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Wastewater Engineering in
Question and Answer

**For Qualification of Students, Technicians and Professionals
in the Wastewater Sector**

11th Edition
Adapted to the Situation in Palestine and Regional Countries
Based on German Experiences

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DWA

"Wastewater engineering in question and answer"

This book is adapted from the titled book "Wastewater engineering in question and answer", 10th edition published by the German Association for Water, Wastewater and Waste (DWA), to suite the wastewater situation in Palestine and other countries in the region. The adaptation and publication of this new version comes within the scope of the German Technical Cooperation support (GTZ) to the Palestinian Water Authority (PWA) in managing and coordinating training in the Palestinian Water Sector.

The revised 11th edition of the book "Wastewater Engineering in Question and Answer" aims at providing knowledge and practical experience to professionals, trainers, university students and to enable technicians and vocational staff to carry out responsible tasks independently and to give master technicians increased competence in leadership and management. This English-language edition covers the main areas of wastewater discharge, wastewater treatment, sludge treatment, sampling and analysis. It comprises two parts: a task part and a solution one, while the diversity of the wastewater engineering subjects is given the widest cover.

The adaptation of the this book has been coordinated and discussed with the Wastewater Technician Training Working Group representing a variety of Palestinian experts and stakeholders in the wastewater field. Without their support and commitment; it would have not been possible to cover the widest spectrum of operational aspects of wastewater services in our region.

We would like also to acknowledge the efforts of all those who have in a way or another contributed to the completion and production of this important work; not to mention all, the Palestinian Water Authority (PWA), Mr. Rudiger Heidebrecht of DWA who without his inspiring ideas this book would have never seen the light. A word of thanks is also due to the water team and consultants of the German TC Water Programme in the Palestinian Territories for the financial support and the high-standard technical input they have provided resulting in timely and quality completion of the book.

Finally, we dedicate this book to all Palestinian and regional experts who are thirsty for practical, but relevant challenges in the operational aspects of the wastewater field.

Shaddad Attili - PWA   *Omar Zimmo* - BZU

Nadim Mulhem - GTZ

Omar Rabah Zimmo was born on November 21st, 1958 in the city of Gaza-Palestine. In 1978, he graduated from Palestine high school in Gaza, after which he enrolled in the Al-Mansoura University in Egypt. He obtained a B.Sc. degree in the civil engineering in 1982 with honours. In 1984 he was awarded a scholarship by the AMIDEAST (USA) to study his MSc. degree in Environmental Engineering in Tufts University, Boston, Massachusetts, USA. His thesis was on "Detection of ground water contamination using ultra violet laser". After graduation and from 1986 to date, he has been an instructor in the civil engineering department at Birzeit University.

In September 1997 he was awarded a scholarship from the Dutch government to study his PhD in the UNESCO-IHE, Institute for Water Education, The Netherlands. His dissertation was on "Nitrogen transformations and removal mechanisms in algal and duckweed waste stabilisation ponds". In addition to his lecturing activities at Birzeit University, since 1990, he has been responsible for the successful training of more than 100 environmental specialists for wastewater engineering in Palestine. He has for many years been engaged in most of the wastewater projects in the Mediterranean countries.

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Dipl.-Ing. (TU) Michael Aldick (born in 1944) comes from East Westphalia. He studied civil engineering in Karlsruhe. Since 1972 he has been active with the Ruhrverband (Ruhr Association) in Essen, inter alia as longstanding assistant to the Chairman of the Board of Management. In 1978 he became lecturer for the ATV Wastewater Master Technician courses in Essen. In the 90s he collaborated with both the production of a new master technician course concept and with the production of DWA instructional documentation for female master technicians. Since 1993 he has been member of the Specialist Committee "Wastewater Master Technician" and, since 1995, its spokesman. From 2003 to 2004, as specialist he saw through the amendment process of the [German] Wastewater Master Technician Ordinance. For his services to the training of operating personnel in wastewater engineering facilities he received the golden DWA Badge (pin) of Honour. In addition, since 1985, he has been responsible for the successful training of more than 120 environmental technicians and specialists for wastewater engineering at the Ruhrverband. In addition to his lecturing activities in the interdisciplinary training of operating personnel at BEW in Essen, he has for many years been engaged with the NRW Federal State Environment Office within the specialist examination committee. Together with Gerolf Lenz he took on the elaboration of the collection of tasks of the part on wastewater engineering, Chapters 1 to 6, of the10th Edition.

Dipl.-Ing (TH) Gerolf Lenz was born in 1945 in Altenberg/Erzgebirge. Following successful craft training as a mason he studied at the Technical College in Wuppertal and subsequently civil engineering at the RWTH Technical University in Aachen.From 1974 until his retirement in 2006, as Head of Division at the Wupperverband (Wupper Association), he was responsible for the operation of wastewater treatment works and, in recent years, active as Head of Staffing in the Board of Management.
In 1985 he took over as spokesman of the DWA Specialist Committee "Specialists". He is director of DWA external courses in Nordrhein-Westfalen for the preparation of examinations of the environmental engineering occupation "Specialist for Wastewater Engineering". As director and lecture of these external courses he has prepared more than 1,800 examinees for the examination. Furthermore, from 1998 to 2002 he collaborated as specialist in the amendment process of the environmental engineering occupations of the Federal German State of Nordrhein-Westfalen. Together with Michael Aldick he is responsible for the wastewater engineering part, Chapters 1 to 6 of the 10th Edition.

Jörg Moosburger (born in 1958).comes from Gelsenkirchen. Up until 1984 he worked as an electrician in the coal mining industry. On moving to the Lippeverband (Lippe Association) he was employed first in the mechanical sludge dewatering area, later in various fields of wastewater treatment. As external environmental technician he passed the Wastewater Master Technician examination in 1990 and in 2001 further trained as "Technical Business Economist CCI". Since 1994 he has been employed as Master technician at the Dortmund Scharnhorst wastewater treatment plant.
In 1997 he was appointed as member of the examination committee for wastewater master technicians at the Federal State Environment Office NRW.In addition, since 1999, as lecturer he has instructed future specialists and master technicians in environmental occupations in the fields of electrical, measurement and control and wastewater engineering within the framework of interdisciplinary training and occupational further training. In 2003 he took over the technical direction of the DWA course for the preparation for the wastewater Master technician examination in Essen. In addition he is responsible for the DWA additional training for electro-technically qualified persons. He elaborated the electro-technical part, Chapter 7 of the collection of tasks of the10th Edition book.

Contents

Contents

In Palestine, the existing water and wastewater/sanitation infrastructure suffers from inadequate level of skills in planning, designing, managing, operating and maintaining of the infrastructure to ensure its sustainability. Furthermore, there is no coordinated effort on human resources development aimed to build the needed managerial and technical capacity among water and wastewater service providers. So far, this sector lacks any needs-based capacity building and systematic training arrangements.

The Palestinian Water Authority (PWA) is the official regulatory body within the Palestinian Water Sector responsible for water resource management and protection, as well as being in charge of implementing the water policies, as the Palestinian Water Law issued in 2002 specifies. PWA is mandated in the Water Law to oversee, plan and coordinate training of technical and professional staff at all levels in the water sector. Within this context, PWA has requested the German Technical Cooperation (GTZ) support in managing and coordinating training in the Palestinian Water Sector. GTZ began offering their technical support to PWA since February 2004, through the Training Coordination Project which was integrated into the Human Resources-Sector Development component II of the Water Programme in Palestine as of January 2006.

GTZ is supporting PWA by setting up Training Coordination Units (TCUs) within PWA, appointing technical coordinators, mobilizing support from the German Association for Water, Wastewater and Waste (DWA), carrying out some pilot trainings, planning workshops and organizing study tours.

Four Working Groups, each is chaired by a local expert working in the water sector, has been established in the West Bank and Gaza; consisting of 8 to 10 members representing a variety of stakeholders in the Palestinian Water sector to develop training policy, assess training needs and identify resources. A steering Committee to coach the results of the working groups has been established.

The main objective of the Human Resources- Sector Development Component II of the Water Programme in the Palestinian Territories is that PWA coordination of cooperation between donors, service providers and training providers for professional and technical education and training in the water sector is improved; so that training will be carried out in a coordinated way which is systematic, demand-oriented and uses local, regional and international training resources cost-effectively. This will contribute on the long run to improved delivery of water and wastewater services to the Palestinian population.

The adaptation of "Wastewater Engineering in Question and Answer" comes as a step towards providing quality training material for targeted groups of trainers, students, and vocational staff working in the wastewater field for the aim of enhancing their performance either in delivering or receiving good quality of training feasible to implementation in Palestine and regional countries.

Tasks

Note:

*With the programmed tasks only one
solution is correct*

1.   Types, yields and properties of wastewater

Wastewater is water which is changed in its properties through domestic, commercial, agricultural or other usage and that water flowing off together with this with dry weather (wastewater) as well as that water resulting from precipitation flowing off and collected from the area of built-up and paved surfaces (precipitation water). Wastewater is differentiated according to type, yield and properties

Part (A)

Task 1)

In general the wastewater flowing to a wastewater treatment plant is divided according to its source into four wastewater types.
Name these and give an example for each.

Task 2)

The yield of municipal wastewater corresponds essentially with the domestic consumption of fresh water.
a) Give the average water consumption in countries like Palestine and Jordan in litres per inhabitant and day.

b) Draw a diagram of the typical daily curve of the wastewater inflow to a wastewater treatment plant with 50,000 PT
[y-axis: Q (m³/h); x-axis: time (h)].

Task 3)

Give examples for the following characteristic parameters of municipal wastewater:
1) General parameters.
2) Group parameters.
3) Individual substance parameters.
4) Nutrient parameters.

Task 4)

Municipal wastewater is in part changed in its properties along its flow-path from its place of origin to the wastewater treatment plant.
Name the processes which can lead to changes in the properties of the wastewater along the flowpath.

Task 5)

Protein as part of human nutrition contains nitrogen in the form of amino acids. Correspondingly human metabolic products also consist of organic and inorganic nitrogen compounds.

a) Which organic nitrogen compounds are excreted in large quantities with the urine by humans?
b) On the flow-path from the place of origin to the wastewater treatment plant this organic nitrogen compound is split by enzymes into two inorganic compounds.
  Give the chemical reaction equation of this transformation.
c) How is the transformation process and the corresponding enzyme designated?
d) Inorganic nitrogen compounds flow extensively as ammonium and not as ammoniac into municipal wastewater treatment plants. Describe by what means the position of the balanced reaction
$$NH_3 \; + \; H_2O \; \leftrightarrow \; NH_4^+ \; + \; OH^-$$
  is shifted into ammonium.
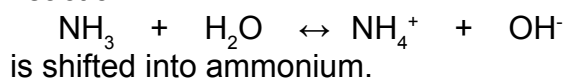
Task 6)

Through the measurement of the electrical conductivity of the wastewater one can determine the:
(a) oxygen content.
(b) concentration of total ions.
(c) acidity.
(d) heavy metal content.
(e) concentration of organic acids.

Task 7)

In the inflow to a municipal wastewater treatment plant the COD = 1000 mg/l and the BOD_5 = 500 mg/l. From these figures it can be identified that one is concerned with:
(a) industrial and domestic wastewater.
(b) domestic wastewater with a high proportion of inorganic content substances from a dairy.
(c) the typical properties of municipal wastewater.
(d) a large amount of stormwater and a very little domestic wastewater.
(e) a large amount of groundwater and precipitation water mixed together with 20 % domestic wastewater.

Task 8)

Nitrogen is present in wastewater in various forms and compounds.
Which of the listed "parameters" is a pure organic composition?
a) Kjeldahl nitrogen (TKN)
b) Amino acid
c) Uric acid ($C_5 H_4 N_4 =O_3$)
d) Total nitrogen (total N)
e) Nitrogen in total (N_{tot})

Task 9)

As infiltration water one designates the inflow into the sewer system of:
(a) damaging commercial/industrial wastewater.
(b) unapproved connections.
(c) water which runs in from roof and courtyard surfaces.
(d) groundwater which penetrates through leaks and drains.
(e) flushing water which is used for sewer cleaning.

Task 10)

A dry weather inflow (Q_{dw}) is 100 litres/s. In this there is an infiltration component (Q_{inf})
of 30 %.
a) How many m³ is the infiltration water inflow per day?

b) What influence has a higher infiltration water component on the operation of the wastewater
     treatment plant?

Task 11)

The quantity of wastewater flowing from a combined system into a wastewater treatment plant with
100,000 inhabitants can be taken from the following diagram.
a) How big is the quantity of dry weather water?
b) According to the diagram, how much water can the plant accept as a maximum?
c) How large is the specific wastewater component (m³/(l x d)) of this wastewater treatment plant?
d) Why does this value deviate from the mean specific water consumption (m³/(l x d))?
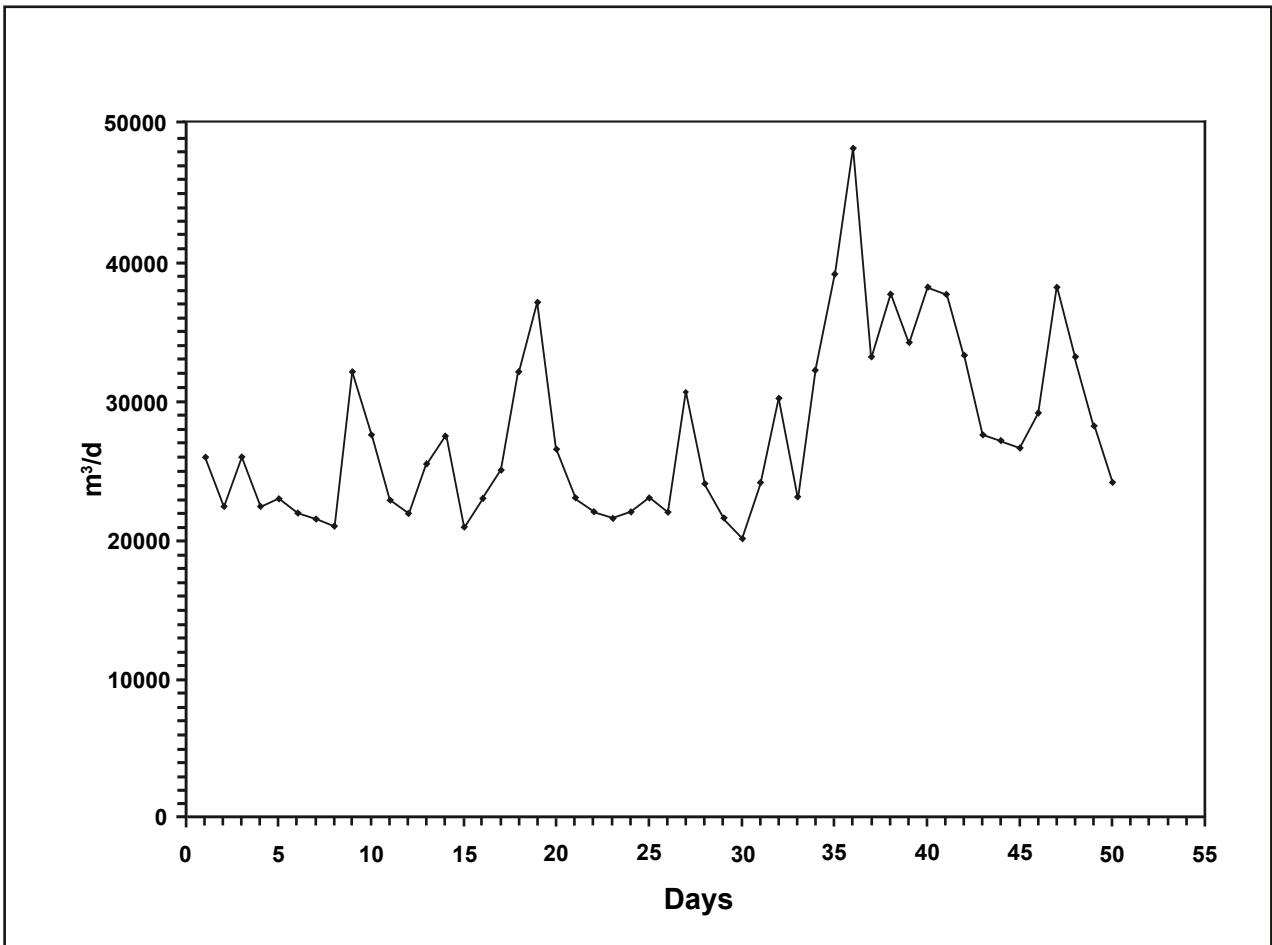
Diag. 1./2:   Inflowing water quantities curve

Part (B)

Task 1)

The hourly variations of the wastewater yield in large wastewater treatment works (with greater wastewater quantities) in comparison with smaller wastewater treatment works (with smaller wastewater quantities) are:
a) Larger
b) Smaller.
c) The same.
d) Larger at night time only.
e) Smaller during the daytime only.

Task 2)

Which type of wastewater contains stormwater?
a) Infiltration water.
b) Commercial/industrial wastewater.
c) Combined wastewater.
d) Domestic wastewater.
e) Municipal wastewater.

Task 3)

Which sum parameter covers "all organic carbon compounds" of the wastewater?
a) BOD_5 - ATH
b) BOD_5
c) COD
d) DOC
e) TOC

Task 4)

What is a typical property of domestic wastewater?
a) high alkalinity.
b) high acid content.
c) high salt content.
d) colloid content.
e) content of substances which are difficult to degrade.

Task 5)

Municipal wastewater contains on average 110 mg/l carbohydrates of which 75 % are undissolved. How many ml/litre carbon dioxide are formed in the biological stage at 20°C and 990 mbar and an 85 % conversion of the dissolved carbohydrates according to the following reaction equation?

$$C_6H_{12}O_6 \ + \ 6 \, O_2 \ \rightarrow \ 6 \, CO_2 \ + \ 6 \, H_2O$$
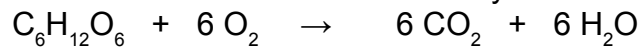
2. Operation and maintenance of drainage systems

2.1   Drainage systems

For the collection and discharge of wastewater, depending on local conditions, there are various systems such as separate, combined and modified processes as well as pressure and vacuum systems. In addition to the discharge of precipitation water there is also the possibility of percolation.

Task 1)

Wastewater yielded in properties which are used both residentially and commercially is collected and discharged in sewers.
a) With wastewater treatment what do you understand under the terms
   - combined sewer system?
   - separate sewer system?
b) Give the respective advantages for the combined and separate sewer systems.

Task 2)

In addition to combined and separate systems there are today also modified drainage systems.
a) Explain the principle of the modified drainage systems.
b) Complete the flowpaths with direction (arrows) in the following schematic diagram of a modified combined system.
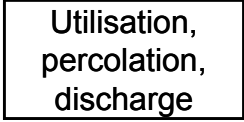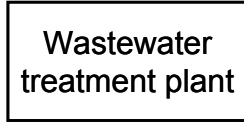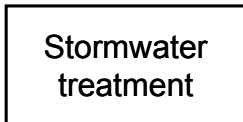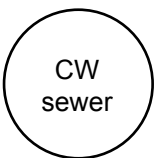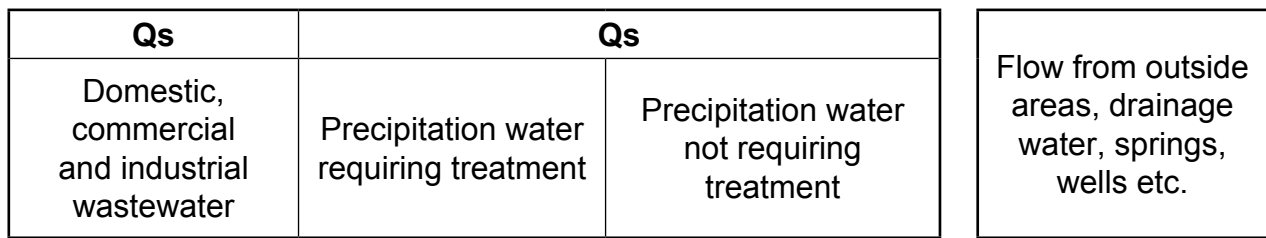
Qs	Qs		Flow from outside areas, drainage water, springs, wells etc.
Domestic, commercial and industrial wastewater	Precipitation water requiring treatment	Precipitation water not requiring treatment	

CW sewer

| Stormwater treatment | Wastewater treatment plant | Utilisation, percolation, discharge |

Body of water ≈≈≈≈≈≈≈ Body of water ≈≈≈≈≈≈≈ Body of water ≈≈≈≈≈≈≈ Body of water

Diag. 2./1/: Schematic representation of drainage in the modified system

Task 3)

Within the framework of domestic and private property drainage explain the following terms:
a) Building/house drain.
b) Down pipe.
c) Connection.

Task 4)

With the separate system wastewater and stormwater sewers are arranged in the road cross-section at different heights.
For what reasons is this arrangement decided?

Task 5)

In addition to the normal drainage processes (separate, combined and modified systems) pressure and vacuum processes are also applied for the disposal of wastewater.
a) Give reasons for the employment of these processes.
b) Name the essential elements of the pressure drainage system.

Task 6)

In addition to discharge the disposal of precipitation water also takes place via percolation.
a) Name the processes for percolation.
b) Give the advantages of wastewater percolation compared with the discharge of precipitation water.

Task 7)

In addition to the conventional discharge systems there are also exist "modified systems". What do you understand by these?
a) Stormwater sewers have to be laid higher than wastewater sewers.
b) Use of precipitation water for the flushing of toilets in households.
c) Limitation of the density of residential development in order to reduce sealed surfaces.
d) To percolate precipitation water not in need of treatment or to discharge it directly into a body of water.
e) Setting up of stormwater collection barrels on private properties.

Task 8)

Which statement about the discharge of wastewater is false?
a) Organic content substances are already converted biochemically with the discharge of the wastewater in the sewer
b) With the combined system, as a rule retention systems are to found in the sewer network.
c) With the separate system only part of the wastewater is treated biologically in the wastewater treatment plant.
d) With the modified system precipitation water not requiring treatment is discharged separately into a body of water.
e) With the combined system wastewater and stormwater are discharged in a common pipeline.

2.2 Sewers and drains

Sewers and drains serve for the collection and discharge of wastewater

Part (A)

Task 1)

Sewers and drains are made from various materials.
a) Name the different materials used for sewers.
b) To which physical and chemical stresses are these materials subjected?

Task 2)

With sewers and drains which factors have an influence on the amount of discharged water?

Task 3)

Name the most important requirements which are placed on sewer pipe connections.

Task 4)

Which tasks have manhole structures in a drainage system?

Task 5)

With sewer construction what do you understand under the terms "Length of reach [sewer section]"?
a) Length of the back-up in the sewer.
b) Covering of the sewer.
c) Maximum length of the sewer.
d) Useful life of a sewer.
e) Separation between two manholes.

Task 6)

A 50 m long drainage sewer is represented on a drawing by a 10 cm line.
Which scale has been selected?
a) 1 : 1000
b) 1 : 500
c) 1 : 200
d) 1 : 100
e) 1 :   50

Task 7)

Calculate the missing details **a – c** in the following value table of the longitudinal section of a sewer:
a) Altitude of invert.
b) Length of reach.
c) Gradient.

Terrain a.m.s.l.	45.22		45.23	45.25		45.17		44.89		44.80
Invert a.m.s.l.	40.90	**a**			40.55	40.35	40.25		40.14		40.14
Gradient	1 : 250		1 : 400			1 : 550		**c**		1 : 250	
Length	47.0 m		65.0 m			**b**		55.0		43.0 m	
Profile	DN 400		DN 400			DN 600		DN 600		DN 600	

Diag. 2.2./1:   Value table of a sewer longitudinal section

Task 8)

A sewer reach is 45.0 m long. The invert altitude at the start of the sewer reach is 317.65 m above mean sea level (a.m.s.l.) and that at the end of the sewer section is 317.15 m a.m.s.l.
Calculate the gradient of the sewer:
a)   in ‰.
b)   in 1 : x

Part (B)

Task 1)

Sewers and intercepting sewers are laid in "free" fall (gradient) and are dimensioned according to the continuity equation.
a) What is the formula for the continuity equation?
b) With sewers and intercepting sewers a minimum velocity must be maintained and, with complete filling, a maximum velocity may not be exceeded.
    Give the minimum velocity (m/s) and the maximum velocity (m/s) each with the respective justification.

Task 2)

With entry into sewers hazards for operating personnel can arise due to gases and vapours.
a) Name the hazardous gases and vapours in sewer systems.
b) For what substance is the sewer atmosphere to be tested before entry and visual inspection?

Task 3)

In addition to sewers and intercepting sewers pressure pipelines also serve for the transport of wastewater.
a) Give the parameters on which the size of the throughflow in the pipeline depends?
b) With a pipeline, about what do the details of the nominal pressure, e.g. PN 10, make a statement?

Task 4)

The securing of pipeline trenches and construction pits is required with the laying of pipelines and with the construction of manholes/special structures
a) Which possibilities exist for the securing of pipeline trenches and construction pits?
b) From what depth of trench must safety measures be taken?

Task 5)

At what height is the back-up level in the public sewer system with domestic connections?
a) 1.0 m under the surface of the road.
b) 1.0 m above the surface of the road.
c) At the height of the cellar floor.
d) At the height of the road surface.
e) Frost-free at a depth of 80cm in the ground.

Task 6)

With the selection of the sewer cross-section and profile what, in general is <u>not</u> taken into account?
a) The discharge.
b) The gradient.
c) The pipe material.
d) The direction of flow.
e) he road profile.

Task 7)

With what water pressure are sewers tested for watertightness after completion?
a) At least 0.1 bar and maximum 0.5 bar.
b) At least 1.0 bar and maximum 5.0 bar.
c) At least 10.0 bar and maximum 25 bar.
d) At least 5.0 bar and maximum 10.0 bar.
e) According to details from the client.

Task 8)

Leaks in the sewer are found mainly:
a) At the crown seam.
b) In the invert drainage.
c) At the pipe walls.
d) At the pipe sockets.
e) At the crown with small earth cover.

Task 9)

Water flows with a velocity of 1.2 m/s through a pipe with cross-section A = 0.8 m^2.
a) How many m^3 of water flow through the pipe per hour?
b) Should the pipe cross-section be reduced or increased if a maximum of 2,000 m^3/h are to flow through this at the same velocity?

Task 10)

The external diameter of a concrete pipe is 1,000 mm. The wall thickness of the concrete pipe is 10 % of the external diameter.
a) Calculate the internal diameter and the wall thickness of the pipe.
b) Calculate the mass of the pipe (in t) with a length of 2.0 m and a density ρ (concrete) of 2.5 kg/m^3.

2.3   Pumps and pumping stations

In wastewater engineering pumps with different impeller shapes are employed depending on rate of delivery/delivery quantity, delivery head, distance and terrain shape (topographical conditions),

Part (A)

Task 1)

In wastewater engineering pumps/pumping stations are often employed.
a) Which types of pump are primarily employed in wastewater engineering?
b) Which parts of a pump wear particularly quickly?

Task 2)

Pumps are dimensioned according to the delivery rate and/or motor drive output.
a) What is the simplified basic formula for pumps?
b) What does manometric head mean?

Task 3)

Which type of pump would you select respectively for the fields of application Nos. I to V listed below?
1. Digested sludge from the sludge silo to the sludge dewatering plant (high pressures).
2. Analyses pumps of an online measuring device in the laboratory (small quantities, low pressure).
3. Phosphate material dosing at a dosing station (precise dosing).
4. Feed pump for the classifier at the grit chamber (large inflow quantities).
5. Primary sludge feeding to the digester (high pressures).

Task 4)

If the rpm of a centrifugal pump are changed (e.g. through change of frequency), then some pump and plant parameters also change. Give the parameters which can change in connection with this.

Task 5)

The total suction head of pumps is limited.
a) How large is the theoretical total suction head at normal pressure?
b) How large is the total suction head achievable in operation?

Task 6)

Two centrifugal pumps of the same size are operated in parallel.
What happens to the delivery rate (Q) following failure of one pump?
a) it is exactly the same as before.
b) It is exactly 50 %.
c) It is less than 50 %.
d) It is more than 50 %.
e) It is zero.

Task 7)

What does the Q-H characteristic diagram of a centrifugal pump show for a certain delivery rate?
a) The appropriate current consumption.
b) The appropriate pressure head.
c) The corresponding economic efficiency.
d) The appropriate total suction head.
e) The corresponding efficiency.

Task 8)

With the emptying of the pump sump the pump is no longer switched off automatically.
What needs to be done?
a) Switch off the pump and check the water level-dependent control.
b) Let the pump continue to run.
c) Slightly loosen the stuffing box.
(d) Switch off the automatic operation and change to manual switching.
(e) Switch of the pump facility completely.

Task 9)

To fill a 750 litre overhead tank at a height of 21.5 m with water a pump requires 18.5 minutes.
How great is the efficiency of the facility if the power fed to the motor is 250 watts?

Task 10)

A reservoir with a volume of 2,400 m3 contents is emptied using three similar Pumps A, B
and C (each pump respectively 100 m³/h capacity). At 0700h all three pumps are switched on
simultaneously. At 0930h (after 2.5 h) Pump A fails. Following successful repair Pump A was
switched on again at 1300h.
At what time is the reservoir tank emptied?

Part B)

Task 1)

With the centrifugal pump of a pumping station various operating situations occur (see table below).
Mark with a cross the respective correct solution from the three possible answers.

- A.   Pump does not deliver.
- B.   The delivery rate is too low.
- C.   Pump runs unevenly and makes loud noises

	Situation:	Solution:		
		A	B	C
1)	Motor does not run			
2)	Air is not completely removed from the pipeline			
3)	Valve pressure line is not opened			
4)	Valve suction line is not completely opened			
5)	Pump bearing is defect			
6)	Motor bearing is defect			
7)	Pressure line is blocked			
8)	With star-delta switching the motor runs only in the star level			

Task 2)

A centrifugal pump with a larger delivery head than planned is employed.
What is changed by this?

Task 3)

A submerged motor pump no longer produces the required rate of delivery and delivery pressure.
Name the possible causes.

Task 4)

What do you understand by the best efficiency point of a pump?

Task 5)

A centrifugal pump creates the highest pressure:
a) With free discharge.
b) With normal delivery.
c) With the lowest delivery head.
d) With opened check valve.
e) With closed pressure valve.

Task 6)

By what is the efficiency of a pump influenced?
a) The impeller diameter.
b) The friction losses in the pressure line.
c)   Leakage and friction losses in the pump.
d) The reactive current consumption.
e) The number of operating hours.

Task 7)

What is a mammoth pump?
a) A special eccentric screw pump.
b) A large centrifugal pump.
c) An air lift pump.
d) A large piston pump.
e) A special propeller pump.

Task 8)

With a pump what does a floating ring seal do?
a) Seal the pump space.
b) Mount the pump shaft.
c) Secure the stuffing box.
d) Seal the shaft end from the pump housing.
e) Ease pump maintenance.

Task9)

The rate of flow with a screw elevator is to be reduced through a reduction of the motor pulley. The motor rotates at 1,300 rpm. The motor pulley has a diameter (d1) of 100 mm, the pulley on the gear a diameter (d2) of 120 mm. The gear has a ratio (GR) of 1 : 20. What are the rpm (n_s) of the screw elevator?

Task 10)

A new underwater pump and a new ascending pipe are to be installed in a deep well. The pump is to deliver 26 l/s at a manometric height of 84.5 m (h_{man}).
Which motor power (P_M) and which nominal diameter of the ascending pipe (DN) are to be selected if the flow rate of v = 2.4 m/s in the ascending pipe may not be exceeded? The efficiency of the pump is 75 % and that of the motor 90 % (acceleration due to gravity g = 9.81 m/s²).

2.4 Sewer operation

Sewer operation has the task of inspecting (monitoring), cleaning (servicing) and the repairing of damage (maintenance) in the sewer networks/systems including their special structures (manholes, stormwater tanks).

Part A)

Task 1)

Sewer operation is divided into three fields of activity. Name the three fields of activity and explain these.

Task 2)

The inspection of sewers is an important prerequisite for the timely recognition of whether the sewer has to be cleaned or damage has to be repaired.
a) Name the normal inspection methods.
b) Which damage to the sewer can be discovered as a result of an inspection?

Task 3)

Name the defects which can possibly occur, which influence the functional capability of a sewer (ultimately also the wastewater treatment plant and receiving water) and list the respective effects associated with these.

Task 4)

A sewer film forms in a sewer.
a) Explain the term "sewer film".
b) Name the characteristics of the sewer film advantageous for the sewer.

Task 5)

Which special points are to be taken into account with the laying of a pressure pipeline with a high point?

Task 6)

Describe the procedure with the smoke test for the determination of faulty connections of a wastewater drain in the separate system.

Task 7)

List the pollutants or groups of pollutants with which operating personnel for the sewer system can come into contact. With this, the pollutants or groups of pollutants can have the following characteristics:
1. Toxic.
2. Combustible.
3. Explosive.
4. Oxygen displacing/depleting

Task 8)

With what protective equipment must personnel employed in sewer operation be equipped as a minimum?
Name these equipment components.

Task 9)

Which compounds in the wastewater can, under certain conditions, cause corrosion on concrete sewer network components?
a) NH_4-N
b) Dissolved phosphate
c) NaCl
d) H_2S and sulphide
e) N_2

Task 10)

Which statement about corrosion processes with wastewater containing sulphur is <u>false?</u>
a) In wastewater pipes static water creates a stronger corrosion than flowing water.
b) Concrete corrosion takes place exclusively below the mean water level.
c) Reducing oxygen content in the water encourages corrosion in concrete pipes.
d) Biogenic concrete corrosion is only possible with the presence of certain bacteria.
e) Wastewater containing sulphur encourages concrete corrosion.

Task 11)

A continuous monitoring of the complete network is necessary in order:
a) to be able to check sewer subsections.
b) to enable early detection of any damage or faults.
c) to satisfy regulations.
d) to be able to employ operating personnel.
e) to maintain monthly inspection dates.

Task 12)

Which of the following does not belong to the inspection of a sewer?
a) Detailed visual inspection.
b) Simple visual inspection.
c) Monitoring and assessment of the actual condition.
d) Cleaning and flushing.
e) Watertightness testing.

Part B)

Task 1)

Which normal processes are applied with sewer cleaning?

Task 2)

Describe briefly the two phases of the high pressure process for sewer cleaning.

Task 3)

Describe the principle of the removal of flushings (flushed out material) from a manhole with the aid of a suction vehicle.

Task 4)

Explain in brief the cleaning of a grease separator.

Task 5)

Which hygienic measures are to be observed following sewer cleaning tasks?
a) With the use of cleaning agents.
b) With the drying of hands.
c) With the separation of working from normal clothes.
d) With eating, drinking and smoking during the working period.

Task 6)

A special problem of sewer operation is the control of rats.
a)   Where are rats mainly to be found?
b)   How does the control of rats take place?

Task 7)

When must a sewer be cleaned?

a)   If it rains frequently.
b)   If, with inspection, groundwater is found to be penetrating at the invert.
c)   If a report comes from the wastewater treatment plant that the stormwater tank is filled.
d)   If appreciable deposits are determined.
e)   At least four times per year.

Task 8)

How are sewers cleaned economically which are not man-accessible?
a)   Using c-hoses.
b)   Using jet-washing equipment.
c)   Using high-pressure flushing equipment.
d)   Using a hand winch.

Task 9)

Using which cleaning equipment are particularly bulky obstacles, solid deposits and roots removed in the sewer?
a)   Winched cleaning equipment.
b)   Sewer "polecat".
c)   High-pressure flushing equipment.
d)   Sewer television camera.
e)   Rubber spheres.

Task 10)

A "polecat" is:
a) a flushing/scouring shield.
b) special high-pressure cleaning equipment.
c) a sewer seal/stopper.
d) equipment for the control of rats.
e) sewer cleaning equipment driven forward using backed-up water.

Part C)

Task 1)

Which structural and operational faults can be determined by a sewer inspection?

Task 2)

For a sewer rehabilitation the required construction work must take place via a public request for tenders.
Name the measures which are necessary for the assignment of the construction work.

Task 3)

Which sewer master data should be recorded and stored using ADP?
Name the appropriate parameters.

Task 4)

With the development of a sewer data base with basic data one differentiates between:
a) Defining data and
b) Basic data
Give examples for a) and b).

Task 5)

With the removal of sludge deposits in a sewer system toxic acting gases (danger to life exists) can occur.
 a)   Name the gases that are toxic
 b) Give the reasons why these gases cannot be sensed by smell.

Task 6)

In sewer operation maintenance means:
a) Production of new plant component.
b) Corrections of nuisances which are removed by maintenance work.
c) Repairs of larger sewer damage for the maintenance of the substance.
d) Cleaning and flushing.
e) Preparation of sealing tests.

Task 7)

Which of the measures given below do <u>not</u> belong to the statutory support obligations of an operator of a public network?
a) Local repairs or exchange of damaged pipes or components.
b) Operation of pre-treatment plants with industrial discharges.
c) Servicing of mechanical equipment.
d) Control of rats.
e) Removal of deposits.

Task 8)

With the examination on non-man-accessible sewers a remote TV camera cannot perform the following.
a) All damage to pipes is detected.
b) Points of damage can be considered from different angles.
c) A precise survey of the point of damage is possible.
d) Examinations can be carried out with completely filled profiles.
e) A permanent documentation (photo, film) is possible.

Task 9)

A DN 600 drain requires testing and evaluation with regard to its efficiency during the complete construction period and also during its useful life.
Which of the given tests and evaluations are <u>not</u> suitable for this?
a) Sealing test using air.
b) Sealing test using water.
c) Monitoring of discharges into the system.
d) Visual check by direct inspection.
e) Testing for infiltration.

Task 10)

How are manhole covers, which are frozen solid, dealt with in order that they can be opened?
a) Using soldering irons.
b) Through direct heat.
c) With powerful blows.
d) Using block and tackle.
e) Using salt.

3. Operation and maintenance of wastewater treatment systems

3.1 Flow charts of wastewater treatment systems

A flow chart of a wastewater treatment system serves for a better overview, shows the operating procedure of this system and indicates important components/structures, installations as well as flow paths.

Task 1)

The flow chart of Wastewater treatment plant A shows a wastewater treatment plant (147,385 PT connected) with nitrification and phosphorus removal, to which flows mainly municipal wastewater. The specific loading is 40 g BOD_5/(l x D). The so-called minimum requirements are maintained. These are:

COD:	75 mg/l	NH_4-N:	10 mg/l
BOD_5 :	15 mg/l	N_{inorg}:	13 mg/l
		P_{tot}:	1 mg/l

The diagram has ten serious errors.
Explain in brief what errors are dealt with here. .

Wastewater treatment plant A

F

Optional

SD   Dig.

Sludge and
filtrate water

Q_{FS} = 515 m²/d DS_{FS} = 3.5 g/l

RS

D

Conductivity

RS

Emergency circulation

I

II

III

IV

Effluent concentrations
BOD_5 : 10mg/l   COD 50 mg/l
NH_4-N : 15 mg/l N_{tot} : 10 mg/l
p_{tot} : 0.8 mg/l

Faecal acceptance station
Influent
Q = 27.043 m³/d
$c(BOD_5)$ = 327mg/l

Counterflow screen
2 lane
v = 0.8 m/h

Aerated grit chamber
2 lane
v = 222mA = 80 m²
t = 0.2 h

Digested sludge to digester (Dig.)

