Reconstruction of urban sewage treatment facilities at the Manfukh site of Riyadh - Saudi Arabia

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Abstract. The article provides the information on all stages of the large facilities’ reconstruction project for domestic wastewater - from the stage of preparing an application for participation in the tender, to the direct implementation of the decisions made. The main conditions presented by the customer, current operating problems before reconstruction, solutions for the treatment facilities’ modernization in accordance with the reconstruction project, as well as the results are indicated.

1. Introduction
The Ministry of Environment, Water and Agriculture of the Kingdom of Saudi Arabia (KSA), as well as the National Water Company (NWC) represented by the current Riyadh city unit in 2011 prepared the terms of reference for the urban sewage treatment plants’ reconstruction at the Manfukh site in Riyadh [1]. In accordance with this terms of reference, two stations were to be reconstructed – the Northern and the Eastern. The total productivity needed to be increased by 25%, subject to the requirements for treated wastewater and without the physical expansion of the plant facilities.

The ECOS Group participation in this competition was the result of the consistent activities that the company has been conducting in KSA since 2005, as well as the successfully implemented pilot project for the after-treatment filters’ supply to the wastewater treatment plant in Riyadh - Al-Jazeera with a productivity of 5000 m³/day. After the comprehensive study of all the terms of reference for the reconstruction by the specialists and engineers of the company, the technological part of the general proposal was prepared, which was submitted jointly with Al Arrab Contracting Co. (ACC). ACC specialists evaluated the construction scope of the proposed work. As a result, a joint proposal was submitted to the NWC in February 2012 with the total value of the proposal amounted to almost 105 million Saudi riyals.

In September 2013 the agreement between ECOS Group and NWC on the Northern and Eastern stations reconstruction of the Manfukh site with an increase in total productivity from 400,000 m³/day to 500 000 m³/day was concluded.

2. The conditions and principles of the Northern and Eastern stations reconstruction
The main announced project conditions were the following requirements:
- increase in the total productivity of two stations from 400,000 m³/day to 500 000 m³/day ensuring the required quality of treated wastewater;
the required quality of treated wastewater according to the main indicators is given in Table 1;

Table 1. Quality requirements for treated wastewater

| Parameter        | Maximum allowed value                                                                 |
|------------------|----------------------------------------------------------------------------------------|
| pH               | 6.0-8.4                                                                                 |
| BPC$_3$          | No more than 10 mg / dm$^3$ on average over 30 days (average daily sample of at least 12 samples) |
| Suspended matter |                                                                                       |
| N-NO$_3$         | 5.0 dm$^3$                                                                              |
| N-NH$_4$         |                                                                                       |

- during the work execution, the creation of new tanks and technological tanks is not allowed;
- during the work performance, the termination or shutdown of incoming wastewater, as well as a decrease in the available quality of treatment, are not allowed;
- replacement of coarse and fine cleaning screens at both stations;
- repair and modernization of structures and mechanisms of sand traps, as well as other head works so that they correspond to the tasks to be solved to increase the stations’ productivity;
- repair or replacement of idle gates at the stations;
- repair of cracks and damaged concrete tanks of the main structures;
- repair or replacement of all non-working or poorly working technological equipment at the stations;
- replacement of all important electrical cabinets, control and monitoring systems;
- creation of a remote monitoring and control system for the equipment installed during the work;
- all reconstruction work proposed by the contractor should not cause new sources of smell;
- all reconstruction work should comply with international regulatory requirements for construction and safety.

The main volume of construction work and the start of commissioning were required to be completed within 12 months from the date of signing the contract.

Also, the terms of the contract required ECOS Groups to mobilize their engineers at the treatment plant site in the form of the following implementation groups:

- design group (engineers for technology, construction, power supply, instrumentation);
- group of construction works (construction engineers, technology, mechanical equipment, power supply, instrumentation);
- commissioning group (commissioning) and putting into operation (engineers on commissioning, operators of treatment facilities);
- Health and Environment Protection Group (Occupational Safety and Health Engineers).

