic radiation) with the dipolar molecules of high loss dielectric properties (eg. Water, protein, etc.) that are initially present at high concentrations in the shrimp sludge. This interaction causes the molecular rotation resulting in the rapid heating of the sludge (Yu *et al.*, 2010).

Fig. 4 shows the effect of microwave power on the drying rate of the sludge. The dying rate curves under these powers show a similar pattern. The graphs can be seen increasing in the beginning, remain constant in the middle and decreasing towards the end. At power 270 W, drying accelerates up to 150 s, remains constant to 270 s and gradually decreases when reaching 390 s. At 450 W drying rate increases up 180 s, remains constant until 270 s and decreases towards the end at 390 s. At 630 W, acceleration occurs from start to 180 s, remains constant until 240 s and it can be seen decreasing gradually towards 390 s. In this experiment, the speciation of heavy metal elements, plumbum (Pb), nickel (Ni), copper (Cu), zinc (Zn) and chromium (Cr) were measured and shown in Table 2.It should be noted that Zn and Cr were mainly retained in the solid residue and exists as stronger bioavailability species in the sludge.

This sludge is mainly made up of the uneaten feeds, faecal matter and dead bodies of shrimp which leads to the accumulation of heavy metals and organic matter in sludge. According to a previous study (Chou *et al., 2009)*, heavy metals are assumed to be present as oxides at the envisaged temperature. Fang *et al., 20*07 studied stabilization of heavy metal in municipal sewage sludge by different dry methods, and found that microwave radiation can promote to stabilize the contaminants in dry sludge. Therefore, the source of water used for the shrimp aquaculture should be monitored and treated at the early stage in order to decrease the level of heavy metals in sludge during the harvesting period.

3.2. Fourier transforms infrared spectroscopy

Sludge samples before and after thermal treatment were characterized by FTIR analysis to determine the availability of the main group presence in sludge. FTIR results show that the main groups in the studied sludge are aliphatic chains with double bonds, as well as carbonyl, hydroxyl and N–H groups in organic compounds. Table 3 shows several absorption bands in the region from 3500 cm-1to 3000 cm-1, and the first peak of the spectra, in 3380 cm-1 is an absorption band related to the stretching of the N–H bond of organic compounds (Francioso *et., 2010)*.

These compounds as depicted in Fig.4(i) also present characteristic bands in 1680 cm-1to 1600 cm-1 related to C = C vibration and 1280 cm-1to 1150 cm-1 related to S = O, as inferred by thermal analysis. Other absorption bands in the region from 1080 cm-1to 980 cm-1 are attributed to the presence of hydrocarbon chains, C-O-C, present on the organic material of the sludge sample. After heating, the highest value for hydrocarbon group being totally absent, or present in only in a very low concentration. Other important bands which appear in the infrared spectrum in Fig. 4 (ii) in the region 775 cm-1to 570 cm-1 is attributed to the un-degraded form of C-S.

Table 2. Heavy metals contents in sludge

Element	Initial (ppb)
Pb	0.236
Cu	0.331
Ni	0.273
Cr	0.427
Zn	0.514

Table 3. Functional groups compound attribution

Sludge Condition	Range (cm^{-1})	Peak Value	Attribution
Raw Sludge	3500 - 3000	3380.57	N-H
	1680 - 1600	1642.08	C=C
	1280 - 1150	1103.03	S=O
	1080	1032.83	C-O-C
	980	913.48	C-C/C-O
	775-570	659.22	C-S
Dried Sludge	775-570	641.94	C-S

