Guideline for Energy Efficiency in Wastewater Treatment

Ankara, October- 2010

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1 Introduction

This guideline which is prepared within the scope of the cooperation between Turkey and Holland and the project named "Energy Efficiency in Wastewater Treatment" aims to achieve energy efficiency in wastewater treatment sector and provide information on how to improve energy efficiency in wastewater treatment plants.

The guideline contains best technological practices and design and operation criteria for UWWT's energy consumption and suggestions for municipalities to enforce energy efficiency and reduce CO_2 emissions.

Regarding the experiences gained by operational practices and implementations, it has been known that the topic of "energy efficiency in the wastewater treatment plants" will be an important issue for the coming years. Therefore, this document will be both a guideline for the sector on energy efficiency policy and a living / developing document by the feedbacks of the wastewater treatment sector.

Turkey will still design quite a number of small, medium sized and large wastewater treatment installations, energy efficiency can be taken into account at least costs. The main problems and challenges can be summarised as follows:

- Create awareness among decision makers on the benefits and opportunities of energy efficiency in waste water treatment;
- Ensure effective operation of wastewater treatment plants taking energy efficiency into account (training of operators);
- Establish sufficient knowledge in Turkey among design and engineering companies in the field of wastewater treatment to allow inclusion of energy efficiency opportunities in future projects.

2 General description of a WWTP

2.1 Description of the WWTP

The typical waste water treatment plant (further: WWTP) is based on BOD/COD removal, P-removal (biological, chemical or combination of both) and biological N-removal through nitrification and denitrification. In the Netherlands 75% of the total P and 75% of the total N has to be removed from the influent. A typical sludge loading is 0,05 kg BOD/kg sludge·day. The typical WWTP consists of the following components:

- Coarse screens;
- Sand trap;
- pre-settlement;
- Anaerobic tank;
- Selector;
- Anoxic tank;
- Aerobic tank;
- Post settlement;
- Return sludge pumping station;
- Secondary sludge pumping station;
- Sludge thickening (primary + secondary sludge);
- Sludge digestion;
- Sludge dewatering;

Coarse screens

Coarse screens remove coarse materials as leaves, hair, paper etc. to prevent any component downstream from clogging.

Sand trap

The sand trap removes sand to prevent damaging of pumps and pipelines.

Pre-settlement tank

In the pre-settlement tank approximately 50% of the total dry solids and 30% of the organic load (COD, BOD) is removed from the incoming waste water and will settle as primary sludge. By installing a pre-settlement tank:

- the volume to be installed for he aeration tank can be smaller;
- primary sludge is produced which causes high gas production at sludge digestion;
- the denitrification can be more difficult because of less BOD available for denitrification.

So whether it is useful or not to install a pre-settlement tank strongly depends on local circumstances.

Anaerobic tank

The anaerobic tank, with strictly anaerobic circumstances, is necessary for selecting the Phosphate Accumulating bacteria (PAO’s). One of the main characteristics of these bacteria is the luxury uptake of phosphate, meaning that they store more phosphate than strictly necessary for growth resulting in 3,5% P instead of 2% P related to dry solids. In order to select these bacteria they need alternating anaerobic and aerobic/anoxic circumstances. Under anaerobic circumstances phosphate is released to the water phase, under aerobic circumstances phosphate is absorbed by the bacteria from the water phase.

The anaerobic tank is fed with wastewater and a recirculation flow from the anoxic tank.

Selector

The selector is a relatively small and unaerated compartment, fed with the outflow of the anaerobic tank and (part of the) return sludge. The meaning of this section of the WWTP is to favour the growth of the flock forming bacteria above the growth of the filamentous bacteria. Filamentous bacteria are not or less capable of absorbing BOD under anoxic conditions, where flock forming bacteria are. So under the anoxic conditions of the selector most of the BOD is absorbed by the flock forming bacteria and is therefore no longer available for the filamentous bacteria under the aerobic conditions in the aerobic tank.

Anoxic tank

The anoxic tank is fed with the outflow of the selector and a nitrate containing recirculation flow from the end of the aerobic tank. In this sector of the WWTP heterotrophic bacteria oxidise COD/BOD using nitrate instead of dissolved oxygen. Nitrate is in this denitrification process reduced to nitrogen-gas.

Aerobic tank

Subsequently the outflow of the anoxic tank enters the aerobic tank where the rest of the CPOD/BOD is oxidised by means of the heterotrophic bacteria and dissolved oxygen is added by means of bubble aeration or surface aeration. Ammonium is oxidised via nitrite to nitrate by the autotrophic bacteria. The excess sludge, as a result of growth, is wasted as secondary sludge by means of the secondary sludge pumping station.

Post settlement tank

Effluent and sludge are separated in the post settlement tank. The settled sludge is returned as return sludge, by means of the return sludge pumping station, to the selector, the effluent is discharged to the surface water.

Sludge thickening

The primary sludge as well as the secondary sludge are thickened from 0,8 – 1,0% dry solids to 3,5 – 6,0% dry solids by means of a gravitational thickener of a mechanical thickener.

Sludge digestion

The thickened sludge is pumped into the sludge digester. At an temperature of ca. 33°C and anaerobic circumstances the organic dry solids content of the sludge will be decreased with approximately 35% - 50%. The organic material is converted to methane gas, CO2-gas and water by means of anaerobic bacteria. The methane gas can be used in a co-generator producing electricity and heat. Heat is used for warming of the digestion and for warming of buildings on the plant. The electricity is used to operate the wwtp.

Sludge dewatering

The digested sludge s subsequently dewatered by means of a centrifuge or a belt press. The total solids concentration afterwards is 20 – 25%. The dewatered sludge is discharged to an incinerator.

2.2 Energy management at operational level

For successful implementation of energy efficiency measures, several aspects at operational level are of importance. At first monitoring of the energy consumption of different process components is essential to prioritise the measures. Secondly awareness of operators on energy efficiency and education of operators to apply operational aspects of energy measures are important. This guide line provides measures for process engineers. When these measures are applied in the field, it is essential that the role of operators is secured such that energy management at operational level is made possible.

3 Energy efficiency measures

3.1 Introduction

WWTP’s differ in size, type and process configuration. The energy efficiency measures presented are meant as a general guide line. The guide line acts as a road map on which basis a first selection of suitable measures can be made. The target group for the use of the guide line is process engineers involved in design and optimisation of wwtp’s. For each case and situation these general guidelines have to be worked out specifically. For this reason, ranges are presented for the effect on the energy consumption and for the payback time. In some cases these ranges can not be given due to a high dependency of the local situation. The guideline can be used to obtain ideas about energy efficiency measures in an existing situation and can be used as a checklist to asses whether energy efficiency measures are sufficiently incorporated in a design. This guideline does not give technical details and specifications for the different measures as these details depend on size, type and other parameters of the WWTP where the measure will be applied. The steps to take are as follows:

1. Select potential measures from the guide line

2. Detail the measure for the specific local situation

- effect on energy efficiency
- additional costs, cost/benefit analysis

3. Decide to apply the measure

The working area of the guide line is step 1, a gross list to be able to make a selection of interesting measures. For step 2 and 3, state of the art waste water treatment engineering capabilities have to be used.

3.1.1 Effect of measures

For the effect of the measure on the energy consumption, the percentage of energy saving is presented in five ranges:

<1 %
1-5 %
5-10 %
10 -20 %
> 20 %

A measure can be taken for two situations:

1. An existing well functioning wwtp, for which energy efficiency measures are taken. The costs involved in this must be completely accounted to this measure.

2. An existing wwtp or new wwtp for which a choice has to be made for equipment, processes, etc. In case of an existing wwtp this could be a renovation, in case of a new wwtp this could be a design issue. In these cases an extra amount of money to be invested is relevant to realise energy efficiency. These additional costs are accounted to this measure.

For the guide line the second situation is applicable. The reason for this is that many measures will have a long payback time when implemented at a well functioning wwtp (as there is no technical need to replace equipment). It is more realistic to consider a choice for additional investment to achieve higher energy efficiency.

The numbers presented are based on a reference wwtp of 100.000 PE. For measures accompanied with digestion a size of 250.000 PE is applicable.

W2.

% Effect	Pay back time	Extra investment
10 – 20%	5 - 15	< 500.000 – 1.500.000 €

Bubble aerators (dish, tube, or plate aerators) have a superior oxygen transfer capacity

% Effect	Pay back time	Extra investment
5 – 10%	5 – 15	< 500.000 – 1.500.000 €

Centrifugal compressors can have a lower energy consumption compared.

3.1.2 Investments

For the additional investment costs the following categories are used (numbers in euro).

< 10. 000
< 50.000
< 100.000
< 250.000
< 0,5 million
0,5-1,0 million
> 1,5 million

The background for this choice is as follows. In the Netherlands the costs for wastewater treatment average at 35 euro per PE. For a wwtp of 100.000 PE this leads to 3,5 million euro's of yearly costs. An investment of 1,0 million euro leads approx. to 100.000 euro of capital costs yearly, a cost increase of 1 euro per PE. Compared to the 35 euro per PE of total cost, 1 euro additional costs are considered to be significant.

