Thermal Effects

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ABSTRACT: This review focuses on the research literatures published in 2014 relating to topics of thermal effects in water pollution control. This review is divided into the following sections: anaerobic wastewater and sludge treatment, biological nitrogen and phosphorus removal, membrane biological treatment, sewage sludge pyrolysis, natural treatment, resource recovery, electrolysis, oxidation and adsorption treatment.

KEYWORDS: Anaerobic Wastewater and Sludge Treatment, Biological Nitrogen and Phosphorus Removal, Membrane Biological Treatment, Sewage Sludge Pyrolysis, Natural Treatment, Resource Recovery, Electrolysis Treatment, Oxidation Treatment, Adsorption Treatment.

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Anaerobic Wastewater and Sludge Treatment

Deng et al. (2014) carried out a study to examine the effect of temperature on the biogas production and heating strategy for anaerobic digestion of swine wastewater. Through a kinetic model, it was found that anaerobic digestion was more sensitive to temperature variation within 15-20 °C than that within 20-35 °C. In terms of energy input-output ratio and total annual cost, the optimal heating strategy was an increase in the fermentation temperature from 15 to 20 °C.

Low-temperature limitation of bioreactor sludge in anaerobic treatment of domestic wastewater was studied. The results demonstrated that the lower temperature limited the performance of anaerobic bioreactor. Decreasing temperature resulted in the decrease of methane and acetate yields and increased 'start-up' times (Bowen et al. 2014).

The effect of temperature on the performance of anaerobic sequencing batch reactor in synthetic dairy wastewater treatment was studied by Dehghani et al. (2014). The results indicated that any decrease in temperature caused reduction in BOD_5 and COD removal. The temperature of 35 °C was optimal for the treatment of high organic load wastewater.

Kundu et al. (2014) aimed to analyze the effect of sudden temperature increase on the performance and microbial community structure of a hybrid anaerobic reactor (45-65 °C). It was observed that both diversity and relative abundance of methanogenic groups in the hybrid anaerobic reactor were significantly affected by the

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temperature. Absence of any thermophilic acetoclastic methanogens caused system failure at 65 °C.

Chen et al. (2014d) used an anaerobic baffled reactor-septic tank and a Yuhuan drawing three-dimensional-carrier-septic tank for the anaerobic treatment of domestic sewage under a temperature of 16 °C. The results indicated that these two modified septic tanks improved the performance of COD and total solid removal, which were suitable for domestic sewage (pre) treatment at low temperature in northern China.

The application of low-temperature anaerobic digestion for the treatment of complex dairy-based wastewater in an inverted fluidised bed bioreactor was investigated by Bialek et al. (2014). It was shown that Inadequate mixing intensity provoked poor hydrolysis of the protein, which resulted in low COD removal efficiency throughout the trial at 10 °C. The bacterial community in the bioreactor monitored via denaturing gradient gel electrophoresis suggested an influence of organic loading rate stress on bacterial community structure and population dynamics.

Performance and microbial community profiles in a hybrid anaerobic reactor treating synthetic purified terephthalic acid wastewater from 33 °C to 52 °C were studied over 220 d. Results indicated that terephthalic acid wastewater treatment was highly sensitive to temperature variations in terms of COD removal. Meanwhile, δ-Proteobacteria was the most dominant bacterial group in mesophilic anaerobic treatment process, whereas β-Proteobacteria appeared to be favored at temperature higher than 43 °C (Li et al. 2014b).

Scaglia et al. (2014) evaluated a lab-scale study on the ability of anaerobic process to sanitize sewage sludge and produce biogas. The results suggested that mesophilic and thermophilic anaerobic digestion sanitized better than psychrophilic anaerobic digestion, but the total free ammonia concentration under the thermophilic condition inhibited biogas production. The mesophilic condition, however, allowed for both sludge sanitation and significant biogas production.

The anaerobic co-digestion of sewage sludge and tomato waste at mesophilic temperature was studied by Belhadj et al. (2014). The results showed that sewage sludge and tomato waste anaerobic co-digestion was stable and the methane production rate increased with the increase of organic loading rate in the reactors. This valorization process could be a viable option for the centralized management of the studied wastes.

According to Minale and Worku (2014), anaerobic co-digestion of sanitary wastewater and kitchen solid waste for biogas and fertilizer production under ambient temperature was studied. The results suggested that the co-digestion of sanitary wastewater and kitchen organic solid wastes generated from condominium houses in a mixing ratio of 25:75 enhanced the quality and quantities of methane yield.