Primary settling tank
2 lane (1 lane in operation)
v_{tot} = 2,900 m³ A_{tot}= 2,000 m²
t=1.3 h q_A = 1.1 m/h

Precipitant station
NaOH solution (40 %)

Aeration tanks 1 - 6
(Compressed air)
V_{tot}=21,500 m³
$MLSS_{AT}$=3,5 g/l B_{AT}=0.16 kg/(kg*d)
t_{AT} = 20,8 d

Conductivity measurement

RS counterflow screen

Return sludge pumping station
RR = 1

Secondary settling tank
V_{tot}= 6,595 m³ A = 2,800 m²
t = 5.85 h q_A = 0.4 m/h

4 polishing ponds
V_{tot}=27,000 m³
A_{tot}=3,000 m³

Receiving water

Diag, : 3.1 / 1 : Flow chart wastewater treatment plant A

Task 2)

The flow chart of Wastewater treatment plant B shows a trickling filter with an Imhoff tank (6,142 l) connected to which flows mainly municipal wastewater. The specific loading of the biological stage is 40 g BOD_5 /(l x d), the raw sludge yield 1.5.l/(l x d).
The chart contains five serious mistakes.
Explain in brief what mistakes are concerned with this.

Wastewter treatment plant B

Emergency bypass

Percolating water

Primary sludge

E S

RW = 0.5 Q
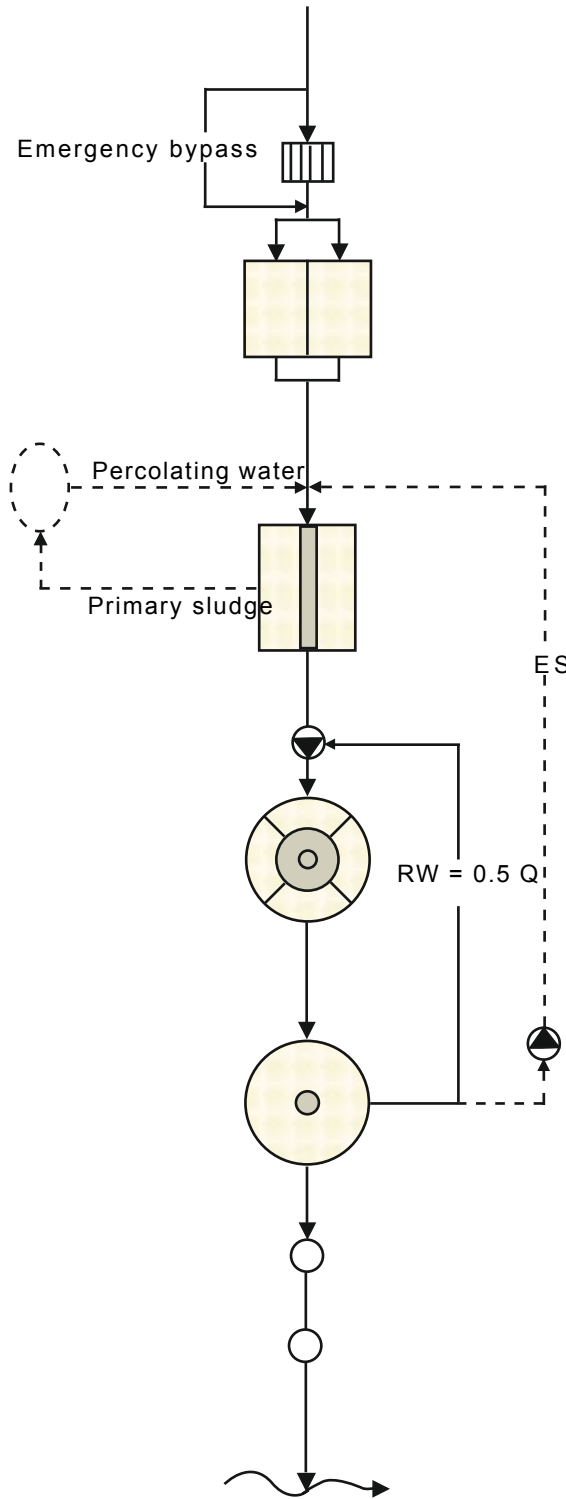
Influent
Q= 1,555 m³/d
$c(BOD_5)$ = 237 mg/litre

Counterflow screen
Gap width 25 mm

Long grit chaber
2 lane (1 lane in operation)
V_{tot}= 12 m³   A= 5.6 m²
t= 0.19 h q_A = 18m/h v_L= 0.3m/s

Primary setting stage
Imhoff tank
V= 155 m³   A= 100 m²
t= 2.4 h q_A = 0.65 m/h
Digester V = 490 m³ t_{dig}= 90d

Trickling filter

V= 263 m³   A= 76.3 m² H= 4.5 m
B_V= 0.62 kg/(m³d) Q_A = 1.3 m/h

Secondary setting stage
Dortmund tank
V= 154 m³   A= 38 m²
t= 24 h (without RW)
q_A = 1.3 m/h (without RW)
RW = return water

Sampling point

Flow measurement

Receiving water

Diag.: 3.1/2: Flow chart Wastewater treatment plant B

3.2   Screen and sieve facilities

Screens and sieves belong to the mechanical treatment stage of wastewater treatment plants. They remove coarse material from the wastewater and are installed as self-cleaning treatment facilities before stormwater and emergency outlets. In the first instance they protect the following mechanical equipment.

Part A)

Task 1)

The mechanical treatment stage in wastewater treatment plants in addition to grit chamber and primary settling tank also includes screens and sieves.
a)   Name the different models of screens.
b)   Name the different models of sieves.
c)   Which rates of flow [m/s] should not be undercut In the screen chamber respectively not exceeded between the screen bars? Justify your answer.

Task 2)

In the side and front elevations of a climbing screen the appropriate components are to be assigned to Nos 1 to 6.
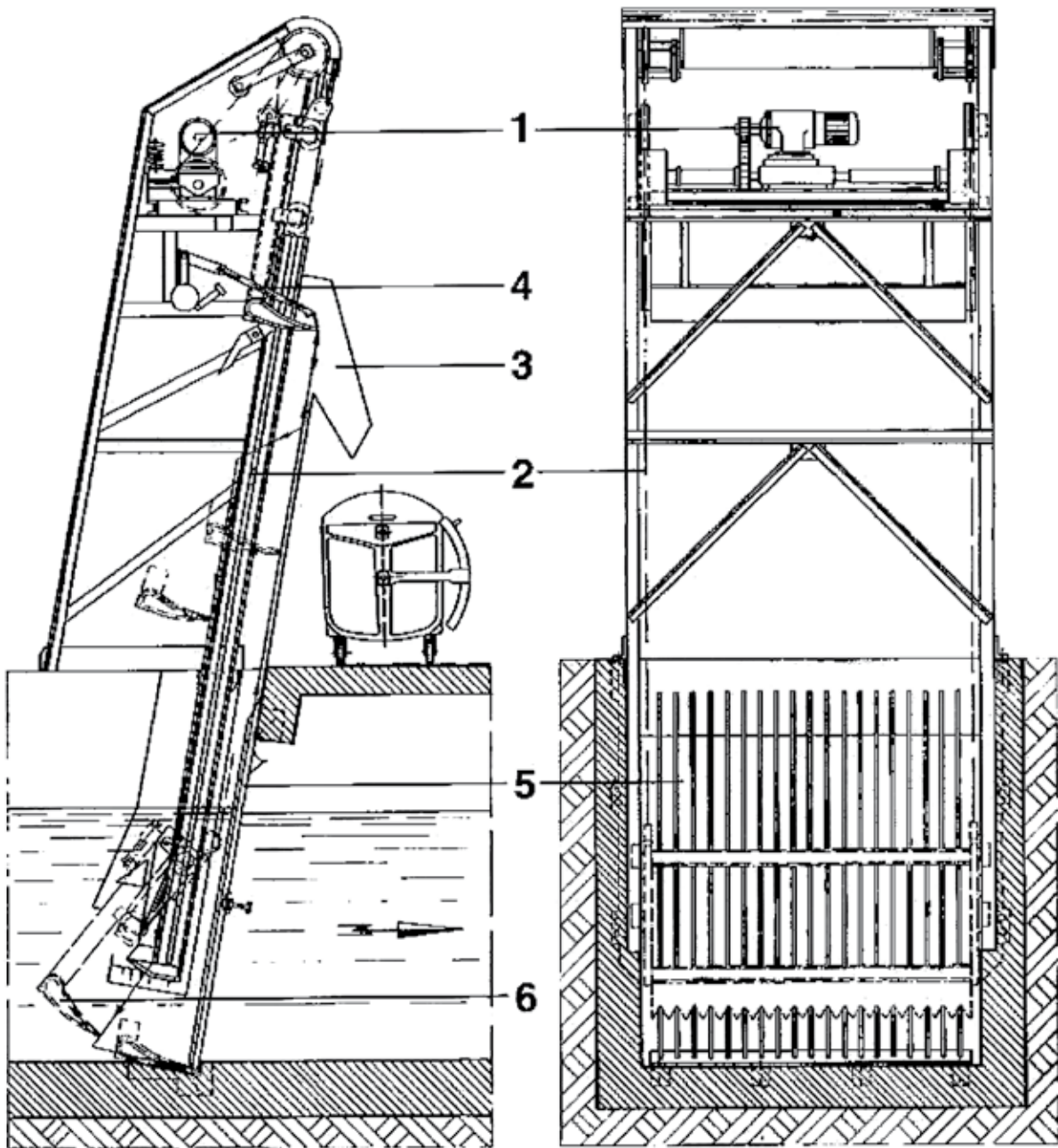
Diag. 3.2/1: Climbing screen

<u>**Task 3)**</u>

In order to control screen facilities a water level difference control is frequently employed.
a) Describe the method of operation of this control system.
b) Which advantage has a control system of this type compared with an operating time-rest time control?

Task 4)

Screen and sieve facilities are today accommodated in buildings. Give the reasons which make installation in a building necessary.

Task 5)

With a closer inspection of the screen you note increased depositing of sand in the area of the screen bars. Name the possible causes for these sand deposits.

Task 6)

Name the advantages of a screenings wash for the operation of the wastewater treatment plant and for the disposal of the screenings.

Task 7)

How often must a mechanically cleaned screen be monitored by the operating personnel?
a) Once or twice a week.
b) Only at the weekend.
c) Once a month.
d)   Once or twice a day.
e)   Almost never, runs automatically.

Task 8)

Which parameter has no influence on the height of the water level before a screen as a result of accumulation of screenings?
a) Rate of flow.
b) Height of the screenings.
c)   Flow velocity.
d)   Shape of the screen bars.
e)   Clear distance between the screen bars.

Task 9)

To what should one pay <u>particular</u> attention with the installation of a heating system in a screen facility?
a) Sufficient aeration and ventilation.
b) Provisions under immission protection law.
c) An explosion protected construction.
d) Provisions under building law.
e) The point of installation in the building

Task 10)

432 m² of screenings are produced annually in a wastewater treatment plant with 48,000 connected inhabitants.
a) How many litres of screenings are produced per inhabitant and year?
b) Is the specific screenings yield with a bar separation of 20 mm seen as being normal, increased or not increased?

Part B)

Task 1)

An existing screen facility with a bar separation of 20 mm is exchanged for a sieve facility with a mesh of 1 mm. Give examples for the effects on the subsequent treatment stages.
a) Grit chamber.
b) Primary settling tank.
c) Aeration tank.
d) Digester.

Task 2)

Name the constructional measures through which, with defects in the screen and sieve facilities, a back-up in the sewer system is avoided.

Task 3)

The inflow is impounded through the installation of a screen or a sieve plant. Name the factors which influence the size of the impoundage.

Task 4)

Name the possibilities which can keep odour nuisances, due to screenings, low.

Task 5)

Which maintenance tasks are to be carried out regularly on screen facilities?

Task 6)

Which answer on the subject of "Screens" is correct?
a) The separation of the screen bars has no influence on the flow velocity.

b) Insufficient removal of coarse material leads to the formation of floating sludge in the grit chamber.
c) The amount of screenings is increased through a washing of screenings.
d) Due to its mineral substances the screenings develop a strong putrid odour.
e) With counter current screens the clearing of the screenings takes place against the direction of flow.

Task 7)

Which particular hazards can occur in a screen building?
a) In winter the screen can freeze.
b) With failure of the screen the screen building can become flooded.
c) With insufficient aeration toxic and explosive air can spread.
d) Change of weather conditions can lead to high condensation in the screen building.
e) With low rates of flow sand can deposit in front of the screen.

Task 8)

What following events result from a filled screen which has not been cleaned?
a) The following grit chamber becomes backed up.
b) The wastewater treatment plant is hydraulically overloaded .
c) An upstream stormwater overflow can activate prematurely.
d) The retention of coarse materials is reduced.
e) The BOD_5 load in the wastewater treatment plant is increased,

Task 9)

The yield of screenings of a wastewater treatment plant results as follows:

January	16.1 t	July	12.3 t
February	16.0 t	August	9.9 t
March	18.0 t	September	18.4 t
April	16.5 t	October	18.2 t
May	20.4	November	16.2 t
June	12.2 t	December	17.8 t

Determine the monthly average and in addition give the minimum and maximum values.

Task 10)

A sieve facility is employed in a wastewater treatment plant (8,000 I) for the removal of coarse material. This sieve facility on average removes 21.5 litre per inhabitant and year
Calculate the annul sieving yield in t (density of sievings: 0.7 kg/l).

3.3   Grit chambers and grease traps

Sand and light materials (such as oil, grease, petrol) disrupt the operational process in wastewater treatment plants in different ways. They are separated out through sedimentation and or floatation processes in grit chambers and grease traps.

Part A)

Task 1)

Name the various types of design of grit chambers and state how these are flowed through.

Task 2)

Aerated grit chambers are favoured for employment in wastewater treatment plants.
a)   Which advantage has an aerated grit chamber over a grit channel?
b)   Why are grit channels built despite this disadvantage?

Task 3)

Using which measures do you check the axial or roller velocities in grit chambers?

Task 4)

How do you determine the efficiency of grit chambers?

Task 5)

Sand is held back in grit channels through:
a) Reduction of the sweeping force.
b) Increase of the flow rate.
c) Density of the wastewater.
d) Aeration of the wastewater.
e) Flotation effect.

Task 6)

The surface flow rate corresponds with the:
a) Horizontal velocity in the grit chamber.
b) Lowest sinking rate of the sand.
c)   Highest sinking rate of the sand.
d) Ratio of throughflow to flowed through cross-section.
e) Ration of throughflow to axial flow rate of the sand.

Task 7)

Grit washers serve for:
a) The avoidance of odour emissions.
b) The increased addition of organic wastewater content substances for the biological phase.
c) The increased reuse of the sand.
d) The lower wear of wastewater pumps and pipelines.
e) The separation of organic substance and sand.

Task 8)

The inflow to a wastewater treatment plan is 200 litres/s. With a surface charging of 0.4 cm/s there results a retention time of 15 min.
a) How deep is the grit chamber
b) How large is the surface area?

Task9)

In a wastewater treatment plant, by means of a grit washer, the organic solid matter (oDS) of 32 % is reduced to 4 %.

The sand mixture yielded (4 litres/I x a) has a DS content of 40 % with a mean density of 1.23 g/cm³.

a) How many tonnes oDS are retained annually through the grit washer if the pure sand has a density of 1.8 g/cm³?

b) How high is the density of the organic solid matter?

Part B)

Task 1)

Name the essential functional elements of a reciprocating classifier.

Task 2)

Following installation of a stronger blower in an aerated grit chamber less sand is yielded.
What is the cause for this change?

Task 3)

Light substances such as oils, greases, petrol, disrupt the clarification process. They are therefore retained at the points where they are produced through the use of oil, grease and petrol separators.
Name:
a) Installations in wastewater treatment plants which separate out light materials which have entered the sewer illegally.
b) Defects in the wastewater treatment plant operation which are caused by light materials.
c) Possibilities for disposal of light materials which are produced in wastewater treatment plants.

Task 4)

The efficiency of grit channels is based substantially on the axial and settling velocities of the smallest grain of sand which is to be deposited (surface charging).
a) Which grain size has the smallest sand grain still to be deposited?
b) Which axial velocity (cm/s) still allows the smallest grain of sand to be deposited and on the other hand keeps sludge particles suspended?

Task 5)

In what way has an aerated grit chamber no advantage compared with a grit channel?
a) Reduction of the organic solid matter fraction in the sand.
b) Flotation of grease.
c) Refreshing of the water.
d) Amount of the level of separation with changing inflows.
e) Degradation of nitrogen compounds.

Task 6)

Grit chamber trappings are not reutilised or disposed of
a) as building material.
b) in landscaping.
c) in waste incineration.
d) on landfills.
e) with recultivation measures.

Task 7)

When a very large amount of sludge settles in an aerated grit chamber, one must
a) reduce the input of air until no more sludge settles.
b) have the sludge pumped out regularly using a suction vehicle.
c) increase the input of air until sludge no longer settles.
d) switch off the aeration completely.
e) increase the return sludge transport.

Task 8)

Complete the system sketch of a light density material separator with all necessary designations and explain to what attention must be paid particularly with emptying in order to guarantee the functional capability of the separator.
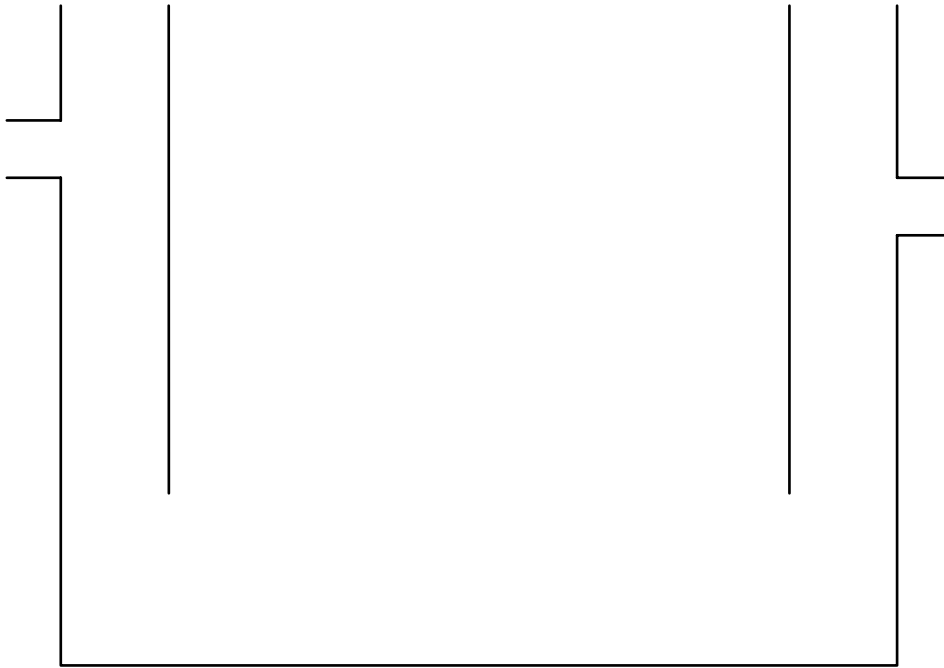
Diag.: 3.3/1: System sketch of a light density material separator

<u>**Task9)**</u>

A grit channel (L = 25 m) with a cross-section as shown below, is charged with Q = 180 litres/s. Determine:

a) The throughflow time (min.)
b) The surface charging.
c) The axial velocity (m/s).
d) Name the measures which are necessary for a secure separation of sand (grain size > 0.2 mm).
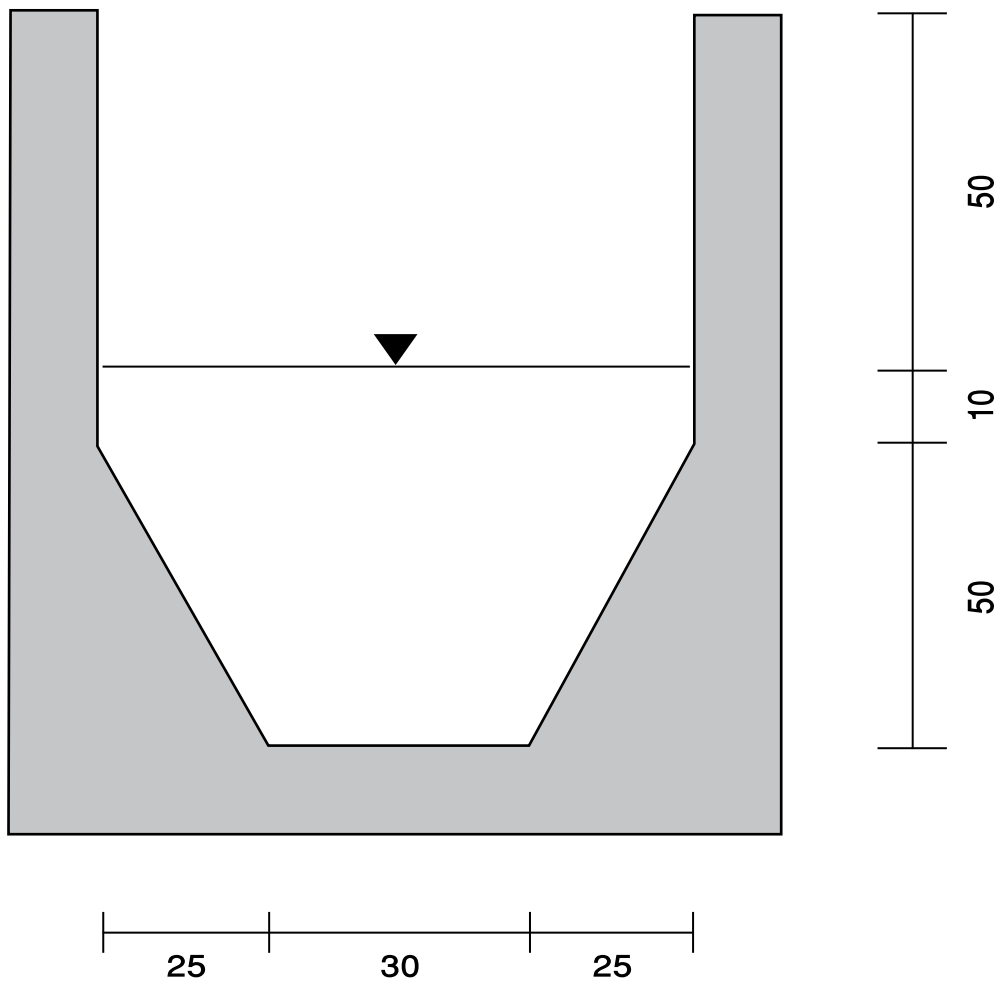
Diag. 3.3/2: Cross-section of a grit channel (in cm)

3.4 Primary settling tanks

Primary settling tanks are sedimentation tanks in which mainly settleable solid matter settles. The settling effect depends on the retention time and the descent velocity of the wastewater content substances.

Part A)

<u>**Task 1)**</u>

Allocate the elements a) to e) below to the appropriate numbers in the top view of the primary settling tank shown:
a) Tank inlet.
b) Bottom clearing scraper.
c) Skimmer.
d) Sludge hopper.
e) Tank outlet.
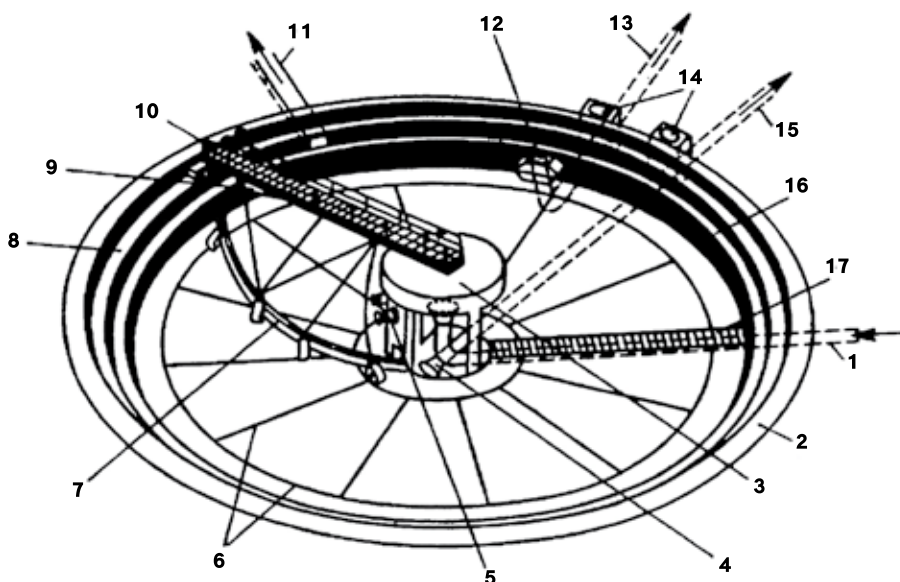
Diag. 3.4/1: Primary settling tank (top view)

From: Hosang: Bischof: Abwassertechnik, 9th Edition 1989 © Teibner, Stuttgart

Task 2)

Primary settling tanks in wastewater treatment plants are differentiated into longitudinal tanks and circular tanks.
a) Which advantages and disadvantages has a longitudinal tank compared with a circular tank?
b) Which types of scraper are employed with longitudinal and circular tanks?

Task 3)

Scraper devices (e.g. longitudinal scrapers) in primary settling tanks serve for the removal of settling and floating sludge.
Which regular maintenance tasks are to be carried out for the ensuring of fault-free operation?

Task 4)

Name the influencing variables which hinder the settling procedure in the primary settling stage.

Task 5)

Which statement about the primary settling stage /the primary settling tank is true?
a) In the primary settling stage the BOD_5 load is reduced by 50 %.
b) In the primary settling tank only suspended solids settle.
c) In the primary settling stage the N load is reduced by 20 %.
d) During a throughflow time of 2 hours almost all settleable matter is deposited.
e) Primary settling tanks are dimensioned larger than secondary settling tanks.

Task 6)

The settling of sludge in the primary settling stage is independent of the:
a) Flow velocity.
b) The rate of clearance.
c) The surface charging.
d) The retention time.
e) The BOD_5 concentration of the wastewater.

Task 7)

A rectangular primary settling tank (L = 50 m and D = 3 m)is charged with a quantity of wastewater of 750 m3/h. The retention time is 1.0 hour. Determine:
a) The surface area (As) in m² of the tank.
b) The flow velocity (v) in cm/s.

Task 8)

200 litres/s flow into a primary settling tank with a volume of 1,080 m³ (L = 54 m; W = 10 m and D = 2.0 m).
a) Calculate the retention time (t) in hours.
b) Calculate the surface charging q_A (m³/(m² x h)).
c) Up to which flow Q (litres/s) will an axial velocity of 2.5 cm/s not be exceeded?

Part B)

Task 1)

Name the effects of a sludge clearance on the primary settling stage at larger time intervals; in particular on the further treatment stages.

Task 2)

Name the causes for buoyancy of sludge cakes (pats) in the primary settling stage.

Task 3)

List the tasks of inlet areas of settling tanks such as, for example, inlet channel, "Stengel"- "Geiger"- or "Stuttgart"-type inlet.

Task 4)

The operation of a primary settling stage of two rectangular tanks causes unpleasant odour emissions which were not to be found in the influent. The sludge hoppers are so designed that the sludge needs to be emptied once a day only. The clearance velocity is 1.5 cm/s and the velocity of the emptying stroke 5 cm/s.
Which operational measures are to be taken in order to guarantee an undisturbed operation of the primary settling stage?

Task 5)

Which effects has an "insufficient" primary settling on the operation of trickling filters?
a) The surface charging is more favourable.
b) The inflow increases.
c) The empty spaces block up.
d) The rotating sprinkler moves more slowly.
e) The degradation performance improves.

Task6)

Which measures do you take if you find an increased sand fraction in the primary sludge?
a) Return the sludge with the sand to the grit chamber.
b) Reduce the flow rate in the grit chamber.
c) Increase the flow rate in the grit chamber.
d) Reduce the flow rate in the primary settling tank.
e) Remove more sludge.

Task7)

The surface charging (m/h) in a primary settling tank is.
a) Smaller than in the secondary settling tank.
b) The same size as in the secondary settling stage.
c) Greater than in the secondary settling stage.
d) Smaller than in the trickling filter.
e) Depends on the composition of the wastewater.

Task8)

200 m^3/h flow into a wastewater treatment plant. The primary settling stage consists of two longitudinal tanks side-by-side with a length of 40.5 m and each a width of 5.0 m. The overfall sill is located over the complete width of the tank.
a) Investigate whether the recommended threshold loading of 35 m^3/(m x h) can be maintained with one tank taken out of operation.
b) What effect has the result on the further treatment of the wastewater.

3.5   Biological wastewater treatment

Biological wastewater treatment corresponds with a shortened and intensified self-cleaning which takes place in bodies of water. It covers the degradation and the removal of dissolved and suspended wastewater content substances (organic carbon, nitrogen and phosphorus compounds) through micro-organisms (mainly bacteria and protozoa) with the utilisation of dissolved oxygen (aerobic conditions). Process steps with bonded oxygen (anoxic) and without oxygen (anaerobic) are also used with this. Treatment takes place in activated sludge or aeration tanks as well as in fixed-bed reactors.

Part A)

Task 1)

The self-cleaning capacity of a body of water depends on the biology of the water and on the nutrients available
List the relevant individual factors for the self-cleaning capacity.

Task 2)

What do you understand by "secondary pollution of a body of water"?

Task 3)

The metabolism of the micro-organisms, in particular of the bacteria, is relevant for the self-cleaning of the body of water.
Explain how and why, below a discharge of wastewater into a body of water the number of bacteria and protozoa changes as well as the oxygen content.

Part B)

Task 1)

In the biological wastewater treatment there are two basic processes: the activated sludge and the fixed-bed processes.
Explain the differences with regard to the important characteristics of the bacteria.

Task 2)

Dissolved wastewater contents are degraded or removed through the biological wastewater treatment.
Give the appropriate biological processes for the three most important substances/substance groups:
-   organic carbon compounds
-   nitrogen compounds
-   phosphorous compounds

Task 3)

The control of the substrate degradation (dissolved organic wastewater content substances) takes place via enzymes which function as catalysers.
a)   Sketch the energy "run" of biochemical reactions.
b)   Name the essential properties of the enzymes.
c)   To which chemical substance group do enzymes belong?

Task 4)

The carbon cycle consists of heterotrophic and autotrophic processes.
Name the respective important characteristics of the two processes and describe these with an equation.

Task 5)

Which statement is correct.
Bacteria:
a) Have a greater operating metabolism than a material metabolism.
b) Are on average 100 m large.
c) Require phosphorous for their metabolism.
d) Possess a nucleus.
e) Breathe dissolved oxygen only.

Task 6)

Which statement about protozoa is correct?
Protozoa:
a) Are pathogenic creatures?
b) Are multicellular.
c) Are a certain type of bacteria.
d) Have a nucleus, mitochondria and an endoplasmatic reticulum.
e) Reproduce themselves more rapidly than bacteria.

Task 7)

Which substances are mainly removed from the wastewater in biological wastewater treatment?
a) Neutral salts.
b) Dissolved organic nitrogen compounds.
c) Odour substances.
d) Dissolved organic substances
e) Adsorbable organic halogen compounds.

Task 8)

Not all dissolved organic Wastewater content substances are converted completely to carbon dioxide and water with biological wastewater treatment. For which compounds and/or substance groups does this apply?
a) Glucose.
b) Ethyl alcohol.
c) Amino acids.
d) Glycerine.

Task9)

Which procedure of wastewater treatment takes place without oxygen?
a) Degradation of dissolved organic carbon compounds.
b) Nitrification.
c) Denitrification.
d) Release of phosphates for the production of energy.
e) Storage of phosphates as energy reserve.

Task10

One describes as "pathogenic germs":
a)   Bacteria not destroyed through sludge digestion.
b)   Germs spread by aerosols.
c)   Suckers from seedlings.
d)   Infectious germs.
e)   Dead bacteria of the activated sludge.

Task11

The rapid and almost complete degradation of organic dissolved carbon compounds with biological wastewater treatment is based on the high metabolic activity of the bacteria.
a) Name the essential elements of bacteria cells.
     State the function of ribosomes.
b) Determine after how many cell divisions more than one million bacteria result from one bacterium and the time for this if their number doubles after every 20 minutes.
c) How much food must a human being weighing 70 kg eat per day if he/she had the same daily food consumption of 10,000 times his/her body weight as do bacteria?

Task 12)

From 100mg/litre carbohydrates in wastewater 75 % are undissolved.
How many millilitres of carbon dioxide are formed by the biological degradation of dissolved carbohydrates (T = 17°C and p = 990 mbars)?
The 90 percentile conversion takes place according to the following equation:

$$C_6\ H_{12}\ O_6\ +\ 6\ O_2\ \rightarrow\ 6\ CO_2\ +\ 6\ H_2O$$
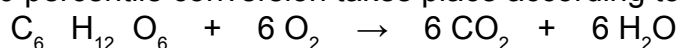
3.6 Activated sludge processes

3.6.1 Aeration tanks (without nitrification)

In the aeration tank without nitrification the degradation of dissolved organic carbon compounds takes place mainly through floc forming bacteria using dissolved oxygen. With this, aeration tank and secondary settlement stage form a process engineering unit. In order to maintain the treatment process the activated sludge retained in the secondary settlement stage must be fed back into the reaction tank. The increase in biomass is removed from the system as excess sludge.

Task 1)

In order to guarantee a secure operation of an activated sludge plant, various characteristic values are to be determined regularly.
Name the essential characteristic values and give their respective process engineering information.

Task 2)

The microscopic picture makes a good statement on the loading condition of the activated sludge plant and possible operational defects.
Describe the characteristics (floc structure, type and number of protozoa) of the activated sludge for the following operating conditions of an activated sludge plant:
a) Highly loaded: $B_{DS} > 1$
b) Normally loaded: $B_{DS} = 0.3$
c) Lightly loaded: $B_{DS} < 0.15$

Task3)

Changes in loading and faults have effects on the operation of aeration tanks and their treatment performance.
Explain in brief the effects of the respective changes and influences on the operation of the plant (aeration tank, secondary settling stage) and the quality of the effluent.
a) Over a longer period of time there is less excess sludge (ES) removal.
b) Due to a fault in the last stormwater overflow (SO) before the wastewater treatment plant there is a hydraulic overloading of 3 Q_{DW} in place of the otherwise inflow of 2 Q_{DW} with rainy weather.
c) The automatic oxygen measurement in the aeration tank has drifted off and instead of a value of 0.5 mg/litre indicates a too high value of 1.5 mg/litre.
d) Through increasing the influent loading the sludge loading of B_{DS} = 0.3 is increased to B_{DS} 0.4 kg BOD_5/(kg DS x d).
e) Through the failure of one return sludge pump the recirculation ratio of RR = 1 has sunk to RR = 0.5.

Task4)

The inflow to an aeration tank is Q = 125 litres/s. 100 litres/s of return sludge are transported with 0.8 % solid matter.
a) With the aid of the diagram determine the mixed liquor suspended solids in the aeration tank (kg $MLSS_{AT}$/m³).
b) How can the $MLSS_{AT}$ be changed to 3.3 kg/m3 without the amount of sludge in the aeration tank being reduced?

RP Recirculation ratio
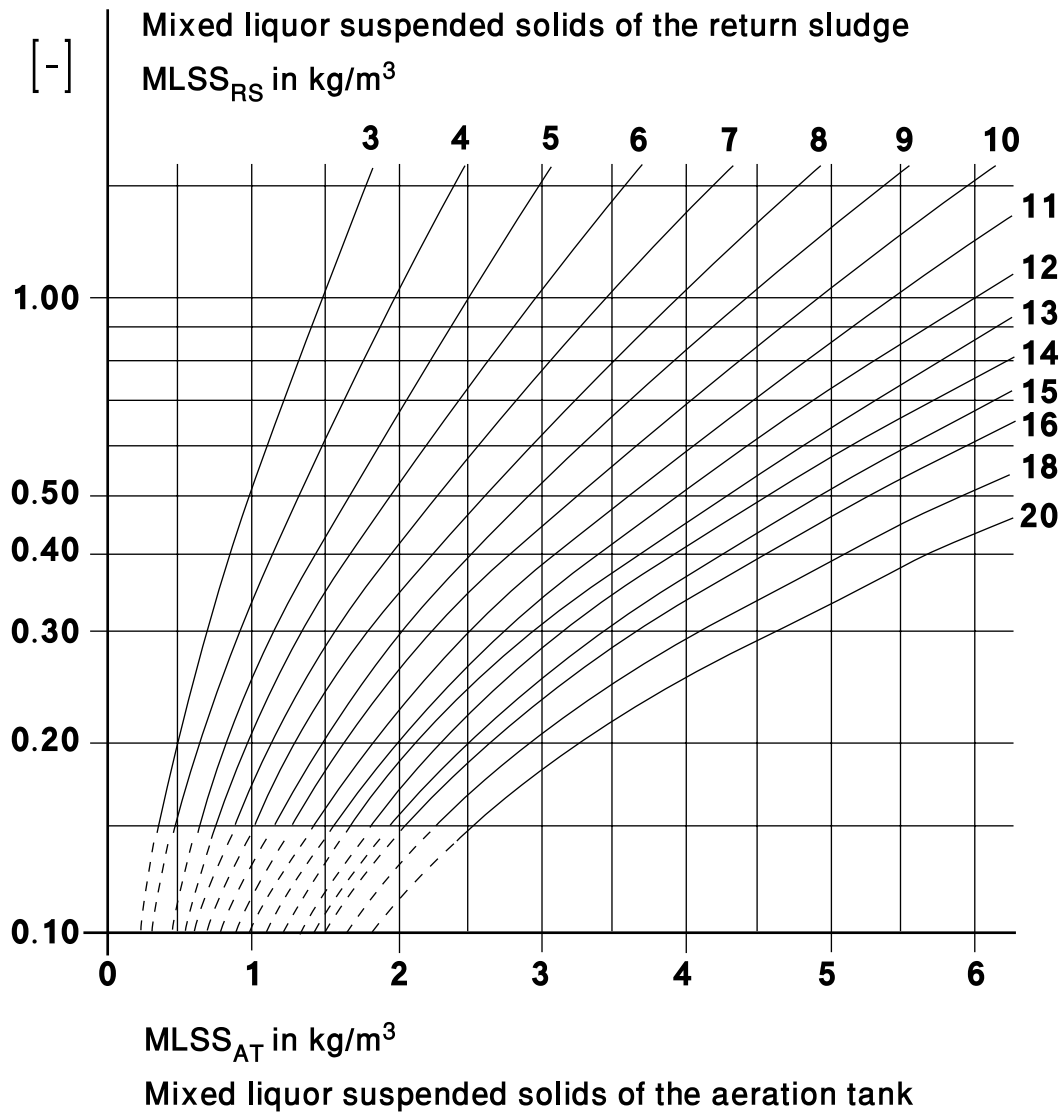
Diag. 3.6.1/1: Recirculation ratio (RR)

Task 5)

The red-brown colour of the activated sludge clearly indicates that:
a) Anaerobic conditions exist in the sludge flocs.
b) The sludge flocs appear as optically "healthy" and oxidised ferric iron (III) is present.
c) The sludge requires more oxygen.
d) The sludge flocs have a high proportion of nitrificants.
e) The sludge flocs have a high proportion of denitrificants.

Task 6)

Which statement on the characteristics of activated sludge flocs is <u>NOT</u> correct.
Activated sludge flocs:
a) Are irregularly formed, have a diameter of from 50 to 500 μm and a specific weight of over 1.0 kg/dm³.
b) Consist of biomass as well as of organic and inorganic accumulations and deposits.
c) Are actively involved in the treatment process with less than 10 % of their volume.
d) Include active and dead biomass.
e) From lightly loaded plants possess a nucleus which consists mainly of inorganic and inactive substances.

Task 7)

In what way does excess sludge differ from return sludge?
a) It is coarse grained and has a lighter colour.
b) It has a darker colour and smells unpleasant.
c) It ha a higher organic solid matter content and has worse thickening characteristic.
d) It has the same solid matter content and is not permanently transported.
e) It has a higher oxygen depletion rate and a greater sludge volume.