The amount of additional investment presented is based on Dutch prices. No translation is made between the investment figures for the Dutch situation to the Turkish situation. It is assumed that the ratio between additional investments and savings expressed as a payback time is comparable for the Dutch and Turkish situation.

3.1.3 Payback time

For the payback time three ranges are defined.

Short: < 5 years
Average: 5-15 years
Long: > 15 years

The payback time is defined as the investment divided by the annual saving. Measures with a short pay back time are financially interesting and can be applied immediately. In this case the payback time is shorter than the technical life time. Measures with an average payback time can be financially interesting when the payback time is in the range of the technical lifetime. The measures with a long payback time are financially not interesting and will be realised when non-financial issues are in consideration or when e.g. a higher energy price is expected in the future.

3.2 Categories of measures

Energy efficiency measures at wastewater treatment plants can be divided in three main categories:

1. Water related, the treatment of the wastewater in the wwtp;
2. Sludge related, the treatment of sludge resulting from the treatment of the influent.
3. Air treatment related, the treatment of air coming from different parts of the wwtp to prevent odour.

3.2.1 Water related measures

Energy efficiency measures with respect to the wastewater treatment system are predominantly related to the aeration of the biomass. A subdivision can be made between hardware and process control measures. In addition several other measures can be mentioned which are not related to aeration. All measures for wastewater treatment are mentioned in Table 3-1.

Table 3-1: Energy measures for wastewater treatment (water related)

Number	Measure
W1	Disconnection of aeration and liquid propulsion.
W2	Bubble aeration instead of surface aeration.
W3	High efficiency surface aerators.
W4	Remove covers for spray prevention at surface aerators.
W5	Adjust water head at surface aerators.
W6	Plate aeration instead of tube or dish aeration.
W7	Centrifugal compressors instead of displacement or roots compressors.
W8	Optimise tank depth.
W9	Intermittent aeration control.
W10	Reduce oxygen concentration setpoint.
W11	Process operation on the basis of sludge age.
W12	Improve alpha-factor.
W13	Alarm report in case of unexpected high aeration rate.
W14	Optimise configuration.
W15	Upflow Sludge Blanket Filtration (USBF).
W16	Sequencing Batch Reactor (SBR).
W17	Treatment at source.
W18	Thermal energy exchange.
W19	Avoid frequent switching off and on of hardware.
W20	Avoid unfavourable ranges for hardware.

W21	Manage scraper operation in clarifiers.
W22	Advanced pre-treatment (sieves).
W23	High efficiency mixers for propulsion and mixing.
W24	Periodical adjustments in the propulsion propeller operation.
W25	Type and positioning of propellers for propulsion in combination with bubble aeration.
W26	Exchange between compartments in direction of flow.
W27	Mix by aeration instead of propellers.
W28	Switch off propulsion propellers during aeration.
W29	Gravity transport.
W30	Disconnection of rain water.
W31	Avoid infiltration water.
W32	Optimise transport system.
W33	Nutrient removal
W34	Creation of additional anoxic volume.
W35	Choose the energetically most favourable design.
W36	Managing return sludge flow rate.
W37	Regulate nitrate recirculation to the anoxic zone.
W38	Couple aeration rate to process parameters.
W39	Optimise position and number of sensors.
W40	Regular calibration of the sensors.
W41	Optimise phosphorous removal.
W42	De-ammonification
W43	Aerobic granular sludge (Nereda).

3.2.2 Sludge related measures

Energy efficiency measures in the sludge line can be subdivided in thickening, dewatering, digestion, biogas utilisation and other measures. The measures are given in Table 3-2.

Table 3-2: Energy measures for sludge treatment (sludge related)

Number	Measure
S1	Worm bloom.
S2	Timing of sludge transport.
S3	Cannibal.
S4	Sludge digestion and cogeneration.
S5	Thermophilic multiple stage digestion.
S6	Utilise existing digestion capacity.
S7	Insulation of (old) digesters.
S8	Sand removal prior to sludge treatment.
S9	Direct operation compressor/blower by gas motor.
S10	Energy production in small gas turbines or gas engines.
S11	Add small gas turbine or extra biogas buffer.
S12	High efficiency heat power coupling.
S13	Optimise heat power coupling.
S14	Gas conditioning prior to heat power coupling.
S15	Fuel cells for higher efficiency.
S16	Utilisation of the heat buffering capacity of the digester.
S17	Blend biogas with natural gas.
S18	Transport biogas to third parties.
S19	Convert biogas into methane and supply it (back) to the gas network.
S20	Installation of (additional) gas storage buffer.
S21	High efficiency primary settling.
S22	Sludge disintegration techniques prior to digestion: ultrasonic/hydrodynamic.
S23	Sludge disintegration techniques prior to digestion: high pressure, thermal, hydrolysis, cambi.
S24	Constant feeding of the digester.
S25	Proper mixing in the digester.
S26	Mixing in the digester with a mixer instead of blowing gas to the digester.
S27	One-time removal of sand from the digester.
S28	Maintenance removal of sand from the digester
S29	Use waste heat from surroundings.
S30	Supply waste heat to third parties.
S31	PE dosing.
S32	Mechanical thickening instead of gravitational thickening of sludge.
S33	Treatment of return liquors with SHARON.
S34	Chemical nitrogen precipitation to struvite.
S35	Anaerobic de-ammonification.
S36	Two-stage Sharon-Anammox process with 2 reactors.
S37	Reuse of low value heat
S38	Reuse of heat from gas engine exhaust gases.

S39	Feasibility of dewatering
S40	Belt press instead of centrifuge after thickening.
S41	Cascade line-up and belt press for direct sludge dewatering.
S42	Belt press for sludge dewatering after digestion.
S43	Dry matter content in the dewatering installation.
S44	Drainage of water from the activated sludge storage.
S45	Back drive operation on centrifuges
S46	Control system for operation of the centrifuges.
S47	Well mixed sludge to the dewatering installation.

3.2.3 Air treatment related measures

Energy measures for air treatment can be divided into measures for exhaust air treatment and air extraction. The measures are given in Table 3-3

Table 3-3: Energy measures for air treatment

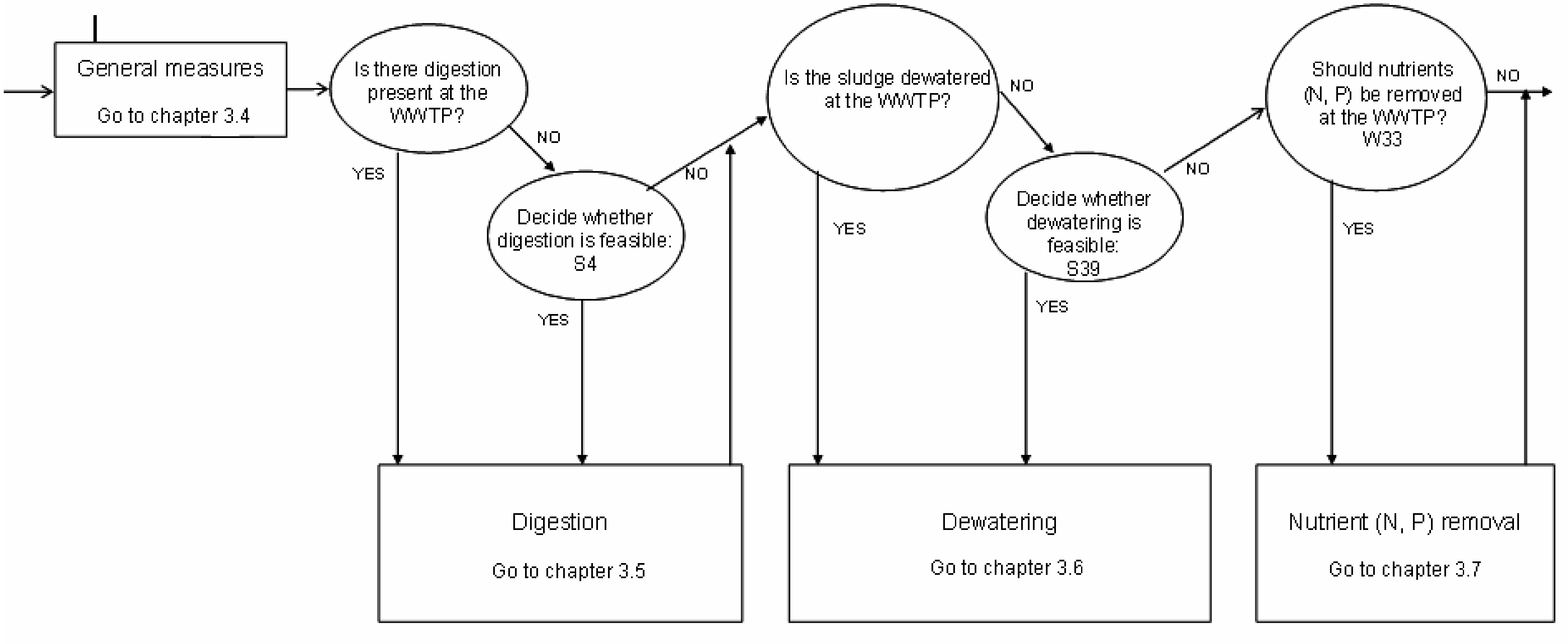
Number	Measure
A1	Send exhaust air from the treatment process to the aeration tank.
A2	Replace compost filters by lava filters.
A3	Breathing filter.
A4	Optimise air extraction.
A5	Reduction of the extracted air volume.
A6	Regulate air extraction on the basis of H_2S measurements.
A7	Increase ventilation flow rate above the aeration tank.

