Special reproduction from “KA-Betriebs-Info”, issue 1/2007, pages 1437 to 1442

New Ways in Wastewater Treatment

Situation

The Felsalbe wastewater treatment plant in the German state of Rhineland Palatinate was designed for 30,000 inhabitants.
It is run by the wastewater disposal company of the City of Pirmasens. The plant with its primary clarification(primara settling), activation basin(aeration tanks) and digestion tank can be described as a classical treatment plant and corresponds to the “general state-of-the-art-technology“ (fig. 1).

Fig. 1: Original situation at the wastewater treatment plant Felsalbe

So far, everything is OK(looking good) – the problem is that the City of Pirmasens intends to connect an additional 8,000 inhabitants. The target is to optimize the process and energy technique of the existing wastewater treatment plant so the increased load can be processed without the need of constructional(structural) measures. An ambitious plan, but how is that possible?

New process operation

It was clear that such an optimization could not be realized with the present state of the plant instrumentation. Prerequisites were complete measurement data to be able to identify every change in the load early and the digital processing of these data to be able to react quickly and according to demand.
This meant that the following operational equipment had to be available (fig. 2):

1. Process control system
2. PLC (programmable logic controller)
3. Online D. O. measurement
4. Online nitrate measurement, online ammonium measurement
5. Online measurement of the power consumption of the biological treatment process
6. Controllable ventilation / sludge recirculation pumps

Fig. 2: The wastewater treatment plant with new operation procedures for 40,000 inhabitants

Among other, a reliable online measuring technique was an important prerequisite for the success of this new concept. We decided on the IQ SENSOR NET system of the company Wissenschaftlich-Technische Werkstätten (WTW). The sensors are characterized by their high dynamics, measured value stability and simple operation. Maintenance activities are barely mentionable and can easily be carried out by the staff.

Thus the parameters nitrate, ammonium and dissolved oxygen can be measured trouble-free (fig. 3 and 4).

Fig. 3: Ion selective sensor for ammonium (AmmoLyt by WTW)

Fig. 4:
Ion selective sensor for ammonium, potassium compensation and nitrate (VARiON by WTW)

Process functioning

The basic elements of the software package of the PLC program are the basic module part 1: Load classification (definition) and the basic module part 2: Operation.

Basic module, “Load classification” (definition of the different elements)

In the first step, a load profile is compiled consisting of the nitrogen load, the power consumption of the biological treatment process (measured energy value) and the nitrification and denitrification performance. For the making of a characteristic load profile, the parameters indicated in figure 5 are essential. An even more sensitive load recognition is realized by defining further elements not described here.

Fig. 5: Function of the module, Load classification.

Basic module, “Operation”
After the specific load classification (definition), the “Operation“ program for the process control is now adapted to the characteristic online load profile. All following elements are run according to this classification. For the Operation element, there are different variants corresponding to the used procedure. The mentioned parameters can be adjusted variably using the process control system and are visualized as operation and load states with measured values and trends. The load profile is stored.

Variant 1 – Plant with intermittent nitrification/denitrification
In the nitrification cycle, a minimal nitrification time is started. After it has expired, the denitrification cycle is started when the maximum nitrate value or the maximum nitrification time is exceeded. The denitrification cycle is terminated either by the simultaneously started maximum denitrification time or by achieving the minimum nitrate value after the minimum denitrification time has expired (see fig 6).

Fig. 6: Nitrate controlled regulation

Based on the developing cycle times (ventilation ON/OFF), the efficiency of the nitrification/denitrification characteristic for the plant and its load can be determined.
This assessment now generates the situation dependent control commands and adapts the times for nitrification and denitrification to meet the requirements of the ammonium or nitrate values.