Samaras et al. (2014) investigated the removal of endocrine disrupting compounds and non-steroidal anti-inflammatory drugs in three lab-scale anaerobic digestion systems (a single-stage mesophilic, a single-stage thermophilic and a two-stage thermophilic/mesophilic). It was observed that all anaerobic digesters were efficient throughout the entire study period. However, the use of two-stage anaerobic digestion system slightly favored the removal of endocrine disrupting compounds.

Kinnunen et al. (2014) discussed the influence of temperature and pretreatments on the anaerobic digestion of wastewater grown microalgae in a laboratory-scale accumulating-volume reactor. The results illustrated that low-temperature thermal and freeze-thaw pretreatments enhanced protein hydrolysis and increased methane yields.

Biological Nitrogen and Phosphorus Removal

The morphological, biological and chemical characteristics of the aerobic granulation developed in a sequencing batch reactor at mesophilic temperatures were investigated. The results showed that the heterotrophs and the nitrifying autotrophs were simultaneously enriched in the reactor. Significant organic and ammonia were simultaneously removed, which demonstrated that these mesophilic aerobic granules were appropriate for combined treatment of high temperature effluent (Cui et al. 2014).

According to Gilbert et al. (2014), a lab-scale moving bed biofilm reactor with carrier material (K3 from AnoxKaldnes) was used to test the tolerance of overall partial nitritation/anammox process to a temperature gradient from around 20 °C in summer to about 10 °C in winter. The results showed that the ammonium conversion dropped with the temperature decrease, and doubling of the hydraulic retention time occurred over the temperature ramp.

Zou et al. (2014) conducted experiments about high-efficient nitrogen removal by coupling enriched autotrophic-nitrification and aerobic-denitrification consortiums at cold temperature. The results showed that the successful coupling of both aerobic consortiums with excellent performance not only provided new insights into simultaneous nitrification and denitrification but also huge potential of practical application, particularly for high-efficient total nitrogen removal in low-strength domestic wastewater at low temperature.

The impact of temperature on nitrification kinetics of a pilot-scale moving-bed biofilm reactor was studied by Zhang et al. (2014c) for treating polluted raw water. It was observed that the oxidation rates of ammonia and nitrite increased with the increase of temperature, although the biomass concentration decreased. The specific ammonia and nitrite oxidation rates were highly dependent on the temperature.

Cho et al. (2014) investigated the influence of pH and temperature on the nitrification performance of full-scale wastewater treatment plants. It demonstrated that nitrification performance was significantly influenced by the variations of pH and temperature. Based on these results, different model equations were developed for predicting the combined effects of temperature and pH on nitrification rates at wastewater treatment plants, reflecting the propensity of nitrifying bacterial communities to flourish under different conditions.

The effect of temperature on the performance of laboratory-scale phosphorus-removing filter beds with different filter materials was investigated by Herrmann et al. (2014) in an on-site wastewater treatment process. It was observed that the phosphorus binding capacity of different materials increased with increasing temperature. Meanwhile, the reduction in total organic carbon content in wastewater was positively correlated with the temperature, while the pH and reduction of dissolved organic carbon remained unaffected.

Membrane biological Treatment

The performance of a novel integrated anaerobic fluidized-bed membrane bioreactor (MBR) was investigated by Gao et al. (2014) for treating practical domestic wastewater at a step dropped temperature from 35, 25, to 15 °C. It was observed that the COD removal depended both on influent strength and operational temperature. The accumulation of volatile fatty acids was affected by temperature, and acetic acid was most sensitive to the decrease of temperature. Additionally, low temperature accelerated membrane biofouling.

A laboratory staged anaerobic fluidized MBR system was applied to treat primary clarifier effluent from a domestic wastewater treatment plant with temperature decreasing from 25 to 10 °C. No noticeable negative effect of low temperature on organic removal was found in the research. However, the rate of trans-membrane pressure increased as temperature decreased (Yoo et al. 2014).

Giménez et al. (2014) evaluated the effect of seasonal temperature variation on the anaerobic treatment of urban wastewater in MBRs. The results illustrated that sludge production increased and energy recovery potential decreased when temperature decreased, while COD removal and membrane permeability remained nearby stable throughout the whole experimental period.

