Environment

PIRAT-Systems: Energy- and Resource-Efficient Wastewater Treatment Processes for China

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PIRAT–系统：适用于中国的能源和资源高效型的污水处理工艺

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Wastewater treatment is of high importance for societies as it prevents diseases and protects the environment. Nevertheless, wastewater treatment plants (WWTP) belong to the most cost- and energy-intensive municipal infrastructures whose main goal is seen in wastewater disposal. However, at a closer look, wastewater contains many valuable resources, which are mostly lost during traditional treatment processes. Nowadays a paradigm shift in wastewater management can be seen, transforming from wastewater disposal management to a more resource-oriented approach where valuable wastewater components are recovered for reuse, as well as energy is produced and its consumption reduced during the treatment process.

Germany already implements advanced new technologies, which improve the energy balance of WWTPs and start to recover valuable nutrients. Other countries, e.g. China, are farther away from resource-oriented approaches and still need to adapt, develop, and transform their WWTPs into resource factories.

In this context, the project PIRAT-Systems aims to find solutions to improve the energy and resource balance on WWTPs in China, while taking national and local regulations, political structures, and wastewater constitutions into account. Within the project, German and Chinese partners cooperate closely to jointly engineer selected technologies for the Chinese market and to develop successful implementation strategies.

The technologies get tested in pilot plants and adapted in simulation models helping to construct

污水处理对于社会具有高度的重要性，因为通过污水处理可以预防疾病和保护环境。然而，污水处理厂属于最耗费成本和能源的市政基础设施之一，其主要目标是污水处理。但进一步考虑，污水中含有许多宝贵的资源，而其中的大部分资源在传统的处理过程中都流失了。如今可以看到污水管理模式的转变，是由污水处置管理转变为更注重资源的管理方式，通过此方式，有价值的污水成分得到回收以再利用，并在处理过程中生成能源和减少消耗。

Chinese and German partners work in close cooperation to analyse differences between German and Chinese wastewater treatment plants
中德双方密切合作讨论分析中德污水处理厂差异
Source / 图片来源: PIRAT-Systems

德国已经采用了先进的新技术，改善了污水处理厂的能源平衡，并开始回收有价值的营养物质。其他国家（例如中国）的污水处理离资源导向的方法更远，仍需要适应和发展，并将污水处理厂转变为资源工厂。

在此背景下，PIRAT系统项目旨在，综合考虑国家及地方法规、政治结构及污水处理章程的同时，为中

planning and decision-making tools. The main products recovered in WWTPs PIRAT-Systems looks at are sludge-based biogas for power production and phosphorus-compounds as a substitute for mineral-fertilizer.

Energy recovery

Sludge is a by-product of mechanical and biological wastewater treatment. It can be digested by micro-organisms under anaerobic conditions whereupon biogas is produced, and sludge stabilization takes place. This biogas can either be used as heat or power source, covering a high amount of energy used on the WWTP, leading to lower demand for fossil fuels. While anaerobic sludge digestion is widely spread in Germany, it is rarely used in China.

One reason is the different wastewater characteristics in China compared to the one in Germany. The concentrations of organic components, measured by Chemical Oxygen Demand (COD), and nutrients are lower in China than in Germany (see table below). This might be due to rain and groundwater intrusions into the sewer system, as well as different user habits (e.g. toilet paper disposal). Additionally, in China, septic tanks are often used for residential buildings, which pre-treat the wastewater and lower concentrations of organic components, the most important compounds for biogas production. This leads to challenges in realization of anaerobic sludge digestion under Chinese conditions.

PIRAT-Systems is looking for ways to make anaerobic digestion of and the production of biogas from sewage sludge feasible under those hindered conditions. One solution being co-digestion of other biological waste products like restaurant food waste to raise the organic content of the feedstock for digestion.

Besides the generation of biogas, the big advantage of anaerobic sludge digestion is stabilization leading to easier handling of the waste substance. After stabilization, the sludge contains fewer pathogens and should be inodorous. Due to the changed structure of the sludge, water can be drained easier reducing the sludge volume significantly before further transport.