Variant 2 – Multistep plants with optional basin or cascades

For this case the nitrification volume is increased by connecting an optional basin when the maximum ammonium value is reached. This state is retained during a minimum nitrification time.
It is, however, also retained until either the maximum nitrification time has expired or a minimum ammonium value is achieved. The additionally connected basin is then run as a denitrification basin again.
After the now started minimum denitrification time, the cycle is restarted if the maximum ammonium value or the maximum denitrification time is reached (fig. 7). The nitrification and denitrification performance is determined according to variant 1.

At multistep plants without optional basin, different D. O. levels in the individual cascades (steps) can be defined and changed by the nitrate or ammonium contents.

Fig. 7: Ammonium controlled regulation

The Felsalbe plant is operated with a combination of variant 1 (NO_3^-) and variant 2 (NH_4^+), which is enabled by the new combination instrumentation based on ion selective measurement for nitrate and ammonium.

Load and nutrients optimized operation according to load profile

The system has a modular structure. The biological treatment process is used as the interactive coordinator. Depending on the requirements and design of the plant, the two basic modules, Load classification and Operation, can be supplemented by the following modules as necessary (fig. 8)

Fig. 8: Additional modules to improve efficiency

Module 1: “Biology”

Ventilation control
At intermittent plants, the ventilation is started load depending after the denitrification cycle. Ventilation control takes places according to the oxygen demand in the activation basin, depending on the specific load classification. To do so, the ventilation control is adapted from the previously defined basic setting to the actual demand (definition and operation) by means of a frequency converter.

Load-related return sludge circulation / recirculation
In the case of the load-related return sludge circulation / recirculation, the biomass is controlled depending on its specific load classification.
Especially during ammonium peaks, more nitrificants are provided that can work on the increased nutrient supply. If BOD_5 peaks occur, supply and demand can also be better adjusted to each other. An infinitely variable control of the return sludge / recirculation pumps by a frequency converter makes adjustment to the individual load levels easier.

Module 2: “Process water management”

Filling or emptying of the process water storage tank as a load compensation

The load classification is the basis for the filling or emptying of the process water storage tank. The continuous feeding of the process waters into the biological treatment process eliminates extreme load peaks and provides more constant operating conditions.

Module 3: “Nutrients optimization by adding raw wastewater”
During low load periods (such as longer-lasting precipitation), the bypass amount (bypassing the primary clarification) is adjusted gradually. This works against a nitrogen nutrients shift or autolysis of the activated sludge. If this option is exhausted, carbon can be added specifically.

Module 4: “Inlet load management”
Filling or emptying the load compensation basin
The load classification is the basis for the filling or emptying of the load compensation basin.

Early recognition mode (early warning system)
By evaluating precipitation data, peaks of the contamination load, e. g. after heavy rainfall (“flush peaks“) from the sewage network can be discovered early, depending on the dimension of the sewage network, and countermeasures can be taken.

Module 5: “Integration of preliminary treatment plants”
Treatment plants for highly loaded partial flows such as those from indirect dischargers or process water treatment plants can be integrated in the management concept.

Module 6: “Fine regulation”
The fine regulation module works process optimizing in the Operation program. The trend recognition for ammonium/nitrate/power consumption of the biological treatment process is done by the most efficient ventilation control in the relevant component for Operation. For this the maximum and minimum limit value pairs of the oxygen concentration are optimized.

Module 7: “Sewage network management”
The management of rain storage reservoirs / rain spillway basins is possible based on the load classifications. The intake of larger inlet quantities is enabled by the fact that the load and the amount of return sludge is considerably reduced after the first flush. In agreement with the supervising authorities, it can be checked whether lower ratings for rain storage systems could be applied.

Failure strategy – emergency operation

Even in the case of malfunctions, operation of the plant with granted by the following measures:

a) Plausibility checks due to measured values checked against each other with measurement of the power consumption of the biological treatment process.
b) In the case of automation failure or missing measured values:

Cancellation of the respective limit values, switching to emergency program, on/off times of ventilation according to load profile of the last few days (emergency profile).