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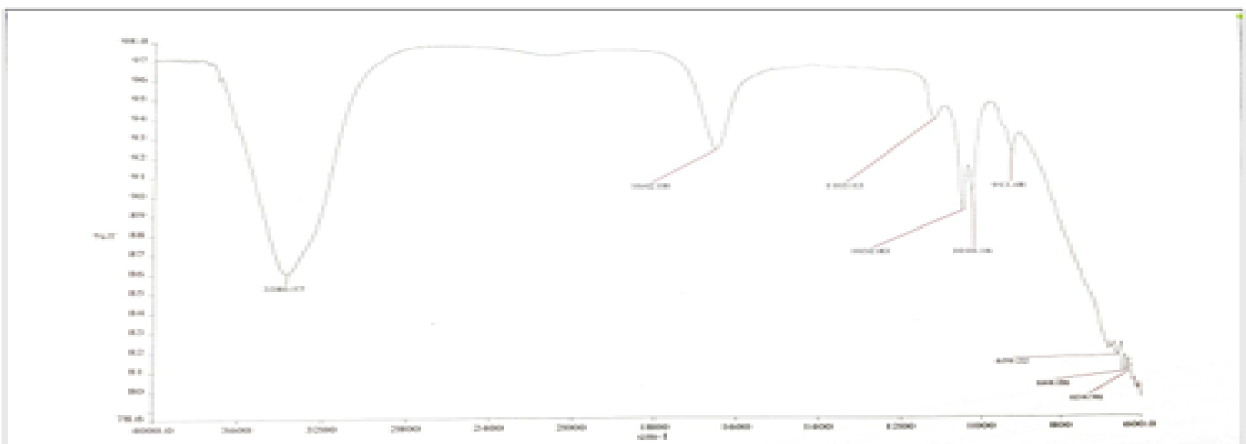
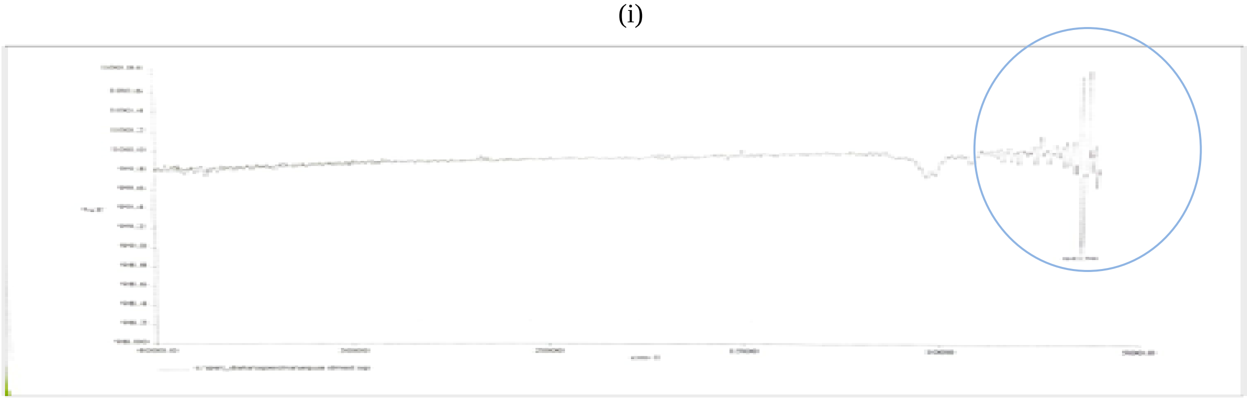
Degradation The effectiveness of thermal treatment on drying shrimp aquaculture sludge at different power and time of 270 W, 450 W 630 W and 60s, 90s, 120s, 180s, 240s, 300s, 330s, 360s, 390s, respectively, have been carried out. Heavy metals concentrations and chemical compounds were also determined. It was noted that the best drying rate recorded were at power and time of 630W and 240 s, respectively. Zinc and Chromium were detected. FTIR spectrum showed that the main groups presence are aliphatic chains with double bonds, as well as N–H groups in organic compounds.



(i)



(ii)

Figure 4: FTIR spectrum of sludge: (i) before (ii) after heating.

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Conflict of interest

The authors declare that they have no conflict of interest.

References

ANKA, I.Z., FARUK, M.A.R., HASAN, M.M., AZAD, M.A.K., 2013. Environmental issues of emerging pangas (Pangasianodonhypophthalmus) farming in Bangladesh. J. Prog. Agric. 24, 159–170.

ANASTAS P, WARNER J. Green chemistry. Frontiers; 1998.

CHOU, S.Y., LO, S.L., HSIEH, C.H., CHEN, C.L., 2009. Sintering of MSWI fly ash by microwave energy. J. Hazard. Mater. 163 (1), 357–362.

CRIPPS, S.J., BERGHEIM, A., 2000. Solids management and removal for intensive land-based aquaculture production systems. Aquacult. Eng. 22 (1), 33–56.

C.W. JIN, S.J. ZHENG, Y.F. HE, G.D. ZHOU, Z.X. ZHOU, Lead contamination in tea garden soils and factors affecting its bioavailability, Chemosphere 59 (2005) 1151–1159.