With the transformation to anaerobic digestion, a WWTP can become more self-sustaining in terms

国的污水处理厂寻找改善能源与资源平衡的解决方案。在该项目中，中德双方密切合作，共同设计适用于中国市场的技术，并制定可行的实施策略。

这些技术将在试点工厂进行测试，并在模拟模型中进行调整，借以建立规划和决策工具。PIRAT系统关注的污水处理厂的主要回收产品是由污泥处理中产生的可用于发电的沼气和作为矿物肥料替代的磷化合物。

能源回收

污泥是污水机械和生物处理的副产物，可在厌氧条件下被微生物消化，从而产生沼气，并进行污泥的稳定化处理。这种沼气可以作用为热源或作用为电能，产生的沼气可以满足污水处理厂的大部分能源需求，从而减少化石燃料的需求。虽然污泥厌氧消化已在德国广泛应用，但在中国却很少投入使用。

原因之一是中国的污水水质与德国污水不同，中国污水的有机物浓度（以化学需氧量COD作为测量指标）及营养物质浓度低于德国污水（见下表）。这可能是由于雨水和地下水进入管网系统，以及不同的居民生活习惯（例如厕纸的处理）造成的。此外，在中国，化粪池经常被用于住宅区，对污水进行预处理及降低沼气生产中最重要的化合物的浓度即有机物的浓度。这也使得在中国水质条件下污泥厌氧消化的实现面临挑战。

PIRAT系统正在寻找方法，使厌氧消化和污泥中的沼气产生在这些受阻的条件下可行，其中一个解决方案是与其他的生物垃圾（如餐厅厨余）混合厌氧消化，以提高消化原料中的有机物含量。

Parameter/参数	Unit/单位	Germany/德国	China/中国
Influent/进水			
COD	mg/L	582 (459–1,068)	260 (115–388)
TN	mg/L	54 (43–89)	19–51
TP	mg/L	7.6 (6.2–13.1)	1.8–5.9
COD : TN : TP	-	100 : (7.5–15.3) : (1.3–2.3)	100 : (7.3–19.6) : (0.7–2.3)

Influent concentration of Chemical Oxygen Demand (COD), Total Nitrogen (TN) and Total Phosphorus (TP) in wastewater treatment plants in Germany and China
德国与中国污水厂的进水化学需氧量（COD），总氮（TN）及总磷（TP）
Source / 图片来源: German Association for Water Management, Wastewater and Waste (DWA) and Journal of Cleaner Production

除了沼气的生产，污泥厌氧消化的一个优势是污泥稳定化，从而使废弃物的处置变得容易。稳定化后的污泥含有较少的病原体，并且应是无臭的。由于污

of energy. Such a transformation affects the whole process of the plant, therefore in PIRAT-Systems decision-making tools are being developed for the operators. These tools will help to assess if the transformation to anaerobic digestion and biogas production is feasible for the operator, along with technical and administrative pre-arrangements including an assessment as to how much energy can be produced.

Nutrient removal and recovery

Natural streams and lakes all over the world suffer from eutrophication, a phenomenon, which describes the excessive supply of nutrients, leading to poor water quality and the failure of ecosystems. The nutrients made accountable for this are mostly nitrogen and phosphorus, which enter the stream due to poorly treated wastewater or agricultural run-off.

To lower the impact of WWTP- effluents, additional phosphorus removal from wastewater is practiced worldwide. However, due to phosphorus being a scarce mineral with high importance in food production, focus has been shifted to recovery rather than only elimination. PIRAT-Systems develops on-site strategies to produce struvite, a phosphorus-nitrogen derivate, from sludge and sludge-water, making the treatment plant a fertilizer production plant. In laboratory experiments within the framework of PIRAT-Systems, the best conditions to produce a safe fertilizer are investigated. Due to the diverse wastewater composition of municipal and industrial wastewater, possible impurities of produced fertilizers are still a challenge and need to be further examined. Additional chemical models together with the laboratory experiments help to understand the underlying processes and give useful hints for the operation of the phosphorus recycling pilot plant.

The phosphorus recovery plant is fed with sludge from the wastewater plant. Chemicals are added to induce the precipitation of struvite crystals. Those crystals can be used in agriculture as fertilizer. In spring 2020, field trials were set up in the city of Yantai following joint planning by SF-Soepenberg GmbH and the Chinese project partners (Center for International Research Center of BioEnergy Science and Technology (iBEST) and the College of Engineering of China Agricultural University, Beijing), to investigate the effects of struvite on vegetable and maize production in a large test field. For the field trial, 52 plots

泥结构的改变，水可以更容易地被排出，从而有效的减少污泥的体积，方便进一步进行运输。

随着向厌氧消化的转变，污水处理厂可以在能源方面更加的自给自足。这种转变会影响到污水处理厂的整个过程，因此PIRAT系统为污水处理厂运营者开发决策工具。这些工具将有助于运营者评估向厌氧消化和沼气生产的转变是否可行，以及技术和管理方面的预先安排，包括评估可产生多少能量。

营养物质的去除及回收

世界各地的天然河流和湖泊长期处于富营养化的状态，这是一种营养物供应过剩的现象，导致水质变差和生态系统的衰退。造成这一现象的营养物质主要是由于污水处理不当或农业径流进入河流的氮和磷。