Task 8)

Indicate the <u>false </u>statement about aeration tanks.
a) In the aeration tank the wastewater runs through zones with both higher as well as with lower O_2 concentration.
b) In totally thoroughly mixed tanks the wastewater concentration in all parts of the tank are very nearly the same.
c) In tanks with plug flow there is a BOD_5 concentration gradient from inlet to outlet.
d) An increased oxygen transfer (> 3 mg/litre) brings about an improved treatment performance.
e) In activated sludge plants with significant loading variations (day/night) the separation of aeration from circulation effects a saving of energy.

Task 9)

The sludge loading of an activated sludge plant is determined from the following parameters:
a) Inflow quantity activated sludge stage, BOD_5 effluent wastewater treatment plant (WTP), size of aeration tank, DS activated sludge stage.
b) BOD_5 influent WTP, size of aeration tank, DS return sludge, inflow quantity WTP, quantity of return sludge.
c) BOD_5 influent WTP, quantity of inflow WTP, size of aeration tank, DS activated sludge stage, DS return sludge.
d) BOD_5 inflow to activated sludge stage, size of aeration tank, quantity of return sludge, quantity of inflow to activated sludge stage, DS return sludge.
e) BOD_5 influent WTP, DS activated sludge stage, size of aeration tank, quantity of inflow WTP.

Task 10)

An activated sludge plant of V = 1,350 m³ has the following operating data:
Inflow: Q = 75 litres/s
BOD_5 influent: (BOD_5) = 200 mg/litre
Mixed liquor suspended solids in the aeration tank: $MLSS_{AT}$ = 3.3 g/litre
Specific excess sludge production: ES_A = 0.8 kg DS/kg BOD_5
Recirculation ratio: RR = 1.1
Determine:
a) The sludge loading.
b) The daily quantity of excess sludge Q_{ES} (m³/d) produced daily.
c) How many inhabitants (I) per m³ tank volume are treated if the specific influent load to the activated sludge plant is 40 g BOD_5/(I x d)?

Task 11)

In the effluent of a WTP a mean BOD_5 value of (BOD_5) = 35 mg/litre is measured. With this the efficiency is 90 %.
How high must the BOD_5 value be in the effluent in order to achieve an efficiency of 93 %?

Task 12)

In order to match an increase in loading of an activated sludge plant (V = 2,000 m³) the solid matter content is increased from 3.3 g/litre to 3.5 g/litre. 250 m³ of excess sludge with a solid matter content of 6.6 g/litre have to be removed from the plant daily.
For which period of time must the excess sludge removal be set in order to achieve the desired DS content?

3.6.2 Aeration

> **The supply of the aerobic bacteria with oxygen required for their metabolism takes place with the activated sludge process through artificial aeration. In addition, this takes care of the circulation and the mixing of wastewater and sludge.**

Part A)

Task 1)

A sufficient supply of oxygen for the bacteria is the essential task of the aeration in aeration tanks.
a) Which factors have an influence on a modification of the oxygen demand in aeration tanks? Justify your answer.
b) In these cases can one assume a modification of the oxygen concentration in an aeration tank with oxygen regulation?

Task 2)

Substrate and basic respiration are connected with certain types of metabolism of the bacteria.
In wastewater engineering what do you understand by:
a) Substrate respiration?
b) Endogenous respiration?

Task 3)

The transfer of oxygen in wastewater is based on the physical principle of diffusion. Name the different factors on which the diffusion depends.

Task 4)

How does an air bubble, which is inserted into the water at the bottom of an aeration tank, change its rate of climb on the way to the surface of the water?
Explain this process.

Task 5)

With the activated sludge process which statement about aeration is <u>false</u>?
The aeration:
a)   Serves for the supply of oxygen for the bacteria, the circulation and the mixing of the sludge wastewater mixture.
b) Takes place using compressed air, surface and special aeration.
c)   May not be switched off.
d)   Is the greatest energy consumer in wastewater treatment.
e)   Has a low efficiency.

Task 6)

The oxygen transfer (kg O_2/h) in an aeration tank is:
a) Independent of the size of the bubbles and the depth of the tank.
b) With small bubbles is less than with large bubbles.
c) With an O_2 content in the tank of 4 mg/litre smaller than with one of 2 mg/litre.
d) Independent of the type of wastewater (quality).
e) With pure oxygen is greater than with atmospheric oxygen.

Task 7)

A doubling of the oxygen content from 2 mg/litre to 4 mg/litre in an aeration tank causes an:
a) Increased metabolic activity of the bacteria in the same ratio.
b) Increased degradation of the carbon compounds.
c) Increased formation of macroflocs.
d) Increased energy consumption.
e) Increased switching activity of the blower.

Task 8)

Following failure of the aeration the oxygen content in an aeration tank immediately sinks because:
a) The ambient air has too low an oxygen content.
b) The available oxygen immediately escapes from the wastewater.
c)   The bacteria stop the metabolism.
d) The bacteria consume further oxygen through "respiration".
e) The oxygen saturation deficit is too small.

Task9)

By how many percent does the oxygen transfer in an aeration tank sink and thus also the energy consumption if the oxygen content is reduced from 3 mg/litre to 2 mg/litre (oxygen saturation C_s = 10 mg/litre)?

Task10

An aeration tank with a volume: V = L x W x D =
37.5 m x 10.0 m x 4.0 m = 1,500 m³ has an oxygen load with a 24 h mean of 1.08 kg O_2/kg BOD_5. The aeration plant functions with a transfer value of O_N = 1.6 kg O_2/kWh.
Does the power density necessary at night for the oxygen supply of the bioprocess with the existing loading conditions suffice in order to guarantee a sufficient circulation at the floor of the tank?
Solve the task with the aid of both diagrams shown below.
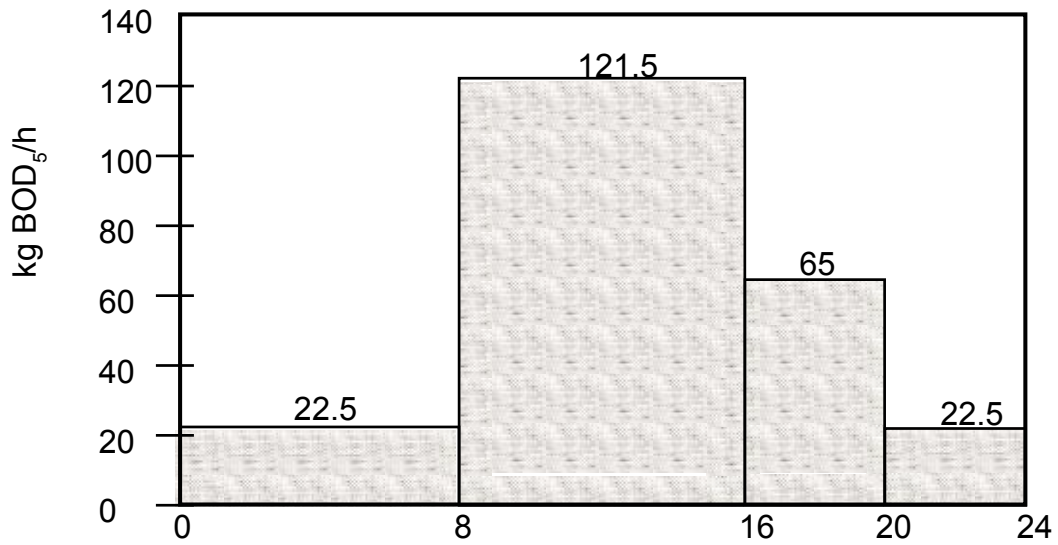
Diag. 3.6.2/1: **BOD$_5$ load hydrograph**
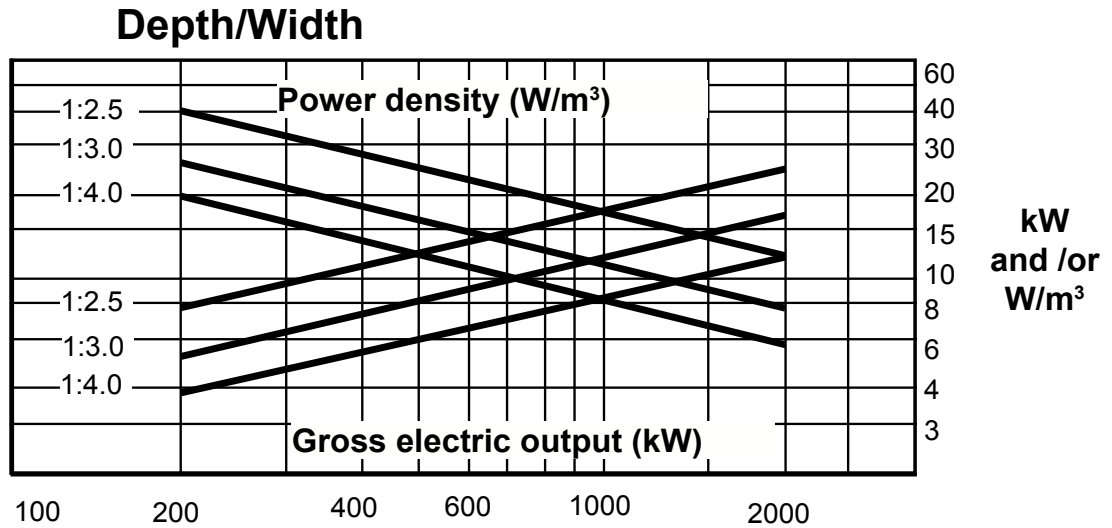
Diag. 3.6.2/2: Performance diagram for tank circulation

From: Hosang; Bischof: Abwassertechnik, 9th Edition 1989 © Teubner, Stuttgart

Part B)

Task 1)

Oxygen is incorporated in the water following different processes and using different plant such as, for example, compressed air, surface aeration and special methods.

a) Name the different aeration devices with which oxygen is incorporated using compressed air aeration.
b) How are surface aerators denoted:
    1. - using vertical wave
    2. - using horizontal wave
c) Which type of special aerators do you know and according to which principle do they function?

Task 2)

With increasing duration of use of compressed air aerators without plastic membrane the required blower output increases continuously in order to guarantee the necessary oxygen transfer.
Give possible causes for this.

Task 3)

With surface aerators the oxygen transfer is regulated in different ways.
Give the possible control systems with:
a) Aerators with vertical wave
b) Aerators with horizontal wave

Task4)

The oxygen transfer in an aeration tank takes place using four roller aerators
d = 0.70 m, L = 2.50 m.
a) With the aid of the diagram (below) determine how many kg oxygen can be transferred by four
rollers with a submerged depth of 15 cm.
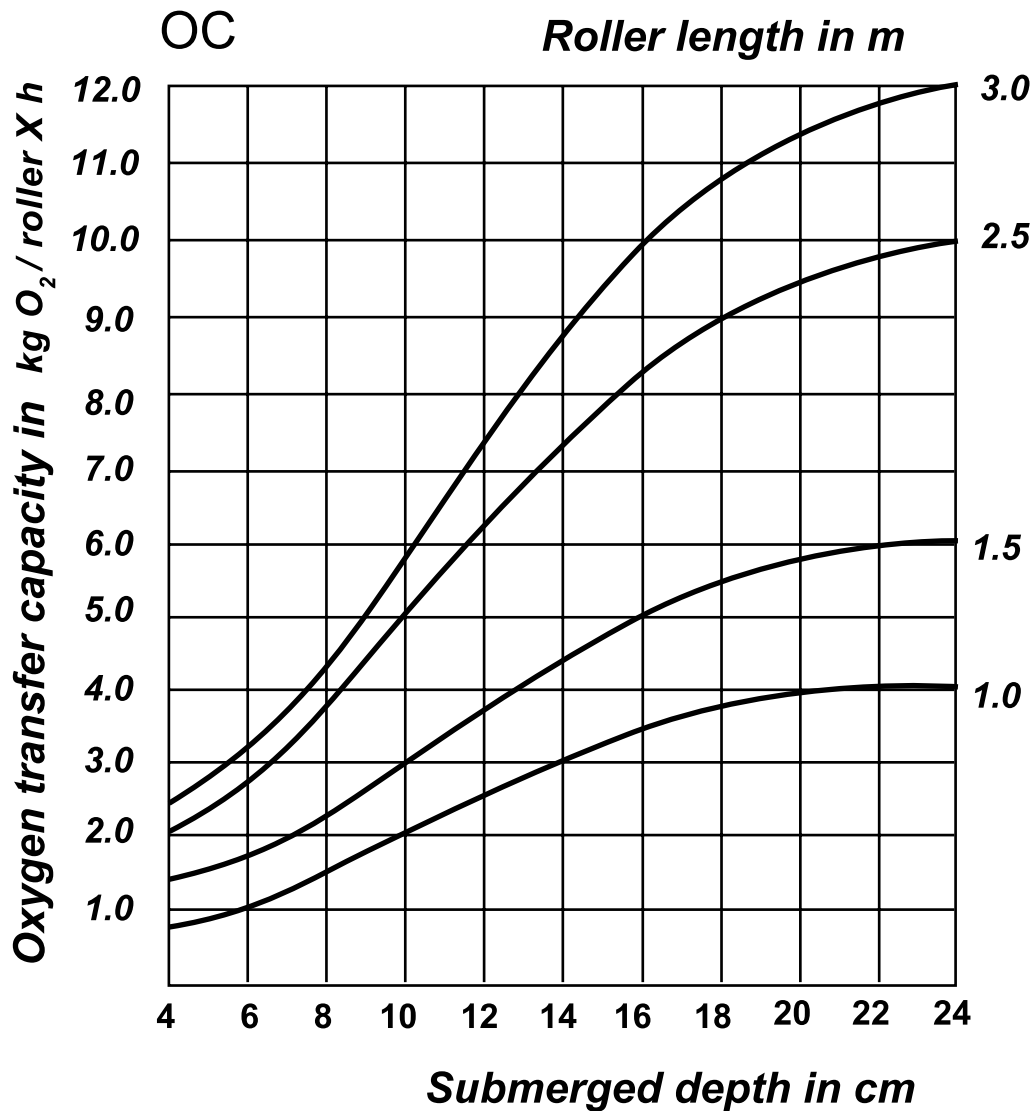
Diag: 3.6.2/3: Oxygen transfer for roller aerators

b) For repair purposes one of the rollers is inactive.
   Give the maximum possible transfer capacity of the remaining three rollers.
c) Why with the increase of submerged depth does the O_2 transfer at first increase up to a max.
   value and then fall again with further increase of the submerged depth (see diagram)?

Task 5)

Which of these devices is <u>not</u> a pressure aeration element?
a) Membrane aerator.
b) Disk aerator.
c) Diffusion aerator.
d) Point aerator.
e) Ball aerator.

Task 6)

Membrane aerator elements do <u>not</u> fulfil the following conditions.
  They:

a) do not block on switching off the aeration.
b) embrittle due to biogenic encrustation of the pores.
c) require an air pressure at least 1 bar higher than ceramic aerators.
d) are employed in tanks with alternating aeration.
e) also exist as disk and plate.

Task 7)

The generation of the quantity of air with the activated sludge process takes place using blowers. Which statement about these air delivery facilities is <u>false</u>?
a) Turbo-blowers produce larger quantities of air than rotary piston blowers.
b) Delivery pressures of blowers in wastewater engineering lie between 500 and 1,000 mbar.
c) Rotary piston blowers are positive displacement devices.
d) Roots blowers are dynamic air generators.
e) With turbo-blowers compression of air takes place through deceleration of the air flow.

Task 8)

A wastewater treatment plant with 50,000 I and a specific loading of the activated sludge stage of 40 g BOD_5 /(I x d) has an OC load in the 24 h mean of O_B = 2 kg O_2/kg BOD_5.
a) How large is the output to be produced by the aeration plant for the required oxygen transfer with a transfer value: ON = 1.5 kg O_2/kWh?
b) The aeration tank with a depth of 5.0 m has an oxygen transfer of 8 g O_2/m$_{depth}$ x m³). What diameter has the main air line if v_{max} = 10 m/s?

Task 9)

A 4.0 m deep aeration tank (V = 4,000 m³) is supplied daily with 259, 200 Nm³ of air.
a) How many Nm³ air per cubic metre and hour are transferred?
b) With the aid of the diagram below determine how high the oxygen transfer efficiency and the amount of oxygen transferred.
c) How much oxygen reaches the aeration tank daily?
d) How much energy is used daily for this?
e) How large is the oxygen capacity factor with 280 g O_2/Nm³ air?
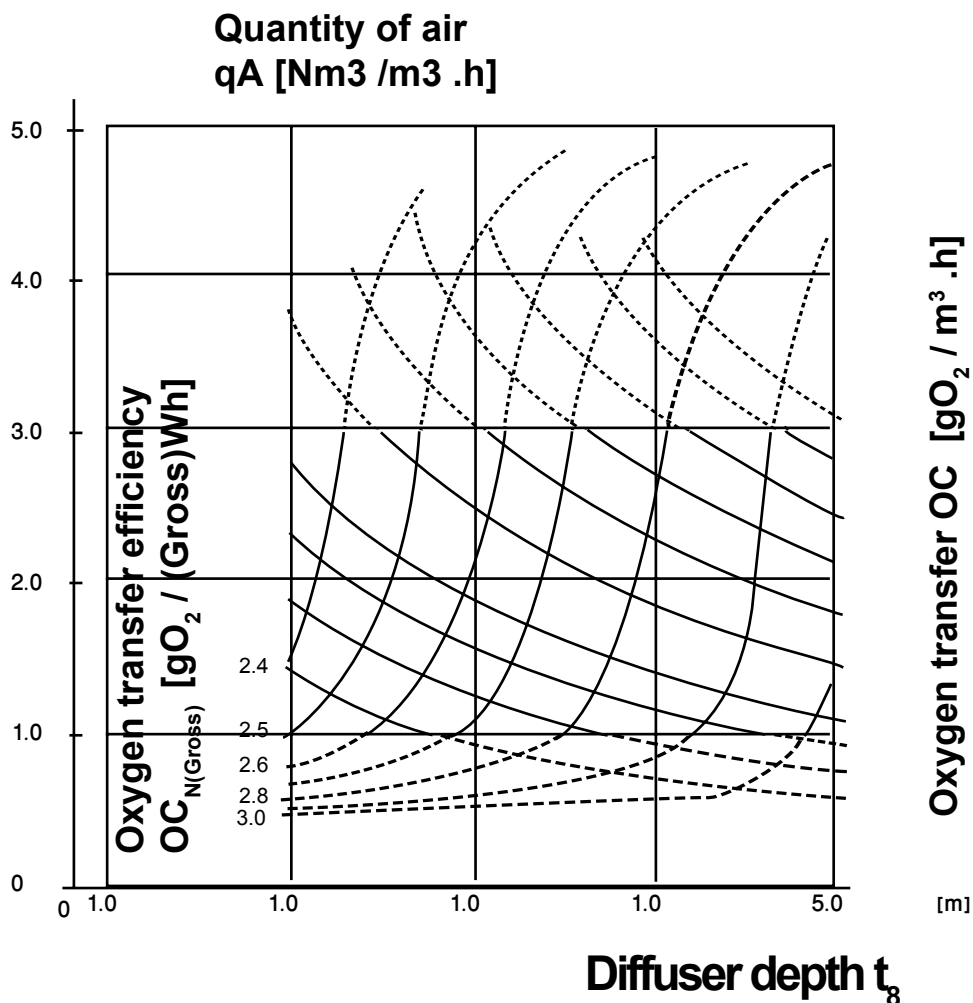
Diag. 3.6.2/4: Nomograph for oxygen transfer efficiency and oxygen transfer

3.6.3 Secondary settling tanks

With the activated sludge process secondary settling tanks together with the reaction tank form a process engineering unit.

Part A)

Task 1)

Within the activated sludge process secondary settling tanks take on important technical process tasks.
a) Which essential functions do secondary settling tanks have to fulfil?
b) Designate the function zones 1 to 4 of a secondary settling tank represented in the diagram.
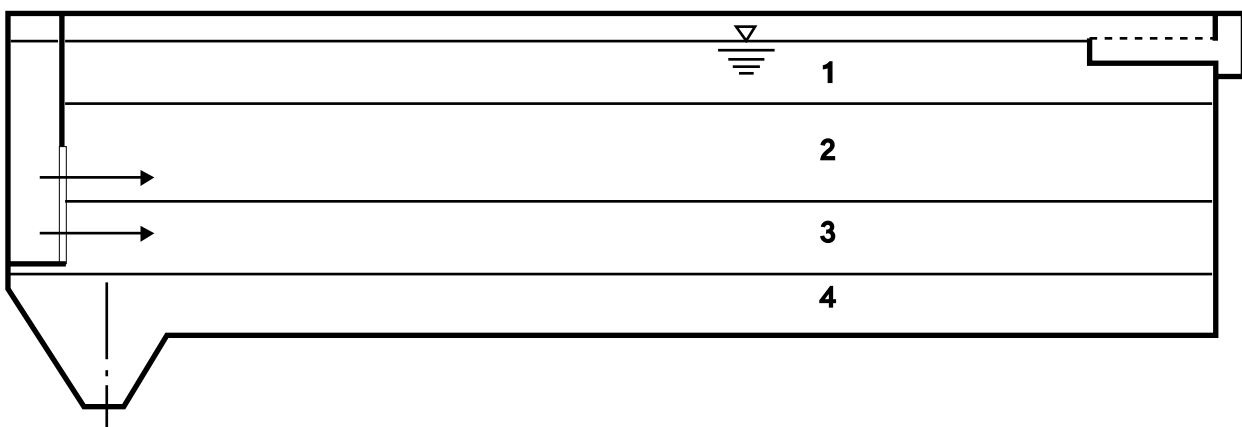
Diag. 3.6.3/1:   Function zones of the secondary settling tank

Task 2)

Assign the following plant and equipment of a circular secondary settling tank to the appropriate numbers 1 to 8 from the section shown below

Plant and equipment	Number
Runoff channel	
Smoothing screen	
Sludge removal pipeline	
Sludge pipeline to the thickener and/or digester	
Sludge chamber	
Sludge hopper	
Floating sludge/scum removal	
Inlet pipe	
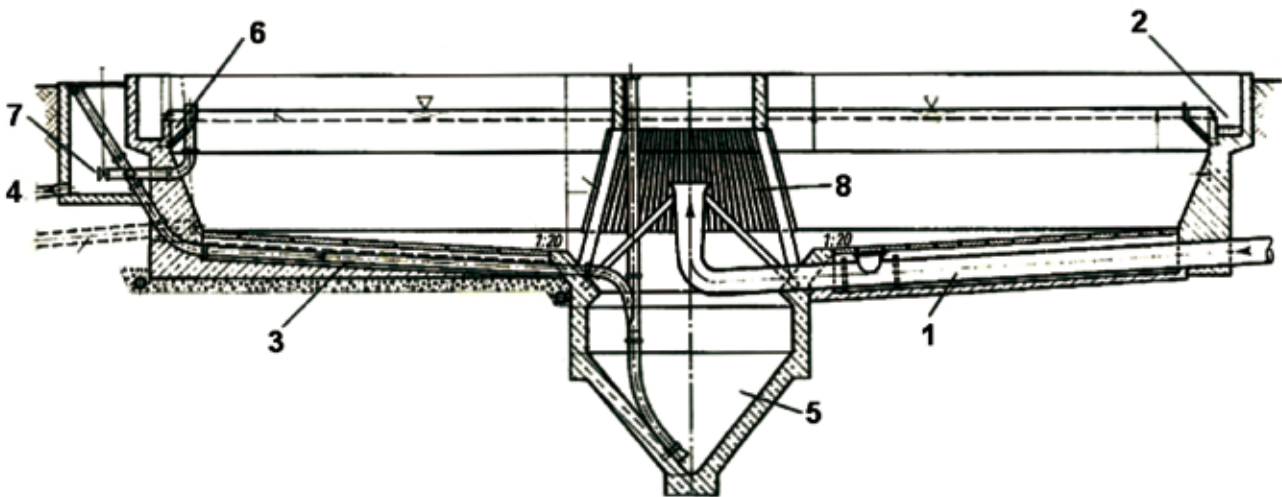
Diag. 3.6.3/2: Section of a circular secondary settling tank

From: Hosang; Bischof: Abwassertechnik, 9th Edition 1989 © Teubner, Stuttgart

Task 3)

The regular, best continuous clearance of the activated sludge deposited in the secondary settling stage and its rapid recirculation into the aeration tank is important for the wastewater treatment process. This takes place depending on the tank design using different scrapers.

a) Which of the three types of scraper
    A: Sludge scraper.
    B: Suction dredge.
    C: Flight scraper.
can be employed for the clearing of sludge in the different tank shapes of secondary settling tanks?
Enter the letters A, B and C in the following table according to all possibilities for employment.

Type of tank	Type of scraper
Longitudinal tank	
Circular tank	
Hopper-bottom tank	

b) List the causes which can lead to an operational fault of the clearance operation.

Task 4)

Which statement about secondary settling tanks (SST) is <u>false</u>?
a) SST of aeration tanks are larger than those of trickling filters.
b) Rectangular SST can also be transversely through-flowed.
c) The efficiency of SST can be improved by the installation of lamella separators.
d) In SST no flotation phenomena can occur.
e) SST are dimensioned for the highest water inflow.

Task 5)

Preferably, circular tanks are employed as secondary settling tank due to the cost-favourable manufacture.
As opposed to rectangular tanks:
a) The hydraulic radius is larger.
b) Scrapers are operated discontinuously.
c) The natural weir overflow charging is greater.
d) The requirement for space is less with the same surface area.
e) The surface area is greater with the same hydraulic loading.

Task 6)

Hopper-bottom tanks:
a) Are designated as Imhoff tanks.
b) Require no mechanical sludge clearance.
c) Have an integrated sludge blanket.
d) Are fitted mainly with suction dredges.
e) Have a hopper slope of ca. 30°.

Task 7)

Which statement about scrapers in secondary settling tanks is <u>false</u>?
a) Suction dredges in circular tanks are operated discontinuously.
b) Sludge scrapers in rectangular tanks are raised during the return run.
c) Scrapers with a friction gear have a non-positive drive.
d) Clearing speeds range from ca. 36 to 72 m/h.
e) In tanks with flight scrapers floating sludge is cleared to the end of the tank.

Task 8)

The circumferences (C) of two circular tanks of a wastewater treatment plant are
A: C = 100 m and B: C = 120 m. The scraper on tank A requires 150 min and that on tank B 180 min for one cycle.
a) After how many minutes are both scrapers for the first time meet in the same staring position?

b) What distance has each scraper covered?

Task 9)

A secondary settling tank with a surface area of A = 3,250 m^2 has a combined water inflow Q_{CW} = 2 QDW = 1,000 litres/s. With meeting a recirculation ratio of RR = 0.5, the solid matter content in the aeration tank is DS = 3g/litre. The sludge volume is determined as SV = 300 ml/litre.

Calculate the sludge index taking into account the highest inflow (Q_{CW} + Q_{RS}), the sludge volume charging and the surface charging.
Assess this result.

Part B)

Task 1)

The presence of suspended solids and sludge particles in the effluent of the secondary settling stage is an unwanted bit frequent phenomenon which, in the worst case, can lead to the non-fulfilment of the wastewater treatment plant monitoring value.
List the causes for these problems

Task 2)

How does the negative lift of sludge affect the operation of an activated sludge plant?

Task 3)

Name the different causes of the formation of bulking sludge in activated sludge plants

Task 4)

Why do fully mixed aeration tanks tend more to the formation of bulking sludge than plug flow tank?

Task 5)

Bulking sludge is recognised through three combined forms of phenomena and conditions.
Which combination is correct?
a) -   Occurrences of large quantities of sapling bacteria
   -   High sludge index
   -   High sludge loading

b) -   Abnormally large turbulence in the aeration tank
   -   Poisoning of the sludge
   -   Break-down of the sludge flocs

c) -   Occurrences of large quantities of filamentous bacteria and, to a lesser degree, fungi.
   -   High sludge index.

- Quantity of sludge standing in the body of water.
d) - Freely suspended bacteria in the secondary settling stage.
- Lack of protozoa in the sludge.
- High sludge loading
e) - Occurrences of large quantities of actinomycete.
- Gas bubbles enclosed in the sludge flocs.
- Formation of a sludge blanket on the surface of the water.

Task 6)

Not among the measures for combating or preventing the formation of bulking sludge is:
a) Taking the primary settling stage out of operation.
b) Simultaneous p-precipitation.
c) Chlorinating the activated sludge.
d) Balancing the nutrient ratio through addition of commercial fertiliser.
e) Addition of an upstream lightly loaded tank before the aeration tank.

3.7   Nitrogen removal

Nitrogen compounds, as plant nutrients, lead to eutrophication of the body of water. They are therefore removed from the wastewater using expensive process technology in wastewater treatment plants.

Part A)

Task 1)

Nitrogen removal takes place in wastewater treatment plants through the biological-chemical processes of nitrification and denitrification.
Describe both processes briefly.

Task 2)

As opposed to the degradation of dissolved organic carbon compounds a stable elimination process of nitrogen compounds is dependent on several constraints:
a)   Name and explain the appropriate prerequisites for nitrification.
b)   Name and explain the appropriate prerequisites for denitrification.

Task 3)

The sludge age with nitrification is an important process-technical parameter. Which statement is false?
a) Is larger or at least the same as the generation time of the micro-organisms.
b) Is the ratio of sludge removed daily to the total quantity of sludge in the aeration tank.
c) Corresponds with the mean retention time of the sludge in the biological stage.
d) Is in plants with low sludge loading greater than in plants with high sludge loading.
e) Is an important parameter in connection with the oxidation of the nitrogen compounds in the aeration tank.

Task 4)

Which end products result with complete nitrification?
a) Nitrite and water.
b) Nitric acid and water.
c) Nitrate and OH ions
d) Ammonia and water.
e) Nitrate and nitrogen

Task 5)

In which lines are all changes of the four given parameters for the nitrification (NIT) and denitrification (DN) of a plant with upstream denitrification reproduced correctly?

	H^+	NH_4^+	NO_3^-	OH^-
a) NIT:	f	f	i	f
b) DN:	f	s	f	i
c) NIT:	i	f	i	i
d) DN:	f	f	f	i
e) NIT:	i	i	i	f

I = increasing;   f = falling;   s = remains the same

Task 6)

In which lines is a "nitrogen conversion" reproduced correctly?

	Initial substance	Conversion	End product
a)	NO_2^-	Nitritation	NO_3^-
b)	NO_2^{2-}	Nitrification	NO_3^-
c)	NH_4^+	Denitrification	N_2
d)	$NH_2\text{-}CO\text{-}H_2N$	Ammonification	NH_3
e)	NO_3^-	De-ammonification	N_2

Task 7)

An activated sludge plant with upstream denitrification for 30,000 l is loaded in the biological part with B_d (BOD_5) = 50 g/(l x d) and B_d (NH_4-N) = 10 g/(l x d). The influent to the 4,500 m³ large aeration tank is 100 litres/s. With a recirculation ratio of RR = 1 daily 108 m³ excess sludge with a solid matter content DS_{ES} = 6.6 g/litre are removed.
Calculate:
a) The sludge loading.
b) The sludge age.
c) How large must the volume of the DN tank (V_D) be in order to maintain the minimum requirement (N_{tot} = NH_4-N + NO_3-N) = 18 mg/litre.
    Determine the required volume with the aid of Table 4 of the DWA Standard A 131E

Denitrification	Upstream	Simultaneous
	Denitrification capacity in kg NO_3-N_D / kg BOD_5 ; T = 10°C	
V_D/V_{AT}		
0.20	0.07	0.05
0.30	0.10	0.08
0.40	0.12	0.11
0.50	0.14	0.14

Diag. 3.7/2:   Table 4 DWA-A 131E

Part B)

Task1)

There are numerous process variants for nitrogen removal.

a) Give the designation of the four processes presented:
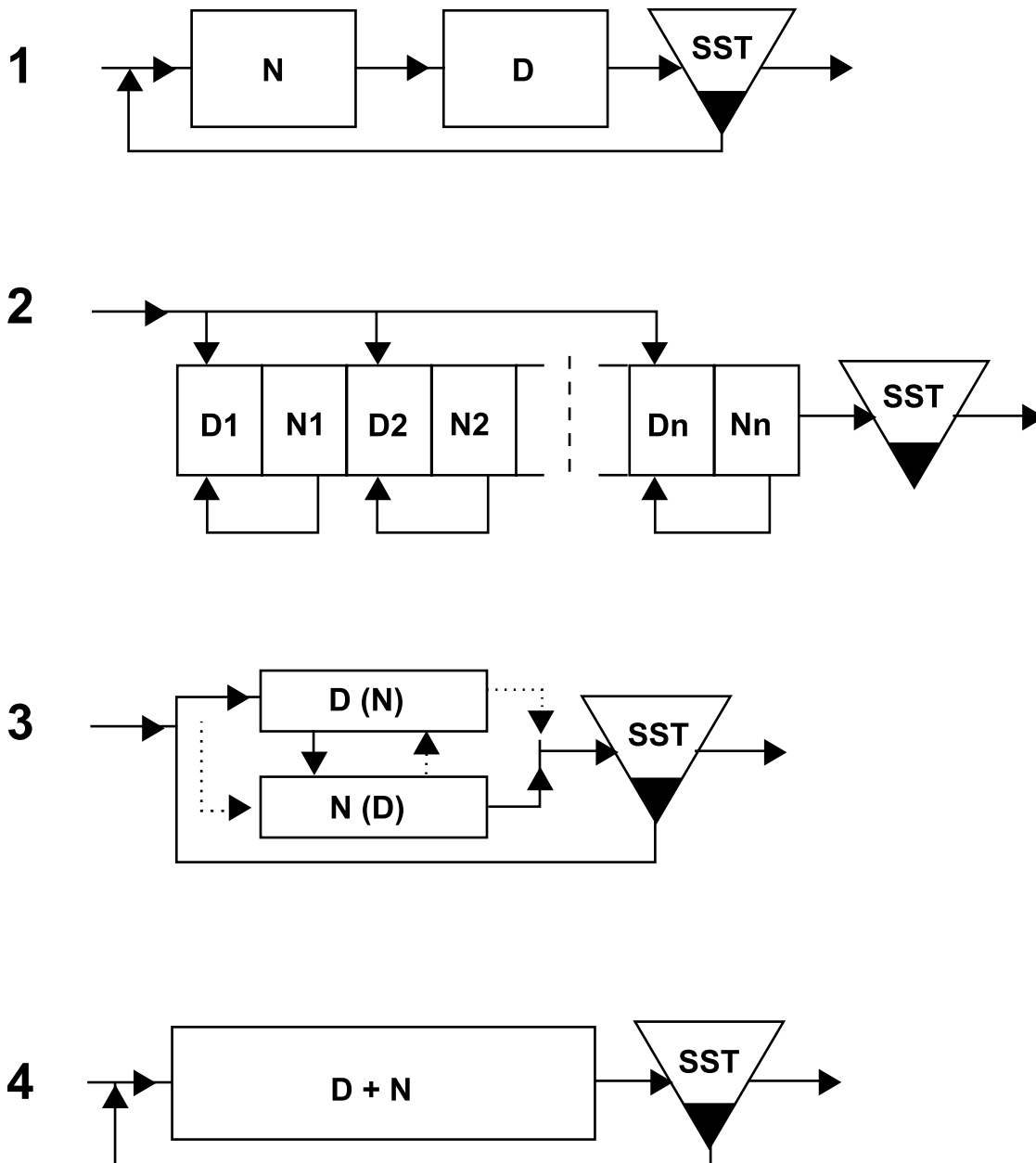
Diag. 3.7/3: DN process diagram

b) Give the advantages of process Variant 2 compared with the other variants.

c) Explain the difference of Variant 4 to an intermittent DN

Task2)

With an upstream denitrification there are several control loops for the control of the process.
a) Complete the flow diagram (Diag. 3.7/4) with a control concept for the O_2 transfer efficiency
    taking into account an O_2 design value for a possible aeration of DN
    Tank 2.
    Represent the controller using an R in the circuit.

AIR

RETURN FEED
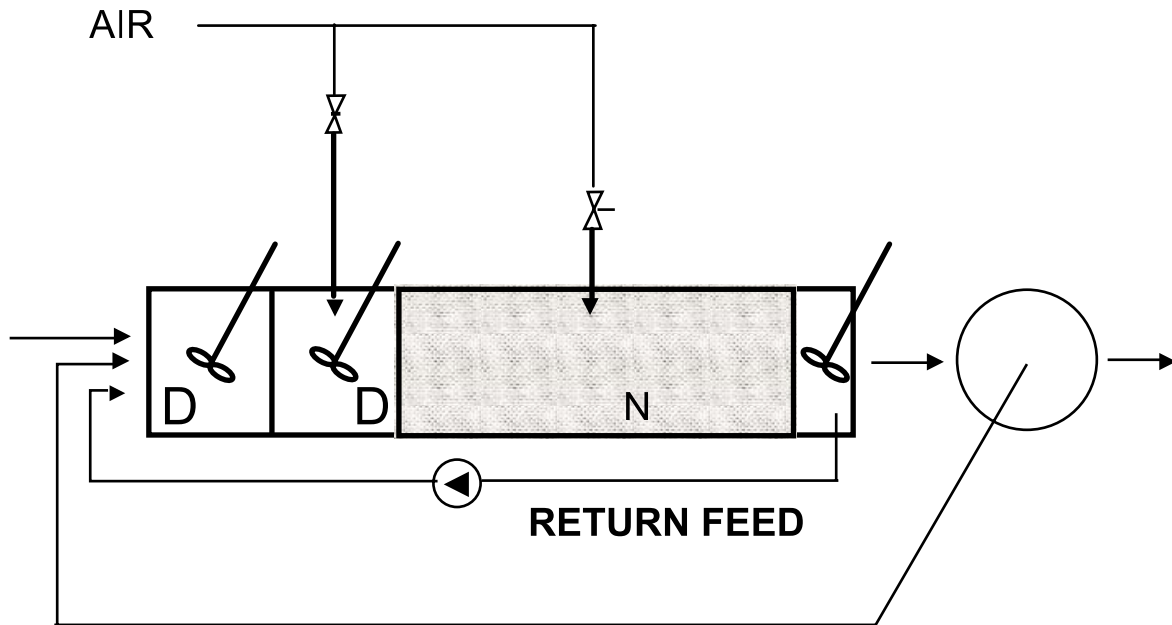
Diag. 3.7/4:   Control concept of an upstream denitrification

b) Complete the flow diagram (Diag. 3.7/4) with a control concept for the NO_3^- transfer efficiency
    taking into account NO_3 design values in Tanks DN 1 and Tank DN 2.

c) Give the following process, measuring and control (PMC) parameters for the control concept b)
    recirculation.
    1. Disturbance variable.
    2. Control member.
    3. Measured/controlled variable.
    4. Design value.
    5. Correcting variable

Task 3)

Through the comparison of which measured values can the nitrification performance of a wastewater treatment plant be determined?
a) TKN value effluent PSS and TKN value effluent WTP.
b) TKN value effluent PSS and NO_3 value effluent WTP.
c) NO_3 value effluent PSS and NO_3 value effluent WTP.
d) NH_4 value effluent PSS and NO_3 value effluent WTP.
e) NH_4 value effluent PSS and TKN value effluent WTP.

Task 4)

For the optimisation of the nitrogen removal from activated sludge plants with upstream denitrification various parameters are measured. Which measurements are useful?
a) O_2 measurement in the secondary settling stage.
b) NO_2^- measurement in the nitrification zone.
c) NH_4^+ measurement in the denitrification zone.
d) NO_3^- measurement in the denitrification zone.
e) N_2 measurement in the nitrification zone

Task 5)

In addition to methanol there are numerous compounds which are added as external carbon source with denitrification.
Which organic compounds are among these?
a) $CH\,Cl_3$
b) $C_6\,H_5\,OH$
c) $C_6\,H_{14}$
d) $CH_3\,COOH$
e) $H_2\,CO_3$

Task 6)

With the aid of the reaction equation
$$NH_4^+ + 2\,O_2 \quad \rightarrow \quad NO_3^- + H_2O + 2\,H^+$$
determine how many g O_2 are required for the oxidation of one gramme NH_4-N to nitrate.