The commissioning procedure required the following sequence of actions:

- readiness of construction and erection work (CER);
- elimination of construction and survey observations that impede testing;
- preliminary tests - checks for tightness, correct direction of rotation, conditions for the first putting the equipment into operation, etc.;
- operational tests - checking the operability of equipment, control algorithms, etc.;
- performance tests - verification of equipment and structures in real operating conditions with the achievement of their basic design characteristics;
- elimination of comments that hinder the start of the preliminary acceptance procedure;
- one-year service life between preliminary and final acceptance, during which the contractor guarantees the required quality of treated wastewater, as well as their design consumption;
- final work acceptance.
3. Basic design solutions for the reconstruction
The customer did not present any specific requirements for technological solutions or management principles; however, the main ones were formulated very clearly regarding the quality and quantity of treated wastewater. In this regard, the ECOS Group engineers developed a reconstruction plan that not only fulfilled the list of all the requirements specified in the technical task, but also individually changed the technology for wastewater treatment at the Northern and Eastern stations.

3.1. State of the Northern Station before reconstruction
The existing technology for wastewater treatment at the Northern Station (Figure 1) was based on the use of free-floating activated sludge in aeration tanks-mixers, with dedicated aerobic and anoxic zones. 12 secondary settling tanks were used to separate the sludge mixture; excess activated sludge from the secondary settling tanks was discharged to the end of the aerated sand trap. For the biologically treated wastewater purification, free-flow sand filters were used. The station implemented a joint treatment of primary sediment and excess sludge by fermenting them under mesophilic conditions in sludge digesters. Such a solution of sludge treatment subsequently negatively affected the water-taking properties of sludge during mechanical dehydration. The mechanical dewatering workshop at the site was common for the Northern and Eastern stations, it received sediment after digestion in sludge digesters. Dehydrated to a dry matter content of 14-16%, the sludge was taken out of the sewage treatment plant.

![Figure 1. Schematic diagram of the Northern station before reconstruction](image)

The analysis of the treatment facilities’ operation made it possible to establish that, along with the technical operation problems caused by the use of physically obsolete equipment and structures, there are problems of a technological nature that consist in the implementation at the station of an inoperative scheme for the sludge preparation and treatment. According to the initial design decisions, the digestion process in sludge digesters should be 23 hours. However, there was a situation at the treatment plants, in which, taking into account the quality of the initial wastewater, the volume of primary sludge and excess activated sludge increased and amounted to 3000-4000 m³/day, which exceeded the design by more than 2.5 times, and therefore, the length of stay in sludge digesters decreased to 9 hours, the fermentation process could not be completed. To implement the full cycle of fermentation by the operating service, it was decided to reduce the sludge output from technological tanks.

Taking into account the technological features of the design solutions, the sediment accumulated in the primary sedimentation tanks, and then in the aeration tank-secondary sedimentation system. Long-term operation of the station under such conditions led to a 2–3-fold increase in sludge dose relative to the design decisions and amounted to 9–12 g / dm³, which negatively affected the secondary sumps operation, in particular, sludge was removed in concentrations of more than 20 mg / dm³, which blocked...
the aftertreatment filters’ sand loading operation. Thus, the problems associated with the sludge treatment entailed the imbalance of all wastewater treatment systems. The analysis of the sludge accumulation situation in quantities exceeding the design values made it possible to establish that the sludge has a significantly greater moisture content than envisaged by the project. Therefore, it is advisable to concentrate sludge in sludge compactors, which are not provided for by the project, and which, in accordance with the conditions of reconstruction, cannot be additionally built.

Providing the conditions for the wastewater treatment and sludge treatment implementation required the new technological solutions.

3.2. Re-technology and reconstruction of the Northern Station

During the reconstruction, the technological equipment was replaced: coarse and fine screens; scraper mechanisms, sand pulp pumps and blowers for aerated sand traps; a system for the transportation and waste pressing from screens, as well as floating substances from the aerated sand traps and primary settlers, was organized; the mixers and aeration tank aeration system were submerged; the scraper mechanisms of the primary and secondary sedimentation tanks were replaced, and the sand loading in the after-treatment filters was replaced by the brush loading [2] (Figure 2).

