Successful implementation and operation of a semi-centralised resource recovery centre for quickly growing megacities

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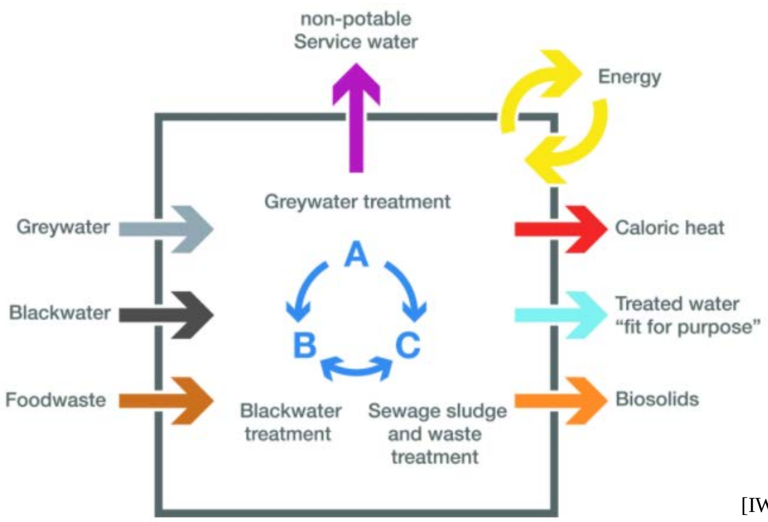
Abstract: As a solution for fast growing urban areas, a new semi-centralised concept for integrated wastewater treatment, service water supply and biosolids utilisation has been implemented by a Resource Recovery Centre (RRC) in Qingdao. Putting this innovative infrastructure concept into practise has caused enormous challenges in terms of the reliable implementation and operation. How to successfully deal with those challenges has been shown by the case study of Qingdao RRC, particularly regarding the development of specific operational instructions, O&M procedures and trainings.

Keywords: maintenance, operation, operational instructions, resource recovery, service water, sizing, waste-water, water reuse

Introduction: The SEMIZENTRAL approach

The development of the People's Republic of China is characterized by high economic growth rates and a constantly increasing degree of urbanization. Many Chinese high-density urban areas (especially megacities) are confronted by insufficient natural water supply and severe burdens for the environment by inadequate sewage and waste treatment. As a solution, the SEMIZENTRAL approach for newly developed urban areas has been developed by Chinese and German scientific and industrial partners, to integrate water reuse and resource recovery in so called Resource Recovery Centers (RRC) [TU Darmstadt et al. 2017].



[IWAR, TU Darmstadt]

Figure 1 Mass flow in the semi-centralised Resource Recovery Center

The first implementation of a SEMIZENTRAL Resource Recovery Center in Qingdao has been designed for 12,000 population equivalents and consists of four process units for the treatment of grey water, black water, bio-waste and sewage sludge. All processes have been integrated in a compact plant, as shown on the figure 1. In the grey water unit (module A) wastewater from showers and washing machines is purified by aerobic biological treatment and reused as service water for toilet flushing. Thus, nearly a third of the domestic daily water requirement is saved. In the black water unit (module B) the wastewater from toilets and kitchens passes through a reverse A/A/O procedure. The treated and disinfected effluent will be reused for irrigation and street cleaning. Up to 100% water recycling quotas are achieved. In the sewage sludge unit and energy center (module C) the anaerobic co-digestion of bio-waste and sewage sludge from modules A and B is conducted. The produced biogas is collected in a gas storage to be converted into electricity and heat, which will partly meet the energy needs of the other processes in the RRC. Thus the dependency and emission on fossil fuels can be reduced. The biosolids remaining from fermentation are particularly rich in nutrients and will be used as soil improver in horticultural utilization.

Challenges and solutions for implementation and operation

The successful implementation of such an innovative infrastructure concept by an industrial-scale pilot facility in a real-life surrounding requires not only an adequate design but also causes enormous challenges for the reliable implementation and operation of the whole system. How to successfully deal with those challenges has been shown by the case study of Qingdao RRC, especially for operational aspects like the development of specific instructions, maintenance and trainings.