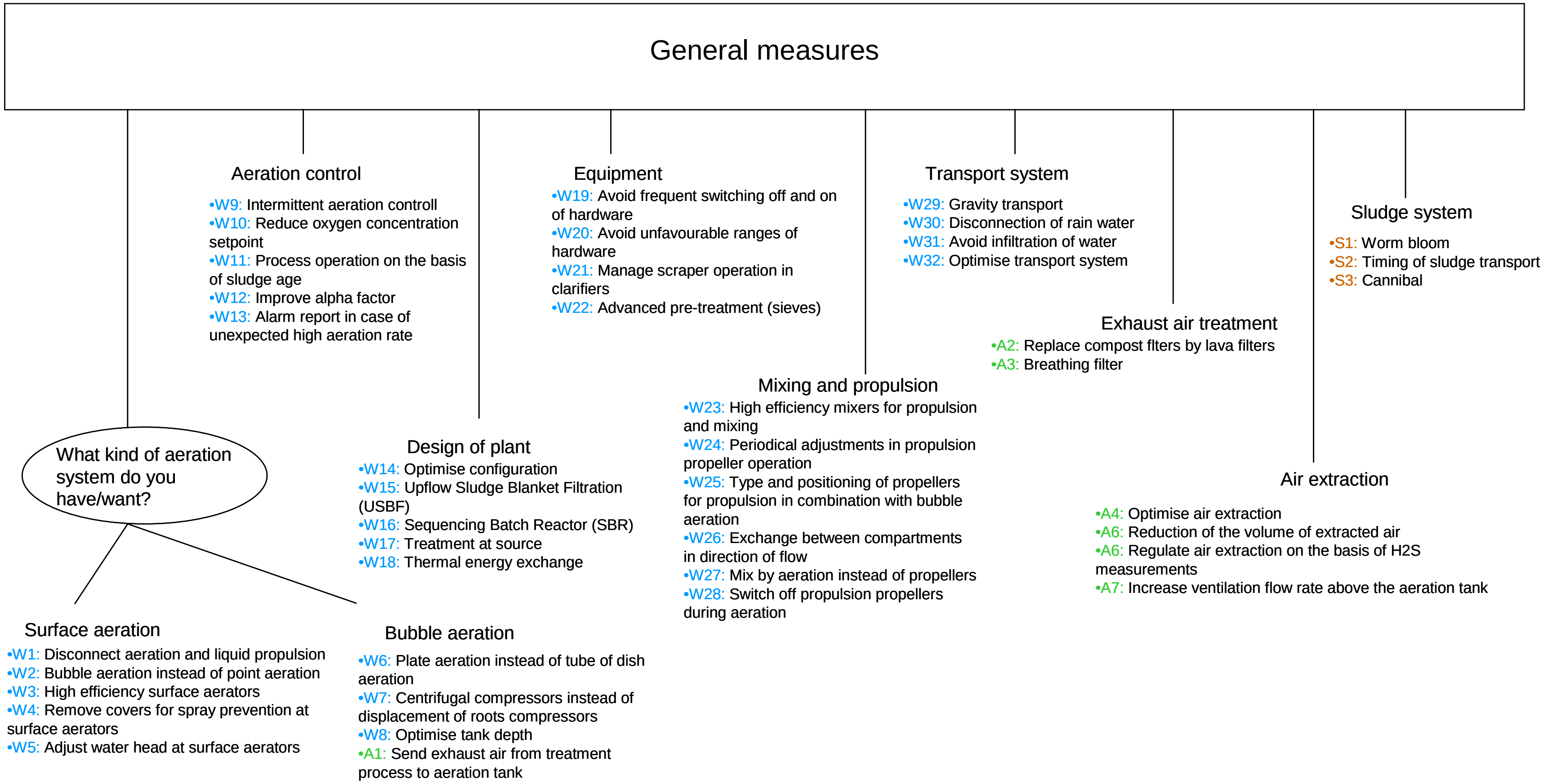
3.3 Decision tool

To assist on the choice of measures on energy efficiency for municipal wastewater treatment, a decision tree is provided. Based on the structure of the decision tree, the measures of tables 3-1, 3-2 and 3-3 are subdivided into main categories:

- General, applicable for all wwtp’s
- Digestion
- Sludge dewatering
- Nutrient removal
- Air treatment

The decision tree is presented in the following figures. Subsequently the measures are presented in more detail compromising a short description of the measure and a summary of the effect of measures on energy saving, additional investment costs involved and the payback time (as explained in 3.1). The measures are numbered, the ranking and numbering is not related to the importance of the measure.


General measures
Go to chapter 3.4
Is there digestion present at the WWTP?
NO
YES
Decide whether digestion is feasible: S4
NO
YES
Digestion
Go to chapter 3.5
Is the sludge dewatered at the WWTP?
NO
YES
Decide whether dewatering is feasible: S39
NO
YES
Dewatering
Go to chapter 3.6
Should nutrients (N, P) be removed at the WWTP? W33
NO
YES
Nutrient (N, P) removal
Go to chapter 3.7



General measures

What kind of aeration system do you have/want?

Surface aeration

- W1: Disconnect aeration and liquid propulsion
- W2: Bubble aeration instead of point aeration
- W3: High efficiency surface aerators
- W4: Remove covers for spray prevention at surface aerators
- W5: Adjust water head at surface aerators

Bubble aeration

- W6: Plate aeration instead of tube of dish aeration
- W7: Centrifugal compressors instead of displacement of roots compressors
- W8: Optimise tank depth
- A1: Send exhaust air from treatment process to aeration tank

Aeration control

- W9: Intermittent aeration controll
- W10: Reduce oxygen concentration setpoint
- W11: Process operation on the basis of sludge age
- W12: Improve alpha factor
- W13: Alarm report in case of unexpected high aeration rate

Design of plant

- W14: Optimise configuration
- W15: Upflow Sludge Blanket Filtration (USBF)
- W16: Sequencing Batch Reactor (SBR)
- W17: Treatment at source
- W18: Thermal energy exchange

Equipment

- W19: Avoid frequent switching off and on of hardware
- W20: Avoid unfavourable ranges of hardware
- W21: Manage scraper operation in clarifiers
- W22: Advanced pre-treatment (sieves)

Mixing and propulsion

- W23: High efficiency mixers for propulsion and mixing
- W24: Periodical adjustments in propulsion propeller operation
- W25: Type and positioning of propellers for propulsion in combination with bubble aeration
- W26: Exchange between compartments in direction of flow
- W27: Mix by aeration instead of propellers
- W28: Switch off propulsion propellers during aeration

Transport system

- W29: Gravity transport
- W30: Disconnection of rain water
- W31: Avoid infiltration of water
- W32: Optimise transport system

Exhaust air treatment

- A2: Replace compost flters by lava filters
- A3: Breathing filter

Air extraction

- A4: Optimise air extraction
- A6: Reduction of the volume of extracted air
- A6: Regulate air extraction on the basis of H2S measurements
- A7: Increase ventilation flow rate above the aeration tank

Sludge system

- S1: Worm bloom
- S2: Timing of sludge transport
- S3: Cannibal

Digestion

Hardware

- S5: Thermophilic multiple stage digestion
- S6: Utilise existing digestion capacity
- S7: Insulation of (old) digesters
- S8: Sand removal prior to sludge treatment

Energy production

- S4: Sludge digestion and cogeneration
- S9: Direct operation compressor/blower by gas motor
- S10: Energy production from biogas in small gas turbines
- S11: Ad small gas turbine or extra biogas buffer
- S12: High efficiency cogeneration
- S13: Optimise Combined Heat Power installation (CHP installation)
- S14: Gas conditioning prior to CHP installation
- S15: Fuel cells for higher efficiency

Biogas

- S16: Utilisation of the heat buffering capacity of the digester
- S17: Blend biogas with natural gas
- S18: Installation of (additional) gas storage buffer
- S19: Convert biogas into methane and supply it (back) to the gas network
- S20: Transport of biogas to third parties

Primary sedimentation

- S21: High efficiency primary settling

Pre-treatment of sludge

- S22: Sludge desintegration techniques prior to digestion: ultrasonic/hydrodynamic
- S23: Sludge desintegration techniques prior to digestion: high pressure, thermal, hydrolysis, Cambi

Operation

- S24: Constant feeding of the digester
- S25: Proper mixing in the digester
- S26: Mixing in the digester with a stirrer instead of gas input
- S27: One-time removal of sand from the dister
- S28: Regular removal of sand from the digester

Third parties

- S29: Use waste heat from surroundings
- S30: Supply waste heat to third parties

Thickening

- S31: Mechanical thickening instead of gravitational thickening of sludge
- S32: PE dosing