![Figure 2. Schematic diagram of the Northern station after reconstruction](image)

Re-technification consisted in changing the technological approaches to the system for removing sludge from wastewater treatment tanks. An analysis of the excess sludge state made it possible to establish that its additional compaction is necessary and, therefore, it is inappropriate to mix the excess activated sludge with raw sludge. To achieve this goal, the flows of excess activated sludge and primary sludge were separated for the possibility of their separate preparation before dehydration. It was decided that only primary sediment in an amount of about 1000 m$^3$/day is sent to the digesters, that will allow not to overload them hydraulically, providing the design residence time - more than 23 days. To reduce the amount of excess activated sludge, the sludge compactors of the Eastern Station were involved. Thus, it was possible to reduce the load on the mechanical sludge dewatering workshop by increasing the sludge concentration. The proposed scheme for separate treatment of the primary sludge and activated sludge made it possible to provide a sludge dose of 4-5 g/dm$^3$ in the aeration tank, thereby improving the operation of secondary sumps and obtaining the required quality of clarified wastewater, preventing the sludge removal and stabilizing the filters operation. The implemented measures, even
with an increase in plant capacity, have reduced the number of secondary sumps to 10 out of 12 existing. Two secondary sumps have been converted to the sludge compactors for the East Station.

Biological purification was implemented in accordance with the modified Ludzak-Ettinger (MLE) process [3], which is a nitro-denitrification implementation with pre-included denitrification, which involves deep removal of total nitrogen. The process diagram is shown in Figure 3.

![Figure 3. Schematic diagram of the modified Ludzak-Ettinger process.](image)

According to the calculation, the sludge mixture recycling from the end of the propellant displacer to the anoxic zone was 260%. In order to implement this process properly, it is necessary to ensure a sufficient supply of readily degradable organic substances, approximately 3-4 mg BPC\textsubscript{5}, into the anoxic zone of the aeration tank for 1 mgN-NO\textsubscript{3}. However, the initial technological scheme provided for the primary sedimentation tanks presence in which the concentration of organic substances identified by BPC\textsubscript{5} decreased by 25% -30% and amounted to less than 100 mg / dm\textsuperscript{3}. This situation led to a shortage of easily decomposable organics and, accordingly, to a violation of the denitrification process. To prevent excessive reduction of organic matter at the stage of primary sedimentation, it was decided to reduce the wastewater sedimentation duration, and therefore reduce the number of primary settlers.

Taking into account the necessary and sufficient efficiency of suspended solids removal - 65%, the calculation determined the duration of wastewater stay in the primary settlers and the operation service recommended that one of the four primary settlers.

The measures taken for re-technification and reconstruction of treatment facilities made it possible to achieve a stable quality of water treatment in accordance with the requirements and increase the treatment facilities’ productivity.

Table 2 shows the results of the initial (Int.) and the final quality (Fin.) of treated wastewater, which were achieved as a result of the measures taken and the work performed.

**Table 2.** The average annual quality of the source and treated wastewater after the Northern Station reconstruction

| Content, mg / dm\textsuperscript{3} | Project requirement | 2016  | 2017  | 2018  | 2019  |
|-----------------------------------|---------------------|-------|-------|-------|-------|
|                                   | Int. | Fin. | Int. | Fin. | Int. | Fin. | Int. | Fin. |
| **BPC\textsubscript{5}**          | 10   | 367  | 7    | 335  | 8    | 318  | 9    | 405  | 10   |
| **Suspended matter**              | 10   | 374  | 8    | 332  | 9    | 310  | 7    | 380  | 8    |
| **N-NH\textsubscript{4}**         | 5    | 25   | 0.7  | 21   | 1.5  | 20   | 1.4  | 17   | 1.1  |
| **N-NO\textsubscript{3}**         | 10   | -    | 6.5  | -    | 4.7  | -    | 4.4  | -    | 4.1  |

3.3. State of the Eastern station before reconstruction
The Eastern station was built 14 years later than the northern station - in 2003. The coarse screen and the first screw pump station are common headquarters for both stations (Figure 4). The main units of treatment facilities are fundamentally different from the Northern station. So, for example, the primary station does not include primary sedimentation tanks and initial wastewater after two-stage filtering on the screens, and the passage of the aerated sand trap immediately enters the carousel type aeration tanks. In each of the 6 channels of aeration tanks, anoxic and aerobic zones are constantly alternated. The oxygen introduction, as well as ensuring the necessary speed of water movement through the channels, was carried out by the surface aerators. To separate the sludge mixture from treated wastewater, radial secondary settling tanks were used, and for the post-treatment purpose, free-flow filters with two-layer loading with quartz sand and anthracite were used. After-treatment filters, as well as the general workshop for mechanical sludge dewatering, were removed by the NWC from the work scope, since at that time they were already at the construction completion stage.