Integrated operational instructions for a complex pilot system

Because of the complex technical treatment processes and RRC’s high flexibility for adaption to the actual development in quickly growing urban areas, comprehensive operational instructions had to be documented and adopted to RRC’s modular structure. In cooperation with the equipment suppliers and Chinese partners on site, an integrated service and operating instruction manual has been developed on the basis of DWA-A 199-1 and 199-4 (German guidelines of service and operational instructions for personnel of wastewater systems) [DWA 2011 and 2006] as an example for the present application. Specifically, the RRC is operated according to the following six aspects which have been announced in the instruction manual:

- Organization
  The responsibilities of staff and duty schedules are clearly to be defined and each employee shall exercise the assigned activity.
- Occupational safety and health
  In order to avoid any accident, the operation master shall sign all danger areas in the RRC. Employees should be regularly trained in the area of occupational health and safety. For example, for the work with sewage and handling of kitchen waste related hazards and corresponding measures should be explained.

- Description and operational instructions of each treatment component
  This is the most important part of operational instruction manual in terms of the practical use, including the layout plan and flow charts, standard requirements of the effluent, authorisation notices, detailed descriptions of the process technology, regular operation procedures (automatic and manual operation) of each equipment and its corresponding technical data. In addition, the operator shall also find instruction of the process control system, which is used to visualize and set important plant components and measuring devices of the RRC. With the instructions of each facility the each operator can look up detailed information about running processes and equipment of his/her related service and operating area.

  The service and operating instruction manual has continuously to be updated to changing operational situations.

- Maintenance and operational monitoring
  Operational maintenance is one of the most important task in RRC. It includes measures for the inspection, repair and improvement of equipment. A daily control of the running status shall be carried out. Regular inspection and maintenance routines have to be implemented according to the maintenance plan, based on the above mentioned operational instructions which describe the types of failure and the possible reasons for it. For example, the conduction of a functional check of each valve every year and the oil change according to the equipment's instruction book.

  The operational monitoring includes the control of wastewater disposal, water supply and sludge treatment e.g. by determining the concentration of the constituents in the effluent, process water and sludge. There are two monitoring methods implemented in the RRC: online measurement and manual measurement. The online measurements are carried out by installed measuring instruments at relevant monitoring points and local laboratory staff is responsible for manual measurements.

- Operational disruptions
  In the instruction manual for most relevant operational disruptions standard procedures are described. Operational disruptions may result from incidents inside or outside the RRC. Internal disruptions include all unintended operating conditions caused by internal events such as machine and electrotechnical failures, malfunctions and accidental process settings. External incidents, like power failure, in most cases cannot be directly influenced by the plant operation. In principle, external faults must be reported immediately to the operator master.

- Operational reporting
  All operations data, measure values and disruptions related to the plant's operation must be documented. Some reports and evaluations (such as monthly reports, operational error data) are generated by the PLS. Any important operating data shall be reported in the operating diary.

Implementation of a specific reliability-centred maintenance approach

To ensure sustainable, low-risk and economic operations of the RRC facilities, a specific reliability-centred maintenance (RCM) method has been executed, combining several purposes: to guarantee the reliability of equipment and assets, to determine the necessary amount of maintenance work and inspections, to document the knowledge of the staff and to make it available to concerned personnel. With the RCM approach, the maintenance and inspection measures for wastewater facilities are determined according to objective standard rules resulting in an overall maintenance and inspection schedule for all equipment at the facility. Automatic execution of such time- or operating-hour-dependent maintenance and inspection plans ensures the fulfilment of the necessary works on the plants. In the future, the documentation of proper maintenance will be ensured by the feedback and technical completion of the work. By the RCM approach vulnerabilities shall be eliminated systematically by constructive measures, in order to sustainably optimize repair costs and to improve operating safety.

The operators should intensively learn all the plant functions and the consequences of possible disturbances. Thereby unobserved risks should be uncovered, possible operating errors avoided and specific experience to be made available in general. For optimal maintenance procedures, local and cross-generational transfer of knowledge should be encouraged.

The maintenance planning for the plant has also to comply with the requirements of the operating company. Therefore, all decisions – why which maintenance measures and how often are they planned – should be justified und developed in a comprehensible manner to ensure a high degree of safety compliance for the operating company. The correct and complete execution of planned maintenance measures must be documented in order to verify their proper action.