Zhang et al. (2014a) determined the effect of low temperature operation on MBR performance and activated sludge characteristics. It was observed that the average effluent COD concentration increased when the wastewater temperature decreased from 22 to 13 °C, while the nitrogen removal efficiency appeared not to be affected. Meanwhile, the abundance and diversity of nitrifying bacteria in activated sludge reduced under low temperature exposure.

Three novel multi-sparger multi-stage airlift loop membrane bioreactors were set up in parallel for treating synthetic high-strength 7-ACA pharmaceutical wastewater under different HRTs, temperatures and pH, respectively. Results showed that different temperatures and pH influenced contaminant removals by affecting MLSS concentration and β-lactamase activity significantly (Chen et al. 2014c).

Arévalo et al. (2014) analyzed the effect of temperature on membrane bioreactor performance working with high hydraulic and sludge retention time. It was found that low temperatures affected COD biodegradation. Meanwhile, lower temperatures led to a decrease both in endogenous respiration rate and observable biomass yield coefficient for heterotrophs.

Ran and Lu (2014) reviewed the effect of temperature on soluble microbial products in membrane bioreactor systems. Besides, the future trends in the effect of temperature in the coming years were addressed, which will be conducive to the application of MBR in the future.

Chang et al. (2014) proposed an enhancement start-up strategy for accelerating the start-up of a MBR for treating micro-polluted surface water under low temperature. Results indicated that the enrichment of ammonia oxidizing bacteria and nitrite oxidizing bacteria lasted for 27 days at 7.3 °C and the acclimation was completed within 3 days at 5.9 °C. However, the MBRs exhibited stable but unsatisfactory organic removals under low temperature during the start-up.

Campo et al. (2014) discussed the feasibility of direct bio-hydrogen production from the real industrial fruit juice wastewater in a short high temperature proton exchange membrane fuel cell (PEMFC) stack with composite polybenzimidazole (PBI) based membranes. The results demonstrated that the composite PBI-based PEMFC tolerated quite well with the presence of 45% CO_2 and trace CO in the feed stream at high temperature (100-200 °C).

Sewage sludge Pyrolysis

Applying biochar products from sewage sludge pyrolysis as soil amendment for plant cultivation was investigated by Song et al. (2014). Special attention was paid to heavy metal accumulation in the plants when pyrolysis temperature and biochar-to-soil mass ratio (C:S) were changed. The results demonstrated that C:S ratio related to garlic yields changed when the pyrolysis temperature was changed. The sludge biochar produced at 450 °C is the most suitable one for garlic cultivation when C:S was 1:4.

Chen et al. (2014a) assessed systematically the influence of pyrolysis temperature on sludge biochar properties and heavy metal adsorption potential, which was pyrolyzed from biophysical dried sludge under temperature varying from 500 to 900 °C. It was found that the biochar yield decreased with the increase of pyrolysis temperature. The structure became porous as the temperature increased, and the concentrations of surface functional group elements remained low. For both energy recovery and heavy metal removal, the optimal pyrolysis temperature was 900 °C.

According to Zhang et al. (2014b), pyrolysis of sewage sludge was studied in a free-fall reactor at 1000-1400 °C. The results illustrated that high temperature pyrolysis of sewage sludge was efficient for producing tar-free fuel gas. Complete tar removal and volatile matter release were realized at 1300 °C and the energy conversion efficiency for gas production was 72.60 %.

Wet sewage sludge was pyrolyzed using conventional pyrolysis (CP) at 400-900 °C and microwave pyrolysis (MWP) at 400-900 W. The results demonstrated that production yields in MWP and CP behaved similarly for different power inputs in MWP and for different temperatures in CP, whereas liquid yielded more than 75% of the total weight for the high content of water in wet sewage sludge. Liquid yield went through a high peak at 500 W for MWP and 700 °C for CP (Dai et al. 2014).

The influence of sewage sludge-based activated carbons (SSAC) on sewage sludge liquefaction was studied at 350 and 400 °C. It was found that 350-SSAC was beneficial to lowering the risk of Cu, Zn and Pb, while 400-SSAC was effective in lowering the risk of Cd, Cu and Zn. Meanwhile, considering the bio-oil yield, liquefaction at 350 °C was preferable (Zhai et al. 2014).