Task 7)

The oxygen consumption of an activated sludge plant is 58.4 g O_2/(l x d) for the degradation of carbon compounds. In addition 48.8 % of this quantity is required for the nitrification.

a) How many percent of the nitrogen inflow load of 11 g N/(l x d) are oxidised with a specific oxygen consumption of 4.6 g O_2/g N?

b) If 12 g O_2/(l x d) are recovered through denitrification how large is the NO_3-N concentration in the effluent of the plant (q = 200 litres/(l x d))?

Oxygen demand for nitrogen removal:
OV_N = 4.6 g O_2/g NO_3-N_e - 1.7 g O_2/g NO_3-N_D
(N_e: in the effluent no denitrified; N_D: denitrified)

3.8   Fixed-bed processes

The aerobic degradation and the conversion of dissolved wastewater content substances take place in fixed-bed processes (trickling filters, biological contactors and biologically activated filters), mainly through sessile (adherent) bacteria with the employment of dissolved oxygen. The dead and flushed-out biomass is separated from treated wastewater in the secondary settling stage.

Task 1)

In the section of a rock-filled trickling filter shown below, name the assemblies and installations marked 1 to 7.
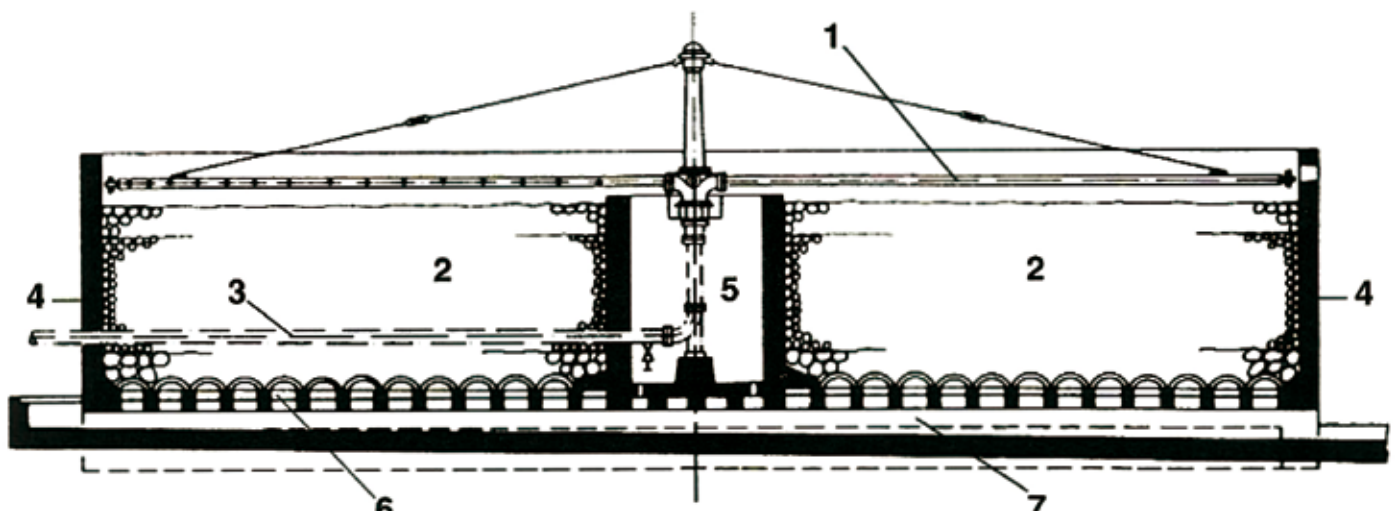
 Diag. 3.9/1: Section through a rock-filled trickling filter

Task 2)

Different substances can be employed as carrier material of the fixed biological film in trickling filters.
a) Name the different filler materials for trickling filters.
b) List the characteristics which these filler materials must possess.

Task3)

Using the given parameters make a tabular comparison between a lava and a plastic filler. As far as possible give the appropriate characteristic values.

Area of application, filler material, weight, structural design, construction height, specific surface (film area), size of hollow space, throughflow or contact time, danger of blockage, loading range (B_V), treatment performance (BOD_5)

Task4)

With appropriate loading a nitrification is also possible in trickling filters.
a) In the diagram below enter the concentration process of BOD_5 and NO_3-N within a rock-filled trickling filter

Influent

Above

± 0

- 1

- 2

- 3

- 4

Trickling filter filling height

Below

Efluent 0   50   100   150   200   250 mg/litre
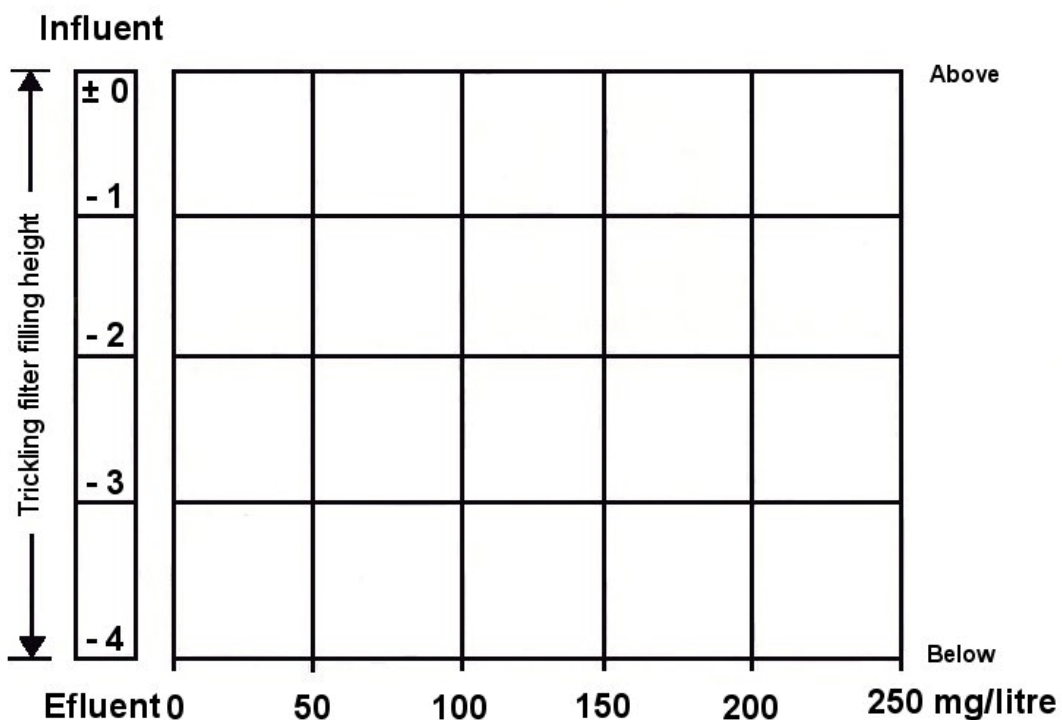
Diag. 3.9/2:   Treatment process in the trickling filter

b) Give the reasons why a complete nitrogen removal is not possible in a normal trickling filter.

Task 5)

In which line is the air flow in a trickling filter at different seasons and times of the day correctly crossed?

	Decreasing:	Increasing:
a) Summer, day		X
b) Summer, night	X	
c) Winter, day	X	
d) Winter, night	X	
e) Artificially aerated	X	X

Task 6)

Which statement on rotary distributors is <u>false</u>?
Rotary distributors:
a) Move according to the recoil principle.
b) Rotate on a pivot bearing.
c) Have an uneven distribution of the exit holes on their arms.
d) Require a pressure head of at least half a metre for progression.
e) Must be cleaned daily.

Task 7)

Which of the five statements on the flushing force of rotary distributors is <u>not</u> correct?
The flushing force:
a) Is lowest when the rotary distributor is stationary.
b) Reduces with the number of rotary distributor arms.
c) Reduces with increasing rotational speed of the rotary distributor.
d) Increases with increasing quantity of influent.
e) Increases with increasing surface overflow rate.

Task8)

A biological film is <u>not</u> characterised by the following properties
The biological film:
a) Is populated by single- and multi-cell organisms.
b) Is stirred up by, inter alia, psychoda larvae.
c) Usually has a green surface.
d) Can consist of aerobic and anaerobic zones.
e) Has a greater growth in the upper TK zone than in the lower one.

Task9)

Which filling height and which diameter has a trickling filter with the following loading values: B_V = 0.458 kg BOD_5/(m^3 x d) and q_A = 0.573 m/h, if the influent values are Q = 50 litre/s and (BOD_5) = 150 mg/litre?

Task10

Which BOD_5 effluent concentration is achieved by a 4 m high trickling filter which, at 16°C wastewater temperature, is loaded with a concentration (BOD_5) = 150 mg/litre?
Surface overflow rate is laid down as 0.8 m/h.
Determine the value with the aid of the following nomogram.
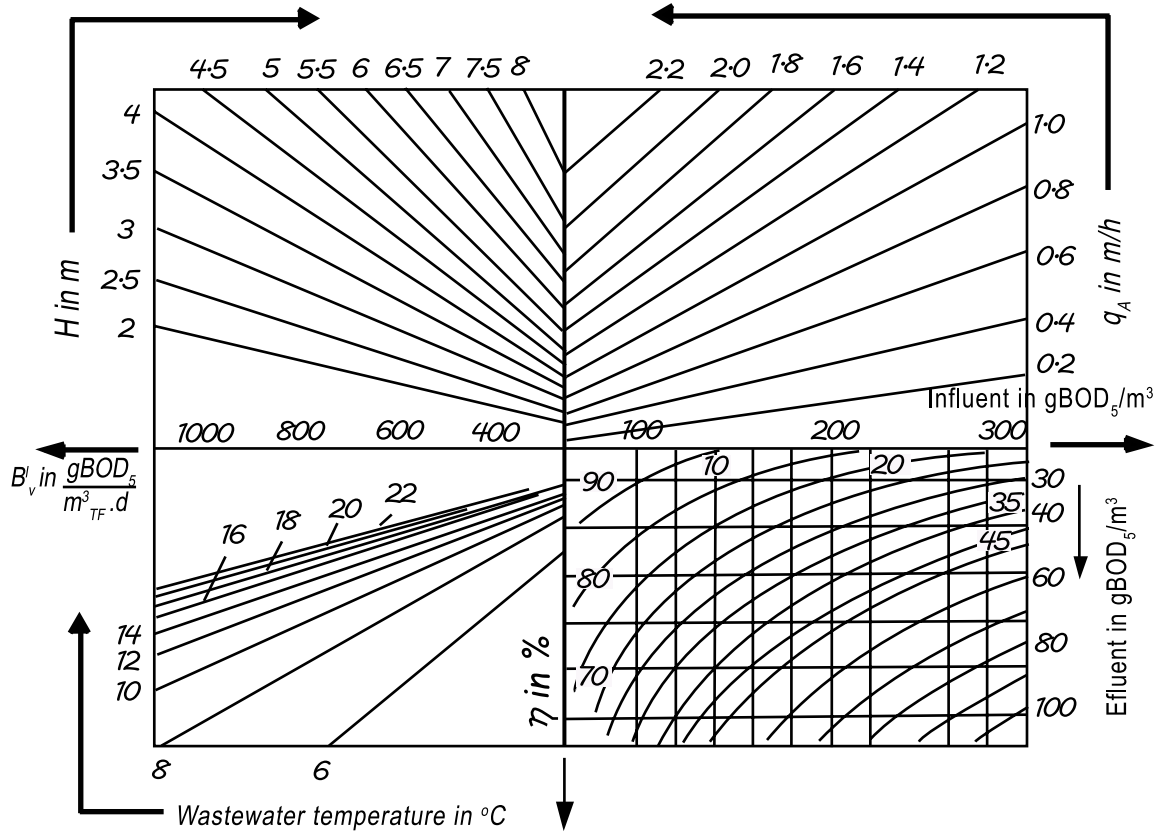
Diag. 3.9/3: Dimensioning nomogram for trickling filters

Hosang; Bischof: Abwassertechnik, 9th Edition 1989 © Teubner, Stuttgart

Part B)

Task1)

Using the parameters listed produce a tabular comparison between trickling filter and activated sludge processes,

> Primary settling stage; biomass; biomass enrichment; loading (B_V/B_{DS});
>
> Controllability; O_2 transfer; specific treatment volume (l/m^3);
>
> Efficiency; energy consumption; nitrogen removal; secondary settling stage

Task2)

Disruptions of the trickling filter operation can occur due to blockages of the filler material and the formation of puddles.
a) Name the possible causes.
b) Name the measures suitable for removing blockages.

Task3)

The pumping of treated wastewater onto the trickling filter is the sole control possibility of the trickling filter process.
a) The transport of recirculation water of a trickling filter plant (RR = 1 + 1) from the outflow of the secondary settling stage into the charging pumping station has failed.
    How do you rate the proposal of solving the problem through an appropriate increase of the ES transport into the primary settling stage?
b) What advantages result for the operation of the trickling filter from a transport of recirculation water?

Task4)

Which description of the trickling filter sludge is <u>false</u>?
The flushed out trickling filter sludge:
a) Reduces with decreasing volumetric loading.
b) Increases quantitatively in spring.
c) Sediments better than the ES (excess sludge) of an activated sludge plant.
d) Has a higher water content than the ES of an activated sludge plant.
e) Dewaters better than the ES of an activated sludge plant.

Task 5)

Which substance is not employed as filler material in biological intensified filters?
a) Active carbon
b) Anthracite.
c) Expanded shale.
d) Basalt.
e) Sintered glass.

Task 6)

Indicate the correct statement about filters.
The flushing of filters takes place:
a) Continuously.
b) With the aid of gravity.
c) With the same velocity as the rate of flow.
d) Under operation of the filter.
e) Mainly with air and water.

Task 7)

10,000 m³ of wastewater flow with a BOD_5 concentration of 200 mg/litre flow daily into a daily trickling filter plant with a volume of 5,000 m³. The residual pollution is to be reduced through the delivery of recirculation water. To what residual concentration is the effluent reduced with a 50 % recirculation water deliver (one return feed), if the following applies:
$\eta = 93 - 0.017\ B_V$ (B_V in g BOD_5 /(m³ x d))?

Task 8)

A filter plant (12 units each of 34 m²) is charged with Q = 3,000 m3/h.

a) Taking into account the backwashing of two units, the filter rate and the percentage, determine by how much the dimensioning velocity of v = 7.5 m/h is exceeded.
b) Determine the required quantity of flushing water per unit and overall, if the following velocities and flushing times are observed during the three flushing phases:
  Phase I   20 m/h each of 2 min.
  Phase II   50 m/h each of 5 min.
  Phase III   80 m/h each of 2 min.

4. Sewage sludge treatment and utilisation of sludge from wastewater treatment facilities

4.1 Flow diagrams of sewage sludge treatment facilities

A flow diagram of a sewage sludge treatment facility serves to improve the overview, shows the operational procedure of the facility and shows the most important components, structures, installations as well as the flow paths of the facility.

Task 1)

The sludge flow diagram of the wastewater treatment plant S (7,233 PT) shows the locations of the sludge production and the treatment including the transport paths, supplemented by a tabular representation of the substance flows and conversions.
a) Determine the values missing in the conversion diagram in the fields with grey background.
b) In addition calculate the efficiency of the digester (degree of degradation oDS).
c) Using the now available data and the listed standard values, assess the digestion process of wastewater treatment plant S.

Standard values for the operation of a single-stage mesophilically operated digester		
Plant capacity < 50,000 PT		
Digestion time	d	20-30
Organic volumetric loading	kg oDS/(m³ x d)	2
Degree of degradation	%	> 45
Specific gas production	litre/(kg oDS	400 - 500
Specific gas yield	litre/(I x d)	20
CO_2 content in the digester gas	%	26 - 36

Wastewater treatment plant S

Q	m³ /a	2,111
R	%	5.60
IL	%	60.00
m_{DR}	Mg $_{DR}$ /a	
m_{oDR}	Mg $_{DR}$ /a	

Q	m³ /a	13,140
R	%	0.70
IL	%	96.40
m_{DR}	Mg $_{DR}$ /a	
m_{oDR}	Mg $_{DR}$ /a	

Q	m³ /a	4,782
R	%	
IL	%	
m_{DR}	Mg $_{DR}$ /a	

V	m³	500
T	°C	36
t	d	
Q_{out}	m³/a	4,782
DR_{out}	%	
IL_{out}	%	48.70
m_{DRout}	Mg $_{DR}$ /a	153
m_{oDRout}	Mg $_{DR}$ /a	
B_R	kg $_o$DR/m	
Gas yeild	m³/a	64,308
Gas production	l/kg $_o$DR	
spec. gas yeild	l/Id	
CO_2	%	34

Composting	
Incineration	153
sludge site	

Sludge liquor

Storage

Dig.

P S + E S

E S

R S

D
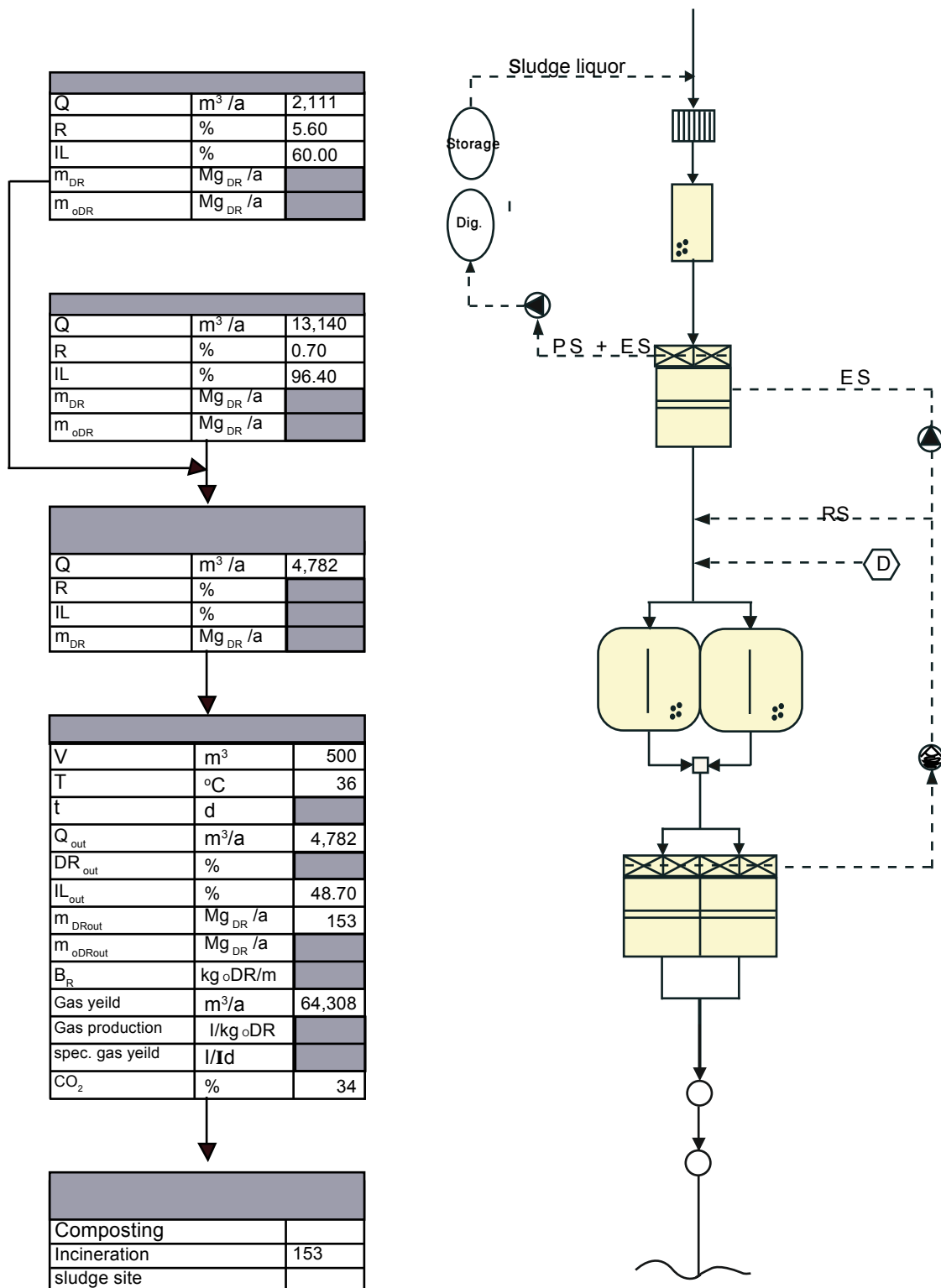
Diag. 4.1/1: Sludge flow diagram - wastewater treatment plant S

Task2)

An energy balance is to be produced for a wastewater treatment plant with 300,000 PT (activated sludge process, sludge digestion, combined heating plant (CHP) with digester gas usage to drive the blowers, as well as use of the blower heat for the heating of the raw sludge) and using this, it is to be determined how much outside energy is required (see Diag. 4.1/2).

1) Determine the daily digester gas yield and its energy content with a specific dry solid matter fraction of 80 g DS/(PT x d).
   a) Calculate the organic solid matter produced daily with an organic fraction of 2/3.
   b) How high is the daily gas production with a specific production of 500 litres gas/kg oDS)?
   c) How large is the daily energy content of the digester gas if a cubic metre of gas represents 6.4 kWh?

2) Determine the energy requirement for the heating up of the raw sludge.
   a) How large is the quantity of the daily yield of raw sludge (m³/d) if the mixed liquor suspended solids are 6 %?
   b) Calculate the necessary energy (J/m³) in order to heat one cubic metre of sludge by 23.86 K, if the specific energy requirement for water is 4.19 J/(g x K).
   c) Give the overall amount of energy in (J/d) for the heating up of the amount of raw sludge produced daily.
   d) How large is the energy requirement determined (kWh/d)?

3) Residual and outside energy, and energy saving.
   Primarily the aeration energy requirement is to be covered using the existing energy. How much of the residual energy requirement can be covered using the remaining digester gas energy if, of the useful amount of energy, only 32.61 (mechanical efficiency) can be used for aeration and the rest.

```
                        ┌─────────────────┐
                        │   Raw sludge    │
                        │    .... tDS/d   │
                        │   66.6% oDS     │
                        └─────────────────┘
                                 │
                        ┌─────────────────┐
                        │ 500 lit gas/kg oDS │
                        └─────────────────┘
                                 │
   ┌──────────────┐     ┌─────────────────┐
   │    Flare     │ ◄── │   Gas yeild     │
   │  ...... kWh/d│     │   ...  m gas/d  │
   └──────────────┘     │  51,200 kWh /d  │
           10.156%      └─────────────────┘
                                 │
                        ┌─────────────────┐
                        │ Quality of useful│
                        │    energy       │
                        │  ...... kWh /d  │
                        └─────────────────┘
                                 │
                        ┌─────────────┐       ┌──────────────┐
                        │    CHP      │ ────► │    Losses    │
                        │ ή = ........ %│      │ ....... kWh /d│
                        └─────────────┘       └──────────────┘
   ┌────────────────────────────────────────────────────┐
   │ Quantity of energy used        .......  kWh  /d     │
   └────────────────────────────────────────────────────┘
```

	Residual	Aeration	Sludge heating through waste heat
Use of the digester gas - energy:	.... k Wh /d	.... k Wh /d	.... k Wh /d

	Residual	Aeration	Sludge heating
Energy requirement:	.... k Wh /d	.... k Wh /d	.... k Wh /d

Outside energy :	.... k Wh /d
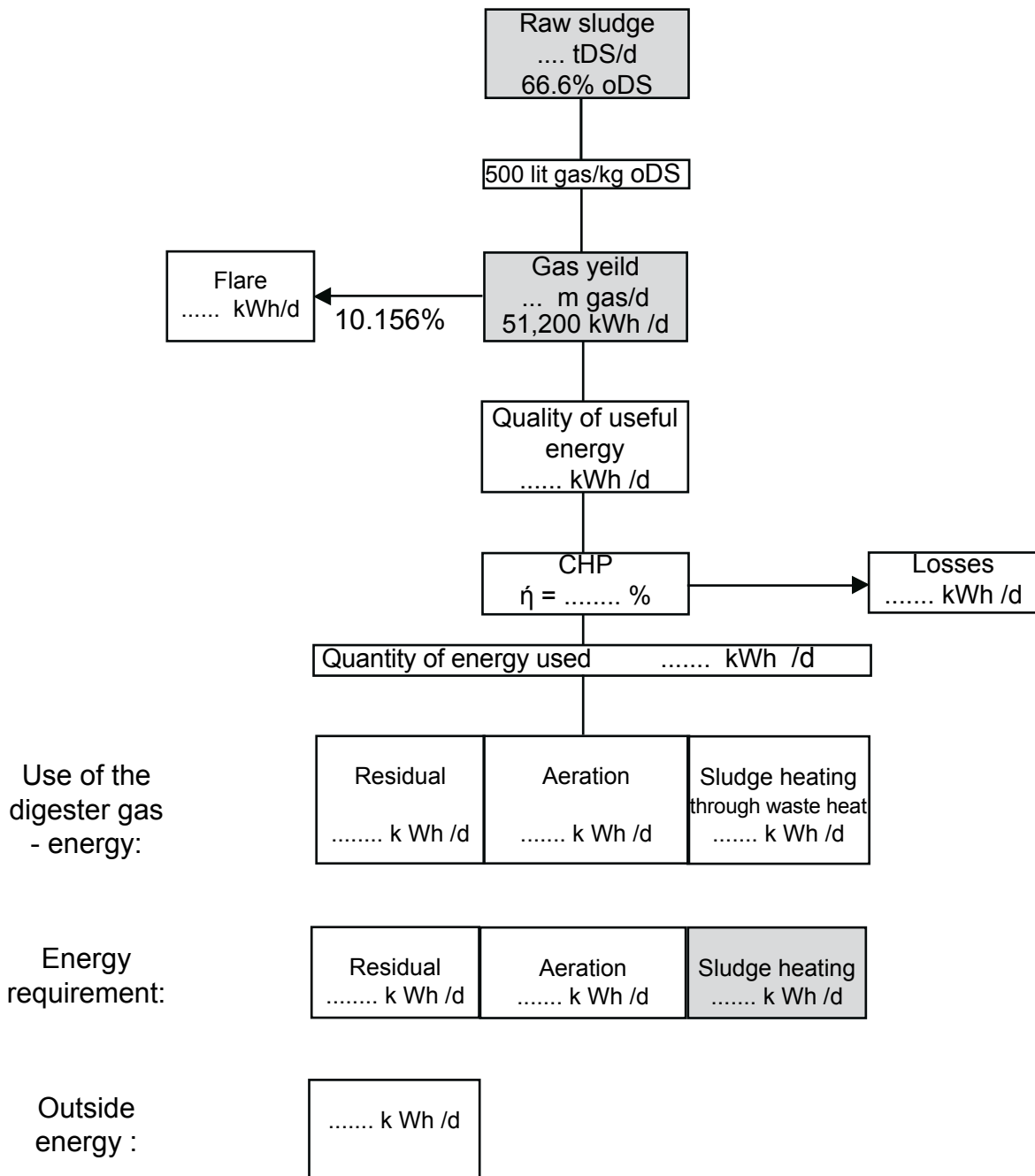
Diag: 4.1/2 Energy balance

4.2   Types of sludge and sludge stabilisation general

The degradation of organic substances in the sewage sludge can take place both aerobically and anaerobically. There are various processes of sludge stabilisation, whereby mesophilic digestion is used the most extensively.

Task 1)

Describe the following types of sludge according to origin, characteristics and operating condition:
a) Raw sludge.
b) Primary sludge.
c) Activated sludge.
d) Aerobically stabilised sludge.
e) Digested sludge.

Task 2)

Answer the following questions on the subject of sludge.
a) How large is the daily yield of raw sludge referred to the inhabitant?
b) What is the percentage ratio of the wastewater yield and raw sludge yield in a biological wastewater treatment plant?
c) With what percentage reduction of the amount of solid matter can one reckon with, with the digestion of the sludge?

Task 3)

Name the essential objectives of sludge stabilisation.

Task 4)

Sludge can be stabilised both aerobically and anaerobically.
a) Explain the difference between aerobic and anaerobic sludge stabilisation.
b) In which cases does one use aerobic sludge stabilisation?

Task 5)

Which statement about sludge is correct?
a) Primary sludge is designated as secondary sludge.
b) Return sludge has lower mixed liquor suspended solids than the sludge in the aeration tank.
c) Anaerobically stabilised sludge is more heavily mineralised than raw sludge.
d) The mixed liquor suspended solids of activated sludge are about 10 %.
e) Digested sludge is epidemic-hygienically harmless.

Task 6)

The organic fractions of raw sludge with aerobic sludge stabilisation are:
a) To the greatest part flushed out with the sludge liquor.
b) Not influence at all.
c) Crystallised out.
d) To the greatest liquefied.
e) Converted to mineral substances.

Task 7)

Which sludge changes its pH value in the air?
a) Pasteurised sludge.
b) Raw sludge.
c) Aerobically stabilised sludge.
d) Dewatered sludge.
e) Digested sludge.

Task 8)

What do you understand by "sludge stabilisation"?
a) The conversion of mineral components into energy-rich carbon compounds.
b) The formation of a solid sludge layer through flotation.
c) The conversion of activated sludge into sludge capable of digestion.
d) The conversion of energy-rich organic substances into low energy compounds.
e) The physical-chemical conversion of sludge with the exclusion of air.

Task 9)

Which statement on sludge loading is <u>false</u>?
a) With aerobic sludge treatment the organic substances are oxidised into inorganic end products, which remain dissolved in water or disperse in gaseous form.
b) With aerobic sludge treatment an end oxidation due to oxygen is possible.
c) The end products of anaerobic sludge treatment are low in energy.
d) The rate of degradation of the aerobic bacteria is greater than that of anaerobic bacteria.
e) The anaerobic sludge treatment is more sensitive with regard to temperature influences than aerobic sludge treatment.

Task 10)

Which statement on anaerobic stabilisation of sludge is <u>false</u>?
The anaerobic stabilisation:
a) Can be carried out separately from wastewater treatment.
b) Requires a minimum sludge age of 25 days.
c) Releases process heat.
d) Is not temperature-dependent.
e) Converts organic substances into CO_2, H_2O and mineral substances.

4.3 Anaerobic sludge stabilisation (digestion)

An essential and frequently applied process step in wastewater treatment plants (> 10,000 PT) is the anaerobic sludge stabilisation (digestion). It is a sensitive process. Regular checks, measurements and examinations are necessary.

Part A)

Task 1)

Allocate the five terms listed below to the correct numbers of the digester cross-section (Diag. 4.3/1
a) Raw sludge input.
b) Sludge pump for recirculating sludge.
c) Heat exchanger.
d) Digested sludge removal.
e) Screw mixer with motor.

Task 2)

The digestion process in a digester of a municipal wastewater treatment plant basically runs in four phases.
Name the four phases of this conversion in the correct sequence.

Task 3)

Name the products which result respectively in the four degradation phases of the digestion process.
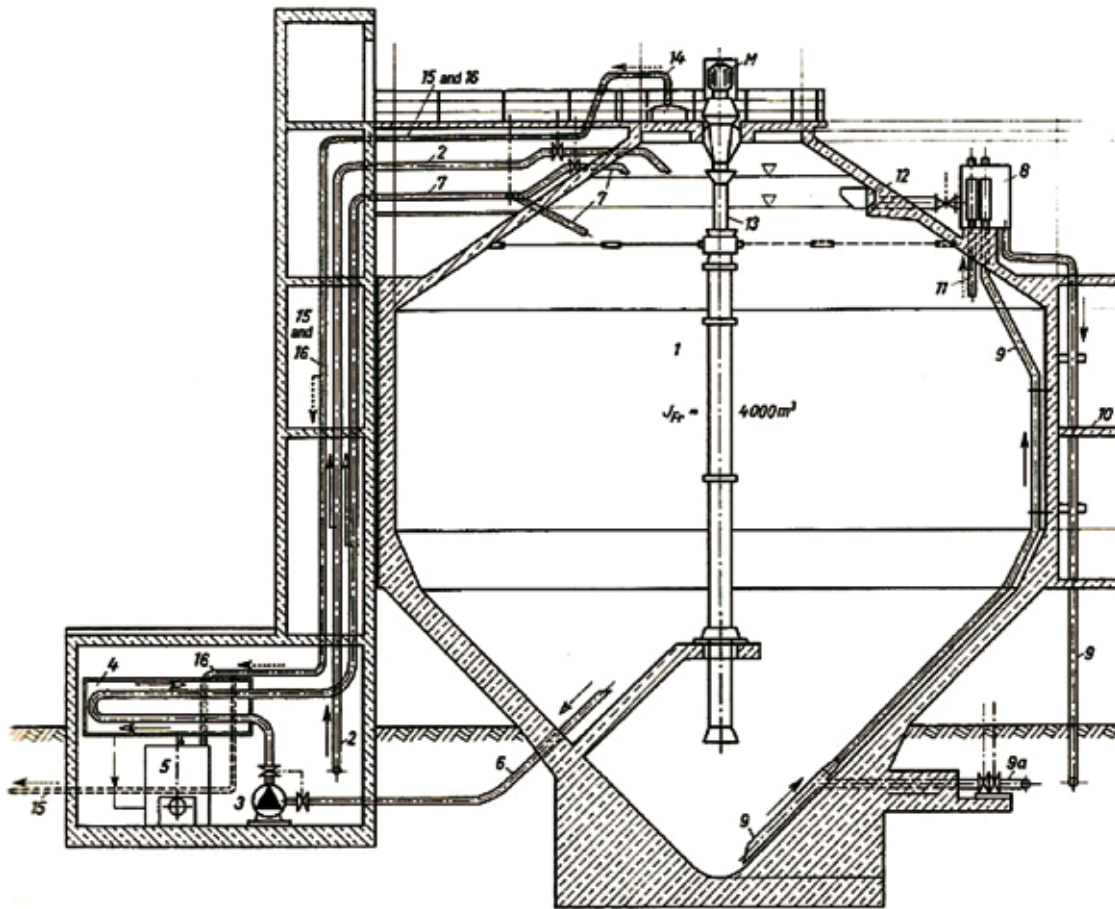
Diag. 4.3/1:   Digester cross-section

Task4)

Various parameters are to be checked for the monitoring of the digestion process.
a) Which are the essential parameters?
b) Why must these values be monitored?

Task5)

The digestion process can be disrupted for various reasons. Name the possible causes.

Task 6)

Which of the following values apply as standard values for the digestion time and process temperature of a mesophilic heated digester?
a) Digestion time 100 – 120 days / process temperature   < 10°C
b) Digestion time   60 – 90 days / process temperature 25 – 30°C
c) Digestion time   20 – 30 days / process temperature 32 – 38°C
d) Digestion time   10 – 15 days / process temperature 40 – 45°C
e) Digestion time   5 – 10 days / process temperature 50 – 55°C

Task 7)

Why may there be no oxygen in a digester?
a) In order that no floating sludge blanket forms.
b) Because with the presence of oxygen the hydrolysis phase is disrupted.
c) In order to avoid odour nuisances
d) In order to avoid an excessive formation of organic acids.
e) Because methane bacteria stop their metabolism with the presence of oxygen.

Task 8)

Which data apply with anaerobic sludge stabilisation (digestion)?
a) The CH_4 gas production of the methane bacteria in the digester is not reduced due to temperature variations.
b) $CH_3COOH \rightarrow CH_4 + CO_2$
c) Methane bacteria are sensitive to oxygen.
d) Glucose $\rightarrow$ starch + water
e) $2\ C_2H_5OH + 2\ CO_2 \rightarrow C_6H_{12}O_6$

Task 9)

A digester with a volume of 1,200 m³ is operated with a temperature of 36°C. Calculate the maximum temperature change in the digester if the digester is charged with 50 m³ of raw sludge (T = 11°C).

Task 10)

110 m³ of raw sludge (DS of 5.7%) is fed daily to a digester with a volume of 2,500 m³ and an ignition loss (IL) of 75%.

a) Calculate the fraction of organic DS (kg oDS/(m³ x d)), with which the digester is loaded (ρ = 1.05 g/cm³).

b) In which order of magnitude does the normal loading limit of the digester lie?

c) Which effects on the operation of the digester does a significant exceeding of the normal loading with organic solid matter (kg oDS/(m³ x d))? Explain the procedures.

d) Determine the retention time.

Part B)

Task1)

Name the hazards for persons and installations which can occur with the operation for a sludge digestion plant.
Explain the causes.

Task2)

A digester is emptied and is to be cleaned.
a) Which safety precautions must be taken in order to be able to undertake cleaning work in already emptied digesters?
b) With sand blasting work can detonations occur? if so, what can be undertaken to counter these?

Task3)

A digester has been repaired and is to again be taken into service.
a) Name the essential steps for the reincorporation of the digester.
b) Which measurements and records are important with this?

Task4)

Name: a) Different types of sludge circulation systems for digesters.
            b) Different types of digester heating facilities.

Task5)

The extraction pipeline of the digester tip is blocked.
What measures do you take?
a) Clear the digester.
b) Purge the digester tip with pressure water.
c) Force compressed air into the digester tip.
d) Add milk of lime.
e) Deliberately inject solvent.

Task 6)

How high is the fraction of carbon dioxide (CO_2) in the digester gas under normal conditions?
a) 50 to 60 %.
b) 40 to 50 %.
c) 30 to 35 %.
d) 20 to 25 %.
e) 15 to 20 %.

Task 7)

How can a formation of floating sludge be kept small?
a) By increasing the digester temperature.
b) By increasing the charging.
c) By circulating the contents of the digester.
d) By lowering the sludge level.
e) By reducing the charging.

Task 8)

In a wastewater treatment plant with fully charged digester, increased sludge is produced in rainy weather.
What measures do you take?
a) Feed the sludge produced into the digester in batches.
b) Place a part of the sludge, untreated, on sludge sites.
c) Digest the sludge in storage tanks.
d) Store the sludge temporarily in the primary settling stage.
e) Discharge part of the sludge into the receiving water.

Task 9)

Additional catchments areas with, in total, 20,000 additional total number of inhabitants and population equivalents (PT) are connected to a wastewater treatment plant with 40,000 PT.
a) Calculate the digestion time in days if the quantity of sludge referred to the PT value is 2.0 litres/(l x d) and the volume of the mesophilically operated digester is 1,600 m³.
b) Which operational possibilities are there in order to achieve a sufficient sludge stabilisation?

Task10

With anaerobic sludge stabilisation acetic acid (CH_3COOH) is decomposed into methane and carbon dioxide.
a)   How many g of carbon dioxide result with the decomposition of 100 g of acetic acid?
b)   How many litres of methane at 20°C and 900 hPa result here from 100 g acetic acid?

4.4　Gas production, processing, storage and utilisation

Digester gas is yielded with the process of anaerobic sludge stabilisation. With this the amount of gas yielded and the composition of the gas are important parameters for the control of the digestion process. In addition, the use of the digester gas is an important source of energy in the wastewater treatment plant.

Part A)

Task 1)

Digester gas is an essential source of energy in wastewater treatment plants.
What possibilities are there for utilising the digester gas?

Task 2)

Answer the following questions on the storage of digester gas.
a)　Which possibilities for digester gas storage do you know?
b)　Which disadvantages do wet tanks have compared with other gas containers?

Task 3)

Which tasks do the following installations have within the framework the tapping, storage and utilisation of digester gas with anaerobic sludge digestion?
a)　Gas hood.
b)　Gravel pot.
c)　Gas flare.