Return liquor treatment

- S33: Return liquor treatment by SHARON
- S34: Chemical nitrogen precipitation to struvite
- S35: Anaerobic de-ammonification
- S36: Two-stage SHARON-Annamox process with 2 reactors

Reuse of heat

- S37: Reuse of low value heat
- S38: Reuse of heat from gas engine exhaust gasses

Dewatering

Hardware/configuration

- S40: Belt press instead of centrifuge after thickening
- S41: Cascade line-up and belt press for direct sludge dewatering
- S42: Belt press instead of centrifuge after digestion
- S42: High dry matter content in the dewatering installation
- S44: Drainage of water from activated sludge storage

Control

- S45: Backdrive operation on centrifuges
- S46: Control system for operation of the centrifuges

Sludge supply

- S47: Well mixed sludge to the dewatering installation

Nutrient (N, P) removal

Configuration of plant

- W34: Creation of additional anoxic volume
- W35: Choose the energetically most favourable design
- W36: Managing return sludge flow rate
- W37: Regulate nitrate recirculation to the anoxic zone

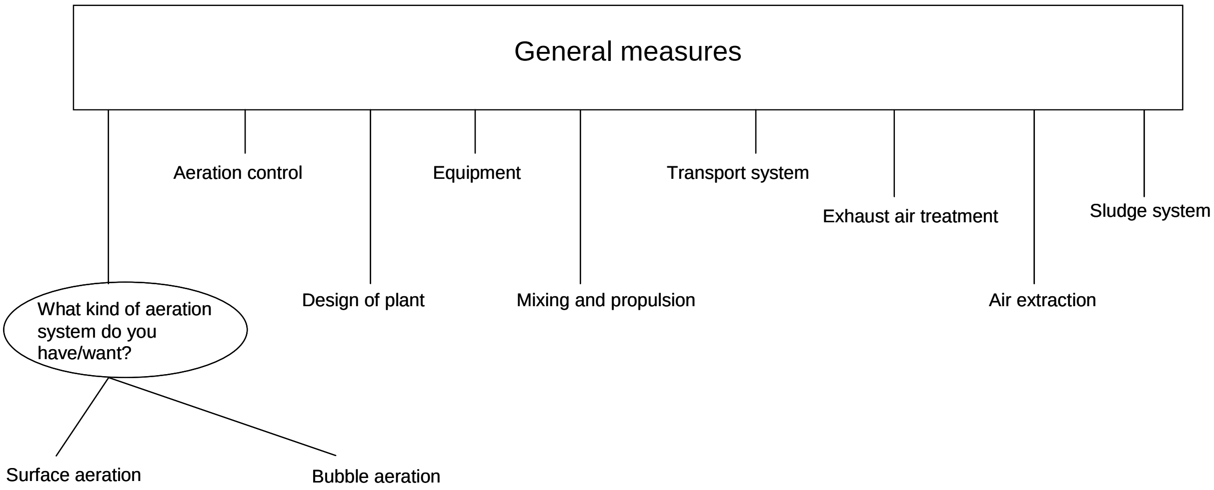
Process control

- W38: Couple aeration rate to process parameters
- W39: Optimise position and numbers of sensors
- W40: Regular calibration of the sensors
- W41: Optimise phosphorous removal

Advanced treatment techniques

- W42: De-ammonification in the waterline
- W43: Aerobic granular sludge (Nereda)
- W44: Urine separation

3.4 General measures



In this chapter general measures for energy efficiency at a WWTP are described. These measures can be taken irrespective the configuration of the WWTP. In the first paragraph measures for the aeration system are describes, divided by the kind of aeration system. After that measures for aeration control, design of plant, equipment, mixing and propulsion, transport system, exhaust air treatment, ventilation and the sludge system are described.

3.4.1 Type of aeration system

3.4.1.1 Surface aeration

W1. Disconnection of aeration and liquid propulsion.

% Effect	Pay back time	Extra investment
< 1%	> 15	< 250.000 €

By decoupling the liquid propulsion from the aeration the aerators can be employed exclusively for oxygen input. As a result the aerators do not have to operate at a fixed capacity to create a sufficient liquid flow rate in the system.

W2. Bubble aeration instead of surface aeration.

% Effect	Pay back time	Extra investment
10 – 20%	5 – 15	< 500.000 – 1.500.000 €

Bubble aerators (dish, tube, or plate aerators) have a superior oxygen transfer capacity compared to surface aerators (rotors or surface aerators), enabling a lower energy input for aeration. Note that additional liquid propulsion hardware might be required, implying extra energy consumption. But overall energy will be saved. Water depth of tanks is an important parameter in this respect.

W3. High efficiency surface aerators.

% Effect	Pay back time	Extra investment
5 – 10%	5 -15	< 250.000 €

By replacing conventional surface aerators by modern high efficiency surface aerators the oxygen transfer efficiency can be improved and the energy consumption for aeration can be forced back. Water depth of tanks is an important parameter in this respect.

W4. Remove covers for spray prevention at surface aerators.

% Effect	Pay back time	Extra investment
< 1%	> 15	< 50.000 €

Covers above surface aerators hamper the oxygen input. On the other hand removing them promotes the diffusion of aerosols.

W5. Adjust water head at surface aerators.

% Effect	Pay back time	Extra investment
1 – 10%	> 15	< 50.000 €

Applying a baffle behind the surface aerator or elevating the overflow height increases the immersed water depth and provides more efficient oxygen transfer efficiency. On the other hand a baffle leads to additional resistance and requires more energy for liquid propulsion. Elevating the overflow height is the more conventional measure.

3.4.1.2 Bubble aeration

W6. Plate aeration instead of tube or dish aeration.

% Effect	Pay back time	Extra investment
5 – 10%	> 15	< 500.000 – 1.500.000 €

Plate aeration provides higher oxygen transfer efficiency compared to tube or dish aeration. The loading on plates is lower, resulting in a higher efficiency. Similar efficiency can be reached by installing more tube or dish aerators operating at a lower loading rate.

W7. Centrifugal compressors instead of displacement or roots compressors.

% Effect	Pay back time	Extra investment
5 – 10%	5 – 15	< 500.000 – 1.500.000 €

Centrifugal compressors can have a lower energy consumption compared to displacement or roots compressors. The energy gain is strongly depending on the specific situation, especially on the required control range for the oxygen input. Centrifugal compressors are only feasible in case of high aeration rates and relatively large WWTPs.

W8. Optimise tank depth.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

The oxygen transfer efficiency is more efficient when the air travels a longer distance (i.e. when the tank is deeper). On the other hand compressors have to operate at higher capacity to overcome additional pressure due the increased water level. Design should be based on the maximum energy efficiency and oxygen transfer efficiency.

A1. Send exhaust air from the treatment process to the aeration tank.

% Effect	Pay back time	Extra investment
< 1%	> 15	Dependent on situation

The exhaust air can be transported to the aeration tank through an air blower instead of being treated by a lava filter or compost filter. This measure is only applicable for (partly) continuous aeration operation.

3.4.2 Aeration control

W9. Intermittent aeration control.

% Effect	Pay back time	Extra investment
1 – 5%	5 – 15	< 250.000 €

Application of intermittent or non-step-wise aeration control increases the control range and makes it possible to adjust the aeration input more accurately (0-100%) to the actual oxygen need of the system.

W10. Reduce oxygen concentration setpoint.

% Effect	Pay back time	Extra investment
1 – 10%	No investments required	None

The aeration rate can be reduced by decreasing the dissolved oxygen concentration setpoint of the system. Note that reduction of the aeration rate does not cause a disadvantageous effect on the oxygen transfer rate in the system or leads to other undesirable situations (such as bulking sludge).As a rule of thumb for completely aerated and well mixed tanks a minimum of approx. 0,8 mg/l and a maximum oxygen concentration of approx 2,0-2,5 mg/l can be applied.

W11. Process operation on the basis of sludge age.

% Effect	Pay back time	Extra investment
1 – 10%	No investments required	None

The oxygen requirement of the system can be reduced by decreasing the sludge concentration. In summer time the sludge concentration (MLSS) might be decreased even further. This will result in a higher sludge loading (F/M ratio), higher sludge production and lower sludge age. Note that the treatment efficiency has to comply with the permit requirements. Because the sludge production and thereby the energy consumption in the sludge line increases, attention should be paid to the total energy balance.

W12. Improve alpha-factor.

% Effect	Pay back time	Extra investment
1 – 10%	No investments required	None

The alpha factor is important for the oxygen transfer efficiency. High sludge concentration in the aeration tank usually results in a deterioration of the alpha-factor above a certain critical value (about 6 to 8 g/L). In addition several other factors affect the alpha-factor, such as shear rate and stress on the biomass. Low alpha-factors can also occur at standard sludge concentrations, thereby requiring a higher aeration rate to reach the same treatment efficiency. It is advisable to measure the alpha-factor.

W13. Alarm report in case of unexpected high aeration rate.

% Effect	Pay back time	Extra investment
1 – 5%	< 5	< 10.000 €

When the aeration rate is much higher than expected something might be wrong with the aeration system, for instance a leakage. Excessive aeration might be prevented by tracing this.