Gondek et al. (2014) determined the influence of the process of low-temperature transformation process and the plant material addition to sewage sludge on diversifying the content of mobile heavy metals and their ecotoxicity. It was found that thermal transformation of mixtures of sewage sludge and plant materials caused an increase in total contents of heavy metals. Besides, the content of water soluble form of heavy metals decreased significantly in all prepared mixtures.

Chen et al. (2014b) explored the effect of different pretreatments on ash reduction and the thermal decomposition of wastewater alage. The results demonstrated that pretreatment of centrifugation followed by ultrasonication could improve the thermal decomposition behavior of wastewater algae and enhance the bio-crude oil conversion efficiency.

Natural Treatment

A pilot-scale integrated vertical constructed wetlands system was implemented for the treatment of primary domestic wastewater from student dorms in a university, and the nitrogen transformation properties were investigated. It was found that the temperature affected the nitrification intensity, because most of the bacteria had a significant positive correlation with the influent temperature (Peng et al. 2014).

Redmond et al. (2014) assessed the role of cyclic aeration, vegetation, and temperature on nitrogen removal by subsurface-flow engineered wetlands. For the conditions tested, temperature had only a minimal effect on effluent ammonia or total nitrogen concentrations.

The evaluation of hybrid treatment wetland after six years operation in cold climate in northern Japan was conducted by Harada et al. (2014). The results manifested that the purification efficiency and removal efficiency of all the pollutants were relatively high after 6 years of operation. Some removal efficiencies such as TN, NH_4^+-N, COD, and BOD_5 were improving, because of formation of organic layer, enhancement of soil ecosystem, active macroorganism such as earthworm, and maturation of vegetation that is associated with enriched rhizosphere with flourishing microorganisms. This system still had the potential to remove treat all wastewater pollutants at an acceptable level.

Long term experience of sequencing batch reactor (SBR) system and wetland treatment from a municipal wastewater treatment plant with low temperature wastewater in Sweden was analyzed by Morling et al. (2014). It was observed that the combination of a SBR system along with classical chemical precipitation and a polishing step based on ‘natural’ extensive treatment was a sustainable way to keep the discharge levels low.

Yan and Xu (2014) reviewed current engineering practices including case studies showing ways to increase winter treatment effectiveness of constructed wetlands in northern China, which demonstrated that the performance of constructed wetlands in cold climates could be improved through better operation strategies.

Variations in potential CH_4 flux and CO_2 respiration from freshwater wetland sediments with different temperatures were assessed by Brooker et al. (2014). The results showed that an increase of 10 °C in temperature accelerated the rate of methane production and carbon dioxide respiration by 2-3 fold across all microsites.

Han et al. (2014) investigated how the soil respiration and its temperature sensitivity were affected by the different vegetations in the Yellow River Estuary. The results suggested that vegetation patchiness at a field scale might have a large impact on ecosystem-scale soil respiration. Modeling soil respiration should not only take into account the simple soil temperature and moisture relationships, but also incorporate the patchy distribution of vegetation type as they affected the spatial and temporal variation of soil respiration.

Kauppinen et al. (2014) studied the microbiological and nutrient removal properties of three different pilot-scale sand filters over a one-year period. The system that effectively removed microbes was also efficient at removing nutrients. However, seasonal conditions appeared to have a clear effect on purification efficiencies, emphasising the vulnerability of these systems especially in cold climates.

Subhash et al. (2014) investigated the influence of temperature induced stress on biodiesel productivity during mixotrophic microalgae cultivation with wastewater. Experiments documented regulatory function of operating temperature as physical stress on enhancing lipid synthesis during stress induced starvation phase. Mixotrophic growth phase documented increments in biomass growth and cell density while temperature induced stress phase showed increments in lipid productivity. Temperature stress also showed influence on the saturated fraction of fatty acids composition.

Resource Recovery

The possibility to use wastewater as alternative energy source for heating and cooling buildings was studied by Cipolla and Maglionico (2014). They analyzed the daily and seasonal variability of wastewater flow rate and temperature in the sewer system of Bologna, Italy. The results are useful in the accurate design of structures for wastewater conveyance or treatment, and in the design of heat recovery systems that need the knowledge of wastewater flow rate and of temperature time patterns.

Dürrenmatt and Wanner (2014) explored a mathematical model that calculated the discharge in a sewer conduit, and the spatial temperature profiles and dynamics in wastewater, sewer headspace, pipe, and surrounding soil. The model was implemented in the simulation program TEMPEST and was used to evaluate measured time series of discharge and temperature. It is a useful tool to determine the optimal site for heat recovery and the maximal amount of extractable heat.