FANG L, TIAN Y, HUANG J L, ET AL. Mechanism study on the stabilization of heavy metal and organics in microwave dried sludge. J HarbinInsti Technol, 2007, 39(10):1591-1595.

FAO, 2007. Food and Agriculture Organization of the United Nations. Aquaculture—new opportunities and a cause for hope. /http://www.fao.org/ focus/e/fisheries/aqua.htmS.

GOWEN, R.J., ROSENTHAL, H., MIKINEN, T., EZZI, I., 1990. Environmental impacts of aquaculture activities. In: de Pauw, N., Billard, R. (Eds.), Aquaculture Europe'89 — Business Joins Science. European Aquaculture Society, Spec. Publ, No. 12. Bredene,Belgium, pp. 257–283.

HAQUE, M.M., MONIRA, M.S., SALAM, M.A., SHINN, A.P., Little, D.C., 2013. Use of Pangasius pond sediment for rooftop bag gardening: potential for rural-urban integrated aquaculture-horticulture. Aquacult. Asia Mag. XVIII (Oct–Dec (4)), 21–23.

HONG S.M., PARK J.K., LEE Y.O., 2004. Mechanisms of microwave irradiation involved in the destruction of fecal coliforms from biosolids. Water Resource. 2004:38:1615-1625.CAPPUCCINO, J. G. & SHERMAN, N. 2005. Microbiology: a laboratory manual.

LIN Q.H., CHENG H., CHEN G.Y. 2012. Preparation and characterization of carbonaceous adsorbents from sewage sludge using a pilot-scale microwave heating equipment. Journal Analytical Applied Pyrolysis. 2012:93:113-119.

M. CHEN, X.M. LI, Q. YANG, G.M. ZENG, Y. ZHANG, D.X. LIAO, J.J. LIU, J.M. HU, L. GUO, Total concentrations and speciation of heavy metals in municipal sludge from Changsha, Zhuzhou and Xiangtan in middle-south region of China, J. Hazard. Mater. 160 (2008) 324–329

MENENDEZ J.A., INGUANZO M., PIS J.J. 2002. Microwave-induced pyrolysis of sewage sludge. Water Resource. 2002:36:3261-3264.

O. FRANCIOSO, M.T. RODRIGUEZ-ESTRADA, D. MONTECCHIO, C. SALOMONI, A. CAPUTO, D. PALENZONA, Chemical characterization of municipal wastewater sludges pro- duced by two-phase anaerobic digestion for biogas production, J. Hazard. Mater. 175 (2010) 740–746.

P.MANARA AND A. ZABANIOTOU, "Towards sewage sludge based biofuels via thermochemical conversion: a review. "Renewable and Sustainable Energy Reviews, vol 16, no5, pp 2566-2582, 2012.

RICHEL A, JACQUET N. Microwave-assisted thermochemical and primary hydrolytic conversions of lignocellulosic resources: a review. Biomass-Convers Biorefinery 2015;5(1):115–24.

SANDRA T. MADARIAGA AND SANDRA L. MARÍN. (2016). Sanitary and environmental conditions of aquaculture sludge. Wiley.CULLEN, W. R. & REIMER, K. J. 1989. Arsenic speciation in the environment. *Chemical reviews*, 89**,** 713-764.

TANG B., YU L., HUANG S., LUO J., ZHUO Y. 2010. Energy efficiency of pre-treating excess sewage sludge with microwave irradiation. Bioresource Technology. 2010;101:5092-5097.

U. KROGMANN, L.S. BOYLES, W.J. BAMKA, S. CHAIPRAPAT, C.J. MARTEL, Biosolids and sludge management, Water Environ. Res. 71 (1999) 692–714

YANG, H.C., SEO, Y.C., KIM, J.H., PARK, H.H., KANG, Y., 1994. Vaporization characteristics of heavy metal compounds at elevated temperatures. Korean J. Chem. Eng. 11 (4), 232–238..

YU Q., LEI H., LI Z., LI H., CHEN K., ZHANG X., LIANG R. 2010 Physicaland chemical properties of waste activated sludge after microwave treatment. Water Res. 2010; 44:2841-2849.

ZHENYU CHEN, MUHAMMAD T. AFZAL, AND ARSHAD ADAM SALEMA, 2014. Microwave drying of wastewater sewage sludge. Journal of Clean Energy Technologies, Vol. 2.

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