3.4.3 Design of plant

W14. Optimise configuration.

% Effect	Pay back time	Extra investment
5 – 10%	Dependent on situation	Dependent on situation

When designing a WWTP (newly built or renovation) minimisation of the water head elevation and the return and recirculation flows should be incorporated. By choosing a smart configuration the hydraulic energy losses (minimise flow resistance and water heads) can be minimised.

W15. Upflow Sludge Blanket Filtration (USBF).

% Effect	Pay back time	Extra investment
1 – 5%	Dependent on situation	Dependent on situation

The USBF process is a sludge/water separation technique with a V-shaped construction. In this configuration no scraper is required and the return sludge pump requires a lower head of discharge compared to conventional clarifiers. Both differences allow lower energy consumption, but a thorough comparison with conventional clarification has to be made.

W16. Sequencing Batch Reactor (SBR).

% Effect	Pay back time	Extra investment
1 – 10%	Dependent on situation	Dependent on situation

By applying batch wise treatment of wastewater, energy can be saved with respect to recirculation. This operation mode is only applicable for Dry Weather Flow systems or for systems with a very low Rain Weather Flow to Dry Weather Flow ratio. SBR systems can be build modularly, for larger wwtp’s more SBR units are required.

W17. Treatment at source.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	> 1.500.000 €

In case of a concentrated discharge (for example from a hospital, or a large residential or office complex) wastewater can be treated locally, thereby decreasing the loading rate on the WWTP. Especially for problematic micropollutants, such as medicines, decentralised treatment might be interesting because degradation from a concentrated flow is easier than from a diluted flow. The energy profit is highly dependent on the current and the reference situation.

W18. Thermal energy exchange.

% Effect	Pay back time	Extra investment
< 1%	> 15	> 1.500.000 €

The temperature of groundwater is reasonably constant throughout the year. This water can be used to heat or cool down office buildings or the water in WWTPs. For WWTPs levelling of the influent temperature can be achieved. The effect of temperature levelling of the influent on the energy consumption is dependent on the specific circumstances at the WWTP. Detailed research is required and thermal energy exchange has not been applied yet in practice at wwtp’s.

3.4.4 Equipment

W19. Avoid frequent switching off and on of hardware.

% Effect	Pay back time	Extra investment
< 1%	5 – 15	< 100.000 €

By implementing small adjustments in the process operation, frequent switching of hardware with high energy consumption during the start-up phase can be prevented. Examples are compressors and surface aerators.

W20. Avoid unfavourable ranges for hardware.

% Effect	Pay back time	Extra investment
1 – 5%	5 – 15	< 100.000 €

Energy is needlessly consumed when (big) installations (pumps, blowers) operate in unfavourable ranges. In this case the process operation should be adjusted.

W21. Manage scraper operation in clarifiers.

% Effect	Pay back time	Extra investment
< 1%	> 15	< 50.000 €

Energy can be saved by managing the scrapers in clarifiers (primary or secondary) on the basis of the influent flow rate and the return sludge flow rate or in combination with the suspended solids concentration in the aeration tank or of the return sludge, instead of on the basis of a fixed flow rate (usually Rain Weather Flow). To this aim scrapers should have an adjustable speed and adjustments in the operating system (process control) are required.

W22. Advanced pre-treatment (sieves).

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

By application of fine sieves/filters instead of primary clarification more BOD can be removed from the wastewater and converted into biogas through digestion. Note that sufficient BOD has to be available in the water to comply with the requirements for nitrogen removal. By improving the digestion process an increase in the nitrogen load in the rejection water can be encountered; in this case advanced side stream rejection water treatment can be applied.

3.4.5 Mixing and propulsion

W23. High efficiency mixers for propulsion and mixing.

% Effect	Pay back time	Extra investment
1 – 5%	5 – 15	< 250.000 €

The application of high efficiency stirrers is preferred over conventional mixers due to lower energy consumption. A selection out of different suppliers should be made.

W24. Periodical adjustments in the propulsion propeller operation.

% Effect	Pay back time	Extra investment
< 1%	5 – 15	< 10.000 €

Energy can be saved by optimising the propeller operation on the basis of the measured liquid flow velocity in the tank. Continuous measurements are not feasible due to the difficulty in measuring the velocity profile over the tank. The velocities can be measured periodically and the operation of the propellers can be adjusted. To this aim the propellers require variable frequency drive operation, high/low speed operation or blade operation and adjustments in the operating system are required.

W25. Type and positioning of propellers for propulsion in combination with bubble aeration.

% Effect	Pay back time	Extra investment
< 1%	> 15	Dependent on situation

The choice of type of propellers determines the distance between the propeller and the aerated zone. The aerated zone can be disturbed when the propeller is located too nearby and additional energy is required to realise the desired liquid flow velocity. Positioning the propellers in a bend of the tanks is also not advisable.

W26. Exchange between compartments in direction of flow.

% Effect	Pay back time	Extra investment
< 1%	> 15	Dependent on situation

Between compartments in a wwtp, often liquid flow is exchanged. By realising the direction of the exchanged flow in an angle of the main flow (rather than perpendicular to it), the energy required for liquid propulsion can be reduced.

W27. Mix by aeration instead of propellers.

% Effect	Pay back time	Extra investment
1 – 5%	No investments required	None

By applying bump aeration (intensive aeration during a very short time) during non-aerated periods almost no oxygen is transferred, but the sludge is still mixed. As a consequence propellers might become redundant, thereby reducing the energy consumption.

W28. Switch off propulsion propellers during aeration.

% Effect	Pay back time	Extra investment
1 – 5%	No investments required	None

By switching off the propellers in fully aerated tanks during aeration, energy can be saved with respect to liquid propulsion.

3.4.6 Transport system

W29. Gravity transport.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

For newly built WWTPs the construction should aim to utilise gravity transport as much as possible. This reduces the energy consumption for pumping stations. Depending on the specific situation a (partly) underground construction is an option, to optimise the height of the waterline. The higher costs (including the pumping of groundwater during construction) have to be considered in relation to lower energy costs for utilities over a longer period of usage.

W30. Disconnection of rain water.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

By disconnection of the rain weather flow from wastewater less water has to be transported to the WWTP. For the WWTP this implies that various devices and tanks can be implemented with smaller dimensions and that various devices are less frequently or intensively in use. Drawback is that in case of “strict” effluent discharge regulations (for example N_{tot} = 10 mg/L) the treatment efficiency of the WWTP has to be improved (as rain water has a diluting effect). This requires a higher energy consumption, especially for aeration. The preferable extent of disconnection depends on the specific situation, especially with respect to the influence of the Rain Weather Flow on the treatment process.

W31. Avoid infiltration water.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

Infiltration of e.g. (ground)water in sewage systems should be avoided. Sewer infiltration water results in a higher flow rate to be treated by both the sewer and the WWTP. This implies higher energy consumption than necessary for both systems. By avoiding the infiltration of (ground) water less water has to be transported to the WWTP. As a result the installations and tanks can be designed on smaller and various devices are less frequently or intensively in use. Drawback is that because of the lower flow rate the concentrations in the wastewater increase and that in case of “strict” effluent discharge regulations (for example N_{tot} = 10 mg/L) the treatment efficiency of the WWTP has to be improved. This implies higher energy consumption, especially for aeration.

W32. Optimise transport system.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

By optimising the process control over the pumping stations in the transport system, for example by Real Time Control, the supply of wastewater to the WWTP can be distributed more evenly. This has a positive effect on the energy consumption in the total treatment process.

3.4.7 Exhaust air treatment

A2. Replace compost filters by lava filters.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

The filter type affects the energy consumption of the ventilators by the pressure loss over the filter. For lava filters the pressure difference is more constant in time. Lava filters have superior odour removal efficiency. For newly built exhaust air treatment filters lava filters are preferred.

A3. Breathing filter.

% Effect	Pay back time	Extra investment
< 1%	Dependent on situation	Dependent on situation

If part of the exhaust air contains a low H_2S concentration it might be possible to disconnect this part and install a breathing filter. A breathing filter is connected with the open air and is used without a ventilator. Natural ventilation induces the air flow through the filter. As a consequence less air has to be transported to the (lava) filter and its efficiency will improve. On the other hand the extra investments and exploitation costs for a breathing filter have to be considered.

3.4.8 Air extraction

A4. Optimise air extraction.

% Effect	Pay back time	Extra investment
< 1%	5 - 15	Dependent on situation

By reconsideration of the design principles the possibility of reducing the volume of exhaust air can be assessed. Reduction of the electricity consumption can be realised by technical adjustments such as the installation of smaller ventilators, application of variable frequency drive or the use of time switches.

A5. Reduction of the extracted air volume.

% Effect	Pay back time	Extra investment
< 1%	> 15	Dependent on situation

By reducing the volume of space to be ventilated, the volume of exhaust air can be reduced. Pay attention to minimal requirement.

A6. Regulate air extraction on the basis of H_2S measurements.

% Effect	Pay back time	Extra investment
< 1%	5 – 15	Dependent on situation

By regulating the air extraction on basis of the measured H_2S concentrations the air flow can be reduced.