Results

As a result, lower outlet values along with increased process stability proved to be continuous with the new process concept. Thus the already good outlet values of the Felsalbe wastewater treatment plant could still be improved. Table 1 compares the values before the concept was implemented and after.

	Value before	Value after
COD	30 mg/l	20 mg/l
$N_{total\ anorg}$	2 to 12 mg/	< 5 mg/l
P_{total}	1.0 mg/l	0.75 mg/l
Power consumption	0.5 kWh/kg COD	0.35 kWh/kg COD

Table 1: Improved outlet values and power consumption

This success is caused by a considerably improved load and nutrients optimization. Apart from that, it is also due to the immediate reaction options on impact loads including low load periods with a continuous 24h operation.

One main target of this procedure is the clearly improved energy efficiency, which exceeded out expectation. This factor cannot be overestimated at times of rising energy costs. The specific power consumption per kg COD (decomposed) could be lowered by 30 % at this plant. This is made clear by fig. 9.

Fig. 9: Power consumption of the biological treatment process (February 2003 to September 2005)

As shown by the operation data (table 2), the management concept is oriented by the actual demand of the biological treatment process, balances its load, records the plant-specific capacity and optimizes operation.

Mode	**Eco**	**Standard**	**Load**	**Oxygen**	**Nitrification**	**Denitrification**	**Nitrification/denitrification performance (g N^{elimin}/kg TSS and h)**		**Process water (m^3)**	**Load compensation (m^3)**
Operating hours	2256	4957	1531	17	6961	1799	0.8	3.1	50,800	73,200
Percentage (%)	25.8	56.6	17.5	0.2	79.4	20.6	Power requirement (kWh/kg COD) of biology	Power requirement (kWh/kg COD) of total plant	Mean values of process water (mg/L) COD/TN_b	
Sum %	82		18		Total %	100	0.33	0.50	1,300	145
Wastewater amount in (m^3/a)			Precipitation agent consumption (PO_4-P) [t/a]		Recommended TSS of biology at > 11 °C biology temperature		Degradation capacity of sludge	Sludge output (g BOD_5/kg TSS and h)	Load management Load balance (kg COD/TN_b)	
1,814,000			82.1		4.4		0.06	6.6	212,000	29,700
Power consumption (kWh) Biology / Total			Phosphate elimination Biologically / chemically		Sludge removal quantity per day		Aerobic sludge age in d Activation 1 / activation 2		Load management Load ratio in % COD/TN_b	
342,900	529,900		63.3	36.7	5.5	5.5	24.6	24.2	17.7	28.0

Table 2: Excerpt from the operation data

Summary

The process concept tested at the Felsalbe wastewater treatment plant is tailor-made to meet today's requirements of wastewater treatment plants. It grants a process-integrated, optimal and economic operation with flexible adjustments to differently run wastewater treatment plants.

This procedure is special because a load profile of the biologic treatment process is compiled based on data from the whole plant and including further parameters. Unlike the previously known procedures, which reacted only in the biological treatment process, this procedure actively changes the processes of the wastewater treatment plant due to measurement data and is intended as a superordinated control concept. Using this procedure achieves a load and nutrient optimized operation of the plant with fewer pollutants for lakes and rivers and increased energy efficiency.

Optimizing the processes according to this concept results in saving working material and costs of approx. 35,000 € per year (energy costs, wastewater rates, auxiliary materials). The investment costs could be completely set off against the wastewater rate because the pollutants relevant for the rate were reduced by more than 20%. Even without taking into account the wastewater rate, the ROI (**R**eturn **o**n **I**nvestment) after one year was still 75%.

Modern online instrumentation is an important prerequisite for this procedure. The ion-sensitive sensors measure reliably and dynamically, directly in the medium and without any sample preparation.

Simultaneously with the implementation of this procedure, an interface was created for company cost accounting, which is also the basis for the business management optimization (controlling). Patent was applied for the concept for wastewater treatment by the wastewater treatment company of the City of Pirmasens.

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