Task 4)

Digester gas is composed mainly of two main components.
a)　Name these components and their percentage fraction.
b)　How large is the yield of digester gas in litres referred to one kg of organic dry solid matter and per inhabitant and day?

Task 5)

A digester (V = 1,150 m³) has the following operating values:

Digester gas yield: 300 Nm³/d

Gas composition: CH_4 = 50 %

                               CO_2 = 48 %

Digester loading: 0.91 oDS/(m³ x d)

Assess: a)   The digester gas yield.

                b)   The digester gas composition.

                c)   The digester loading.

Task 6)

With the drawing-off of digester gas, which causes give rise to serious variations of the pressure indicator in a manometer?

a)   Manometer damaged.
b)   Marked variations in the weather.
c)   Entry of air via leaks.
d)   Air bubbles in the gas pipeline.
e)   Accumulation of condensation in the gas pipeline system.

Task 7)

When is a digester gas – air mixture particularly explosive?
a)   30 % air and 70 % digester gas.
b)   40 % air and 60 % digester gas.
c)   60 % air and 40 % digester gas.
d)   90 % air and 10 % digester gas.
e)   98 % air and   2 % digester gas.

Task 8)

Can the aeration and ventilation of a gas-filled space be closed with a danger of frost?
a) Yes, if it is previously checked that no gas is in the space.
b) Yes, if no space heating is present.
c) No, aeration and ventilation must always be effective.
d) Yes, but first at temperatures below – 5°C.
e) Yes, if a frost detector is installed.

Task 9)

10 m³ of digester gas are burnt daily in a wastewater treatment plant. The fraction of methane (volumetric fraction) is 65 %.
How many kg H_2O result from the combustion?

Part B)

Task 1)

The production of digester gas is mainly dependent on the composition of the sludge / the types of substance.
a) Which of the three types of substance – carbohydrates, organic fats and proteins – produce the highest specific methane yield (m^3 CH_4 per kg)
b) Assess the charging of a digester with animal and vegetable fats and oils compared with that of mineral oils.

Task 2)

With the burning of surplus digester gas using a gas flare carbon monoxide (CO) can result.
a) Under what conditions does CO result?
b) On what can you recognise its production?

Task 3)

In addition to other gases hydrogen sulphide can also be present in digester gas.
a) Which hazards are associated with a high hydrogen sulphide content in the digester gas?
b) How can hydrogen sulphide be removed from digester gas?
c) Formulate the reaction equation with the conversion of hydrogen sulphide using iron(II) hydroxide

Task 4)

Digester gas is given intermediate storage in wastewater treatment plants.
a) Which tasks has a gas tank separated from the digester?
b) How large should the volume of the gas tank be?

Task 5)

Which special requirements are to be placed on digester gas pipelines?

Task6)

With which colours are digester gas pipelines marked?
a) Green.
b) White.
c) Bright red.
d) Yellow.
e) Blue.

Task7)

Why must surplus gas be burned in a gas flare?
a) Because it protects the digester from freezing.
b) Because gas production is improved.
c) Because a mixture capable of explosion can result from released gas and air.
d) In order that residents can recognise that the wastewater treatment plant is staffed.
e) Because gasworks cannot utilise digester gas due to its high thermal value.

Task8)

Which statement about siloxanes is <u>false</u>?
a) Siloxanes are constituents of detergents.
b) Siloxanes can condense out through the deep freezing of digester gas.
c) Siloxanes form with the combustion of crystalline silicon oxide.
d) Siloxanes are constituents of biogas.
e) Siloxanes are AOX compounds.

Task9)

Following the failure of the gas engines in a combined heating plant (CHP) the digester gas produced must be given intermediate storage in a high pressure tank. For what period of time does a storage volume of 250 m³, p_{max} = 8 bar and t_{max} = 20°C suffice with a gas yield of 510 m³/d, p = 1.035 bar and T = 37°C?

Task 10)

How high is the annual energy content (365 days), which is theoretically available from the digester gas of an anaerobic stabilisation facility of a wastewater treatment plant with 15,000 inhabitants and the following operating data?

Specific dry matter fraction:	80 g DS/(l x d)
Ignition loss:	65 %
Digester gas yield.	460 litres digester gas/ kg oDS
Calorific value:	5.85 kWh/m³

4.5   Conditioning, thickening, storage and sludge dewatering

The separating of sludge liquor and the reduction of volume associated with this represents an important process step within the framework of sludge treatment, utilisation and disposal.

Part A)

Task 1)

Sewage sludge is a suspension which consists of a liquid and a solid fraction.
a) In the drawing enter the different types of water (adhesive (retained) and adsorption water, internal water, capillary water and interstitial water):
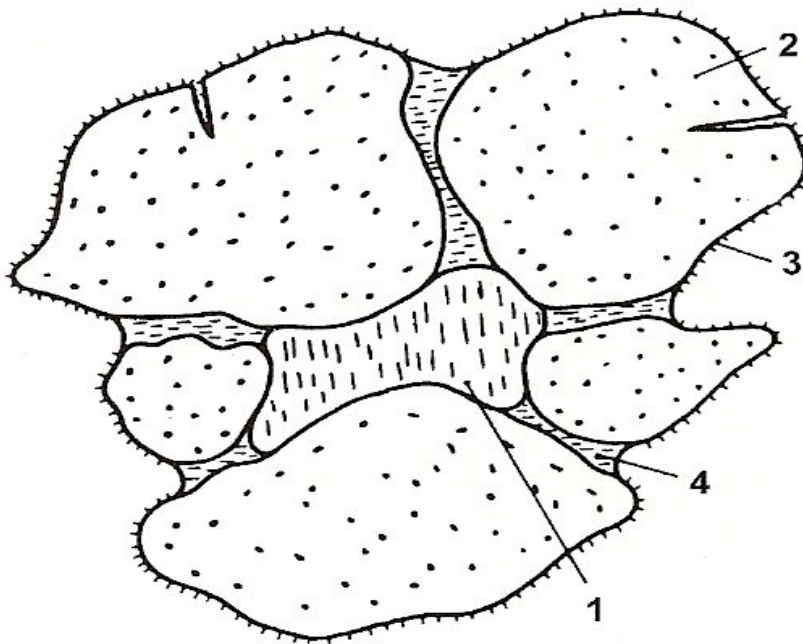
Diag. 4.5/1: Types of water in sludge

b) Arrange the types of water according to their capability of bonding on to or into the sludge flocs (from slight to large)

Task 2)

Allocate the following types of water
a) Adsorption and internal water
b) Retained and capillary water,

c) Interstitial water,

to the following separation processes:

1. Thickening   2.   Mechanical dewatering   3.   Thermal energy

Types of water	Separation process
a) Adsorption and internal water	
b) Retained and capillary water	
c) Interstitial water	

Task 3)

Conditioning serves for the improvement of the dewatering properties of the sludge.
a) With conditioning, inter alia, the following inorganic flocculants are employed.
    Give the respective chemical formulas for these
    1. Ferric chloride
    2. Iron chloride sulphate
    3. Ferrous sulphate
    4. Aluminium sulphate
    5. Unhydrated lime
    6. Milk of lime

b) Explain the operation of conditioning agents.

Task 4)

The natural thickening of sewage sludge takes place, inter alia, in static and throughflow thickeners.
a) Name the five zones of a thickener.
b) Name the four functional devices numbered 1 to 4 in the cross-section below of a static thickener.
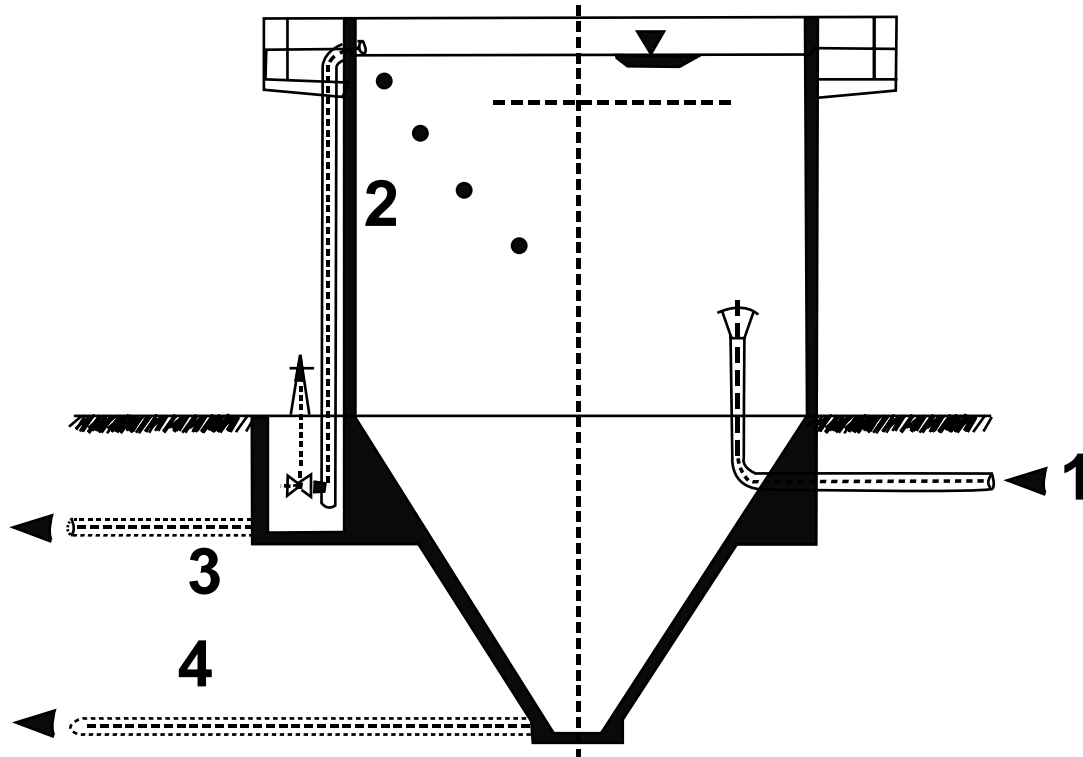
Diag. 4.5/2 : Cross-section of a static thickener.

Task 5)

Which of the following processes and facilities <u>do not</u> belong to thickening
a) Thickening in the hoppers of the primary settling stage.
b) Sludge basins.
c) Static thickeners.
d) Flotation.
e) Centrifuges

Task 6)

Which method is not a sludge conditioning process?
a) Sludge elutriation.
b) Addition of lime.
c) Heating with high temperatures.
d) Employment of ash.
e) Injection of air.

Task 7)

Of the following what does a throughflow thickener have?
a) Inlet cylinder.
b) Stirring staves.
c) Sludge volume.
d) Stepped outflow.
e) Removal pipe for thickened sludge.

Task 8)

On average how long is the retention time in thickeners?
a) 5 – 10 days.
b) 3 weeks.
c) 1 – 2 days.
d) 1 month.
e) Half a year.

Task 9)

Which statement applies to polyelectrolytes?
a) Polyelectrolytes do not change the pH value of the sludge.
b) Polyelectrolytes lead to blockage of filter clothes.
c) Polyelectrolytes are high molecular organic compounds
d) Polyelectrolytes increase the DS content of the sludge.
e) Polyelectrolytes can be employed in dewatering processes with pressures greater than 3.5 bar.

Task 10)

The specific sludge yield of a wastewater treatment plant (20,000 I) is 2.0 litres/(I x d). How large is the sludge volume after the pre-thickener, if an increase of the solid matter content from 2.5 % to 4.5 % has been achieved?

Task 11)

Sludge is removed from a thickener via a DN 150 pipeline. How many m^3 of sludge are removed per hour with a flow rate of 80 cm/s?

4.6   Utilisation, disposal of sludge and residues

Sludge and residual matter result with the discharge and treatment of wastewater. These substances must be disposed of in accordance with the Recycling and Waste Law (utilised or disposed of).

Task 1)

What unavoidable residues are produced:
a) In the sewer network?
b) In the wastewater treatment plant?

Task 2)

Give the different possibilities of sewage sludge utilisation and the benefits to be achieved with this.

Task 3)

Name the arguments/reasons for the advantages and disadvantages with:
a) Agricultural utilisation of sewage sludge.
b) Sewage sludge incineration

Task 4)

What type of removal of the sewage sludge to agricultural areas is, in general, the most economic disposal?
a) Wet transport after thickening.
b) Removal of sludge from the sludge basins.
c) Scattering of dried sludge.
d) Composting.
e) Removal of dewatered sludge from chamber filter presses

Task 5)

What distribution equipment is most frequently used with agricultural utilisation of "small quantities of liquid sludge"?
a) Liquid manure barrel with distributor at the outlet.
b) Static pipeline.
c) Container with tipping device.
d) Multi-purpose scatterer.
e) Tractor with normal trailer.

Task 6)

A wastewater treatment plant has a capacity of 5,000 PT with a wet sludge yield of 0.5 m³ per PT and year (ρ = 1.05 kg/dm³). The dry solid matter content is 4 %.
Calculate the minimum surface area requirement in ha for an agricultural utilisation if, according to the Sewage Sludge Ordinance, a maximum of 5 t within 3 years may be applied.

Task 7)

What calorific value does 1 kg of dewatered sludge with a dry solid matter (DS) content of 40 % have? Take the following values for the calculation of the sludge calorific value:
Calorific value of 1 kg DS is: 9,500 kJ
Vaporisation energy for 1 kg H_2O: 3.0 MJ

5. Sampling, measurement and examinations of wastewater and sludge

5.1 Sampling

The examination of wastewater with regard to concentrations and loads of various parameters is indispensable for the monitoring and control of the treatment process. With this, a correct sampling is also important for the analysis.

Task 1)

Prerequisite for a correct sampling is a detailed preparation.
a) What aspects are to be considered within the scope of the preparation for sampling?
b) What is to be understood by "representative sample"?

Task 2)

Wastewater samples, in their composition and material properties, can change through biological, chemical and physical procedures if they are not examined immediately.
a) Give examples of and causes of changes.
b) Name the measures for the conservation of samples with the parameters BOD_5 , COD and NO_3-N.
c) For the three parameters named under b) give the type and material of the appropriate sampling vessel (bottles).

Task 3)

Investigations for self-surveillance of wastewater treatment plants serve for the monitoring and control of operations.
a)   What two areas are covered by the self-monitoring of wastewater treatment plants?
b) At what are the type and scope of the investigations aimed?
c) What advantages have the so-called operating methods?

Task4)

With discontinuous sampling it is differentiated between time-, flow- and volume-proportional sampling.
a) Explain the three different methods.
b) Indicate the differences by means of a diagram.

Task 5)

You have taken a wastewater sample which you are not going to examine yourself.
What details are <u>not</u> required on the sampling bottle label?
a) Type of sample.
b) Date.
c) Time.
d) Reason for sampling.
e) Name of the person taking the sample.

Task 6)

Wastewater is characterised, inter alia, through roughly defined and non-conservable parameters which are to be determined during sampling.
Which of the parameters given below do not belong to these?
a) pH value.
b) Temperature.
c) Turbidity.
d) Dry residues.
e) Oxygen concentration.

Task 7)

Automatic sampling equipment is an important aid with continuous wastewater treatment plant monitoring.
What component is not a part of a sampling equipment?
a) Switch point.
b) Switch point control.
c) Scoop beaker.
d) Collecting vessel.
e) Cooling system.

Task 8)

For the determination of the overall efficiency of a wastewater treatment plant (total tank volume 6,000 m³) a conjugate (coupled) sampling is planned in the inlet and outlet.
At what time must the appropriate outlet sample be taken if, with an inflow of Q = 120 litres/s, the practical retention time is 79 % of the theoretical?

Task 9)

A sampling of wastewater is to be carried out in the form of a qualified grab sample over a period of one hour.

a) How many scooping procedures are permitted as a maximum in this period?

b) With this, how large is the respective individual scoop volume to be selected if the collecting vessel has a collection volume of 20 litres and is to be filled to ca. three quarters?
Available are scoop vessels with a capacity of 0.1 litre; 0.5 litre and 1.0 litre.

c) A 2 litre sampling bottle is to be filled.
To what must attention be paid with the filling process?

5.2   Measurements and examinations

The separating of sludge liquor and the reduction of volume associated with this represents an important process step within the framework of sludge treatment, utilisation and disposal.

Part A)

Task 1)

Describe the structure and components of a measuring chain.

Task 2)

Name the different influences on measuring accuracy.

Task 3)

Give the average pH value of the following measured values registered during one hour with constant flow.
   10.00 h - pH value 7.0
   10.10 h - pH value 6.5
   10.20 h - pH value 6.3
   10.30 h - pH value 4.0
   10.40 h - pH value 6.3
   10.50 h - pH value 6.5

Task 4)

The biochemical oxygen demand (BOD_5) is the most important parameter for the efficiency of wastewater treatment plants. It characterises the concentration of the organic pollution of the wastewater due to micro-organisms.
   With the determination of the BOD_5 various factors are to be considered in order to achieve meaningful values.

a) Name the different methods of BOD5 determination.
b) Which prerequisites must the dilution water meet in order that the determination takes place

without error?

c) Why with the determination of the BOD_5 wastewater sample is allylthiourea (ATH) added?

d) Calculate the BOD_5 value of a wastewater sample examined according to the dilution method if, with an application volume of 20 ml, the oxygen depletion after five days is 6.3 mg/litre for the sample and 0.7 mg/litre for the dilution water

Task 5)

Important basic terms of measurement technology are adjustment, calibration and standardising. One designates calibration as the:

a) Setting of the index value of measuring equipment.

b) Matching of measuring equipment with specified standards.

c) Stamping of sets of weights by the Board of Weights and Measures.

d) Minimisation of measurement errors.

e) Setting of the zero point of measuring equipment

Task 6)

In which line do you find on-line measuring equipments which all function according to one physical-chemical measurement process?
Is it measuring equipments for:

a) Conductivity, pH value, oxygen.

b) pH value, pressure, quantity of water.

c) Quantity of sludge, COD, ammonia.

d) Oxygen, pressure, solid matter.

e) BOD_5, pressure, nitrate.

Task 7)

In which line are given only velocity measurement processes for flow measurement?

a) Volume meter, impeller, meter fall.

b) MID, float, venturi.

c) Ultrasonics, MID, float.

d) Meter fall, ultrasonics, volume meter.

e) Ultrasonics, MID, volume meter.

Task 8)

Turbidity is a simple, indirect parameter for recognising changes in the biological treatment stage. Which statement on the measurement of turbidity is false?

(a) The measurement of turbidity according to the reflex principle is designated as scattered light method.

(b) A contamination of the measurement probes has an effect on the measurement results.

(c) With the light absorption method the light ray emitted is weakened by suspended solids and discoloration of the wastewater.

(d) Turbidity can be measured using light absorption and light reflection.

(e) The turbidity (TE/F) is proportional to the content of settleable solids in the area of small values of settleable solids.

Task 9)

How high is the percentage mass fraction of dry residue, ignition loss and residue on ignition of a sludge sample if the following measured values are the basis of the determination?

a) Crucible, empty m_1 = 27.18 g
b) Crucible + sludge sample m_2 = 78.18 g
c) Crucible + dry residue m_3 = 30.75 g
d) Crucible + residue on ignition m_4 = 28.43 g

Part B)

Task1)

Within the scope of the self-monitoring of wastewater treatment facilities examination of wastewater using photometers as so-called operating method is used as a standard.
a) Describe briefly the functional principle of photometry.
b) Name the different content substances of a COD cell and the appropriate tasks of the content substances.
c) Name the possible causes which can lead to (serious) deviations of the measured values with photometry.

Task2)

The calibration of a pH meter means the determination of the specific characteristic measurement curve and the adjustment of the equipment.
a) What characteristic parameters of the pH electrode and the characteristic measurement curve are checked and adjusted with the calibration?
b) Which items are required for a 2-point calibration of a pH meter?
c) How often is a pH meter to be calibrated?

Task3)

In aeration tanks the oxygen concentration is measured for the regulation of an oxygen transfer which is both necessary process-technically and economical.
a) Which oxygen parameters are directly measured using a membrane covered probe according to Clark and are directly proportional to the flow into the probe?
b) Through what chemical reactions is a current flow generated in the oxygen probe?
c) With the measurement of oxygen, why is a simultaneous recording of the temperature necessary?
d) Why should the velocity in the blower stream at an oxygen probe be at least 0.3 m/s?

Task 4)

For the production of a microscopic image within the scope of the biological treatment of wastewater knowledge of the microscope and of the correct handling are important prerequisites.
a) What optical picture of the object observed is provided by the microscope?
b) What magnification steps does a microscope possess?
c) In addition to magnification through what is the efficiency of a microscope indicated and which equipment parameter is relevant for this?
d) Which optical parameters are influenced by the change of aperture diaphragm (aperture stop) and how do these change with reduction of the aperture diaphragm?
e) For what is a black field illumination particularly suitable?

Task 5)

The determination of various sludge parameters counts amongst the regular activities of the operating personnel in wastewater treatment plants.
a) How do dry solid matter (DS) and dry residues (DR) differentiate with regard to definition and determination of the recorded content substances?
b) Which method records the group of organic sludge content substances on total?
c) Describe the determination of the volumetric fraction of the activated sludge (VF) and give the points which are to be observed with implementation?

Task 6)

Activities in operational laboratories in wastewater treatment plants count among the daily tasks of operating personnel. With this, the handling of hazardous substances and contact with pathogenic agents are unavoidable.

a) What are the personal protective equipment in the wastewater treatment plant laboratory?
b) List the details with which the packaging of hazardous substances must be marked.
c) Explain the designations R- and S-principles.

Task 7)

With the biological-chemical processes of wastewater treatment the pH value plays a decisive role for the course of the conversion of substances (nitrification, anaerobic digestion etc.).
Which statement on pH value measurement does <u>not</u> apply?
The pH measurement:
a)   Can take place in aqueous solution only.
b)   Is an electro-chemical process.
c)   Is temperature-dependent.
d)   Records the voltage difference between measurement (glass) and reference electrodes.
e)   In the form of a single bar measuring chain requires no calibration.

Task 8)

The continuous conductivity measurement (on-line measurement), together with pH measurement, serves for the monitoring of the wastewater treatment plant inflow and helps to determine undesirable inflow of acids, lyes or salts.
Conductivity measurement possesses a series of special characteristics.
a)   It is measured in the unit mS/cm^2.
b)   It increases superproportionally with the number of dissolved charged particles.
c)   Is very high in solutions of sugar and other organic substances.
d)   It is temperature-independent.
e)   It reduces with the degree of disassociation of the dissolved substances.

Task 9)

Which statement on microscopy applies?
a) With the employment of bright field illumination the definition of the image can be changed by modification of the height setting of the condenser.
b) For a dark field illumination it is necessary to set the illumination lower.
c) The best definition of the image is achieved with bright field illumination if the aperture diaphragm is stopped down as far as possible.
d) With specimens, which have little contrast bright field illumination is best suited in comparison with other methods of illumination.
e) Dark field illumination is particularly suited for specimens which allow little light through.

Task 10)

Which diagram indicates the titration of the acid capacity of a municipal wastewater (influent)?
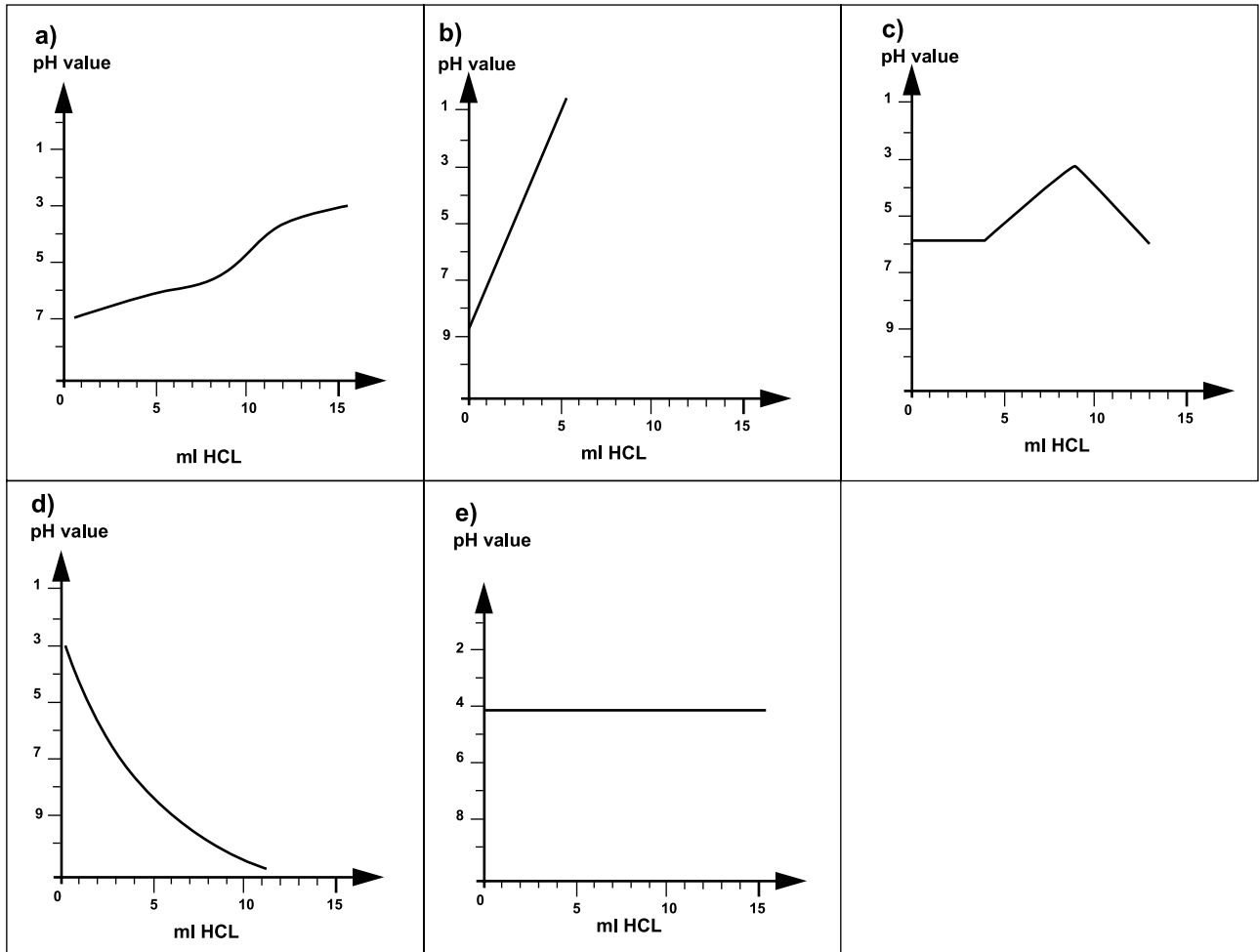
Diag. 5.2/2: Titration of the acid capacity of a municipal wastewater (influent)

Solutions

Section

Solutions to Chapter 1.

Types, yields and properties of wastewater

Part A)

Solution to 1):

1. Domestic wastewater (Q_d):
   - Washing water
   - Bath water
   - Washing-up water
   - Faecal water
2. Commercial/industrial water (Q_{c+i}):
   - Production water
   - Cleaning water
   - Cooling water
3. Infiltration water (Q_{inf}):
   - Drain water
4. Stormwater (Q_r):
   - Precipitation water
   - Melt water

Solution to 2):

a) 100 to 120 litres/(I x d).

b)

Wastewater discharge factors

$$\frac{24}{14} = 1.72$$

$$\frac{24}{18} = 1.33$$

$$\frac{24}{24} = 1.00$$

$$\frac{24}{36} = 0.67$$
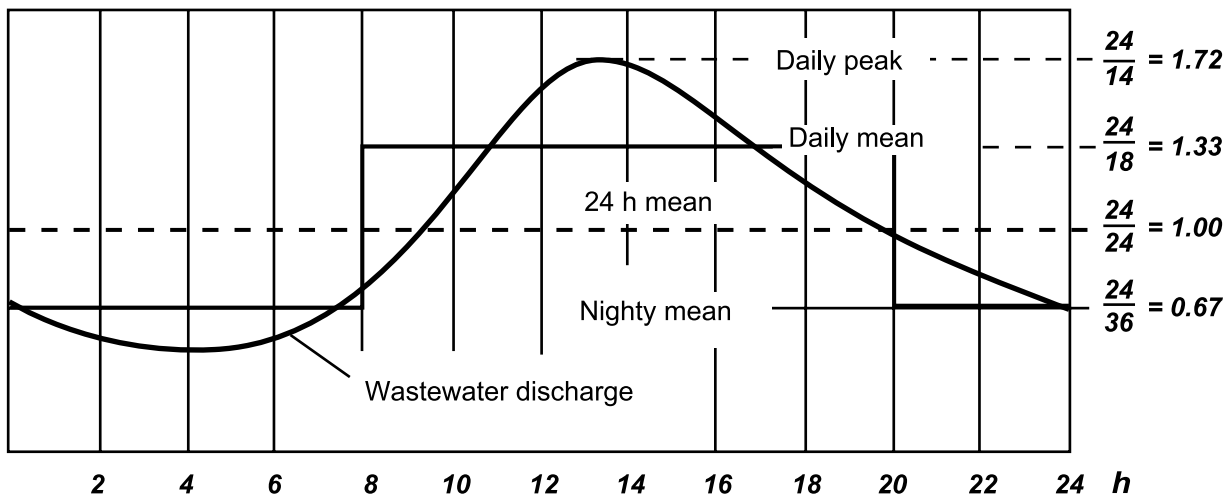
Diag. 1./1: Daily variations of the wastewater discharge

Solution to 3):

1. General parameters:
   - BOD_5
   - COD
   - TOC
2. Group parameters:
   - Fats/oils
   - Carbohydrates
   - Proteins
   - phenols
   - Hydrocarbons
3. Individual substance parameters:
   - Nitrogen
   - Oxygen
   - Carbon dioxide
   - Phosphorous
   - Sulphur
4. Nutrient parameters:
   - PO_4^{-3}
   - NO_3

Solution to 4):

- Oxidation
- Reduction
- Sedimentation
- Dilution

Solution to 5):

a) Urea: $H_2N - CO - NH_4$

b) $H_2N - CO - NH_4 + H_2O \rightarrow 2\ NH_3 + CO_2$

c) Ammonification; urease

d) This equilibrium reaction is pH-dependent. With pH values (about 7) normal in wastewater NH_4^+ ions are present. NH3 is exclusively present at pH values (> 11).

Solution to 6):   **(b)**

Solution to 7):   **(c)**

Solution to 8):   **(e)**

Solution to 9):   **(d)**

Solution to 10):

a) X = $\dfrac{100 \text{ litre/s X } 30}{100}$ = 30 litres/s = **2,592 m³/d**

b) - Heavy dilution and through this reduced treatment performance
      (in particular with nitrogen removal)
   - Hydraulic overloading and shortened retention time
      (particularly critical for the settling process in the secondary settling stage)
   - Higher energy costs
   - Increased wastewater charges
      (greater annual amount of wastewater)

Solution to 11):

a) **21,000 to 24,000 m³/d**

b) **48,000 m³/d**

c) **210 to 240 litres/(I x d)**

d) Due to infiltration of water fraction

Part B)

Solution to 1):   **(b)**

Solution to 2):   **(c)**

Solution to 3):   **(e)**

Solution to 4):   **(d)**

Solution to 5):

Dissolved carbohydrates: $(1 - 0.75)$ x 110 mg/l = 27.5 mg/litre

$$C_6 H_{12} O_6 \ \rightarrow \ 6 \ CO_2 + 6 \ H_2O$$
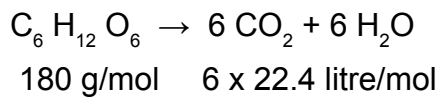
180 g/mol   6 x 22.4 litre/mol

27.5 mg/litre   X

$$X = \frac{0.0275 \ g \ / \ litre \ x \ 6 \ x \ 22.4 \ litre \ / \ mol}{180 g / mol} \ = \ 20.5 \ ml \ CO_2/litre$$

= 20.5 ml CO_2/litre x 0.85 = 17.4 ml CO_2/litre

$$\frac{V_0 \ x \ p_0}{T_0} = \frac{V_1 \ x \ p_1}{T_1}; \qquad\qquad V_1 = \frac{V_0 \ x \ p_0 \ x \ T_1}{T_0 \ x \ p_1}$$

$$V_1 = \frac{17.4 \, ml \, CO_2 \ / \ litre \ x \ 1{,}013 \, mbar \ x \ 293 \, K}{273 \, K \ x \ 990 \ mbar} \ = \ \textbf{19.1 ml CO}_2\textbf{/litre}$$

Solutions to Chapter 2.1

Drainage systems

Solution to 1):

a) Combined sewer system: wastewater and precipitation water are discharged together in one sewer

   Separate sewer system   wastewater and precipitation water are discharged in two separate sewers

b) Advantages of the combined sewer system:
   - only one sewer
   - flushing away of deposits with large stormwater discharges
   - no false connections
   - low construction and operating costs
   - low costs for private property drainage

   Advantages of the separate sewer system:
   - smaller wastewater treatment plants and pumping stations with small variations in operation
   - even inflow to wastewater treatment plant
   - small pipe cross-section of main sewer
   - easier possibilities for expanding network

Solution to 2):

a) With modified drainage systems (possible in both separate and also in combined systems) precipitation water requiring treatment and that not requiring treatment are kept separated and the latter is not treated in the wastewater treatment plant, but rather is discharged via percolation or directly into a body of surface water.

b)

Qs	Qs		Flow from outside areas, drainage water, springs, wells etc.
Domestic,commercial and industrial wastewater	Precipitation water requiring treatment	Precipitation water not requiring treatment	

CW sewer — Stormwater treatment — Wastewater treatment plant — Utilisation, percolation, discharge

Body of water ≈≈≈≈≈≈≈ Body of water ≈≈≈≈≈≈≈ Body of water ≈≈≈≈≈≈≈ Body of water
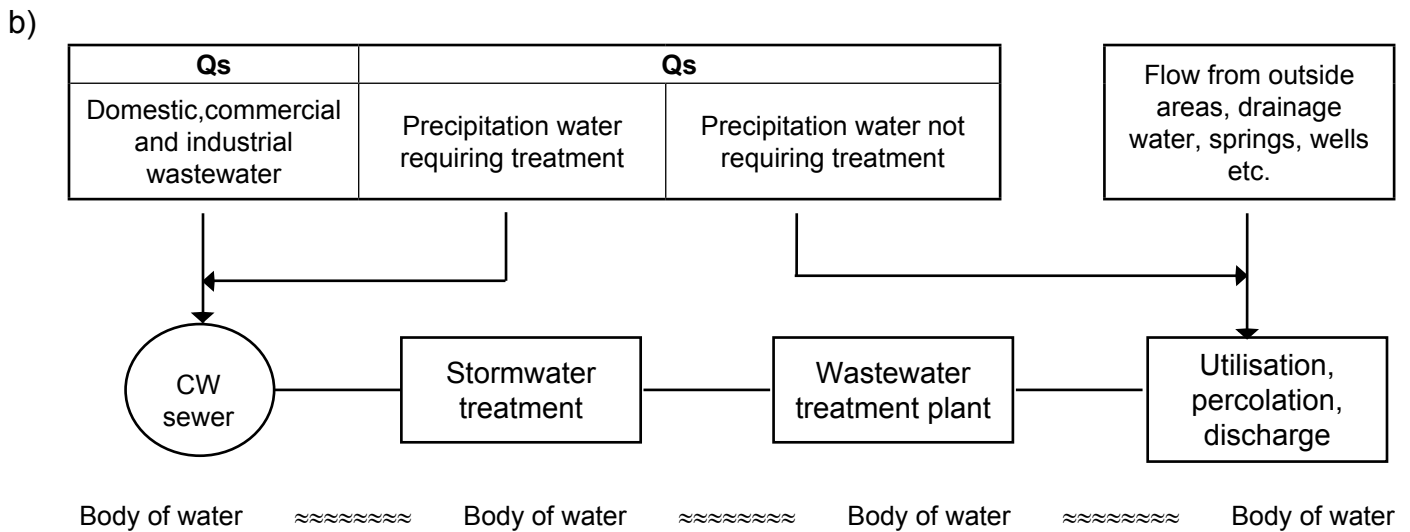
Diag. 2./1/: Schematic representation of drainage in the modified system

Solution to 3):

a) Building/house drain is the pipeline laid in the ground – also under buildings – up to the inspection manhole/service sewer
b) Down pipe is the pipeline with ventilation installed vertically inside buildings
c) Service sewer is the connection from the public sewer up to the boundary of the private property or up to the first inspection manhole/building drain.

Solution to 4)

In the separate system wastewater sewers lie higher than storm water sewers in order that, with damaged sewers, no wastewater can get into the stormwater sewer system and thereby untreated wastewater can be discharged directly into the receiving water.

Solution to 5):

a) -   Expansive building development.
   -   Lack of terrain gradient.
   -   Unfavourable subsoil.
   -   High groundwater level.
   -   Avoidance of inflow of infiltration water.
   -   Simple construction.

b) -   Pressure pipe network (ring pipeline).
   -   Connections with wastewater conveyance facility for each connection.
   -   (Automatic) flushing station.

Solution to 6):

a) - Shaft percolation.
   - Areal percolation.
   - Basin percolation.
   - Swale and pipe percolation
   - Basin-swale percolation.
   - Percolation tank.

b) - Reduction of direct stormwater discharge to wastewater treatment plant and receiving water (reduction of flooding).
   - Recharge of groundwater.
   - Reduction of the sewer discharge profile.

Solution to 7):   **(a)**

Solution to 8):   **(c)**

Solutions to Chapter 2.2

Sewers and drains

Part A)

Solution to 1):

a) - Concrete.
   - Reinforced concrete.
   - Vitrified clay.
   - Plastic.
   - Steel and cast iron.

b) Physical:
   - Wear through sediments.
   - Temperature change of the wastewater.
   - Earth and traffic loads.

   Chemical:
   - Discharge of acids.
   - Discharge of alkaline solutions.
   - As a result of gases (e.g. H_2S).

Solution to 2):

- Gradient (gravity feed pipelines); pressure (pressure pipelines).
- Material characteristics/roughness.
- Cross-sectional area.
- Installations such as manholes or fittings.
- Wetted cross-section (R = Area/Circumference).
- Rate of flow.

Solution to 3):

- Resistant to acids and alkaline solutions.
- Resistant to roots.
- Temperature stable
- Non-ageing/
- Watertight.
- Elastic against movements with pipe thrust.

Solution to 4):

Manhole structures arranged every 40 m to 70 m serve in drainage networks for:
- Monitoring.
- Cleaning.
- Ventilation.
- Overcoming height differences.
- Measurement and sampling.

Solution to 5): **(e)**

Solution to 6): **(b)**

Solution to 7):

a) Altitude of invert: $40.55 \text{ m} + (G \times I) = 40.55\text{m} + \dfrac{1}{400} \times 65.0$

$$= \textbf{40.71 m (a.m.s.l.)}$$

b) Length of reach (I): $I = h/I = (40.35 \text{ m} - 40.25 \text{ m}) \times 550$

$$= \textbf{55.0 m}$$

c) Gradient (G): $i = \dfrac{h}{I} = \dfrac{40.25 \text{ m} - 40.14 \text{ m}}{55.0 \text{ m}} = \dfrac{0.11}{55.0 \text{ m}}$

$$= \textbf{1 : 500}$$

Solution to 8):

a) $G = \dfrac{h}{l} = \dfrac{327.60 \text{ m} - 327.15 \text{ m}}{45.0 \text{ m}}$ x 1,000 ‰

         = **10 ‰**

b) 10 ‰ = 10 : 1,000 → **1 : 100**

Part B)

Solution to 1):

a) **Q = v x A**

b) Minimum velocity: ≥ **0.5 m/s;**
in order to avoid deposits (sweeping force must be sufficient)).
Maximum velocity: ≤ **6 to 8 m/s;**
in order to keep the wear of sewers and main collectors due to coarse material within limits.