A7. Increase ventilation flow rate above the aeration tank.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

This measure is only applicable in case of point/surface aeration. When aeration tanks are covered the exhaust air might contain less oxygen than the open air. As a consequence more intensive or prolonged aeration is required. Increasing the ventilation rate above the aeration tank can lead to an increase in the oxygen concentration in the air, resulting in a decrease in the energy consumption for aeration. However, this measure has to counteract with the extra energy consumption by the blowers supplying the air to improve the ventilation rate.

3.4.9 Sludge system

S1. Worm bloom.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

Worms reduce the sludge volume in a WWTP, which effects the energy consumption in the sludge line, the transport and the final processing of the sludge. Research into energy profits for the specific location is required.

S2. Timing of sludge transport.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

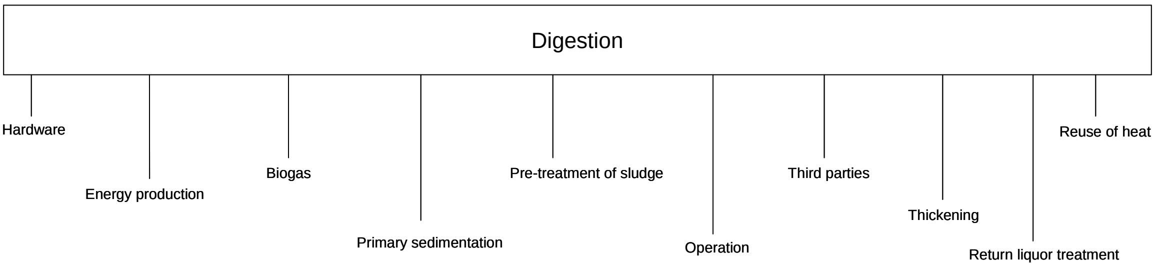
By smartly choosing the moments of (excess) sludge transport fuel can be saved, for example by avoiding traffic jams.

S3. Cannibal.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	> 1.500.000 €

In the Cannibal process the activated sludge is “starved” for a certain period in a separate tank. The sludge will “eat itself” with less net sludge mass as a consequence. This affects the energy consumption in the sludge line, the transport and the final sludge processing of the sludge. This requires additional aeration, however. Research into the energy benefit for the total water chain for each specific situation is required.

3.5 Digestion



In this chapter the energy measures for with respect to digestion are described. The first question is whether it is feasible to digest the sludge at the WWTP and after that measures for hardware, energy production, biogas, primary sedimentation, pre-treatment of sludge, operation of the digester, co-operation with third parties, thickening of the sludge, return liquor treatment and reuse of heat are given.

S4: *Sludge digestion and cogeneration.*

% Effect	Pay back time	Extra investment
>20%	> 15	> 1.500.000 €

In case of the absence of digestion at the WWTP, a digester can be constructed. In addition a combined heat and power installation (CHP-installation) needs to be constructed to generate heat and electricity. Or other equipment capable of converting the biogas into useful energy (like heaters, or transfer of biogas to the natural gas network) can be considered. The choice whether a digestion is feasible depends on the criteria (costs and/or energy) and specific local conditions. Sludge digestion reduces the amount of sludge and the costs related with the transport and removal of it. Secondly biogas is produced which can provide savings on purchasing electricity. The economic feasibility depends on the investment, and savings on operational costs and on the financial criteria for return on investments. Economy of scale is important for the economic feasibility of digestion. For that reason, digesters mainly are realised at larger wwtp's. However, transport of sludge form different smaller wwtp's to a larger digestion facility at a wwtp can provide an increase of scale also.

3.5.1 Hardware

S5. Thermophilic or multiple stage digestion.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

By operating the digestion process at a higher temperature (thermophilic) or operate a multiple stage digester the conversion efficiency in the process can be increased. Stability of the process is a point of attention. Application depends on sludge characteristics, specific point of attention is inhibition by ammonia.

S6. Utilise existing digestion capacity.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

In case of excess digestion capacity this can be complemented with sludge from other wwtp's or organic waste suitable for digestion (from third parties). This can have a positive effect on the degradation of the sludge, resulting in a higher biogas production. The possibilities are strongly dependent on the specific situation (and the permit).

S7. Insulation of (old) digesters.

% Effect	Pay back time	Extra investment
< 1%	5 – 15	< 100.000 €

By insulation measures the temperature in the digester remains higher and the conversion process is improved. This results in a higher biogas production. In addition less heat is required for maintaining the required temperature in the digester. This is of importance for useful application of the biogas. This measure is in particular applicable for older digestion tanks.

S8. Sand removal prior to sludge treatment.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

In the course of time sand accumulates in the digester. To prevent this, measures can be taken to remove sand in the sludge- or waterline before it ends up in the digester. When this can not be prevented, the degree of sand accumulation is strongly depending on the measures for removal of sand in the water and sludge line, the mixing in the digester and the volume of sand that is supplied with the wastewater. The sand in the digester causes a reduction of the effective residence time in the tank and thereby results in a lower conversion efficiency of the sludge. This also results in a lower biogas production.

To prevent sand entering in the digestion, sand can be removed prior to the sludge treatment by e.g. sand cyclones.

3.5.2 Energy production

S9. Direct operation compressor/blower by gas motor.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

Direct operation (instead of electricity) of the compressor/blower with produced biogas by a gas motor can often be applied in combination with a conventional Combined Heat Power installation (CHP installation) to utilise the gas in case of a low aeration demand. The CHP installation produces electricity which can be used at the WWTP, or can be supplied to the network.

S10. Energy production in small gas turbines or gas engines.

% Effect	Pay back time	Extra investment
Dependent on situation	> 15	Dependent on situation

Energy production in several small gas turbines rather than one big one, thereby coping more flexible with variations in the biogas supply. Point of attention is that bigger gas turbines have a higher efficiency.

S11. Add small gas turbine or extra biogas buffer.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

In case of a temporary gas surplus a small gas turbine can be added, thereby increasing the biogas usage for energy production at the WWTP. In addition fluctuations in the biogas supply can be handled more flexible. Additional buffering capacity for the biogas is also possible. The advantage is that flaring or storing of biogas is less or not required. Additional maintenance is required, however.

S12. High efficiency heat power coupling.

% Effect	Pay back time	Extra investment
5 – 10%	5 – 15	< 250.000 €

In case of a newly built WWTP application of a high efficiency combined heat and power (CHP-) installation can be a good investment. Electric efficiency of 38-42% can be achieved. Applying ORC (Organic Rankine Cycle) technology additional to a heat and power installation can increase the electric efficiency to 45%. ORC technology is based on evaporation and condensation of organic solvents. For cost efficient use, relatively large (> 1 MW electricity) heat and power installations are required.

S13. Optimise heat power coupling.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

Be alert for maintaining maximum efficiency of the CHP-installation by adequate maintenance. Compare performance with specifications from supplier.

S14. Gas conditioning prior to heat power coupling.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

By improving the gas quality (less polluted) the efficiency of the CHP-installation can be improved. Check specifications of supplier for specific components.

S15. Fuel cells for higher efficiency.

% Effect	Pay back time	Extra investment
10 – 20%	> 15	> 1.500.000 €

WWTPs with a digester and gas turbines/cogenerators usually have a surplus of heat energy and a considerable lack of electricity. Application of fuel cells can produce considerably more energy than gas engines or gas turbines; in addition the total efficiency (heat and electricity) on the biogas utilisation increases. Fuel cells based on biogas are available, but still developing. Efficiency amounts to 45%.

3.5.3 Biogas

S16. Utilisation of the heat buffering capacity of the digester.

% Effect	Pay back time	Extra investment
1 – 5%	No investments required	None

The temperature in the tank is usually maintained at 33 ± 2 °C. In case of a heat surplus an increase of the temperature to 36 °C does not cause a provable disadvantageous effect, but a higher biogas production on the contrary. Additional heating in periods that the temperature is not reached are required less frequently.

S17. Blend biogas with natural gas.

% Effect	Pay back time	Extra investment
>20%	> 15	Dependent on situation

When the supply of biogas is lower in certain periods and the capacity of the gas engine is not fully utilised, blending with natural gas allows for continuous running of the gas engine ensuring an acceptable efficiency.

S18. Transport biogas to third parties.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

After minor post-treatment the biogas can be transported by pipeline to a location that has better possibilities for supplying surplus heat or electricity generation at a higher efficiency. In case of electricity generation at the WWTP from biogas, alternative electricity supply provisions are required. Transport distance is an important cost factor. Complete energy balance should be calculated for best option.

S19. Convert biogas into methane and supply it (back) to the gas network.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

Biogas can be upgraded to natural gas. The natural gas can be supplied to the network. Part of the biogas can be used for heat production for the digester. When in the previous situation electricity was produced at the WWTP from biogas an additional electricity supply is required. A complete review on the energy production and energy consumption is necessary to determine whether electricity (primary energy) is conserved.

S20. Installation of (additional) gas storage buffer.

% Effect	Pay back time	Extra investment
1 – 5%	> 15	< 250.000 €

Supplementary buffering capacity can yield an improved annual average biogas utilisation. This requires regular surplus biogas production and a useful application of the gas.