In general, the RCM analysis applied to the RRC has been developed in accordance with the norm JA 1011/1012 "Assessment Criteria for RCM Processes" of the SAE (Society of Automotive Engineers), a procedure for the determination of the maintenance measures. In the RCM process, each individual machine of the treatment procedure is analysed according to seven criteria [Moubray 1996].

1. What are the functions of the machine?
2. How can the machine be broken during execution of their functions?
3. What causes each of these individual malfunctions?
4. What happens when each of these individual malfunctions occurs?
5. Does it matter if each of these malfunctions occurs?
6. What could be done to anticipate or prevent the malfunctions?
7. What to do if a malfunction is not predictable and cannot to prevent it?

Thus, after each technical equipment of the plant have been determined according to its function, its performance, the possible malfunctions and its causes, the next step in the RCM process involves a quantitative and qualitative assessment of the consequences of disturbances. It is ultimately a question of whether a malfunction must be avoided at all costs, or if you can wait for its occurrence. Above questions 1 to 5 are used to perform the so-called Failure Possibility and Effect Analysis (FPEA).

There are three essential criteria for defining appropriate maintenance measures and their intervals (according to above questions 6 and 7) [Kraft et al. 2012]:

- If there is a known service life of the part causing the malfunction, then a regular overhaul (restoration of the wear stock of a part after a fixed period) or a regular replacement (replacement of a part after a fixed period) shall take place.
- In the event of a potential disturbance or during a period from the occurrence of the potential disorder to the functional disorder, condition-dependent measures are taken.
- In the event of a concealed fault, a regular fault search must be carried out (for example, function test). If no planned maintenance is possible, the fault is allowed to occur. In this case, there must be a reserve, which can maintain the function, or the spare part must be available in stock.

The implementation of the RCM analysis at the RRC has been conducted in a team of RCM moderator, plant operator and maintenance engineer.

Quality assurance of the facility operation

Operational quality assurance comprises the performance control of wastewater disposal, water supply and sludge treatment, e.g. by determining the concentrations and flows of wastewater, process water and sludge etc. through self-monitoring and external quality control. For economic reasons the efforts for monitoring have to be reduced to an adequate level. So the optimization of instrumentation and analysis plans covers not only the extent of monitoring but also cost reductions e.g. by automation.

Furthermore, analytical quality assurance (AQA) is essential to verify examination results and to ensure a sufficient quality of the measurement results. AQA must be carried out at relevant points in the analysis process in order to achieve maximum quality of the analytical results. That includes both internal and external quality control measures, which contribute to the safeguarding, usability and comparability of the measurement results [DWA 2016].

For internal quality control pre-prepared control cards, so-called IQK cards [DWA 2016], which are based on MS Excel sheets, are user-friendly, clearly structured, and therefore easy to use in everyday work. For the various quality assurance measures there are different IQK cards available, each containing standard examples and giving orientation for the specific operational analysis. The DWA-A 704 [DWA 2016] worksheet complies with the IQK map framework, which is based on regulations and DIN standards, but can be adapted to individual needs, for example, by setting own quality objectives and quality assurance measures and their frequencies [DWA 2016].

The AQA measures carried out so far in the RRC are mostly double determinations, for example the measurement of standard and addition solutions, and the verification of the photometer (Pharo 300) by Photo-Check, as well as the checking of the pipettes. The results are recorded in the IQK cards (see example in figure 2)

IQK - Card 1 - Overview

On the sewage system: **Qingdao Semizentral RRC**

12000 EW oder m^3 daily wastewater volume) was by Operator

in the period from 01.01.16 to 31.12.16 below IQK-Measurt carried out:

(a) IQK for the measurements measurement point:

1	2	3	4	5	6	7
Parameters	**Tested Samples**	**Multiple Determination** **IQK-Card 3**	**Standard Measurement** **IQK-Card 4**	**Plausibility Checks** (Increase, Dilution) **IQK-Card 5**	**Comparison Measurement** (Operation Methode) **IQK-Card 6**	**Parallel-messungen** to reference method **IQK-Card 7**
COD	780 (Amount)	☑ 24 (Amount)	☑ 24 (Amount)	☑ 4 (Amount)	☑ 2 (Amount)	☑ 2 (Amount)
BSB5	780 (Amount)	☑ 52 (Amount)	☑ 52 (Amount)	☐ (Amount)	☑ 2 (Amount)	☑ 2 (Amount)
NH4-N	780 (Amount)	☑ 24 (Amount)	☑ 24 (Amount)	☑ 4 (Amount)	☑ 2 (Amount)	☑ 2 (Amount)
NO3-N	312 (Amount)	☑ 12 (Amount)	☑ 12 (Amount)	☑ 4 (Amount)	☑ 2 (Amount)	☑ 2 (Amount)
NO2-N	312 (Amount)	☑ 12 (Amount)	☑ 12 (Amount)	☑ 4 (Amount)	☑ 2 (Amount)	☑ 2 (Amount)
TN	624 (Amount)	☑ 1 (Amount)	☑ 1 (Amount)	☑ 4 (Amount)	☑ 2 (Amount)	☑ 2 (Amount)
TP (>1 mg/l)	780 (Amount)	☑ 12 (Amount)	☑ 12 (Amount)	☑ 4 (Amount)	☑ 2 (Amount)	☑ 2 (Amount)
TP (<=1 mg/l)		☑ 12 (Amount)	☑ 12 (Amount)	☑ 4 (Amount)	☑ 2 (Amount)	☑ 2 (Amount)
PO4-P	104 (Amount)	☑ 12 (Amount)	☑ 12 (Amount)	☑ 4 (Amount)	☑ 2 (Amount)	☑ 2 (Amount)
AC	104 (Amount)	☑ 12 (Amount)	☑ 12 (Amount)	☑ 4 (Amount)	☑ 2 (Amount)	☑ 2 (Amount)

Figure 2 Example of analytical quality assurance measurements at the RRC

Double or multiple determinations belong to the laboratory day, the previously measured value deviations resulting from double determinations has to be in the range specified by the manufacturer, e.g. here by Merck KGaA. The measurement of standard and addition solutions is carried out with the CombiCheck series. The CombiCheck series contains a standard solution for checking the entire system, as well as an addition solution for checking matrix effects. The Spectroquant®PhotoCheck is comparable to international standards for device monitoring and meets the requirements for instrument test purposes. The Spectroquant® PhotoCheck was performed in RRC once in the quarter, which consists of cuvettes with stable colour solutions, cuvettes with distilled water and cuvettes for checking the bar code reader.

These pipettes are checked by setting a specific volume with certain weights once a month [Holschuh 2016].

Adopted training of operational staff

The problems of operational management in the practical implementation of an innovative technology or concept are often underestimated. It is evident that many locations lack experienced operational personnel for the operation of advanced wastewater treatment systems efficiently and without major defaults. Therefore, an essential part of quality assurance is the development and implementation of adapted training programmes for operators, too. The implementation of the training program in the RRC included three phases for preparation, technical and practical training:

During the preparatory phase, the training level and the existing experience of the operating staff (e.g. in process management, maintenance, administration etc.) were analysed. Typical weaknesses or specific problems during plant operation were revealed, so that the general and special needs of the participants for the training program could be determined. By this enquiry, it was identified that the majority of the staff employed at the RRC so far has work experiences only at water reclamation plants. Their general educational level is very high, however, special experience, especially with modern sewage technology, is limited.

Based on the findings, a concept for the training program was developed in consultation with the representatives of the sewage treatment plants and further Chinese partners. During the technical trainings, not only theoretical knowledge was taught, but also a wealth of case studies from the company's practice in China and Germany were discussed.

In the practical trainings, concrete operational improvements in all important areas were to be achieved as quickly as possible by the direct handling with the existing equipment. In view of this objective, particular emphasis was placed on the following areas of the practical training:

- Operation management and process optimization;
- Maintenance and repair of the existing technical equipment;
- Corrosion protection;
- Occupational safety and health.

During the training all participants have not only received basic knowledge about waste-water treatment and process technology in the RRC, but also personally took part in the practical training on the job to gain firsthand experiences for their future work at the RRC.

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