Solution to 2):

a) - Methane (CH_4)
   - Hydrogen sulphide (H_2S)
   - Hydrogen cyanide (HCN)
   - Gasoline vapour

b) - Sufficient ventilation (O_2 content ≥ 17 %)
   - Concentration of combustible gases and vapours
   - Toxic gases and vapours.

Solution to 3):

a) - Rate of flow
   - Pressure head
   - Pipe cross-section
   - Roughness of the pipe material
   - Length of pipeline
   - Accoutrements and fittings

b) About the maximum permitted operating pressure
   (PN 10: $p_{perm.}$: 10 bar at 20°C)

Solution to 4):

a) - Escarpments (slopes) (dependent on soil class and depth
                          with or without benching)
   - Pipe trench sheeting, horizontal or vertical
                          (such as Essen sheeting, sheet piling, bored pile wall sheeting, girder
                          bored wall sheeting, slotted wall sheeting)
b) - From **1.25 m** depth

Solution to 5):   **(d)**

Solution to 6):   **(d)**

Solution to 7):   **(a)**

Solution to 8):   **(d)**

Solution to 9):

a) Q = A x v ;   v = 1.2 m/s x 3,600 s/h = 4,320 m/h
    Q = 0.8 m² x 4,320 m/h = **3,456 m³/h**

b) Q = A x v ;   A = $\dfrac{Q}{v}$ = $\dfrac{2{,}000 \text{ m}^3\text{ /h}}{4{,}320 \text{ m /h}}$ = **0.46 m² < 0.8 m²**

Solution to 10):

a) Internal diameter: 800 mm
    Wall thickness: 100 mm

b) m = V x ρ = (D² - d²) x π/4 x l x ρ

    = (1.0² m² - 0.8² m²) x π/4 x 2.0 m x 2.5 t/m³

    = 1.41 t

Solutions to Chapter 2.3

Part A)

Solution to 1):

a) -   Centrifugal pumps.
  -   Spiral/screw pumps.
  -   Eccentric screw pumps.
  -   Rotary piston pumps.
  -   Reciprocating membrane pumps.
  -   Hose pumps.
  -   Mammoth pumps (compressed air elevators)

b) -   Axial face seals.
  -   Stuffing boxes.
  -   Impellers.
  -   Shaft protection sleeves.
  -   Bearings.

Solution to 2):

a) $$P = \frac{Q \times H}{\eta \times 101.9}$$ (with ρ_{water} = 1.0 kg/litre)

  P = Required electric power for the pump motor (in kW)
  Q = Delivery flow (in litres/s)
  H = Manometric delivery head (in m)
  η = Efficiency
  101.9 = Conversion constant (1,000 W/kW : 9.81 m/s²)

b) Manometric delivery head is the same geodetic delivery head plus losses of the pressure pipeline.

Solution to 3):

1. -   Rotary piston pump.
2. -   Hose pump.
3. -   Membrane pump.
4. -   Centrifugal pump.
5. -   Eccentric screw pump.

Solution to 4):

-   Delivery quantity.
-   Delivery head.
-   Pump efficiency.
-   Motor efficiency.
-   Power consumption.

Solution to 5):

a) The theoretical possible suction head is 10.3 m.

b) The suction head achievable in operation is 6 to 8 m.

Solution to 6):   **(d)**

Solution to 7):   **(b)**

Solution to 8):   **(a)**

Solution to 9):

t = 18.5 min. = 1,110 s; V = 750 litres = 0.75 m³

$$P_{out} = \frac{V \times p \times g \times H}{t} = \frac{0.75 \text{ m}^3 \times 1,000 \text{ kg /m}^3 \times 9.81 \text{ m/s}^2 \times 21.5 \text{ m}}{1,110 \text{s}}$$

P_{out} = 142.51 W   (kg m²/s³)

$$\eta = \frac{P_{out}}{P_{in}} = \frac{142.51 \text{ W}}{250.0 \text{W}} = \textbf{0.57}$$

Solution to 10):

1)   7.00 h to 9.30 h   →   3 x 250 m³ = 750 m³   →   Duration: 2.5 h
2)   9.30 h to 13.00 h →   2 x 250 m³ = 500 m³   →   Duration: 3.5 h

                                   Total: 1,250 m³ →   6.0 h

3)   2,400 m³ - 1,250 m³ = 1150 m³   still to be emptied after 6.0 h

        1150 m³ : 100 m³/h (per pump) = 11.5 h   = 11 h + 30 min

        11 h + 30 min. : 3 pumps (A, B and C)   = 00 h + 30 min

Total pumping process : 6 h + (11 h + 30 min)   = **17 h + 30 min**

Part B)

Solution to 1):

	Situation:	Solution:		
		A	**B**	**C**
1)	Motor does not run	X		
2)	Air is not completely removed from the pipeline	X		
3)	Valve pressure line is not opened	X		
4)	Valve suction line is not completely opened		X	
5)	Pump bearing is defect			X
6)	Motor bearing is defect			X
7)	Pressure line is blocked	X		

A. Pump does not deliver.

B. Delivery flow too low.

C. Pump runs unevenly and makes loud noises.

Solution to 2):

- Pump output is increased.
- Friction losses in the pump are smaller.

Solution to 3):

- Impeller wear (pump blocked).
- Trapping of air (electric motor).
- No minimal water cover.

Solution to 4):

At this point the pump achieves its best efficiency, the most favourable flow rate, the lowest surge losses, the greatest smoothness of running, the highest operating safety and thus the longest service life.

Solution to 5):   **(e)**

Solution to 6):   **(c)**

Solution to 7):   **(c)**

Solution to 8):   **(a)**

Solution to 9):

$$i_1 = \frac{d2}{d1} = \frac{120 \text{ m}}{100 \text{ m}} \quad 1.2$$

I_{tot} = i1 x GR = 1.2 x 20 = 24   [GR = gear ratio]

$$n_s = \frac{1{,}200 \text{ min}^{-1}}{24} = \textbf{50 min}^{-1}$$

Solution to 10):

a) $$\frac{Q \text{ x } p \text{ x } g \text{ x } H}{1{,}000} = \frac{0.026 \text{ m}^3 \text{ x } 1{,}000 \text{ kg /m x m/s}^2 \text{ x } 84.5 \text{ m}}{1{,}000 \text{ W / kW}}$$

P_Q = 21.55 kW

η_{tot} = ηP x ηM = 0.75 x 0.90 = 0.675

$$P_M = \frac{P_Q}{\eta} = \frac{21.55 \text{ kW}}{0.675} = \textbf{31.93 kW}$$

b) $$A = \frac{Q}{v} = \frac{0.026 \text{ m}^3 \text{/s}}{2.4 \text{ m /s}} = 0.0108 \text{ m}^2$$

$$d^2 = \frac{A \text{ x } 4}{\pi} = \frac{0.0108 \text{ m}^2 \text{ x } 4}{\pi} \quad ; \quad d = 0.117 \text{ m}$$

Selected: **DN 125**

Solutions to Chapter 2.4

Sewer operation

Part A)

Solution to 1):

- Monitoring equals inspection, i.e. determination of the actual status.
- Servicing equals cleaning, i.e. maintaining the planned status.
- Damage correction equals maintenance, i.e. reinstatement of the planned status.

Solution to 2):

a) 1. Optical methods (qualitative).
   Sewer television inspection.
   Sewer mirror
   Visual inspection (only with sewers ≥DN 1000).

   2. Measurement procedures (quantitative).
   Sealing testing.
   Smoke test.
   Water pressure test.
   Air pressure testing.

b) - Deposits (Ingrowth of roots)
   - Leaks (cracks, defect seals).
   - Subsidence.
   - Corrosion.
   - Surface wear damage to coatings).
   - Defect connections.

Solution to 3):

Defect	Effects
Defective connections in the separate system: stormwater sewer to wastewater sewer	Overloading of the sewer and the wastewater treatment plant
Defective connections in the separate system: wastewater sewer to stormwater sewer	Discharge of untreated wastewater into the receiving water
Leakages with infiltration without entry of soil	Overloading of the sewer and the wastewater treatment plant , deposits, back-up of water, blockages Formation of hollow spaces within the body of the road
Leakages with infiltration with entry of soil	Narrowing of cross-section, blockages
Deposits	Narrowing of cross-section, blockages
Intrusion of roots	Narrowing of cross-section, blockages
Infestation of rats	Entry of earth and creation of hollow spaces, deposits, back-up of water, blockages
Disruption of the sewer (cracks, fragments)	Disabling of the function of the sewer with back-up of water or percolation, stability of the sewer, subsidence of buildings.

Solution to 4):

a) Sewer film is the growth of bacteria and fungi which adheres to the wall of the sewer and is in direct contact with the wastewater.
b) Protection of the sewer against direct contact with aggressive wastewater; possibility of verification of adsorbed wastewater content substances (also over longer periods); with this there is a possibility of discovering illegal connections.

Solution to 5):

The high point of a pressure pipeline must have a ventilation device as the air or gas components carried in the wastewater collect here, lead to a narrowing or even a closure of the pipeline and thus reduce or seriously reduce the flow capacity.

Solution to 6):

Smoke is blown under low pressure into a closed-off sewer section or smoke bombs are placed in the sewer. The spreading smoke enters the connection pipes. Its exiting (e.g. from stormwater drains) can be observed and documented with photos.

Solution to 7):

- Carbon dioxide (CO_2).
- Hydrogen sulphide (H_2S).
- Methane (CH_4).
- Heavy metals.
- Cyanide.
- Organic solvents.
- Radioactive substances.

Solution to 8):

- Waterproof clothing.
- Protective helmets.
- Safety boots.
- Protective gloves.
- Safety lamps (excluding hand lamps).
- Gas detection equipment.
- Rescue belts.
- Tripod.
- Rescue equipment (independent of ambient air).
- Mobile phone (surface).

Solution to 9):   **(d)**

Solution to 10):   **(b)**

Solution to 11):   **(b)**

Solution to 12):   **(d)**

Part B)

Solution to 1):

Normal processes of sewer cleaning are:
- Jet washing.
- Accumulation flushing.
- High pressure flushing.
- Mechanical methods (such as root cutters, winch cleaners).
- Special processes (e.g. boring and cutting equipment).

Solution to 2):

Phase 1: The water jets which exit diagonally towards the back(30° to 45°) drive the cleaning nozzles (flushing jets) against the direction of flow (against the slope) through the sewer and deposits loosen.
A hose length of maximum 120 m and a water tank of 6 to 12 m³ are employed for this (pressure 80 to 150 bar).

Phase 2: With return motion procedures the loosened deposits are washed towards the manhole and are sucked out there (suction device in the flushing vehicle or separate suction vehicle).

Solution to 3):

According to the vacuum principle - a vacuum is created in the tank of the suction vehicle, which extracts the washings. With a normal air pressure the water can be sucked out over a height of maximum 6 to 8 m

Solution to 4):

- Completely empty the sludge trap and separator.
- Prod the grease using a shovel and remove by suction
- Clean the facility and fill with water.
- Dispose of the residues correctly.

Solution to 5):

a) Take detergents from direct dispensers only.
b) Use one-time towels (paper towels).
c) Keep work clothes and normal clothes separate. Do not visit any food or drink facility wearing dirty working clothes
d) Do not eat, drink or smoke while working

Solution to 6):

a) Rats mainly inhabit places where there is a sufficient supply of food and they can build their earth burrows.

b) Control of rats takes place using stomach poisons or contact poisons. In order that no immunity results the types of poisons are to be changed. Measures for controlling rats are to be reported to Public Health and Municipal Offices.

Solution to 7):   **(d)**

Solution to 8):   **(c)**

Solution to 9):   **(a)**

Solution to 10):   **(e)**

Part C)

Solution to 1):

- Leaking pipe connections.
- Leaking manhole connections.
- Incorrect domestic connections.
- Defective gate valves.
- Damage to discharge structures.
- Damage to siphons.
- Damage to stormwater overflows.
- Damage to sewer pipes.
- Deposits.
- Root penetration.

Solution to 2):

- Recording of condition and accurate assessment of the rehabilitated sewer.
- Measurement of the quantity of wastewater to maintain the receiving water.
- Local visual inspection and recording of surrounding criteria such as access to the sewer, road and pathway traffic, noise and odour.
- Observance of accident prevention regulations.
- Selection of cleaning equipment.
- Determination of the construction time.
- Documentation (video recordings).

Solution to 3):

- Sewer number.
- Sewer section/reach number.
- Number of start manhole.
- Number of end manhole.
- Road key and number.
- Drainage region.
- Owner.
- Number and name of the wastewater treatment plant
- Flooding area.
- Type of sewer.
- Drainage system.
- Location in the traffic zone.
- Position in the landscape.
- Year of construction.
- Length of reach.

- Depth of start manhole.
- Date of inspection.
- Direction of inspection route.
- Video number.

Solution to 4):

a) - Sewer reaches.
  - Manholes.
  - Domestic connections.
  - Special structures.

b) - Location.
  - Geometry.
  - Year of construction.
  - Function.
  - Structural design.

Solution to 5):

a) - Carbon dioxide (CO_2)
  - Hydrogen sulphide (H_2S)
b) - CO_2: Absence of the physiological prerequisite for the perception of CO_2 (odourless)
  - H_2S: Crippling of the olfactory nerves.

Solution to 6):   **(b)**

Solution to 7):   **(b)**

Solution to 8):   **(d)**

Solution to 9):   **(d)**

Solution to 10):   **(e)**

Solutions to Chapter 3.1

Solution to 1):

1. Flow rate in the screen far too small: 0.8 m/s instead of 0.8 m/h.
2. Raw sludge to the digester instead of digested sludge.
3. Tank depth of the primary settling stage is too little at 1.45 m.
4. Incorrect precipitant: $FeCl_3$, instead of NaOH.
5. Incorrect $MLSS_{ES}$ value: 7.0 g/l instead of 3.5 g/l.
6. False B_{DS} value: 0.10 kg/(kg x d) instead of 0.16.
7. Excess sludge not in the inlet of the aeration tank but rather to the digester or into the inflow of the primary settling stage.
8. Conductivity measurement in the RS pipeline useless.
9. Polishing pond too deep with 9m.
10. Discharge concentration for NH_4-N (15 mg/litre) cannot be bigger than N_{tot} (10 mg/litre).

Solution to 2):

1. Surface of grit chamber is too large with 5.6 m², correct A = 3.6 m²
2. No primary sludge is removed from the Imhoff tank into the sludge storage but rather digested sludge.
3. Digestion time in the Imhoff tank is too high at 90 d, correct: 53 d.
4. Height of the biological filter is 3.45 m instead of 4.50 m.
5. Return water which is fed directly to the biological filter pumping station is not taken from the excess sludge pipeline but rather from the secondary settling tank discharge.

Solutions to Chapter 3.2

Screen and sieve facilities

Part A)

Solution to 1):

a) 1. Manually cleared screens: coarse screens (as protection)
    2. Mechanically cleaned screens (automatic screens) divided into:
        2.1 Co-current screens, e.g. curved bar screens; climbing screens.
        2.2 Counterflow screens, e.g. vertical screens, double guide bar screens.

b) 1. Trap and rinsing sieves.
    2. Rotary screens.

c) Flow rate in the screen chamber: > 0.5 m/s in order that no sand deposits here.
    Flow rate between the screen bars: < 2.0 m/s, in order that not too much coarse material is transported through the screen.

Solution to 2):

1. Drive.
2. Chains/ropes.
3. Chute.
4. Stripper.
5. Screen grid.
6. Screen rake.

Solution to 3):

a) If a fixed difference of the water level is exceeded in front of behind the screen grid, clearing of the screen starts.
b) A water level difference control operates to meet the requirement (dependent on the degree of accumulation on the screen grid) and, as opposed to time-rest control avoids idle operation and possible defects due to overloading.

Solution to 4):

1. Weather: - protection against increased corrosion as well as freezing of the screen.
2. Vermin: - restraint and restriction of vermin (rats) from the sewer system.
3. Emissions: - Reduction of odour nuisances.

Solution to 5):

The flow rate in this area is too small either due to incorrect dimensioning or structural design of the screen facility or too much of screen bars, e.g. too small clearance intervals.

Solution to 6):

- Volume reduction through washing out adhering organic matter
- Reduction of odour emissions, e.g. in the incineration plant
- To make available additional organic substances for subsequent treatment stages such as denitrification stage and digestion.

Solution to 7):   **(d)**

Solution to 8):   **(b)**

Solution to 9):   **(c)**

Solution to 10)

a) $x = \dfrac{432{,}000 \text{ liter / a}}{48{,}000 \text{ I}}$ = **9.0 litres/(I x a)**

b) As normal: between 2 – 15.0 litres/(I x a)

Part B)

Solution to 1):

a)   Grit chamber: less sand.

b)   Primary settling tank   less settleable solids

                                            less floating sludge.

c)   Aeration tank: less organic carbon compounds for the denitrification

                                            greater protection of the aeration facilities.

d)   Digester: less raw sludge

                                            less floating sludge through which an improved agricultural utilisation exists.

Solution to 2):

-   Arrangement of an emergency circulation.
-   Construction of an additional screen or sieve path

Solution to 3):

-   Bar separation, screen/hole size.
-   Degree of accumulation.
-   Bar shape/shape of sieve.
-   Frequency of clearing.
-   Inflow velocity.
-   Inflow quantity.

Solution to 4):

-   Storage of the screenings in closed rooms which have a ventilation system.
-   Frequent and regulated transport away of the screenings.
-   Packaging of screenings or sprinkling screenings with chalk or deodorising.
-   Washing of screenings.

Solution to 5):

- Functional controls.
- Greasing of moving parts.
- Checking of oil levels.
- Cleaning of the ejected material.

Solution to 6):   **(e)**

Solution to 7):   **(c)**

Solution to 8):   **(c)**

Solution to 9):

$$X_M = \frac{\Sigma \text{ Jan. to Dec.}}{12 \text{ months}} = \textbf{16.0 t/month}$$

Minimum value: **9.9 t**
Maximum value: **20.4 t**

Solution to 10):

$V_S = 21.5 \text{ litres (l x a)} \times 8,000 \text{ l} = 172,000 \text{ litres/a}$
$= 172.0 \text{ m}^3\text{/a}$

$W_S = 172.0 \text{ m3/a} \times 0.7 \text{ t/m}^3 = \textbf{120.4 t/a}$

Solutions to Chapter 3.3

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Grit chambers and grease traps

</div>

Part A)

Solution to 1):

- Flat grit chambers (such as longitudinal and rectangular grit chambers): horizontal
- Circular grit chamber: horizontal and spiral shaped
- Deep grit chamber: vertical
- Aerated grit chamber: screw-shaped

Solution to 2):

a) As a result of the stable air-water screw the degree of separation changes only negligibly with different flows (nights, during the day, with rain).
b) Because it is to be feared that, the oxygen carried into the grit chamber is transported to the upstream denitrification (DN) stage and thus reduces its performance.

Solution to 3):

- Longitudinal velocity: duration of floating of objects (cork test).
- Roller rate: Impeller wheel

Solution to 4):

- Determination of the ignition loss (IL) in grit chamber trappings
- Slurry (decanting) test of the mixed primary sludge (sand fraction in mixed primary sludge)

Solution to 5):   **(a)**

Solution to 6):   **(b)**

Solution to 7):   **(d)**

Solution to 8):

a) $Q = \dfrac{V}{t}$; $Q = A_o \times q_A \rightarrow \dfrac{V}{t} = A_o \times q_A$

$$\dfrac{L \times W \times D}{t} = L \times W \times q_A \rightarrow \dfrac{D}{t} = q_A$$

$D = q_A \times t = 0.4 \text{ cm/s} \times 15 \text{ min} \times 60 \text{ s/min}$

    $= 360 \text{ cm} = \mathbf{3.6\ m}$

b) $A_o = \dfrac{Q}{q_A} = \dfrac{0.200 \text{ m}^3/\text{s}}{0.004 \text{ m}/\text{s}} = \mathbf{50\ m^2}$

Solution to 9):

a)   4 litre/(l x A)   x   1.23 kg/litre = 4.92 kg/(l x a)   Total mixture
-(1 – 0.4 litre/ x 4 litre/(l x a)   x   1.00 kg/litre   = 2.40 kg/(l x a)   Water fraction
   1.6 litre(l x a)   = 2.52 kg/(l x a)   DS
-(1 – 0.32 litre/ x 1.6 litre/(l x a) x   1.80 kg/litre   = 1.96 kg/(l x a)   Sand
   0.51 litre/(l x a)   = 0.56 kg/(l x a)   oDS

Retention: 0.56 kg oDS/(l x a) x (0.32 – 0.04)   = 0.157 kg oDS/(l x a)

0.157 kg oDS/(l x a) x 20,000 l = 3.140 kg oDS/a   = **3.14 t oDS/(l x a)**

b) $\rho_{oDR} = \dfrac{0.56 \text{ kg oDS}/(l\ \times\ a)}{0.51 \text{ liter}/(l\ \times\ a)} = \mathbf{1.1\ kg\ oDS/litre}$

Part B)

Solution to 1):

- Trough with sand-water mixture.
- Sloping level
- Eccentrically arranged scraper (classifying rake)
- Container for cleaned sand

Solution to 2):

Air transfer into the grit chamber was not adjusted;
through this, sand removal decrease due to increased turbulence.

Solution to 3):

a) - Primary settling tanks whose sludge scrapers are equipped with a floating sludge blade and these have an appropriate floating sludge runoff channel.
  - Aerated sand traps.
  - Separate floating sludge chamber in addition to aerated sand traps which use the flotation effect of the injected air.

b) - Pasting up and blocking of pipelines, gate valves, aeration facilities etc.
  - Disruption of the biological treatment process.
  - Disruption of the settling of sludge.
  - Disruption of the digestion process due to mineral oils and fats.

c) - Organic oils and fats can be added, dosed, to digesters. They increase the gas yield.
  - As far as no sludge digestion is available disposal is with screenings.
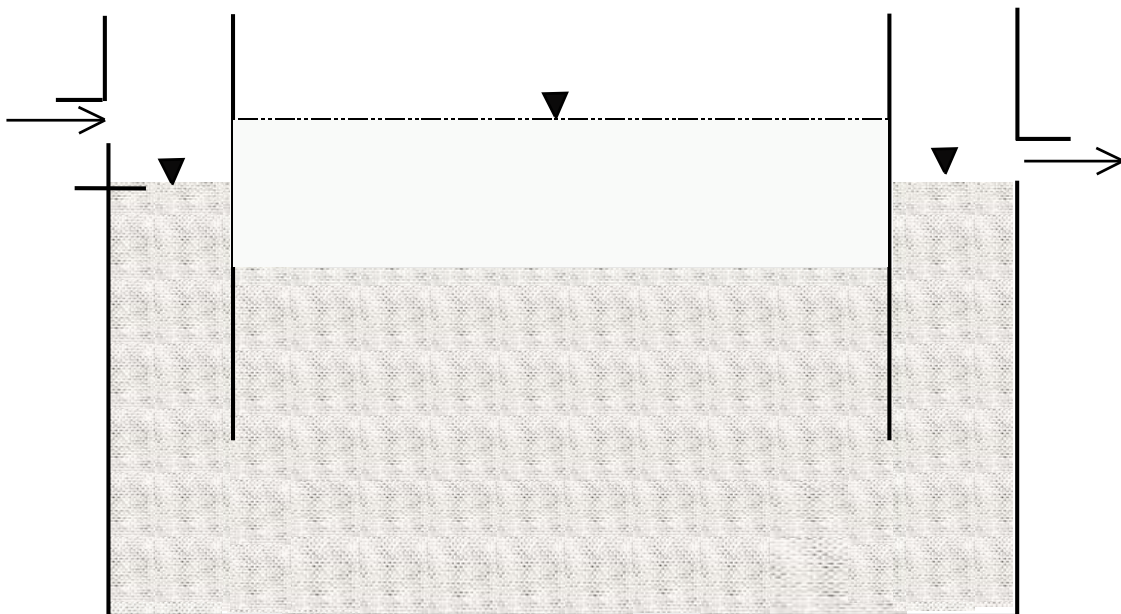 - Mineral oils must be disposed of separately.

Solution to 4):

a) A grain size of **> 0.1 to 0.2 mm**

b) A flow rate of ca. **30 cm/s**

Solution to 5): **(e)**

Solution to 6): **(c)**

Solution to 7): **(c)**

Solution to 8):

| | Heavier liquids |
| | Lighter liquids |

Diag.: 3.3/1: System sketch of a light density material separator

Following an emptying attention is to be paid with a recommissioning that the sludge trap is immediately refilled with water and the water level is not below the scumboard, as otherwise light matter can get into the runoff.

Solution to 9):

a) V = A_o x L = (0.10 x 0.8 + (0.80 + 0.3)/2 x 0.5) x 25 = 8.875 m³

$$T = \frac{V}{Q} = \frac{8.875 \text{ m}^3}{648 \text{ m}^3/h} = 0.014 \qquad = \textbf{0.84 min.}$$

b) q_A = Q/A_o = $\dfrac{648 \text{ m}^3/h}{0.8\text{m} \times 25 \text{ m}}$ = **32.4 m/h**

c) v = Q/A_Q = $\dfrac{0.180 \text{ m}^3/s}{0.355 \text{ m}^2}$ = **0.51 m/s**

d) Reduce longitudinal velocity to ca. 0.3 m/s through:
 - Installation of a baffle plate at the outlet
 - Increase the cross-section of the grit chamber
 - Commissioning of a second grit chamber, if available
 - Placing a venturi flume downstream

Solutions to Chapter 3.4

Primary settling tanks

Part A)

Solution to 1):

a)   **1,**   b)   **7,**   c)   **9,**   d)   **4,**   e)   **11**.

Solution to 2):

a) Advantage of longitudinal tanks compared with circular tanks:
    1. Smaller area requirement.
    2. Hydraulic advantages (with circular tanks uneven exit of water can occur in the central structure).

    Disadvantage of longitudinal tanks compared with circular tanks:
    1. Idle running of scraper (with the employment of blade scrapers).
    2. Difficult arrangement of overfall sills.
    3. No continuous sludge clearance.

b) Longitudinal tanks: → Sludge scrapers
                             → Flight scrapers

    Circular tanks: → Sludge scrapers

Solution to 3):

1. Greasing of bearings and checking of oil levels.
2. Examination of skimming rubbers, rollers and lifting cables of sludge scrapers.
3. Keeping the scraper rails clear of obstacles.

Solution to 4):

- Hydraulic overloading (small retention times, high flow rates).
- Disrupted sludge clearance (defective scraper facilities)
- Uneven distribution of wastewater.
- Density current (inflow of stormwater, condensation water containing salt)
- Too great charging of overfall sills

Solution to 5):   **(d)**

Solution to 6):   **(e)**

Solution to 7)

a) $V = A_0 \times D = Q \times t$

$$\rightarrow \quad A_0 = \frac{Q \times t}{D} = \frac{750 \text{ m}^3 \text{ /h} \times 1.0 \text{ h}}{3.0 \text{ m}} = 250.00 \text{ m}^2$$

$B = A0/L = 250.0 \text{ m}^2/50.0 \text{ m} = 5.0 \text{ m}$

b) $v = \dfrac{Q}{W \times D}$, whereby $W \times D$ = flow area

$$= \frac{750 \text{ m}^3 / \text{h}}{5.0\text{m} \times 3.0 \text{ m}} = 50 \text{ m/h} = \textbf{1.39 cm/s}$$

Solution to 8):

a) $t = \dfrac{V}{Q} = \dfrac{1{,}080 \text{ m}^3}{900 \text{ m}^3 / \text{h}} = \textbf{1.2 h}$

b) $q_A = \dfrac{Q}{A_0} = \dfrac{900 \text{ m}^3 \text{ /h}}{540 \text{ m}^2} = \textbf{1.67 m/h}$

c) $v = \dfrac{Q}{A_Q} \rightarrow Q = v \times A_Q = 0.025 \text{ m/s} \times 20 \text{ m}^2$

$$= 0.5 \text{ m}^3\text{/s} = \textbf{500 litre/s}$$

Part B)

Solution to 1):

- Odour development.
- Digestion of sludge and obstruction of the settling process.
- Uneven charging of the digesters with disruption of the digester operation.
- Pre-acidification of the sludge and thus charging of the DN stage with easily degradable carbon compounds. This can lead to the increase of the DN performance.
- Formation of bulking sludge in the activated sludge stage through increased addition of reduced sulphur compounds.

Solution to 2):

- Digestion of the sludge as a result of the too low frequency of clearing.
- Worn out rubber strips on the floor scraper.
- Hoppers dimensioned too large or too seldom removal of sludge from the hoppers.

Solution to 3):

- Reduction of the flow velocity from ca. 1 m/s in the inlet channel to ca. 1 cm/s in the settling tank.
- Even distribution of the inflow from the complete tank cross-section.
- Avoidance of a too high flow at the bottom of the tank.
- Avoidance of turbulence in the inlet area (sludge hopper).

Solution to 4):

All measures which reduce the retention time of the wastewater and the sludge, such as :
- Decommissioning of a tank if the necessary process-technical parameters (retention time, surface charging, overfall sill charging) are maintained.
- Sludge removal from the hopper more frequently than once a day.
- Increase of the clearance velocity.

Solution to 5): **(c)**

Solution to 6): **(b)**

Solution to 7): **(c)**

Solution to 8):

a) $\dfrac{Q}{L} = \dfrac{200\ m^3\ /h}{5\ m} = 40\ m^3/(m \times h)\ >\ 35\ m^3/(m \times h)$

b) - Increased colloidal dissolved substances and settleable solids get into the following biological stage. An increased excess sludge removal caused by this can lead to a reduction of the sludge age with an activated sludge process.
   - The non-settleable substances can lead to a blocking of the hollow spaces with the Trickling Filter (TF) process.

Solutions to Chapter 3.5

Biological wastewater treatment

Part A)

Solution to 1):

- Type and number of micro-organisms, in particular of bacteria.
- Water regime.
- Flow rate.
- Form and characteristics of the bed of the body of water.
- Temperature of the air and the water (insolation = exposure to the sun's rays).
- O_2 content.
- Type and concentration of the added (pollutant) substances.

Solution to 2):

Bodies of water rich in nutrients lead to an increased production of vegetative biomass (eutrophication). The plants developed in quantity die off, sediment and subsequently decompose. The end products of this digestion process lead to a further pollution (secondary pollution) of the body of water.

Solution to 3):

Determined by the addition of nutrients (wastewater) a high metabolic activity starts with the bacteria (high reproduction rate), which has a large oxygen consumption as a result. The protozoa as so-called bacteria eaters also reproduce more with increasing nutrient supply (bacteria) even though very much slower than the bacteria.
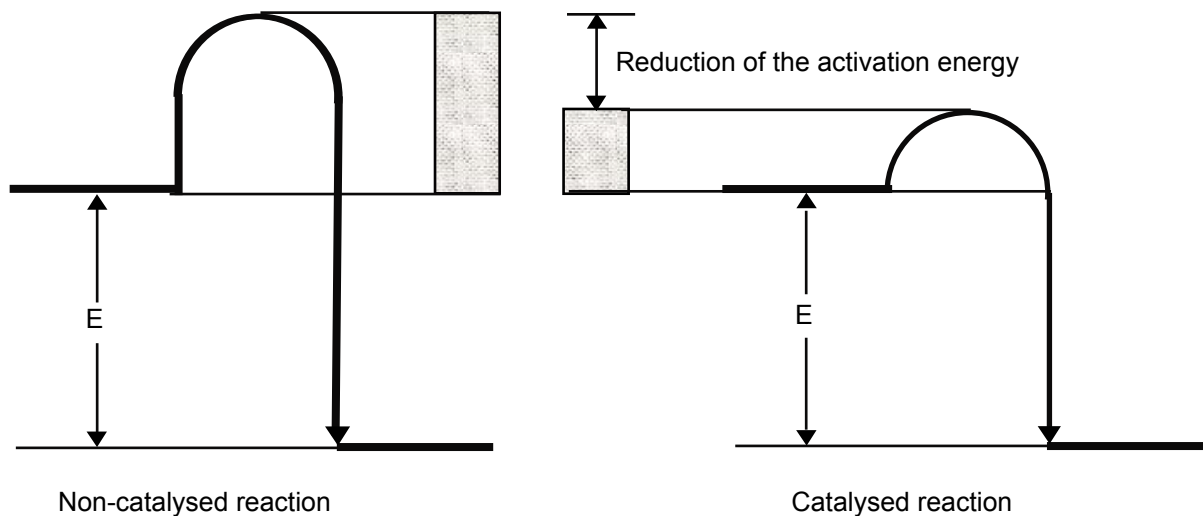
Part B)

Solution to 1):

- The activated sludge process is based on the ability of bacteria to form flocs.
- The fixed bed process is based on the property of bacteria of becoming fixed to substances

Solution to 2):

- C: Heterotrophic degradation.
- N: Nitrification, denitrification.
- P: Excessive storage of phosphates by bacteria as energy reserve.

Solution to 3):

a)

Diag. 3.5/1: Biochemical reactions without and with catalyser

From: Mudrack; Knust: Biologie der Abwasserreinigung, 3rd Edition 10991
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b) - They have an effect in the smallest quantity.
   They are neither changed nor consumed with the reaction.
   They have no influence on the situation of the reaction balance rather accelerate their adjustment.

c) - Enzymes according to their chemical structure are proteins.

Solution to 4):

Heterotrophic: degradation of organic substance:
    org. $C + O_2 \rightarrow CO_2 + H_2O +$ mineral substances

Autotrophic: degradation of organic substance:
    $CO_2 + H_2O +$ mineral substances $\rightarrow$ org. $C + O_2$
                        (sun energy)

Solution to 5):   **(c)**

Solution to 6):   **(d)**

Solution to 7):   **(d)**

Solution to 8):   **(a)**

Solution to 9):   **(d)**

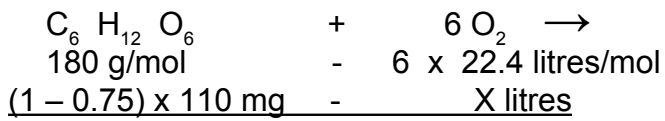Solution to 10):   **(d)**

Solution to 11):

a) - Cell wall, cell membrane, cytoplasm, nuclear equivalent, membrane introversions, ribosome, cilium, mucilaginous layer, reserve substances
   - Ribosomes serve for the synthesis of protein.

b) - $2^{20} = 1,048,576$ **after 21 cell divisions**
     21 cell divisions / 3 divisions per h = **7 h**

c) - 70 kg x 10,000/d = 700,000 kg/d = **700 t/d**

Solution to 12):

$C_6 \, H_{12} \, O_6$ + $6 \, O_2$ $\longrightarrow$
180 g/mol   -   6 x 22.4 litres/mol
(1 – 0.75) x 110 mg   -   X litres

$$X = \frac{0.25 \times 0.11 \, g \times 6 \times 2.4 \, liter / mol}{180 \, g / mol} = 0.02053 \text{ litres} = 20.53 \text{ ml}$$

$$\frac{p_0 \times V_0}{T_0} = \frac{p_1 \times V_1}{T_1}$$

$$\frac{1.013 \text{ mbar} \quad 20.53 \text{ ml}}{273 \text{ K}} = \frac{990 \text{ mbar} \times X \text{ ml}}{290 \text{ K}}$$

$$X = \frac{1,013 \text{ mbar} \times 290 \text{ K} \times 20.53 \text{ ml}}{990 \text{ mbar} \times 273 \text{ K}} = 22.32 \text{ ml } CO_2$$

0.90 x 22.32 ml CO_2 = **20.09 ml CO_2**

Solutions to Chapter 3.6.1

Aeration tanks (without nitrification)

Solution to 1):

oDS:	Organic solid matter content:	Active biomass in the aeration tank, inter alia relevant for the sludge loading and sludge age
SV:	Sludge volume:	Information on active sludge mass
SVI:	Sludge volume index:	Settling behaviour of the sludge
O_2 content:	Oxygen content:	Sufficient O2 supply of the micro-organisms and possible circulation of the sludge
RR:	Recirculation ratio:	Sufficient DS return feed from the secondary settling stage in the aeration tank
ES removal:	Removal of excess sludge:	Size of the biomass growth
Microscopic picture:		Composition and structure of the biocoenosis (loading conditions)

Solution to 2):

a) Strongly developed bacteria flocs; fewer protozoa (flagellates, amoeba); but in greater number of individuals.
b) Compact bacteria flocs; many different types of protozoa, (ciliates).
c) Smaller bacteria flocs; many types of protozoa but in smaller number of individuals (ciliates); in addition rotifers and nematodes.

Solution to 3):

a) - Rise of solid matter contents in the aeration tank.
   - Increased sludge loading without significant influence on the treatment performance.
   - Increased oxygen requirement through enlarged sludge quantity in the aeration tank.
   - Increased sludge volume charging of the secondary settling stage up to the limit of loading.
   - Possible flushing out of increasingly accumulated sludge quantity from the secondary settling stage into the wastewater treatment plant outflow with inflow of stormwater.

b) - Increased removal of sludge from the aeration tank into the secondary settling stage.
   - Increased sludge volume charging of the secondary settling stage.
   - With exhaustion of the storage volume of the secondary settling stage flushing out of sludge into the wastewater treatment plant outflow.

c) - Due to the false indication there is a reduced oxygen transfer into the aeration tank.
   - With the aeration tank without nitrification an oxygen content of 0.5 mg/litre leads to a smaller reduction of the treatment performance.

d) - The increase of the BOD_5 load leads to an increased metabolism of the bacteria and thus to an increased oxygen demand
   - The treatment performance will change only insignificantly – if at all - within the scope of this change of loading

e) - Despite increased thickening of the sludge in the secondary settling stage the quantity of sludge removed from the activated sludge stage with this significantly reduced transfer performance cannot be transferred back completely.
   - Due to the reduced solid matter content the sludge loading will decrease without the treatment performance being significantly influenced.
   - In order to avoid an overloading of the secondary settling stage the quantity of sludge not fed back is to be removed as excess sludge.

Solution to 4):

a) - **MLSS$_{RS}$ = 3.8 kg/m³)**

b) - Through reducing the recirculation ratio **to RR = 0.6**
     in accordance with the diagram.