Słyś and Kordana (2014) presented a calculation model that estimated the financial efficiency of a project involving the construction of a heat recovery system of shower drain water in a single-family dwelling house. The presented method of investment risk assessment will be beneficial to apply in case of swimming pools, sports facilities or fitness clubs with a high rotation of users.

The potential to recover condensate waste heat from paste processing and apply it to the tomato enzyme thermal inactivation processing step (the hot break) is assessed as a novel application by Amón et al (2014). A modeling framework is established to predict the heat transfer to tomatoes during the hot break. The sensitivity of heat recovery to various process variables associated with heat exchanger design and processing conditions was also presented to identify the factors that affected waste heat recovery.

According to Li et al. (2014a), a novel geothermal system combining power output, refrigeration, gathering heat tracing, heating, and oil recovery was put forward. The results demonstrated that the novel system increased the recoverable reserve and enhanced the recovery ratio for oilfields in the high water cut period. Specifically, the auxiliary cold sources lowered the condensing temperature and raised the net power output both in summer and in winter, deserving to be widely spread in engineering applications.

With the reference to the global energy and water resources sustainability concerns, Todorovic and Kim (2014) presented an innovative, energy efficient multipurpose system for a sustainable globally cost-effective building's solar energy use. Relevant dynamic analysis and optimization methodology were discussed. The final result confirmed the sustainability relevant performance - globally cost-effective building integrated photovoltaic powered heat pump, assisted by waste water heat recovery, for solar air-conditioning, water heating and saving.

Prasertsung and Ratanatamskul (2014) examined the effect of organic loading rate (OLR) and operating temperature on the cassava wastewater treatment and power generated by a single-chamber microbial fuel cell. It was found that the maximum efficiency of COD removal achieved was 91.44 ± 0.72 and 90.72 ± 0.87% at 30 and 45°C with the OLR of 0.56 kg COD/m^{3}d, respectively.

Electrolysis, Oxidation and Adsorption Treatment

Heidrich et al. (2014) tested the robustness and applicability of microbial electrolysis cell (MEC) technology for domestic wastewater treatment at temperatures ranging from 1 to 22 °C. It was found that gas production rates declined with time but not with low temperatures. This research has established that the biological process of an MEC will to work at low temperatures with real wastewater for prolonged periods. However, average energy recovery was around half that needed for energy neutrality.

According to Wang et al. (2014b), the feasibility of operating a MEC at low temperatures was evaluated, and the feasibility of using biocathode as an alternative to expensive platinum as the cathode material was examined. The results demonstrated that hydrogen was generated from molasses wastewater by MEC at a low temperature with a cheaper biocathode.

Domínguez et al. (2014) explored the treatment of high-strength real winery wastewater by wet oxidation processes at mild temperature. The results showed that hydrogen peroxide was the unique oxidant capable of achieving an effective reduction of organic load, and the graphite tested was the most active catalyst.

The research on temperature dependent redox zonation and attenuation of wastewater-derived organic micropollutants in the hyporheic zone was conducted by Burke et al. (2014). The results demonstrated that attenuation of organic micropollutants during infiltration was influenced by temperature. A change in temperature resulted in a development of significantly distinct redox conditions. Both temperature dependencies and related redox dependencies were identified for all micropollutants except for benzotriazole and carbamazepine, which behaved persistent under all conditions.

Laboratory batch experiments were conducted in order to assess the impacts of temperature on the performance of goethite in removing arsenate from water. The results showed that both the arsenic uptake rate and capacity were significantly enhanced with increasing temperature, while the crystalline structure of goethite was not changed after adsorption at various temperatures (Hao et al. 2014).

Wang et al. (2014a) investigated how to use cheaply-priced, safety and sanitate of natural clay or nanosilica as coagulant and adsorbent combined with polyaluminium chloride to treat paper mill wastewater with low temperature and low turbidity. The results showed that nano-SiO_2 as coagulant associated with PAC attained best coagulation performance.

Comparison of activated carbon prepared from olive stones by microwave and conventional heating for iron (II), lead (II), and copper (II) removal from synthetic wastewater was conducted by Alslaibi et al. (2014). It was observed that the microwave heating required significantly lesser holding time, compared with conventional heating method to produce similar activated carbon. The adsorption capacity was found higher using microwave heating compared with conventional heating.

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