The structures’ operation analysis made it possible to establish that, despite the relatively small age of the station, the current problems with the main technological equipment have already had their negative consequences. Sand from wastewater was not removed due to breakdown of sand pumps and sand separators of the aerated sand trap assembly. In aeration tanks, a significant difference in the sludge dose was observed, due to the inoperative state of the distribution gates before entering each aeration tank. The volumes of the existing sludge compactors are sufficient only for the design capacity of the station, and for the sludge compaction after an increase in productivity by 35% as part of the reconstruction, a different solution.

![Figure 4. Schematic diagram of the Eastern station before reconstruction](image)

### 3.4. Reconstruction of the Eastern Station
The basis for the possibility of increasing the station productivity up to 270,000 m³/day became the design of new sludge compactors, as after the reconstruction it would be necessary to prepare about 14 000 m³/day excess activated sludge (Figure 5).
In the view of the direct ban on the new construction of reservoirs and structures, it was decided to use the 2 secondary sedimentation tanks removed from the Northern Station and to convert them into the sludge compactors. The calculation of the sludge compactors’ required volume showed that the volume of one existing sump will provide the necessary duration of sludge compaction, the second was used as a reserve. The presence of a backup sludge compactor during the operation of the station after reconstruction completely paid off. To organize the sump operation in the mode of sludge compactor, it was necessary to make changes to the engineering networks to supply the excess sludge and its removal from the structure. So, a pipe section was laid with the original excess activated sludge, a pipe section for discharge of superfluous water and, finally, a pipeline for supplying compacted excess activated sludge to the mixing tank, where all the prepared sludges were mixed before being introduced to mechanical dewatering.

In carousel aeration tanks, the arrangement of zones with dissolved and bound oxygen was changed. To do this, in the first and second corridors of each aeration tank, surface aerators were turned off and submersible flow generators were installed. Thus, this zone was converted into a denitrifier, the remaining 2/3 of the volume was a nitrifier, for which the additional surface aerators were installed along the corridors’ length. These changes were necessary to exclude the possible settling of sludge at the bottom of the structures and the possibility of using the entire volume of the existing tanks. Installation of new flow generators and surface aerators was carried out without drainage and prolonged downtime of aeration tanks, and the replacement of a larger number of gates required the involvement of divers.

The result of re-technification was a significant increase in the station productivity, which currently reaches 310,000 m³/day without deterioration in the treated wastewater quality shown in Table 3.

### Table 3. The average annual quality of the source and treated wastewater after the Eastern station reconstruction

| Content, mg / dm³ | Project requirement | 2017 | 2018 | 2019 |
|------------------|---------------------|------|------|------|
|                  | Int. | Fin. | Int. | Fin. | Int. | Fin. |
| BPC₅             | 10   | 335  | 9    | 318  | 10   | 405  |
| Suspended matter | 10   | 332  | 8    | 310  | 7    | 380  |
| N-NH₄            | 5    | 21   | 1.4  | 20   | 0.1  | 17   |
| N-NO₃            | 10   | -    | 3    | -    | 4.5  | -    | 3.2  |

4. Summary
The re-technification of the Northern Station made it possible to ensure the operation of the sludge treatment system in the mode of design decisions, taking into account the maintenance of the sludge dose in the aeration tank at the level of 4-5 g / dm³ and increase the Northern Station productivity to 230,000 m³/day. The potential of the Eastern station with an optimal solution for compaction of excess activated sludge made it possible to treat a significantly larger volume of wastewater than it was required by the terms of reference for the reconstruction. Thus, ECOS Group successfully coped with all the tasks set and ensured the required quality of wastewater treatment for the administrative center with a population of more than 7 million people.

References
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[3] Water Environment Federation (WEF) 2008 Operation of municipal wastewater treatment plants. Manual of Practice No.11 Sixth Edition (Alexandria, Virginia, USA) 22 22-29.