Solution to 5):   **(b)**

Solution to 6):   **(e)**

Solution to 7):   **(d)**

Solution to 8):   **(d)**

Solution to 9):   **(d)**

Solution to 10):

a) B_{DS} $= \dfrac{Q \times C}{DS \times V} = \dfrac{0.075\ m^3/s \times 86,400\ s/d \times 0.2\ kg\ BOD_5/m^3}{3.3\ kg/m^3 \times 1,350\ m^3}$

$= \textbf{0.29 kg BOD}_5\textbf{/(kg DS} \times \textbf{d)}$

b) Q_{ES} $= \dfrac{ES_d}{MLSS_{ES}}$

ES_d $= ES_B \times Bd$

$= 0.8\ kg\ DS/kg\ BOD_5 \times 0.075\ m^3 \times 86,400\ s/d \times 0.2\ kg\ BOD_5/m^3$

$= 1,036.8\ kg\ DS/d$

$MLSS_{ES} = MLSS_{RS}$

$RR = MLSS_{AT}/(MLSS_{RS} - MLSS_{AT})$

$MLSS_{RS} = MLSS_{AT}/RR + MLSS_{AT} = \dfrac{3.3\ g/liter}{1.1} + 3.3\ g/litre = 6.3\ g/litre$

Q_{ES} $= \dfrac{1,036.8\ kg/d}{6.3\ kg\ DS}$ $= \textbf{164.6 m}^3\textbf{/d}$

c) B_V / Specific load

$\dfrac{0.075\ m^3/s \times 86,400\ s/d \times 0.2\ kgBOD_5/m^3}{0.04\ kg\ BOD_5/(l \times d) \times 1,350\ m^3}$ $= 24\ l/m^3$

Solution to 11):

$\begin{array}{lcl} 35\ mg/litre & - & 10\ \% \\ \underline{\quad X \quad} & - & \underline{\quad 7\ \%} \end{array}$

$X = \dfrac{7\% \times 35\ mg/liter}{10\%}$ $= \textbf{24,5 mg/litre}$

Solution to 12):

Sludge quantity to be increased:
$\Delta\,MLSS_{AT}\,\times\,V\quad=\,(3.5\,-\,3.3)\,kg/m^3\,\times\,2{,}000\,m^3\quad=\quad400\,kg\,DS$

Daily sludge quantity to be removed:
$MLSS_{ES}\,\times\,Q_{ES}\quad=\,6.6\,kg/m^3\,\times\,250\,m^3/d\quad=\quad1{,}650\,kg\,DS/d$

Required duration:
$$\frac{400\,kg\,DS}{1{,}650\,kg\,DS\,/\,d}\quad=\,0.242\,d\,=\,\textbf{5.81 h}$$

Solutions to Chapter 3.6.2

Aeration

Part A)

Solution to 1):

a) - The size of the pollutant load has direct effect on the anabolism (growth) of the bacteria and thus on the oxygen demand.
  - The bacteria complete the anabolism in dependent of the substrate supply. Changes to the biomass in the aeration tank thus have an effect on the oxygen demand.

b) A regulation mechanism for the oxygen is deliberately set up in order to adjust the oxygen transfer to the previously described changes of loading and thus to avoid an under- or over-supply.

Solution to 2):

a) Oxygen demand for the anabolism (assimilation).
b) Oxygen demand for the catabolism

Solution to 3):

- Temperature.
- Partial pressure.
- Saturation deficiency.
- Renewal of contact surface, such as contact surface, contact time, contact path

Solution to 4):

On its way to the surface of the water, the water pressure on the air bubble reduces with diminishing depth of water. In the same way, as the pressure reduces, the volume of the air bubble increases (p x V = const). On the other hand, the buoyancy now, with the growing volume, also increases (corresponds with the weight of the displaced fluid). This means that the rate of rise from the bottom to the water surface continuously increases and the air bubble is driven increasingly more rapidly upwards.

Solution to 5):   **(c)**

Solution to 6):   **(e)**

Solution to 7):   **(d)**

Solution to 8):   **(d)**

Solution to 9):

Saturation deficiency: $\dfrac{Cs}{Cs - Cx}$

With 3 mg/litre $= 10/(10 - 3) = 1.42$
With 2 mg/litre $= 10/(10 - 2) = 1.25$

$1.42 - 1.25 = 0.17$, $\dfrac{0.17 \times 100\%}{1.42}$ = **12.0 %**

Solution to 10):

$\dfrac{D}{W} = \dfrac{4}{10} = \dfrac{1}{2.5}$

$V = 1,500 \text{ m}^3$

From diagrams **Diag. 3.6.2/1** and **Diag. 3.6.2/2**
necessary performance: 15 W/m^3 or 22 kW

$OC = OB \times B_d = 1.08 \text{ kg O}_2/\text{kg BOD}_5 \times 62.6 \text{ kg BOD}_5/\text{h} = 67.61 \text{ O}_2/\text{h}$

$P_{nec} = \dfrac{OC}{O_N} = \dfrac{67.61 \text{ kg O}_2 / \text{h}}{1.6 \text{ kg O}_2 / \text{kWh}}$ = **42.26 kW** < 22 kW required

or

$\dfrac{42,200 \text{ W}}{1,500 \text{ m}^3}$ = **28,17 W/m³** > 15 W/m³ necessary
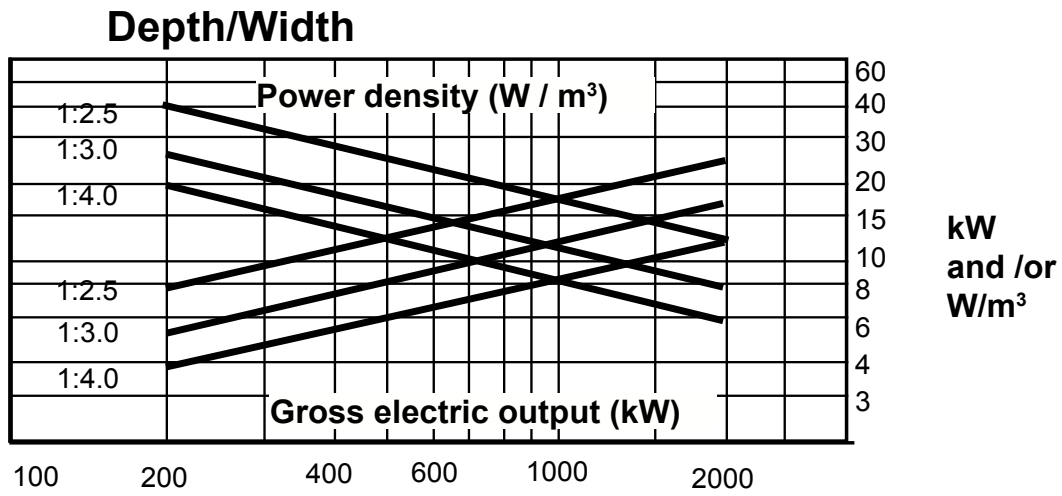
Depth/Width

Diag. 3.6.2/2: Performance diagram for tank circulation

From: Hosang; Bischof: Abwassertechnik, 9th Edition 1989 © Teubner, Stuttgart

Part B)

Solution to 1):

a) -   Candles.
-   Aeration domes or point aerators.
-   Disk, plate and surface aerators.

b) -   1. Spinners,
-   2. Rollers, diameter > 1.0 m: mammoth rotors

c) -   Ejectors or jet aerators.
-   Submerged aerators.

Solution to 2):

-   Increasing blockage of the aerators.
-   Rise of the pollutant load (BOD_5, COD, NH_4)
-   Leakages in the air lines.
-   Wear of blowers, blockage of the staring sieve.
-   Defects in the oxygen measuring facilities

Solution to 3):

a) -   Changes to the rpm of the drive gear.
-   Different submerged depth of the spinners through height adjustment of the axle.
-   Raising and lowering of the water level using weirs (change to the submerged depth).
-   Switching ON and OFF of spinners.
-   Jerky or dragging operation (change direction of rotation)

b) -   Raising and lowering of the water level using weirs.
-   Switching ON and OFF of rollers.
-   Changes to the rpm of the drive gear.

Solution to 4):

a) 4 x 8   = **32 kg O_2/h**

b) 3 x 10 = **30 kg O_2/h**

c) First, the surface renewal (mixing of air and water) increases with intensive circulation; then the surface renewal decreases again as the roller submerges too deeply (after exceeding half the roller diameter).

Solution to 5):   **(e)**

Solution to 6):   **(c)**

Solution to 7):   **(c)**

Solution to 8):

a) 50,000 x 0.04 kg BOD_5/(l x d) x 2.0 kg O_2/kg BOD_5 = 4,000 kg O_2/d

$$\frac{4,000 \text{ kg } O_2 \, / \, d}{24 \text{ h} \, / \, d \ \times \ 1.5 \text{ kg } O_2 \, / \, m^3 \text{ air}} = \ \textbf{111 kW}$$

b) 8.0 g O_2/(m x m^3 Air) x 5.0 m = 40.0 g O_2/m^3 air

$$\frac{4,000 \text{ kg } O_2 \, / \, d}{0.04 \text{ kg } O_2 \, / \, m^3 \text{ air}} = \ 100{,}000 \text{ m}^3 \text{ air/d} \ = \ 1.1574 \text{ m}^3 \text{ air/s}$$

$$A \ = \ \frac{Q}{V} \ = \ \frac{1.1574 \text{ m}^3 \text{ air} \, / \, s}{10.0 \text{ m} \, / \, s} \ = \ 0.11574 \text{ m}^2$$

D = 0.384 m

Solution to 9):
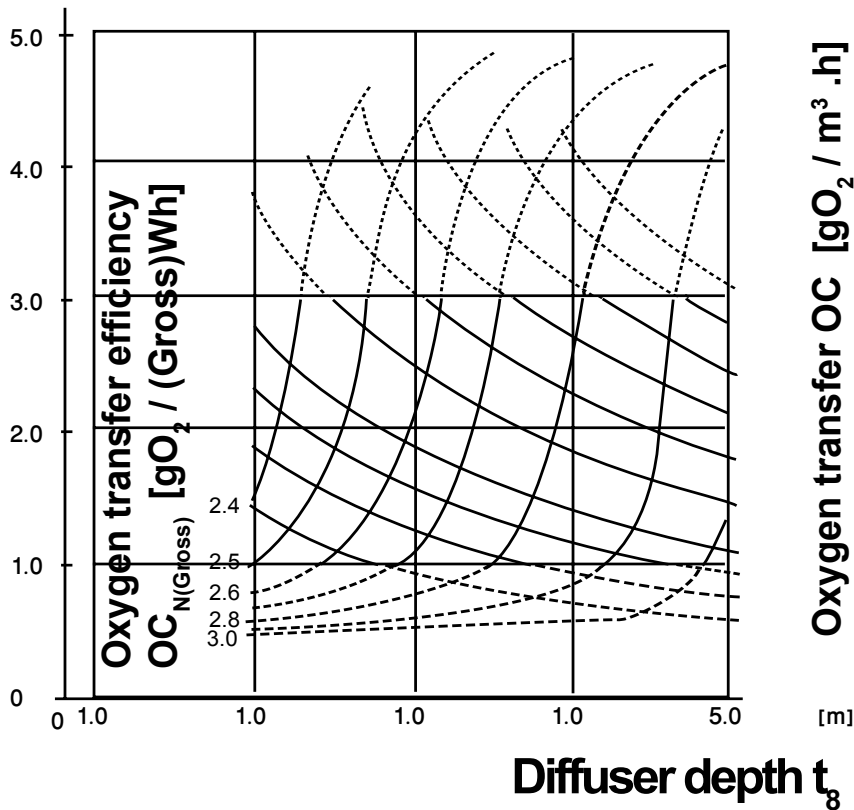
Diag. 3.6.2/4: Nomograph for oxygen transfer efficiency and oxygen transfer

a) $\dfrac{259,200 \ Nm^3 \ air / d}{24 \ h / d \ \times \ 4,000 \ m^3}$ = 2.7 Nm³ air/(m³ x h)

b) Oxygen transfer efficiency: 2.8 g O2/Wh = **2.8 kg O2/kWh**
   Oxygen transfer: **120.0 g O2/(m³ x h)**

c) 120.0 g O_2/(m³ x h) x 4,000 m³ x 24 h/d = **11,520 kg O_2/d**

d) $\dfrac{1,520 \ kg \ O_2 \ / \ d}{2.8 \ kg \ O_2 \ / \ kWh}$ = **4,114 kWh/d**

e) $\dfrac{120 \ g \ O_2 \ / \ (\ m^3 \ x \ h)}{2.7 \ Nm \ air \ / \ (\ m^3 \ x \ h)}$ = 44.4 g O_2/Nm³ air

$\dfrac{4.4 \ g \ O_2 \ / \ Nm^3 \ air}{280 \ g \ O_2 \ / \ Nm^3 \ air}$ x 100 % = **15.9 %**

Solutions to Chapter 3.6.3

Secondary settling tank

Part A)

Solution to 1):

a) - Separation of the wastewater-sludge mixture.
   - Thickening of sedimented sludge.
   - Storage of the sludge frequently washed out of the aeration tank through increased hydraulic loading (combined water inflow).

b) 1: Clarified water zone.
   2: Separation zone.
   3: Storage zone.
   4: Thickening and clearance zone.

Solution to 2):

Plant and equipment	Number
Runoff channel	2
Smoothing screen	8
Sludge removal pipeline	3
Sludge pipeline to the thickener and/or digester	4
Sludge chamber	7
Sludge hopper	5
Floating sludge/scum removal	6
Inlet pipe	1

Solution to 3):

a)

Type of tank	Type of scraper
Longitudinal tank	**A; B; C**
Circular tank	**A; B**
Hopper-bottom tank	**-**

b) - Obstacles on the tank floor.
   - Defective rubber lips on the scraper blade.
   - Motor and bearing damage of the drives.
   - Canting of the scraper bridges with disrupted ganging of the drives (e.g. ice, temperature influences)

Solution to 4):   **(d)**

Solution to 5):   **(a)**

Solution to 6):   **(b)**

Solution to 7):   **(a)**

Solution to 8):

a) According to the Smallest Common Denominator (SCD):

$150 = 2 \times 3 \times 5^2$ and $180 = 2^2 \times 3^2 \times 5$

$SCD = 2^2 \times 3^2 \times 5^2 = $ **900 minutes**

b) After 900 minutes scraper A has covered 6 rounds and scraper B 5 rounds corresponding to each **600 m**.

Solution to 9):

- SVI $= \dfrac{Vs}{DS}$; $\dfrac{300 \text{ ml / liter}}{3 \text{ g / l}} = 100 \text{ ml/g};$ $Q_{RS} = Q_{RS}$ (RR = 1)

- $q_A = \dfrac{Q_M + Q_{RS}}{A} = \dfrac{1{,}000 \text{ liters / s } +500 \text{ liters /s}}{3{,}250 \text{ m}^2} = \dfrac{5{,}400 \text{ m}^3 \text{ /h}}{3{,}250 \text{ m}^2} = 1.66 \text{ m/h}$

- $q_{SV} = q_A \times V_s = 1.66 \text{ m/h} \times 300 \text{ litres/m}^3 = 498 \text{ litres/(m}^2 \times \text{h)}$

Both loading values are marginal. If the recirculation ratio is reduced, for example to 75 % with combined water inflow, the values improve.

Part B)

Solution to 1):

- Freely suspended bacteria with high sludge loading or with the absence of protozoa.
- Deflocculation of activated sludge through turbulence or contamination.
- Incomplete retention of small flocs through the upflow sludge filter.
- Hydraulic overloading of the secondary settling stage, which leads to a high surface charging.
- Too high overfall crest charging.
- Too high sludge volume charging.
- Anaerobic rising sludge as a result of poor or infrequent clearing.
- Occurrence of zoogloea in highly loaded plants.
- Massive development of filamentous bacteria and fungi.
- Excessive growth of so-called actinomycetes.

Solution to 2):

- With sludge quantities less than the daily excess sludge quantity there are no effects on the operation of the activated sludge plant if the excess sludge removal is reduced appropriately.

- With sludge quantities greater than the daily excess sludge quantity the solid matter contents and the sludge age reduce and the sludge loading increases if no concurrent increase of the return sludge quantity takes place.
  The treatment performance related to the BOD_5 degradation will barely change.
  A greater change of the sludge age will, however, have an effect on the nitrification performance

Solution to 3):

- Partial supply of nutrients.
- Too high substrate concentration.
- Shock loading.
- Lack of phosphate.
- To small O_2 content.
- Too long retention time in the secondary settling stage.
- Digestion of sludge in the primary settling stage.
- Rapid temperature change in spring and autumn

Solution to 4):

The reproduction rate of floc-forming bacteria is greater than that for filamentous bacteria with high wastewater concentrations. Plug flow tanks with a high nutrient concentration in the inflow area contribute far less to the massive development of filamentous organisms than thoroughly mixed tanks with an even, low wastewater concentration, which favours the growth of thread-formers compared to those forming flocs.

Solution to 5):   **(c)**

Solution to 6):   **(c)**

Solutions to Chapter 3.7

Nitrogen removal

Part A)

Solution to 1):

Nitrification:
- Oxidation of ammonia to nitrite and nitrate, whereby H⁺ ions are released.
- Autotrophic bacteria (nitrosomonas and nitrobacters) perform this conversion with the aid of inorganic carbon (CO_2) and under aerobic conditions (dissolved oxygen).
- The process is dependent on numerous constraints such as temperature, pH value, growth rate of the bacteria, oxygen content.

Denitrification:
- Reduction of oxidised nitrogen compounds (nitrite and nitrate) to elementary nitrogen.
- Heterotrophic bacteria perform this conversion with the aid of easily degradable, dissolved organic carbon compounds under anoxic conditions (absence of dissolved oxygen).

Solution to 2):

a)
Growth rates:
- Due to the low growth rates of the nitrificants, an increased retention time of the sludge (sludge age t_{DS} > 7 d corresponds with a sludge loading B_{DS} < 0.15 kg BOD_5/ (kg Ds x d)) is required in order that a sufficient number of nitrificants is available for the process.

Temperature:
- the metabolic selectivity of the nitrificants is heavily dependent the temperature. Therefore, in accordance with the wastewater ordinance, the observation of nitrogen values with wastewater temperatures below 12°C, is dispensed with.

Oxygen content:
- For the oxygen uptake of the bacteria a sufficient concentration gradient between wastewater and the inside of the cells is necessary. With the nitrificants, with 1 to 2 mg/litre, this lies higher than the heterotrophic bacteria.

Acid capacity:
- The metabolic activity of the nitrificants is inhibited or disturbed by pH value changes. Without buffering of the H⁺ ions or H_3O^+ ions released by the process the nitrification would fail automatically. The OH⁻ ions created by the denitrification are not sufficient for this. With a sufficient water hardness (acid capacity $AC_{4,3}$ > 2 mmol/litre) there are, however, enough carbonate ions available as buffer in order to avoid a lowering of the pH value.

b)

Anoxic conditions:

- Faculative anaerobic bacteria (heterotrophic), due to the higher energy gain, prefer an oxygen respiration before an anaerobic metabolism and a respiration of bonded oxygen. A respiration of nitrate (reduction of NO_3) therefore only takes place if no dissolved oxygen is present.

Easily degradable dissolved carbon compounds:

- For the energy expensive nitrate respiration, the heterotrophic bacteria prefer easily degradable dissolved carbon compounds. An appropriate supply is achieved through reduction of the settling volume of the primary settling stage or through addition of external C sources such as, for example, methanol.

Sufficient nitrate quantity:

- The denitrification performance depends on the presence of a sufficient quantity of nitrate which is recirculated from the discharge of the nitration tank into the denitrification tank. The recirculation ratio Q_{RC}/Q_{DR} is regulated using a NO3 measurement in the denitrification tank.

Solution to 3):   **(b)**

Solution to 4):   **(b)**

Solution to 5):   **(b)**

Solution to 6):   **(d)**

Solution to 7):

a) B_d = 50 g BOD_5 /(l x d) x 30,000 l = 1,500 kg BOD_5/d

$MLSS_{AT}$, with a RR = 1, is half as big as $MLSS_{ES}$
accordingly 3.3 g/litre

$$B_{DS} = \frac{B_d}{V \times MLSS_{AT}} = \frac{1,500 \text{ kg } BOD_5 \text{ /d}}{4,500 \text{ m}^3 \times 3.3 \text{ kg DS}}$$

= 0.1 kg BOD_5 /(kg DS x d)

b) $t_{DS} = \dfrac{V_{AT} \times MLSS_{AT}}{Q_{ES} \times MLSS_{ES}} = \dfrac{4,500 \text{ m}^3 \times 3.3 \text{ g / liter}}{108 \text{ m}^3 \text{ /d} \times 6.6 \text{ g / liter}}$ = 20.8 d

c)   For the application of Table 4, in addition to the BOD_5 load (B_d = 1,500 kg/d) the NO_3-N_D load to be denitrified is also required

NO_3-N_D load = added N load - discharged N load

Added N load $\quad$ $B_d(NH_4\text{-}N)$ $\quad = $ 10 g NH_4-N/(l x d) x 30,000 l

$\qquad\qquad\qquad\qquad\qquad\quad = $ 300.0 kg N/d

Discharged N load $(N_{tot}) = $ 0.1 m³/s x 86,000 s/d x 0.018 kg N/m³

$\qquad\qquad\qquad\qquad\qquad\quad = $ 155.5 kg N/d

NO_3-N_D load $= $ 300.0 - 155.5 $= $ 144.5 kg N/d

Ratio: $\qquad$ NO_3-N_D load $:$ BOD_5 load

$\qquad\qquad = $ 144.5 $:$ 1,500 $= $ 0.096 $= $ 0.1

According to Table 4 gives a ratio of: $\quad$ V_D/V_{AT} $= $ 0.3

Required volume: V_D $= $ V_{AT} x 0.3 $= $ 4,500 m³ x 0.3 $= $ **1,350 m³**

Part B)

Solution to 1):

a) - 1.   Downstream DN
   - 2.   Cascade DN
   - 3.   Alternating DN
   - 4.   Simultaneous DN

b) - Higher DS content in the individual stages as with plants with central charging without overloading the secondary settling stage.
   - Higher DN efficiency.
   - Recirculation cycles can be dispensed with (other than in the last stage).

c) With the simultaneous as with the intermittent DN, nitrification and denitrification processes take place in one reaction volume. While with the simultaneous DN the reactions are spatially separated from each other, with intermittent DN a temporal separation of the processes takes place due to switching the On and OFF the oxygen transfer at intervals.

Solution to 2):

a)
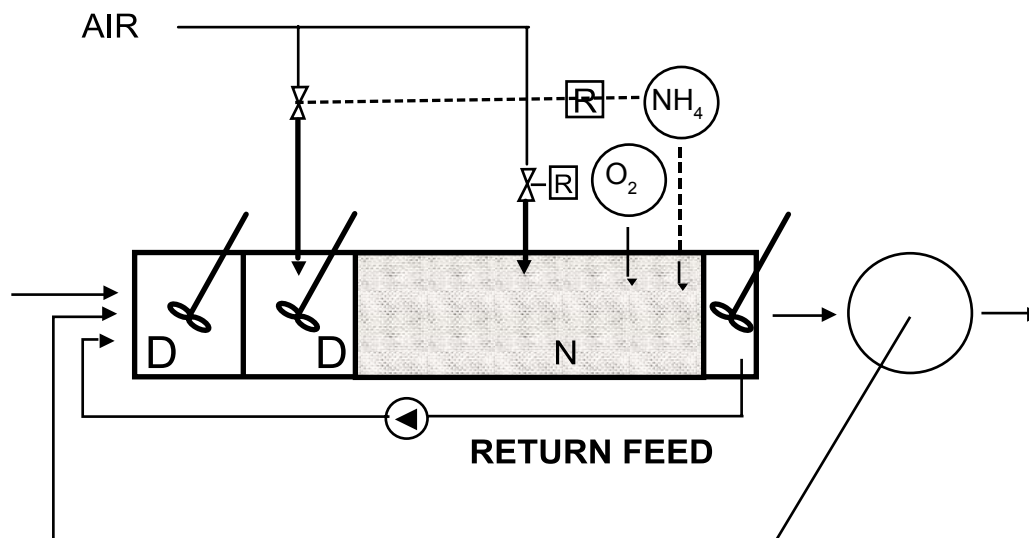
Diag. 3.7/4:   **Control concept of an upstream denitrification** (oxygen regulation)

b)
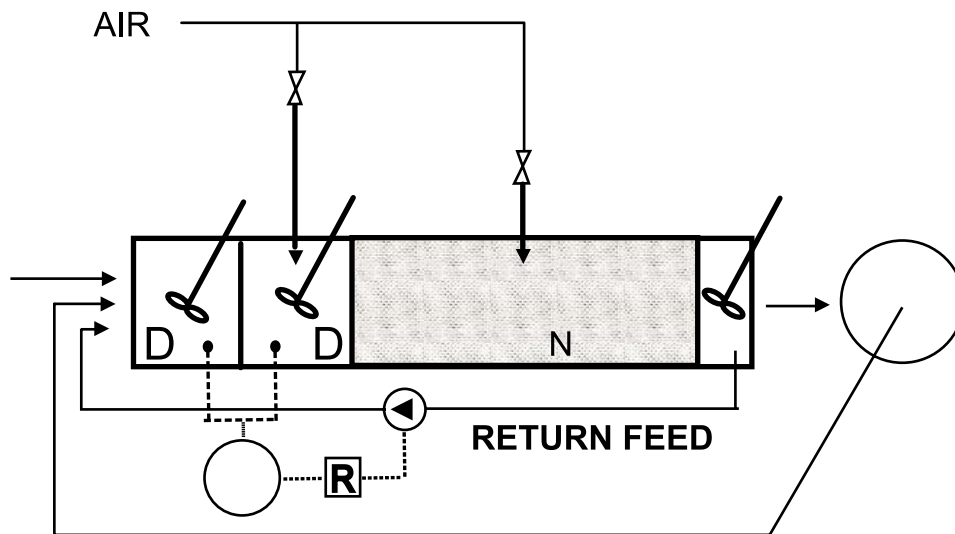
c) 1. Disturbance variable: DN performance
   2. Control member: DN tank
   3. Measured/controlled variable: NO_3-N measured value
   4. Design value: NO_3-N design value
   5. Correcting variable: Pump delivery capacity

Solution to 3):   **(a)**

Solution to 4):   **(d)**

Solution to 5):   **(d)**

Solution to 6):

NH_4^+ + $2\,O_2$

14 g/mol $\longrightarrow$ 2 x 32 g/mol

1 g $\longrightarrow$ X
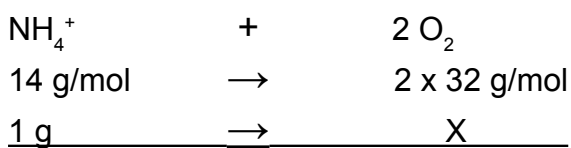
$$X \;=\; \frac{1\,g \;\times\; 64 \;g/mol}{4\;g/mol} \;=\; \textbf{4.6 g O}_2$$

Solution to 7):

a) 58.4 g O_2/(l x d) x 0.488 = 28.5 g O_2/(l x d)

$$\frac{28.5 \text{ g } O_2 /(l \times d)}{4.6 \ O_2 / g \ N} = 6.2 \text{ g N}/(l \times d)$$

$$\frac{6.2 \times 100}{1} = \textbf{56.4 \%}$$

b) The oxygen recovery for the denitrified nitrate quantity is:

4.6 g O_2/g NO_3-N_e - 1.7 g O_2/g NO_3-N_D = 2.9 g O_2/g NO_3-N

$$\frac{12 \text{ g } O_2 /(l \times d)}{2.9 \ O_2 / g \ N} = 4.1 \text{ g N}(l \times d)$$

Oxidised quantity: 6.2 g N/(l x d)
Denitrified quantity: 4.1 g N/(l x d)

Quantity in the effluent: 6.2 g N/(l x d) - 4.1 g N/(l x d) = 2.1 g N/(l x d)

$$\frac{2,100 \text{ mgN }/(l \times d)}{200 \text{ liter }/(l \times d)} = \textbf{10.5 mg N/litre}$$

Solutions to Chapter 3.8

Fixed-bed processes

Part A)

Solution to 1):

1 - Rotating sprinkler with pivot bearing.
2 - Filler media, support layer, filler layer and covering layer.
3 - Inlet pipeline.
4 - Trickling filter casing.
5 - Central structure.
6 - Double bottom for the aeration and the water runoff.
7 - Outlet channel.

Solution to 2):

a) - Lumps of material of all types which must have certain properties (see b)) such a lava, pebbles, slag etc.
   - Plastic: rubble and lumpy materials, plastic sheets.

b) - Sufficient dimensions for the formation of sufficiently large hollow spaces into which the wastewater can flow and air can ventilate.
   - Large specific surface (ratio surface/volume) for the settlement of the biological lawn.
   - Resistance to buoyancy
   - Chemically, biologically and wastewater resistant.

Solution to 3):

	Lava:	Plastic:
Area of application	Municipal wastewater	Organic highly loaded wastewater
Filler material	Lumps	Rubble, block materials Plastic sheets
Weight	Density < 2 kg/m³	Considerably smaller than with lava
Structural design	Massive structure due to great pressure of rubble	Light structure
Construction height	4 to 5 m filling height	Tower trickling filter, possibly up to 10 m in height
Specific surface	80 m²/m³	Up to 200 m²/m³
Size of hollow space		Considerably larger than with lava
Throughflow contact time	Ca. 20 min.	Considerably smaller than with lava – ca. 5 min.
Danger of blockage		Considerably smaller than with lava
Loading range BR	200 to 1,000 g BOD_5/(m³ x d)	Up to 10,000 g BOD_5/(m³ x d)
Treatment performance	Up to 90 %	With higher loading ca. 50 to 60 %

Solution to 4):

a)
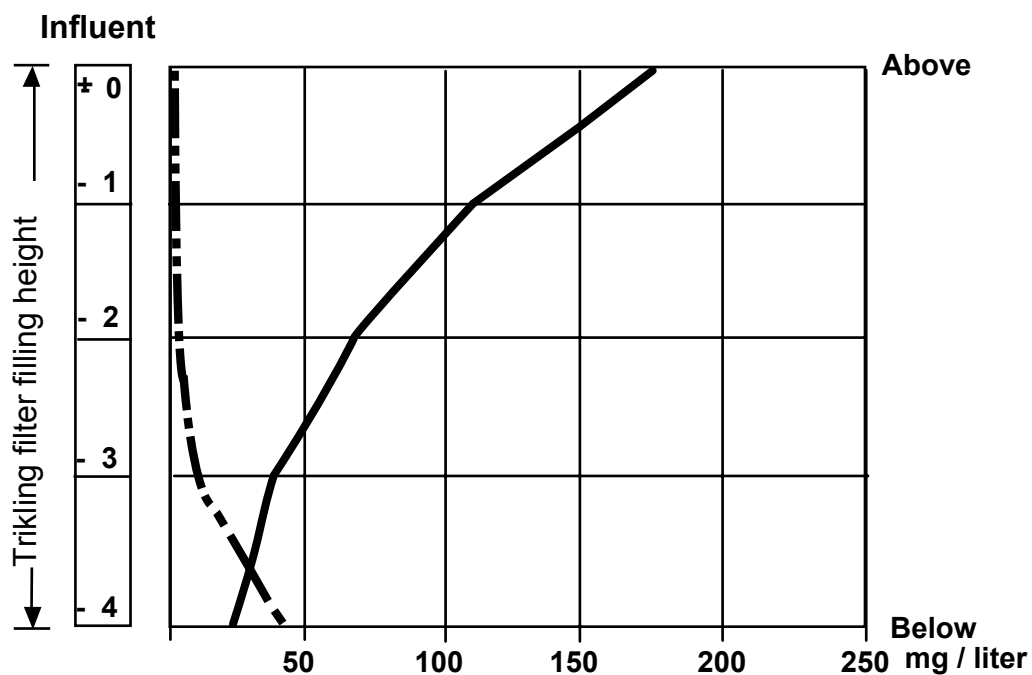
Diag. 3.9/2: Treatment process in the trickling filter

b) - Degradation and conversion of the wastewater content matter takes place in various height zones.
  - Simultaneity of aerobic and anoxic zones is not possible.
  - Lack of substrate for heterotrophic bacteria for the reduction of the nitrate in the lower trickling filter layers

Solution to 5): **(e)**

Solution to 6): **(b)**

Solution to 7): **(a)**

Solution to 8): **(c)**

Solution to 9):

Q = 0.05 m³/s x 3,600 s/h = 180 m³/h

A = $\dfrac{Q}{q_A}$ = $\dfrac{180 \text{ m}^3 \text{ /h}}{0.573}$ = 314 m²

d = $(4 A/\pi)^{1/2}$ = $\sqrt{\dfrac{4 \text{ x } 314 \text{ m}^2}{3.14}}$ = 20 m

B_d = Q x C = 0.05 m³/s x 86,400 s/d x 0.15 kg/m³ = 648 kg/d

B_V = $\dfrac{B_d}{V}$ = $\dfrac{B_d}{A \text{ x h}}$

h = $\dfrac{B_d}{B_v \text{ x A}}$ = $\dfrac{648 \text{ kg /d}}{0.458 \text{ kg BOD}_5 \text{ /(m}^3 \text{ x d)} \text{ x } 314 \text{ m}^2}$ = **4.50 m**

Solution to 10):
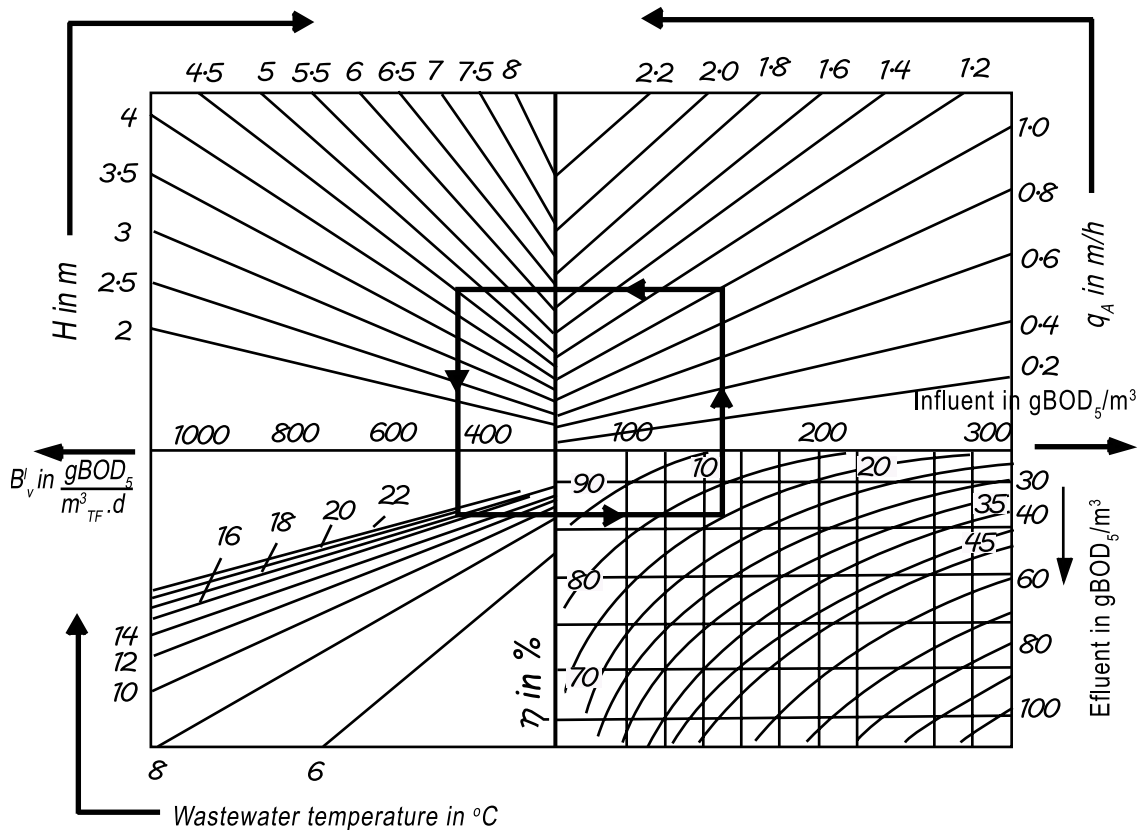
Diag. 3.9/3: Dimensioning nomogram for trickling filters

Hosang; Bischof: Abwassertechnik, 9th Edition 1989 © Teubner, Stuttgart

Result: **20 g/m³**

Part B)

Solution to 1):

	Trickling filter (TF) process	Aeration tank (AT) process
Primary settling stage	Retention of all substances required	With degradation of N only coarse desludging
Biomass	Biological film, fixed	Suspended DS content controllable through removal of excess sludge
Biomass enrichment	On carrier material	Through sludge recirculation
Loading (B_R/B_{DS})	Weakly loaded: 200 g/(m³ x d) Highly loaded: 400 g/(m³ x d)	C degradation: 0.3 kg/(kg x d) N removal: 0.15 kg/kg x d)
Controllability	Only via quantity of recirculation water	Transfer of O_2 DS content
O_2 transfer	Natural circulation Ratio wastewater : air 1 : 20	Artificial aeration
Specific treatment volume (I/m³)	Weakly loaded: 200 g/(m³ x d): 40 g/(I x d) = 5 I/m³ Highly loaded:10 I/m³	C degradation: 25 I/m³ N removal: 12.5 I/m³
Efficiency	$\eta = 93 - 0.017\ B_v$	C degradation according to Imhoff diagram: ca. 90 %
Energy consumption	Pump costs for charging	Pump costs for return sludge (RS) transport: costs for specific O_2 transfer
Nitrogen removal	Normally only nitrification, denitrification possible in separate trickling filter	In different process variants
Secondary settling stage	Small volume, as only excess sludge (ES)	Larger volume because of RS + ES

Solution to 2):

a) - High organic loading (industrial influence).
    - Too low surface charging or flushing force.
    - Insufficient primary settling.
    - Too high influent concentration C > 150 mg/litre
    - Falling leaves.
    - Icing.

b) - Point flushing (Fixing of the rotating sprinkler, strong water jet).
    - Increase of the flushing force.
    - Increase of the amount of recirculation water.
    - Mechanical loosening of the material (surface).
    - Employment of chemicals (e.g. Na NO_3).
    - Covering due to influence of weather.
    - In extreme cases removal of filler material.

Solution to 3):

a) This variants of the recirculation water transport is very current. However, it should be noted that the settling performance (throughflow time and surface charging) of the primary settling stage is sufficient in order that the trickling filter is not blocked by the settleable solids which cannot be held back.

b) - Reduction of the organic loading through dilution ($C_{influent}$ < 150 mg/litre)
    - Increased treatment performance.
    - Maintaining of the required surface charging in times of small inflow (at night).
    - Intensive contact wastewater-biomass.
    - Rapid familiarisation with commissioning of a trickling filter.
    - Enrichment of the trickling filter influent using enzymes and oxygen.