3.5.4 Primary settling

S21. High efficiency primary settling.

% Effect	Pay back time	Extra investment
5 – 20%	< 5	< 100.000 €

By dosing a polymer (PE) or a metal salt the production of primary sludge in the primary clarifier can be increased. Primary sludge has more favourable digestion properties than secondary sludge, resulting in a better digestion and a higher biogas production. However, more chemical sludge is produced by the addition of metal salts, which causes extra costs for sludge disposal. Attention should be paid to the effect of a better primary clarification on the nitrogen removal later in the waterline. Usually a higher efficiency results in an unfavourable BOD/N ratio and can cause problems with respect to the denitrification. Application of energy conserving side-stream techniques for nitrogen removal can provide a solution. A lower BOD loading rate can also affect the bio-P removal.

3.5.5 Pre-treatment of sludge

S22. Sludge disintegration techniques prior to digestion: ultrasonic/hydrodynamic.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	< 500.000 €

By applying sludge disintegration techniques prior to the digestion process (ultrasonic, hydrodynamic), an improved degradation can be affected in the digestion. In addition the biogas production can be increased. The extra energy required for sludge disintegration has to be optimised with the extra energy from the biogas. Cost reduction by reduction of the final sludge volume can be achieved.

S23. Sludge disintegration techniques prior to digestion: high pressure, thermal hydrolysis, Cambi.

% Effect	Pay back time	Extra investment
1 – 10%	> 15	> 1.500.000 €

By applying sludge disintegration techniques prior to the digestion process (high pressure, thermal hydrolysis, etc.) an improved degradation can be affected in the digestion. High temperature and pressure disrupts the biomass in the sludge and releases components which can be digested. In addition the biogas production can be increased. The extra energy required for sludge disintegration has to be optimised with the extra energy from the biogas. Cost reduction by reduction of the final sludge volume can be achieved. Also dewatering characteristics improve.

3.5.6 Operation

S24. Constant feeding of the digester.

% Effect	Pay back time	Extra investment
< 1%	> 15	< 250.000 €

Uniform supply to the digester enables a constant biogas production. As a consequence the gas engines can operate at a constant rate and the need for flaring biogas peaks is reduced. Uniform supply can be realised by buffering the primary sludge in the primary clarifier, the thickener or a new buffer tank, thereby preventing a peak gas production during the first flush.

S25. Proper mixing in the digester.

% Effect	Pay back time	Extra investment
1 – 5%	5 – 15	< 50.000 €

Proper mixing in the digester is required to ensure uniform distribution in the tank. Adapt operation with existing means, by adapting the mixture regime with operational measures (process control of mixing: frequency, intensity). By this an optimum gas production can be achieved. Mixing costs energy, so the costs and profits have to be considered.

S26. Mixing in the digester with a mixer instead of blowing gas to the digester.

% Effect	Pay back time	Extra investment
1 – 5%	< 5	< 100.000 €

Replacing the gas input by a mixer, energy can be saved in mixing. Energy efficiency depends on size of digester. Specific design must be made.

S27. One-time removal of sand from the digester.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

See S8 for explanation. This specific measure is the removal of sand from the digester. For that the digester has to be set out of operation. The removal can be done when the amount of sand accumulation obviously is too high, or can be done on a more regular basis to prevent an unacceptable accumulation.

S28. Maintenance removal of sand from the digester

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	< 500.000 €

See S8 for explanation and S27.

3.5.7 Third parties

S29. Use waste heat from surroundings.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

Waste heat from the surroundings, for example from an industry, can be used for heating buildings, digesters, influent and for dewatering or drying of sludge.

S30. Supply waste heat to third parties.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

The waste heat released from cogeneration that cannot be used at the WWTP, can be supplied to third parties such as industries or urban settlements. Attention has to be paid to legal aspects such as supply guarantee.

3.5.8 Thickening

S31. Mechanical thickening instead of gravitational thickening of sludge.

% Effect	Pay back time	Extra investment
Dependent on residence time and digestion process	Dependent on situation	< 500.000 €

By applying mechanical thickening instead of gravitational thickening a higher dewatering level can be achieved. As a consequence the sludge enters the digester with a higher suspended solids concentration and the retention time can be increased, resulting in a higher biogas production.

S32. PE dosing.

% Effect	Pay back time	Extra investment
Dependent on residence time and digestion process	Dependent on situation	< 10.000 €

By dosing a polymer (PE) in the gravitational sludge thickener the suspended solids concentration can be increased. As a result the residence time and the biogas production in the digester can be increased. The achievable suspended solids concentration through PE dosage is lower than in case of mechanical sludge thickening. The investments for dosing equipment are also lower, however.

3.5.9 Return liquor treatment

S33. Treatment of return liquors with SHARON.

% Effect	Pay back time	Extra investment
5 – 10%	5 – 15	0,5 – 1,5 € / kg N removed

In the SHARON process (Stable and High rate Ammonia Removal Over Nitrite) first ammonium is oxidised into nitrite under aerobic conditions (nitrification) and subsequently converted into nitrogen gas by addition of a carbon source under anoxic circumstances (denitrification). The denitrification process is particularly intended for pH correction of the process, assuming that nitrite is easily denitrified in the process. Compared to conventional N-removal, energy is saved. A temperature of 30-40 °C is required.

S34. Chemical nitrogen precipitation to struvite.

% Effect	Pay back time	Extra investment
< 1%	5 – 15	Dependent on situation

In the struvite process phosphour is removed from return liquor by precipitation of the phosphate with magnesium and nitrogen into struvite (MgNH4PO4, Magnesium-Ammonium-Phosphate (MAP)). The composition of the MAP is a critical factor to utilise as fertiliser.

S35. Anaerobic de-ammonification.

% Effect	Pay back time	Extra investment
10 – 20%	5 – 15	0,5 – 1,5 € / kg N removed

De-ammonification is a biological treatment process for the degradation of ammonium from wastewater, by converting ammonium into nitrogen gas under anaerobic circumstances by using nitrite. This process is autotrophic and does not require the addition of a carbon source. The process consists of two steps: nitrite formation from ammonium and the combining of nitrite and ammonium to nitrogen gas. The process is applicable for highly concentrated waste waters such as return liquors. Low C/N ratio and high temperatures are a requisite. (Techniques: Anammox – Anaerobic AMMonium Oxidation, DEMON – DE-amMONification)

S36. Two-stage Sharon-Anammox process with 2 reactors.

% Effect	Pay back time	Extra investment
10 – 20%	> 15	1,0 – 3,0 € / kg N removed

Nitrite formed in a separate Sharon process without denitrification reacts anaerobically with ammonium in the Anammox process and is converted into nitrogen gas. In the anaerobic oxidation of ammonium specifically Anammox bacteria are involved. The Sharon process converts ammonium into nitrite until a suitable ratio between ammonium and nitrite is reached. Form this process 1 large scale reference is available. Nowadays processes can be performed in 1 step (S19).

3.5.10 Reuse of heat

S37. Reuse of low value heat

% Effect	Pay back time	Extra investment
< 1%	> 15	< 250.000 €

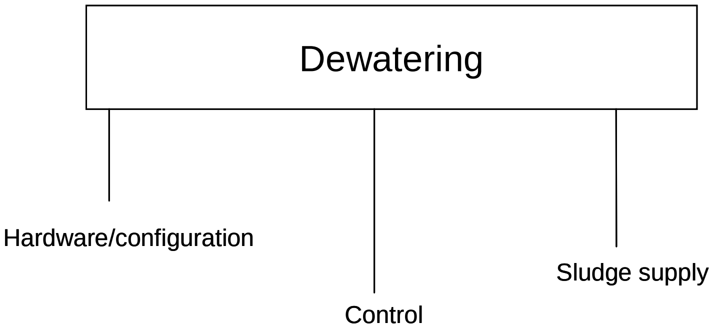
The effluent, digested sludge and excess sludge contain low value heat. This is heat with a relatively low temperature (typically less than 80 °C). This residual heat can be reused in various ways. The heat energy of digested sludge can be used to preheat the sludge that is supplied to the digester. Using a heat pump the low value heat from a big flow can be converted to a small flow of useful heat. This energy can be used to heat up buildings, heating of influent or sludge that has to be dewatered, or for drying of the sludge.

S38. Reuse of heat from gas engine exhaust gases.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

In case of surplus heat production in e.g. a gas engine, heat can be used to maintain the right temperature in the digester, heat the influent, or heat the sludge to the dewatering installation. The effect of heating the influent on the actual energy saving is strongly dependent on the situation. There is a positive effect due to the fact that less sludge is required and a negative effect due to a higher required oxygen input at higher temperatures. When the sludge is warmer it has better dewatering properties. At the same dewatering percentage this results in a lower energy and polymer consumption. These values can also be kept constant, resulting in a higher final dewatering percentage. This can result in lower costs for the final sludge deposition. The latter does not yield energy saving, but it is important for efficient chain management.