为了降低污水处理厂出水的影响，世界各地都采用了对污水进行额外除磷的方法。然而，由于磷是一种在食品生产中具有高度重要性的稀缺矿物质，因此(污水中磷的处理)重点转移为回收，而非仅仅去除。PIRAT系统开发了现场策略，从污泥和污泥水中生产氮磷衍生物鸟粪石，使污水处理厂成为肥料生产厂。在PIRAT系统的框架内进行实验室实验，研究生产安全肥料的最佳条件。由于城市和工业污水中的污水成分各异，生产的肥料中可能存在的杂质仍是一个挑战，需要进一步研究。在实验室基础上建立的化学模型有助于理解过程反应机理，并对磷回收实验厂的运行提供有用的提示。

A researcher from China Agricultural University applies struvite on a test field in China to investigate the impact in plant growth
中国农业大学的一名研究员在实验田上使用鸟粪石，研究其对生物生长的影响
Source / 图片来源: CAU/SF-Soepenberg GmbH

磷回收厂使用污水厂的污泥作为进料，与化学剂混合进行反应，以促使鸟粪石晶体的沉淀，这些晶体可以作为肥料在农业上使用。2020年春季，在SF-

have been set up in which green peppers, sweet potatoes, tomatoes, and corn are grown. In autumn, the field fruits have been harvested and the samples are currently being analysed. Although the final results are still pending, first findings show a promising outcome of the field trials.

The use of struvite for vegetable cultivation is of particular interest since the transport distances between planned struvite production on WWTPs and vegetable fields are usually relatively short since both components are located in the peri-urban area.

Transforming the traditional wastewater treatment

The overall goal of the project is to find solutions to close energy and nutrient cycles while maintaining WWTPs' cleaning performance that comply with the strict Chinese standards and therefore help to improve the environmental situation. Nevertheless, the technological components have to be introduced into a network of different stakeholders, considering their different needs and requirements. PIRAT-Systems develops not only technical equipment, which can help to make the wastewater sector more energy- and resource-efficient, it also encourages cooperation between different sectors and countries.

Soepenberg有限公司和中国项目合作伙伴 (生物质能科学与技术国际联合研究中心 (iBEST) 和中国农业大学工程学院) 的共同策划下, 在烟台市进行了实地测验, 以研究鸟粪石在大型的实地实验中对蔬菜和玉米生产的影响。在实地试验中, 建立了52个区, 分别种植了青椒, 红薯, 番茄和玉米。试验地上的水果已在秋季收获, 样品目前处于分析阶段。虽然还未得到最终结果, 但初步结果表明, 实地试验的成果是有前景的。

因为计划中污水厂的鸟粪石产物与菜地之间的运输距离相对较短, 并且这两部分都位于城市的周边地区, 因此将鸟粪石用于蔬菜的栽种得到了极大的关注。

改变传统的污水处理方式

该项目的总体目标是寻找完善能源和营养物质的循环的解决方案, 并同时保持污水处理厂的清洁性能满足中国标准, 并使环境状况因此得到改善。然而, 考虑到利益相关者不同的需求和要求, 各技术组成部分必须被引入到不同的利益相关者的网络中。PIRAT系统不仅开发了有助于提高污水处理行业的能源和资源效率的技术设备, 而且还鼓励不同部门和不同国家之间的合作。

Sino-German Water Research / 中德水研究

The background of the Sino-German Water Research has been shortly described in the Econet Monitor, June 2019. Current topics are the sponge city concept (KEYS, Econet Monitor, June 2019); sludge treatment (IntenKS, Econet Monitor, September 2019); drinking water safety (SIGN-2, Econet Monitor, September 2020) and removal of organic components in municipal wastewater treatment plants (MWWTP) (PEPcat). Today's article is about the project PIRAT-Systems which focuses on optimization of MWWTP.

在2019年6月份的Econet Monitor期刊中, 我们介绍了德国和中国在水研究领域合作的背景。

目前运行中的中德联合水研究项目的主题分别是: 海绵城市概念 (KEYS, 详见Econet Monitor, 2019年6月刊)、污泥处理 (IntenKS, 详见Econet Monitor, 2019年9月刊)、饮用水安全 (SIGN-2, 详见Econet Monitor, 2020年10月刊), 去除城市污水处理厂 (MWWTP) 中的有机成分 (PEPcat), 以及今天要介绍的致力于城市污水处理厂优化的PIRAT-Systems项目。

BMBF-Project Office "Clean Water" / 德国联邦教育研究部 (BMBF) "清洁水" 创新研究项目办公室

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自2012年7月起, 位于上海同济大学的BMBF "清洁水" 项目办公室协助BMBF与MOST之间的水研究合作以及联合水研究项目。

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