3.6 Dewatering



S39. Feasibility of dewatering

By dewatering the sludge, for example to a dry solids content of 20-25%, cost for transport is saved. Also the caloric value of the sludge is increased, due to the removal of water. Whether dewatering economical feasible is site specifically determined and depends on the costs of transport and sludge disposal. For reasons of economy of scale, the dewatering can be regionally centralised at larger wwtp's. Sludge from smaller wwtp's can be thickened on site and transported to the central dewatering facilities. The dewatering characteristics of sludges may differ. Appropriate mechanical dewatering units should be used depending on the sludge properties, considering the demands on percentage dry-solids and the energy requirements.

3.6.1 Hardware/configuration

S40. Belt press instead of centrifuge after thickening.

% Effect	Pay back time	Extra investment
1 – 5%	> 15	< 250.000 €

Applying a belt press instead of a centrifuge for sludge dewatering after thickening of the sludge reduces the energy consumption. Take into account the achievable dry matter content.

S41. Cascade line-up and belt press for direct sludge dewatering.

% Effect	Pay back time	Extra investment
1 – 5%	> 15	< 250.000 €

Application of a cascade line-up with a belt thickener and belt press or belt press with extended dewatering table instead of a 1-stage centrifuge for direct sludge dewatering reduces the energy consumption.

S42. Belt press for sludge dewatering after digestion.

% Effect	Pay back time	Extra investment
1 – 5%	> 15	< 250.000 €

Application of a belt press instead of a centrifuge for sludge dewatering after digestion leads to reduced energy consumption. Take into account the achievable dry matter content.

S43. Dry matter content in the dewatering installation.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

By choosing for a type of sludge dewatering with a high residual suspended solids percentage (for example membrane filter presses) energy can be saved with respect to the transport mileage and the final sludge processing. Optimise the energy consumption for the dewatering, the transport of sludge and the final sludge processing.

S44. Drainage of water from the activated sludge storage.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	< 50.000 €

Costs and energy consumption for transport can be decreased by improving the drainage of water from storage of activated sludge. Proper design of settlers/buffers with sufficient residence time is required.

3.6.2 Control

S45. Back drive operation on centrifuges

% Effect	Pay back time	Extra investment
< 1%	No investments required	None

Generate electricity with an energy recovery unit during deceleration of the centrifuge.

S46. Control system for operation of the centrifuges.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	< 50.000 €

A control system can be designed to cope with fluctuations in the suspended solids concentration of the supplied sludge (flow rate), whilst producing a constant final dry matter content. For this purpose the flow rate and the suspended solids of the incoming flow are measured, as well as the suspended solids of the centrate. By operating on the basis of the actually measured value of the supply flow rate and/or the centrifuge operational settings, a constant final dry matter content can be reached. This results in a lower transport volume to the final sludge processing and the saving of energy in the chain. In this operation mode the dewatering process will consume less energy and polymer.

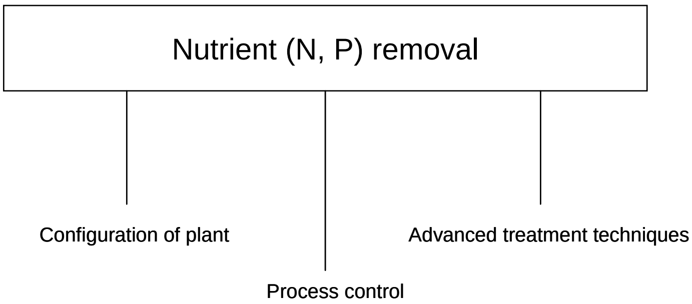
3.6.3 Sludge supply

S47. Well mixed sludge to the dewatering installation.

% Effect	Pay back time	Extra investment
< 1%	> 15	< 250.000 €

By transporting well mixed sludge to the dewatering installation the process will operate at more constant conditions. This results in a lower transport volume to the final sludge processing and a reduction of the energy consumption in the chain. Likely the dewatering process requires less energy and polymer dosing. Regular feeding can be realised by buffering primary sludge in the primary clarifier, thickening tank or new buffer tank.

3.7 Nutrient (N, P) removal



W33: Removal of nutrients

Whether removal of nutrients (nitrogen, phosphorous) is required depends on specific legislation and local conditions related to the receiving surface water. With the removal of nutrients significant costs and energy consumption is involved. In agricultural areas, and specifically dry areas it might be an option not to remove nutrients and use the effluent for irrigation purposes in agriculture. In this way water and nutrients are re-used.

3.7.1 Configuration of plant

W34. Creation of additional anoxic volume.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	< 10.000 €

By realising additional anoxic volume in order to enhance denitrification, aeration energy can be saved, because oxygen is recovered through the conversion of nitrate.

W35. Choose the energetically most favourable design.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

By finding the optimum system with respect to hydraulics and technology energy can be saved, especially with respect to recirculation flows. An example of this is the Phoredox process which is interesting from an energetic point of view, whereas from a technological point of view the M-UCT process is generally preferred. This measure relates to the position of compartments, tanks, piping to reduce hydraulic head loss and minimise energy requirement for pumping, recirculation and mixing.

W36. Managing return sludge flow rate.

% Effect	Pay back time	Extra investment
1 – 5%	5 – 15	< 100.000 €

The return sludge flow rate can be managed by measuring the sludge level and the turbidity in the clarifier, the influent flow rate, the suspended solids concentration in the aeration tank or on the basis of a mass balance over the clarifier. Pumping of return sludge takes place as required. An interesting possibility for systems with a high head of discharge could be to return sludge from the clarifiers alternately, effecting thicker sludge to be returned.

W37. Regulate nitrate recirculation to the anoxic zone.

% Effect	Pay back time	Extra investment
1 – 5%	5 – 15	< 100.000 €

Energy can be saved by regulating the recirculation from the aerated zone to the anoxic zone on the basis of the nitrate concentration using an additional nitrate or redox sensor. The location of the sensor(s) depends on the situation.

3.7.2 Process control

W38.Couple aeration rate to process parameters.

% Effect	Pay back time	Extra investment
10 – 20% (oxygen)	< 5	< 100.000 €
1 – 5% (redox)	< 5	< 100.000 €
1 – 10% (ammonium/nitrate)	< 5	< 100.000 €

By making the supply of oxygen by the blowers dependent on the online dissolved oxygen concentration measurements, redox measurements or ammonium/nitrate concentration measurements the system can be operated on the basis of the actual oxygen requirement. To this aim a sensor (or multiple sensors) should be implemented in the controls of the process.

W39. Optimise position and number of sensors.

% Effect	Pay back time	Extra investment
1 – 5% (position)	< 5	< 10.000 €

1 – 5% (number)	< 5	< 100.000 €

By adjusting the position or the number of sensors the aeration input can be controlled more accurately on the basis of the actual oxygen requirement of the system. Modelling the process can be used to optimise the position and the number of sensors. The position depends on the configuration of the tanks. Typically ammonia, phosphate and nitrate sensors are placed at the overflow to the secondary settling tank, position of oxygen sensors strongly depends on specific situation.

W40. Regular calibration of the sensors.

% Effect	Pay back time	Extra investment
1 – 5%	< 5	< 10.000 €

The accuracy of sensors (oxygen, ammonium, nitrate, redox) decreases in time. Regular calibration can provide more accurate operation of the system on the basis of the actual oxygen requirement.

W41. Optimise phosphorous removal.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

Phosphorus has to be removed as much as possible biologically, thereby minimising the chemical dosage for phosphorous removal. Chemical phosphorous removal results in a higher (chemical) sludge production and a higher energy consumption during sludge treatment. This might result in less BOD to be available for denitrification, but no clear judgement is available about this. Chemical sludge has a positive effect on the ability of dewatering of the sludge. The advantages and disadvantages of minimising the dosage of chemicals for P-removal is specific for each WWTP and should be optimised for each case.

3.7.3 Advanced treatment techniques

W42. De-ammonification

% Effect	Pay back time	Extra investment
Research phase	Research Phase	Unknown (research phase)

Anammox (de-ammonification) bacteria convert ammonium and nitrite in the wastewater into nitrogen gas, which provides a significant energy reduction with respect to nitrogen removal. Technology is developing. Full scale applications are known for higher temperatures and concentrated wastewaters (for example treatment of return liquor from sludge dewatering).

W43. Aerobic granular sludge (Nereda).

% Effect	Pay back time	Extra investment
Research phase	Research Phase	Unknown (research phase)

Nereda is a fed-batch operated process with aerobic granular sludge for the treatment of municipal wastewater. On the basis of pilot-scale experiments and calculations for full-scale application an energy reduction can be expected compared to conventional wastewater treatment, mainly because of a higher applicable water head and the advantages with respect to aeration. Full-scale experience is still required to confirm this. Depending on the rate of clarification a drum sieve has to be installed to remove fine particles.

W44. Urine separation.

% Effect	Pay back time	Extra investment
Dependent on situation	Dependent on situation	Dependent on situation

By separating urine and faeces more efficient wastewater treatment is possible. The scale of treatment plays a major role and a thorough analysis has to be made. Process can also be applied in rural areas were sewage networks are absent. Applications in city’s might also considered, for example for new city extensions and larger buildings like apartment complexes, hospitals, offices, etc.