Solution to 4):   **(d)**

Solution to 5):   **(a)**

Solution to 6):   **(e)**

Solution to 7):

$$B_v = \frac{Q \times C}{V} = \frac{10{,}000 \ m^3 \ /d \ \times \ 200 \ g \ / \ m^3}{5{,}000 \ m^3} = 400 \ g/ \ (m^3 \times d)$$

$$\eta \ = 93 \ - \ (0.0017 \ \times \ 400) \ = \ 86.2 \ \%$$

$$C_{effluent0} = 200 \ mg/litre \ \times \ 0.138 \ = \ 27.6 \ mg/litre$$

$$C_{mix} = \frac{10{,}000 \ m^3 \ /d \ \times \ 200 \ g/m^3 \ + \ 5{,}000 \ m^3 \ /d \ \times \ 27.6 \ g \ /m^3}{10{,}000 \ m3 \ + \ 5{,}000}$$

$$= \ 142.5 \ mg/litre$$

$$B_v = \frac{15{,}000 \ m^3 \ / \ d \ \times \ 142.5 \ g \ /m^3}{5{,}000 \ m^3} = \ 427.5 \ g/(m^3 \times d)$$

$$\eta \ = 93 \ - \ (0.0017 \ \times \ 427{,}5) \ = \ 85.7 \ \%$$

$$C_{effluent1} = \ 142.5 \ mg/litre \ \times \ 0.143 \ = \ \textbf{20.4 mg/litre}$$

Solution to 8):

$$a) \ V_F = \frac{Q}{A} = \frac{3{,}000 \ m^3/ \ h}{10 \ \times \ 34 \ m^2} = 8{,}82 \ m/h$$

$$\frac{8.82 \ - \ 7.5}{7.5} \times 100 \ = 17.6\%$$

$$b) \ Q_I \ = \ (20 \ m/h \ \times \ 34 \ m^2 \ \times \ 2 \ min) \ : \ 60 \ min/h \ = \ 22.7 \ m^3$$

$$Q_{II} \ = \ (50 \ m/h \ \times \ 34 \ m^2 \ \times \ 5 \ min) \ : \ 60 \ min/h \ = \ 141.7 \ m^3$$

$$Q_{III} \ = \ (80 \ m/h \ \times \ 34 \ m^2 \ \times \ 2 \ min) \ : \ 60 \ min/h \ = \ 90.7 \ m^3$$

$$\Sigma Q \qquad \textbf{255.1 m}^3$$

Solutions to Chapter 4.1

Flow diagrams of sewage sludge treatment systems

Solution to 1):

a)

Primary sludge		
Q	m^3 /a	2,111
R	%	5.60
IL	%	60.00
m$_{DR}$	Mg$_{DR}$ /a	118.3
m$_{oDR}$	Mg$_{DR}$ /a	71

Excess sludge		
Q	m^3 /a	13,140
R	%	0.70
IL	%	96.40
m$_{DR}$	Mg$_{DR}$ /a	92.1
m$_{oDR}$	Mg$_{DR}$ /a	88.8

Raw sludge from the primary sludge		
Q	m^3 /a	4,782
R	%	4.40
IL	%	75.80
m$_{DR}$	Mg$_{DR}$ /a	210.4

Anaerobic stabilisation		
V	m^3	500
T	^{o}C	36
t	d	38
Q$_{out}$	m^3/a	4,782
DR$_{out}$	%	3.20
IL$_{out}$	%	48.70
m$_{DRout}$	Mg$_{DR}$ /a	153
m$_{oDRout}$	Mg$_{DR}$ /a	75
B$_R$	kg $_o$DR/m	0.87
Gas yeild	m^3/a	64,308
Gas production	l/kg $_o$DR	404
spec. gas yeild	l/**I**d	24.4
CO$_2$	%	34

Diag. 4.1/1:   Sludge calance of wastewater treatment plant S

b) m_{oDS} (input): 4,782 m³/a x 0.044 x 0.758 = 160 Mg/a

m_{oDS} (discharge): 4,782 m³/a x 0.032 x 0.487 = 75 Mg/a

Degree of degradation oDS: (160 - 75)/160 x 100 % = **53.1 %**

c)

		Planned:	**Actual:**	
Digestion time	d	20 - 30	38	Very plentiful
Organic volumetric loading	kg oDR/(m³ x d)	2	0.87	Very little
Degree of digestion oDR	%	> 45	53	Good
Specific gas production	litre/kg oDR	400 – 500	404	In order
Specific gas yield	litre/(I x d)	20	24.4	In order
CO_2 content in the digestion gas	%	26 – 36	34	In the fringe range

Due to the slight loading and long digestion time the degree of degradation is good. Specific gas yield and production lie only in the range of the guidance values. The almost borderline value of the CO_2 content gives an indication of this

Solution to 2):

1. a) 300,000 PT x 0.08 kg DS/(PT x d) = 24,000 kg DR/d = 24 t DS/d
   24 t DS/d x 2/3 = **16 t oDS/d**.

   b) 16,000 kg oDS/d x 0.5 m³ gas/kg oDS = **8,000 m³ gas/d**

   c) 8,000 m³ gas/d x 6.4 kWh/m³ gas = **51,200 kWh/d**

2. a) $\dfrac{24,000 \ \text{kg DS /d}}{60 \ \text{kg DS /m}^3}$ 400 m³ /d

   b)   4.19 J/(g x K)   x 10^6 g/m³   x   23.86 K   =   **100   x 10^6 J/m³**

   c)   100   x   106 J/m³   x   400 m³/d   =   **40,000   x 10^6 J/d**

   d) $\dfrac{40,000 \ \text{x} \ 10^6 \ \text{j/d}}{3.6 \ \text{x} \ 10^6 \ \text{j/k Wh}}$ = 1.111 kWh /d

3) Useful amount of energy   =   Total amount of energy – flare
      51,200 kWh/d   x   (1 - 0.10156)   =   46,000 kWh/d

   Useful amount of energy for aeration and the rest
      46,000 kWh/d   x   0.3261   =   15,000 kWh/d

   Useful amount of energy for the rest
      15,000 kWh/d   -   10,800 kWh/d (aeration   =   4,200 kWh/d

   Required outside energy:
      12,000 kWh/d   -   4,200   =   7,800 kWh/d

```
                          ┌─────────────────┐
                          │   Raw sludge    │
                          │    2.4 tDS/d    │
                          │    66.6 oDS     │
                          └─────────────────┘
                                   │
                          ┌─────────────────┐
                          │ 500 lit gas/kg oDS │
                          └─────────────────┘
                                   │
  ┌──────────────┐        ┌─────────────────┐
  │    Flare     │ ◄───── │   Gas yeild     │
  │ 5,200 kWh/d  │        │    800 m/d      │
  └──────────────┘        │ 51,200 kWh /d   │
                          └─────────────────┘
                                   │
                          ┌─────────────────┐
                          │ Quality of useful │
                          │     energy      │
                          │  46,000 kWh /d  │
                          └─────────────────┘
                                   │
                          ┌─────────────┐        ┌──────────────┐
                          │     CHP     │ ─────► │    Losses    │
                          │ ή =56.76 %  │        │ 19,889 kWh /d│
                          └─────────────┘        └──────────────┘
```

Quantity of energy used   26,111 kWh /d

Use of the digester gas - energy:	Residual	Aeration	Sludge heating through waste heat
	4,200 k Wh /d	10,800 k Wh /d	11,111 k Wh /d

Energy requirement:	Residual	Aeration	Sludge heating
	12,000 k Wh /d	10,800 k Wh /d	11,111 k Wh /d

Outside energy :   7,800 k Wh /d

Diag: 4.1/2 Energy balance

Solutions to Chapter 4.2

Types of sludge and sludge stabilisation general

Solution to 1):

a) Raw sludge is sewage sludge form a wastewater treatment facility without previous treatment.
b) Primary sludge is the sludge settled in the primary settling stage. It has a high fraction of organic solid matter.
c) Activated sludge is from the activated sludge stage. It consists mainly of "aerobic" floc-forming bacteria.
   In general its solid matter fraction is smaller than 1 %.
d) Aerobically stabilised sludge. With this sludge the organic matter converted into CO_2, H_2O and mineral substances extensively under aerobic conditions
e) Digester sludge is sludge stabilised with a water fraction of 94 to 98 % with the exclusion of oxygen.

Solution to 2):

a) **1 to 2 litre/(l x d)**
b) **ca. 2 to 2.5 %**; 2 litres of raw sludge / d : 80 to 100 litres/(l x d)   x   100 %
c) **ca. 1/3:** with the digestion process ca. 50 % oDR of the raw sludge, which up to 2/3 consists of organic solid matter.

Solution to 3):

- Extensive degradation of organic matter.
- Reduction of the sludge quantity.
- Transfer of energy-rich organic matter into low-energy stable matter in the digested sludge.
- Avoidance of odour emission (through fermentation).
- Improvement of the thickening and dewatering properties.
- Extraction of energy (with anaerobic stabilisation)

Solution to 4):

a) Aerobic sludge stabilisation
      This takes place through long-term aeration of activated sludge and the degradation of
      organic matter combined with this. The sludge age of at least 25 days necessary for this is
      achieved with a sludge loading of B_{DS} = 0.05 kg BOD_5 /(kg DS x d).
    Anaerobic sludge stabilisation
      This takes place through a four-stage conversion of organic matter under the exclusion of
      oxygen (anaerobic). With this energy is produced in the form of digester gas

b) In small wastewater treatment plants (< 10,000 I), with which the economic operation of a
    digester is not present as well as on wastewater treatment plants with (industrial) wastewater
    which has poor digestion characteristics.

Solution to 5):   **(c)**

Solution to 6):   **(e)**

Solution to 7):   **(b)**

Solution to 8):   **(d)**

Solution to 9):   **(c)**

Solution to 10):   **(d)**

Solutions to Chapter 4.3

Anaerobic sludge stabilisation (digestion)

Part A)

Solution to 1):

a)→ **2**;　　b)→ **3**;　　　　c)→ **4**;　　　　d)→ **9**;　　　　e)→ **13**

Solution to 2):

1. Hydrolysis phase.
2. Acidification phase.
3. Acetogenic phase.
4. Methanogenic phase.

Solution to 3):

1st phase →	Hydrolysis:	amino acids, glycerine, fatty acids, monosaccharides (simple sugar)
2nd phase →	Acidification phase:	H_2, CO_2, organic acids, acetic acid, alcohols
3rd phase →	Acetogenic phase:	acetic acid, H_2, CO_2
4th phase →	Methanogenic phase:	CH_4, CO_2

Solution to 4):

a) - Sludge quantity.
   - Dry residues.
   - Organic acids.
   - Lime reserve
   - pH value.
   - Temperature.
   - Gas yield (quantity).
   - Gas composition (CO_2 and CH_4)

b) In order to prevent the "toppling" of the digestion process.

Solution to 5):

1. Overloading through to high input of raw sludge.
2. Larger and more short-term temperature variations.
3. High H_2S gas concentrations.
4. Toxic substances; heavy metals, acid and alkalines, organic compounds (such as chloroform and phenols).
5. High NH_3 concentrations.
6. Slight acid capacity of the digested sludge.

Solution to 6): **(c)**

Solution to 7): **(e)**

Solution to 8): **(b)**

Solution to 9):

$$T_M = (m_1 \times T_1 + m_2 \times T_2)/m_M$$

$$= \frac{1,200\ [m^3] \times 36\ [°C] + 50\ [m^3] \times\ [°C]}{1,250\ [m^3]} = 35\ °C$$

$$\Delta T = T_{Dig.} - T_M = 36°C - 35°C = \mathbf{1°C}$$

Solution to 10):

a) $\frac{5.7}{100}$ = 1,050 kg DS / m³ = 59.9 DS / m³

110 m³ × 59.9 kg oDS/d × 0.75 = 4,942 DS/d

$\frac{4,942\ kg\ oDS\ /\ d}{2,500\ m^3\ \times\ d}$ = 1.98 kg oDS / (m³ x d)

b) Depending on the capacity of the wastewater treatment plant:

< 50,000 PT	2.0 kg oDR/(m³ x d)
50 – 100,000 PT	3.0 kg oDR/(m³ x d)
> 100,000 PT	4.0 kg oDR/(m³ x d)

c) Toppling:
An overloading of the digester with organic solids can, as a result of the increased formation of organic acids, negatively disturb the balance between formation and degradation of acids (methanogenic phase). If the process switches completely to acid digestion, one speaks of the "toppling" of the digestion process.

Frothing over:
As reaction to overloading (stress) the bacteria pour out foam-forming enzymes to excess.

d) $T = \dfrac{V}{Q} = \dfrac{2{,}500 \ m^3}{110 \ m^3 \ /d} = 23 \ d$

Part B)

Solution to 1):

- Hazard   Causes.

- Explosion hazard: Methane-air mixture with 85 – 95 % air and
5 – 15 % methane

- Asphyxiation hazard: Lack of O_2 as a result of digester gas, mainly CO_2,
in manholes/chambers.

- Bursting hazard: Under- or overpressure with the charging of digesters (overfilling) or
fault in the gas system, flare or emergency valve defect.

Solution to 2):

a) So far as no general cleaning has taken place remaining sludge residues can still be gassed
out; therefore attention is to be paid that, for a good ventilation there is a regular measurement
of O_2, and the necessary safety equipment for personnel is available.
b) Yes, therefore ensure a good ventilation and aeration.

Solution to 3):

a) - Fill up digester with process water and bring it to operating temperature.
- After this bring in seeding sludge from the same type of plant and step-by-step input more
and more raw sludge under continuous observation of all relevant parameters.

b) - Temperature.

- pH value.
- Organic acids /lime reserve
- DS / IL input and output.
- Solid matter determinations of the digested sludge.
- Methane gas content.
- Gas production.

Solution to 4):

a) - Forcing in of digester gas.
   - Large-type screw pump.
   - External pumps.
   - Rabble devices/ rakes.

b) - Low pressure steam heating.
   - Internal heat exchanger.
   - External heat exchanger.

Solution to 5): **(b)**

Solution to 6): **(c)**

Solution to 7): **(c)**

Solution to 8): **(a)**

Solution to 9)

a) Q = 2.0 litres/(PT x d) x (40,000 + 20,000)

       = 120,000 litres/d   = 120.0 m³/d

    $t = \dfrac{1,600 \text{ m}^3}{120 \text{ m}^3 /\text{d}}$ = 13.3 d   **13.3 d**

b) Reduce sludge quantity or increase DS and also increase the temperature in the digester.

Solution to 10):

a) CH_3COOH → CH_4 + CO_2

    60 g / mol CH_3COOH →   44 g / mol CO_2
         100g   →   X
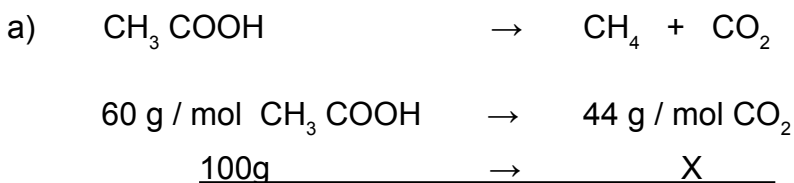
    $X = \dfrac{100 \text{ g } \times 4 \text{ g/ mol } CO_2}{60 \text{ g / mol}}$ = 73.3 g CO_2

b)   60 g/mol acetic acid $\longrightarrow$ 1   x   22.4 litre/mol CH_4
              100 g   Y

$Y \quad = \quad \dfrac{2.4 \text{ liter / mol} \ \text{x} \ 100 \ \text{g } CH_4}{60 \text{ g / mol}} = 37.3 \text{ liters } CH_4 \quad$ in the normal condition

$V_1 \quad = \quad \dfrac{V_0 \ \text{x} \ p_0 \ \text{x} \ T_1}{p_1 \ \text{x} \ T_0}$

$\quad = \dfrac{37.3 \text{ liters } CH_4 \ \text{x} \ 1{,}013 \text{ h Pa} \ \text{x} \ 293 \text{ K}}{990 \text{ h Pa} \ \text{x} \ 273 \text{ K}} \quad = 41.0 \text{ liters } CH_4$

Solutions to Chapter 4.4

Part A)

Solution to 1):

- Heating of the digester.
- Usage via gas machines (air generation, power generation, heat emission).
  Circulation of the digester.
- Heating of buildings.

Solution to 2):

a) - Wet gas tanks.
   - Dry gas tanks.
   - Compressed gas tanks.
   - Gas tanks with storage pillows.

b) - Water in the tank lute can freeze; therefore it is to be heated with low temperatures.
   - Steel cone is subjected to increased corrosion.

Solution to 3):

a) A gas hood in the upper part of the digester gas tank serves as gas storage and as pressure balance within the system.

b) A gravel pot within a gas pipeline. carries out a rough cleaning of the gas and serves for the condensation of the water vapour contained in the gas.

c) By means of a gas flare not only is excess digester gas burnt off but it also serves as safety device (valve) with gas overpressure in the system

Solution to 4):

a) **ca. 60 – 70 % CH$_4$ (methane).**
   ca. 30 – 35 % CO$_2$ (carbon dioxide).
   ca. 1 % component of other gases.

b) **ca. 350 to 500 litres of digester gas / kg oDR$_{added}$**
   ca.   15 to   25 litres / (l x d).

Solution to 5):

a) The digester gas quantity is too small (< 350 Nm^3/d).
b) The digester gas composition is not optimal
    (guidance values: CH$_4$ = 60 – 70 % and CO2 = 30 – 40 %).
c) The digester loading lies well below the orientation value of 1.7 kg oDS / (m^3 x d).

Solution to 6):   **(e)**

Solution to 7):   **(d)**

Solution to 8):   **(c)**

Solution to 9):

10,000 litres   x   0.65   =   6,500 litres CH$_4$

$$CH_4 \; + \; 2\,CO_2 \quad \rightarrow \quad CO_2 \; + \; 2\,H_2O$$
   22.4 litres   36 g
    6,500 litres   x
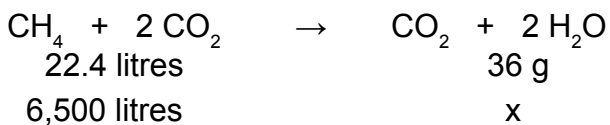
$$x \; = \; 6{,}500 \text{ litres} \; \times \; \frac{6 \text{ g}}{2.4 \text{ liters}} \; = \; 10{,}446.0 \text{ g } H_2O \; = \; \textbf{10.45 kg } \mathbf{H_2O}$$

Part B)

Solution to 1):

a) The gas yield with organic fats is ca. double that with carbohydrates and proteins.

b) Animal and vegetable fats and oils, as opposed to mineral oils, are digestible. Mineral oils prevent the production of digester gas and lead to an increased formation of floating sludge in the digester.

Solution to 2):

a) Through incomplete combustion of the digester gas as a result of too low combustion temperature.
b) The gas flame of the flare burns yellow instead of blue with complete incineration.

Solution to 3):

a) - Poisoning; H_2S has a deadly effect already with small concentrations of 0.1 %.
   - Corrosion through conversion to sulphuric acid.
b) - The desulphurisation using iron oxides.
c) - $H_2S + Fe(OH_2) \rightarrow Fe S + H_2O$

Solution to 4):

a) To balance out varying gas production.
b) The gas storage volume is calculated dependent on the digester charging and the gas usage (with Combined Heating Plant (CHP) operation ca. 30 % of the daily gas yield).

Solution to 5):

- Due to the high corrosiveness of the digester gas stainless steel and/or plastic pipelines are to be employed.
- Due to the formation of condensed water the pipelines are always to be laid with sufficient gradient. It is absolutely essential to plan dewatering devices at low points.
- Gas pipelines are to marked appropriately clearly (colour yellow).

Solution to 6):   **(d)**

Solution to 7):   **(c)**

Solution to 8):   **(e)**

Solution to 9):

$$V = \frac{V_{max} \times p_{max} \times T}{T_{max} \times p}$$

$$V = \frac{250 \text{ m}^3 \times 8 \text{ bar} \times 310\text{K}}{293 \text{ K} \times 1.035 \text{ bar}} = 2{,}044.48 \text{ m}^3$$

$$t = \frac{V}{Q} = \frac{2{,}044.48 \text{ m}^3}{510 \text{ m}^3 /d} = 4 \text{ d}$$

Solution to 10):

oDS: 0.080 kg DS/(l × d) × 15,000 l × 0.65 = 768 kg oDS/d

V_{gas}: 768 kg oDS/d × 0.460 m³ gas/kg oDS = 353.5 m³ gas/d

I: 353.3 m³ gas/d × 0.00585 MWh/m³ gas × 365 d/a = **754.5 MWh/a**

Solutions to Chapter 4.5

Part A)

Solution to 1):

a) 1 →   Interstitial water.
    2 →   Internal water.
    3 →   Adhesive (retained) and adsorption water.
    4 →   Capillary water.

b) External water →   **1,3,4**   - low to high bonding capacity.
    Internal water   →   **2**   - very high bonding capacity.

Solution to 2):

a)   **3.**   b)   **2.**   c)   **1.**

Solution to 3):

a) 1. **Fe Cl$_3$**
    2. **Fe Cl SO$_4$**
    3. **Fe SO$_4$**
    4. **Al$_2$ (SO$_4$)$_3$**
    5. **Ca O**
    6. **Ca (OH)$_2$**

b) The positively charged ions destabilise the negatively charged sludge particles and their water film in electro-chemical manner. Through this large flocs result. In addition, the release of adhesive water is increased

Solution to 4)

a) 1. Sludge liquor zone.
   2. Separation zone.
   3. Transition zone.
   4. Thickening zone.
   5. Clearing zone.

b) 1. Charging or inlet zone.
   2. Removal of sludge liquor – either stepped outlets or height adjustable.
   3. Gate valve at the sludge liquor outlet
   4. Thickened sludge removal pipeline at the tip.

Solution to 5):   **(b)**

Solution to 6):   **(e)**

Solution to 7):   **(d)**

Solution to 8):   **(c)**

Solution to 9):   **(c)**

Solution to 10:

20,000 l x   2 litres/(l x d)   =   40 m³/d

$$V_a = \frac{B_b \times DS_b}{DS_a} = \frac{40 \text{ m}^3/\text{d} \times 2.5\%}{4.5\%} = 22.2 \text{ m}^3$$

Solution to 11):

$$A_{pipe} = \frac{\pi \times (0.15 \text{ m})^2}{4} = 0.0177 \text{ m}^2$$

Q   = A x v = 0.0177 m² x 0.8 m/s = 0.01416 m³/s = **51.0 m³/h**

Solutions to Chapter 4.6

Utilisation, disposal of sludge and residues

Solution to 1):

a) Residual matter in the sewer network:
   - Contents of sewers and gullies.
   - Deposits from sewers and stormwater tanks.
   - Deposits from pump sumps.

b) Residual matter in the wastewater treatment plant:
   - Screenings [2 to 30 litres/(l x a)].
   - Grit chamber trappings.
   - Fats [varying yield].
   - Sewage sludge [quantity of raw sludge at a level of ca. 1 % of the wastewater inflow quantity].

Solution to 2):

   - Incineration: energetic utilisation (calorific value > 11,000 kJ/kg).
   - Agricultural utilisation: fertiliser effect, soil improvement.
   - Composting: fertiliser effect, soil improvement.

Solution to 3):

a) Advantages:
   Feed back of substances into the cycle (utilisation better than disposal).
   Cost-favourable disposal of sewage sludge.
   Reduction of the employment of artificial fertilisers
   Soil improvement.

   Disadvantages:
   Contamination of the soil with long-term application.
   Hygienic problems.
   No all-year-around disposal (frozen ground).

b) Advantages:
    Transfer of the sewage sludge in an environmentally form.
    Reduction of the volume.
    Use of the energy in the sewage sludge
    Yield of recycling products.

  Disadvantages:
    No return feed of substances into eco-systems.
    High energy expenditure.
    High expense to maintain environmental protective conditions.

Solution to 4):   **(a)**

Solution to 5):   **(a)**

Solution to 6):

$$5{,}000 \ PT \ \times \ 0.5 \ m^3/(PT \times a) \ = \ 2{,}500 \ m^3/a$$

$$2{,}500 \ m^3/a \ \times \ \frac{4.0}{100} \ \times \ 1.05 \ t/m^3 \ = \ 105 \ t \ DS/a$$

Surface requirement:

$$A \ = \ \frac{105 \ t \ DS/a \ \times \ 3a}{5 \ t \ DS \ /ha} = 63 \ ha$$

Solution to 7):

Calorific value DS:	$9{,}500 \ kJ/kg \ DS \ \times \ 0.40 \ = \ 3{,}800 \ kJ/kg \ DS$	
Energy for vaporisation:	$3{,}000 \ kJ/kg \ DS \ \times \ 0.60 \ = \ 1{,}800 \ kJ/kg \ DS$	
Calorific value of the sludge:	$3{,}800 \ kJ/kg \ DS \ - \ 1{,}800 \ kJ/kg \ DS \ = \ \mathbf{2{,}000 \ kJ/kg \ DS}$	

Solutions to Chapter 5.1

Sampling

Solution to 1):

a) - Parameters to be investigated.
   - Quantity and content of the sample material.
   - Execution of sampling (type, location, point in time).
   - Type and material of the sampling equipment.
   - Conservation of the sample.

b) A "representative sample" gives a statement on the characteristics of the total matter sample. It must actually correspond in its composition with that of the total matter (wastewater, sludge).

Solution to 2):

a) - Bacteria die off, their cell walls dissolve, through this there is an increase in dissolved substances.
   - Bacteria convert wastewater content substances.
   - Reactions of the content substances with each other.
   - Reactions with the material of the vessel.
   - Attachment of substances on the walls of the vessel (adsorption).
   - Diffusion of volatile substances through the walls of the vessel (PE).
   - Decomposition of the vessel material.

b) - BOD_5: Deep freeze.
   - COD: Acidify with H_2SO_4 (pH value < 2) and cool (2 to 5°C).
   - NO_3-N: Acidify with H_2SO_4 (pH value < 2) and cool (2 to 5°C).

c) - BOD_5: Wastewater treatment plant influent: angular / plastic
              Wastewater treatment plant effluent: wide-necked, round / PE
   - COD: angular / plastic
   - NO_3-N: PE or glass

Solution to 3):

a) -   Determination of operating data.
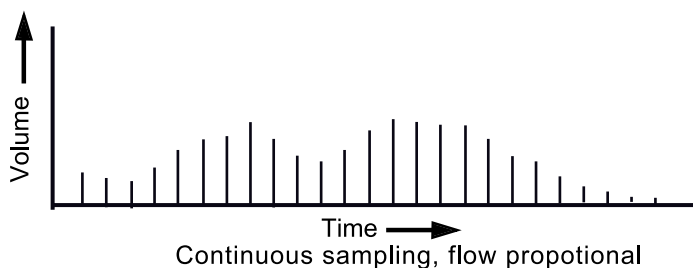   -   Self-monitoring of the discharge.

b) -   Significance of the parameters.
    -   Capacity of the plant.
    -   Related process technology.

c) -   Simple handling.
    -   Implementation by specialist personnel still not instructed in chemistry.
    -   rapid availability (other than BOD_5).

Solution to 4):

a) -   Time-proportional   at equal time intervals – same volumes.
    -   Flow-proportional   at equal time intervals – volumes according to the respective flow (proportional).
    -   Volume-proportional   at different time intervals (following flow of a constant volume) - equal-size sample volumes.

b)

Temporal course of the volume flow

Continuous sampling, time propotional

Continuous sampling, flow propotional
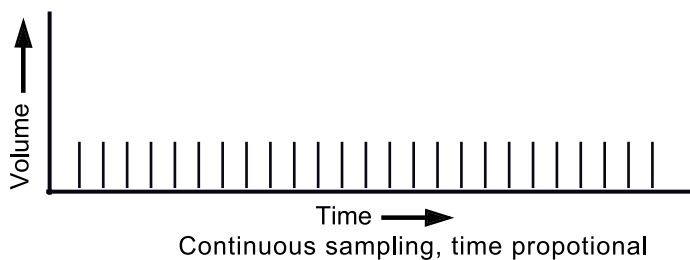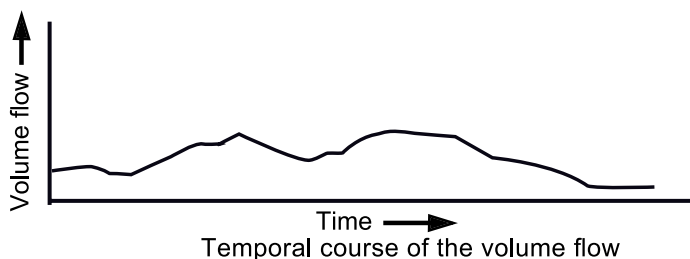
Diag. 5.1/1:   Discontinuous sampling

Solution to 5):   **(d)**

Solution to 6):   **(d)**

Solution to 7):   **(c)**

Solution to 8):

$$t_{theor} = \frac{V}{Q} = \frac{6{,}000 \text{ m}^3}{0.120 \text{ m}^3/\text{s} \times 3{,}600 \text{ s/h}} = 13.9 \text{ h}$$

$$t_{pract} = t_{theor} \times 0.79 = 13.9 \text{ h} \times 0.79 = 1 \text{ h}$$

Start of effluent sample: 8 h + 11 hours = **19 h**

Solution to 9):

a) $\dfrac{60 \text{ min.}}{2 \text{ min.}} = 30 \text{ time intervals} - \text{thus } \textbf{31 scooping procedures}$

b) 20 litres x 0.75 = 15 litres

$\dfrac{15 \text{ litres}}{31 \text{ scoops}} = 0.48 \text{ litre/scoop proc.} - $ **- individual scooping volume: 0.5 litre**

c) - Pre-wash sampling bottle with wastewater.
   - At the end of sampling, fill the 2 litre sampling bottle while continuously stirring the complete sample (collection vessel).
   - Mark sampling bottle.

Solutions to Chapter 5.2

Measurements and examinations

Part A)

Solution to 1):

1. Measured quantity transducer
   - converts physical or chemical quantity into an electrical quantity.

2. Measured value amplifier/converter
   - amplifies or converts the signal provided by 1) to a suitable value for transmission, indication, registration or further processing.

3. Measured value processing (arithmetical operation)
   - converts the measured quantity into another, for example water level into flow.

4. Measured value output of further process
   - Indication
   - Registration
   - Control, regulation

Solution to 2):

Equipment influences:	Material, manufacture, design.
Environmental influences:	Temperature, air pressure, humidity, electromagnetic fields.
Process errors:	Incorrect measurement set-up, incorrect installation.
Personal influences:	Reading errors, incorrect estimating.

Solution to 3):

- The pH value is defined as negative decimal logarithm of the hydrogen concentration.
- In one litre, with pH value 7, there are the equivalent of 10^{-7} H ions.
- In order to form the mean of pH values first the individual load of H ions is to be formed and then from this the mean. The negative decimal logarithm of this value gives the pH value. In this case, with unchanged flow, calculating the H ion concentration suffices.

pH value:		H ion concentration:		
7.0:		10^{-7}	=	0.000,000,1
6.5:		$10^{-6.5}$	=	0.000,000,316,2
6.3:		$10^{-6.3}$	=	0.000,000,501,1
4.0:		10^{-4}	=	0.000,1
6.3:		$10^{-6.3}$	=	0.000,000,501,1
6.5:		$10^{-6.5}$	=	0.000,000,316,2

Sum: 0.000,101,734,6

$0.000,101,734,6/6 = 0.000,016,956$

$\log 0.000,016,956 = -4.77$

Mean pH value: 4.77

Solution to 4):

a) - Dilution methods.
   - Respiratory methods (barometric, manometric).

b) - Dilution water
   - May not be chlorinated.
   - Must contain sufficient nutrients.
   - May only contain so many organic substances that a self-depletion (5 days) is no more than $1 - 1.5$ mg O_2/litre.
   - May not contain high concentrations of inorganic oxidisable substances (Fe^{2+} salts).
   - Due to a sufficient solubility of oxygen may not be too hot.

c) In order to prevent an O_2 depletion through nitrification of ammonia; ATH acts as nitrification inhibitor.

d) O_2 depletion of the sample: 6.3 mg/litre
   O_2 depletion of the diluting water: - 0.7 mg/litre

                                                                                      5.6 mg/litre

$$\frac{5.6 \cdot x\ 1,000}{20} = 280 \text{ mg BOD}_5 \text{/liter}$$

Solution to 5):   **(b)**

Solution to 6):   **(a)**

Solution to 7):   **(c)**

Solution to 8):   **(e)**

Solution to 9):

1) $DS = \dfrac{m_3 - m_1}{m_2 - m_1} = \dfrac{30.75 - 27.18}{78.18 - 27.18} = \dfrac{3.57}{51.0} = 0.07 = 7\%$

2) $IR = \dfrac{m_4 - m_1}{m_3 - m_1} = \dfrac{28.43 - 27.18}{30.75 - 27.18} = \dfrac{1.25}{3.57} = 0.35 = 35\%$

3) $IL = 1.0 - 0.35 = 0.65 = \mathbf{65\ \%}$

Part B)

Solution to 1):

a) - Polychromatic light is converted into monochromatic light with the aid of a filter (interference filter).
   - This monochromatic light, on passing though the coloration of the sample solution is absorbed in a vessel, depending on the layer thickness and concentration of the solution.
   - The remaining light intensity is measured and compared with the emitted light (transmission (%)).
   - The evaluation takes place by means of absorbance, the negative logarithm of the transmission. This is directly proportional to the concentration of the dissolved substance.

b) - $K_2Cr_2O_7$ potassium dichromate   as oxidation agent.
   - H_2SO_4 sulphuric acid   for the acidification of the sample.
   - Ag_2SO_4 silver sulphate   as catalyser.
   - $HgSO_4$ mercuric sulphate   for the masking of chloride ions.

c) - Worn pipette tip.
   - Vessel not cleaned.
   - Incorrect application volume taken.
   - Reaction time, reaction temperature not maintained.
   - Reagent exchanged, input of reagent forgotten or after input not mixed (formation of streaks)
   - Evaluation carried out using the incorrect photometer filter.
   - Interference due to turbidity not corrected.
   - Preservation date of the cuvette test exceeded.
   - Contaminated and damaged photometer filter continued to be used.

Solution to 2):

a) Asymmetry and steepness.

b) 2 buffer solutions; pH 7 and, for example, pH 4 for the acid range as well as a thermometer.

c) - For accurate pH measurements before each measurement.
   - On change of the measuring range very alkaline – very acidic.
   - At the latest following manual of the equipment.

Solution to 3):

a) Oxygen partial pressure in the liquid.

b) Through the reduction of O_2 on the gold cathode with the release of 4 electrons/oxygen molecules and concurrent oxidation of the silver anode with the uptake of 4 electrons.

c) The oxygen mass-concentration (mg/litre) is determined, dependent on the temperature (oxygen saturation), from the measured O_2 partial pressure.

d) Through the reduction of O_2 at the gold cathode, a reduction of the O_2 results on the surface of the protective membrane of the probe

Solution to 4):

a) A magnified, reversed (vertically reversed, laterally reversed) virtual picture.
b) Objective and ocular magnification.
c) Resolution
   Numerical aperture of the object and wave length of the light employed are relevant for the resolution
d) - Resolution, luminosity and depth of field.
   - With reduction of the aperture diaphragm the luminosity and resolution smaller, the depth of field greater.
e) For the examination transparent, low contrast objects (without coloration).

Solution to 5):

a) MLSS: Mass concentration of the filterable solids (g/litre)
           Only the undissolved particles are recorded.
   DS: Mass fraction of all content substances (%)
           Both the dissolved and also the undissolved particles are recorded.

b) Ignition loss of the total dry residue.

c) - Determination is to take place immediately following sampling
   - Fill thoroughly mixed sample up to the 1 litre mark in a 1 litre cylinder (glass or transparent plastic).
   - Position measuring cylinder vibration-free and protected against direct solar radiation (avoid temperature differences).
   - After 30 mins standing time, read sludge volume (ml/litre) at the phase interface sludge-water.
   - With sludge volume SV > 250 ml/litre a sample diluted with secondary settled water is to be examined; according to the amount of dilution the result is to be multiplied using an appropriate factor.

Solution to 6):

a) -   Protective spectacles.
    -   Protective overall.
    -   Laboratory gloves.

b) -   Designation of the substance.
    -   Designation of the components.
    -   Hazard symbols with the indication of danger.
    -   Risk and safety information (R and S principles).
    -   Name of the manufacturer or marketing agent and address.
    -   Additional details with: -   cancer-causing (carcinogenic) substances.
                                    -   preparations containing asbestos.
                                    -   substances releasing formaldehyde

c) -   Risk and safety principles.
    -   R principles: information on particular dangers.
    -   S principles   safety advice.

Solution to 7):   **(e)**

Solution to 8):   **(e)**

Solution to 9):   **(c)**

Solution to 10):   **(a)**

6. Bibliography [Unless indicated, the publications are not available in English. A courtesy translation of the title is added in square brackets].

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§ DWA-Schulungsunterlagen für Electrofachkräfte DWA [Instructional documentation for Electrical Technicians]; DWA, Hennef

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§ Ver- und Entsorger, Aufgaben zur Kenntnisprüfung [Environmental technician, tasks for examination]; Federal State Environment Office RW, Essen

7. Abbreviations for the list of formula:

A   area (m²; mm²)

B_d load (kg BOD_5/d; COD/d)

B_{DS} sludge loading (kg BOD_5/(kg DS x d)

Bv   volumetric loading (kg BOD_5/(m³ x d)

c   specific heat capacity (kJ/(kg x K))

cos φ   efficiency factor (-)

DS_a dry solid matter after dewatering (kg/m³)

DS_b dry solid matter before dewatering (kg/m³)

ES_d excess sludge production (kg DS/d)

F   force (N)

G   gradient (in %)

g   acceleration due to gravity (m/s²)

h   height (m)

I   current strength (A)

$MLSS_{AT}$ mixed liquor suspended solids in the aeration tank (kg DS)

$MLSS_{ES}$ mixed liquor suspended solids of the excess sludge (kg DS)

$MLSS_{RS}$ mixed liquor suspended solids of the return sludge (kg DS)

m   mass (kg)

m_1 mass of solution 1 (kg)

m_2 mass of solution 2 (kg)

P   power (N x m/s)

P_{el} electrical power (W)

P_{in} power in; input power (N x m/s)

P_{out} power out; output power(N x m/s)

p   pressure (N/m²)

p_1 gas pressure, condition 1 (Pa)

Pop population (I)

PE population equivalent (I)

PT total number of inhabitants and population equivalents (I)

Q   flow (m³/h; litres/s)p_2 gas pressure, condition 2 (Pa)

Q_{ES} excess sludge flow (m³/d)

Q_H amount of heat (kJ)

Q_{RS} return sludge flow (m³/d)qA surface charge (m/h)

RR recirculation ratio (-)

s   path (m)

T_M mixture temperature (°C)

T_1, T_2 temperature condition 1 and 2 (K)

t   time (s)

t_{DS} sludge age (d)

V   volume (m³)

V_a volume after dewatering (m³)

V_b volume before dewatering (m³)

V_{AT} volume of aeration tank (m³)

V_S sludge volume (ml/litre)

$V_1; V_2$ gas volume, condition 1 and 2 (m³)

W   work (N x m)

C   concentration (kg/m³)

Δρ change of temperature (K)

η   efficiency (-)

8. Formula

General:		Wastewater engineering:	
1. Weight: $[kg \times m/s^2 = N]$	$F = m \times g$	1. Flow: $[m^3/h; litre/s]$	$Q = V / t;$ $Q = v \times A$
2. Pressure: $[kg/(m \times s^2) = N/m^2]$ hydrostatic pressure	$p = F / A$ $p = \rho \times g \times h$	2. Load: $[kg/d]$	$B_d = Q \times C$
3. Work: $[kg/(m^2 \times s^2) = Nm]$	$W = F \times s$	3. Volumetric loading: $[kg\ BOD_5 /(m^3 \times d)]$	$B_V = B_d / V$
4. Mech. performance: $[kg/(m^2 \times s^3) = Nm/s]$	$P = W / t$	4. Sludge loading: $[kg\ BOD_5/$ $(kg\ MLSS_{AT} \times d)]$	$B_{DS} = \dfrac{Q \times C}{MLSS_{AT}\ x\,V_{AT}}$
5. Amount of heat: $[kJ]$	$Q_H = c \times m\ \Delta\rho$	5. Sludge age: $[d]$	$t_{DS} = \dfrac{V_{AT} \times MLSS_{AT}}{Q_{ES} \times MLSS_{ES}}$
6. Efficiency: $[-]$	$\eta = p_{in} / p_{out}$	6. Recirculation ratio: $[-]$	$RR = Q_{DS} / Q$ $RR = MLSS_{AT}/(MLSS_{RS} - MLSS_{AT})$
7. General state equation of the gases:	$\dfrac{p_1 \times V_1}{T_1} = \dfrac{p_2 \times V}{T_2}$	7. Surface charge: $[m/h]$	$qA = Q / A$
8. Incline (gradient): $[\%]$	$G = h/length \times 100\ \%$	8. Excess sludge production: $[kg\ DS/d]$	$ES_d = MLSS_{ES} \times Q_{ES}$
		9. Sludge volume index: $[ml/g]$	$SVI = V_S / MLSS_{AT}$
		10. Change of volume: $[m^3]$	$Va = Vb \times DSa/DSb$
		11. Mixture temperature: $[K]$	$T_M = \dfrac{m_1 \times T_1 + m_2 \times T_2}{m_1 + m_2}$
		12. Total number of inhabitants and population equivalents: $[I]$	$PT = Pop + PE$

Omar Zimmo; (Adaptation)
Wastewater Engineering in Question and Answer
Adapted to the Situation in the Palestinian Territories and Regional Countries

This book is adapted from the titled book "Wastewater Engineering in Question and Answer", 10th edition published by the German Association for Water, Wastewater and Waste (DWA), to suite the wastewater situation in Palestine and other countries in the region. The adaptation and publication of this new version comes within the scope of the German Technical Cooperation support to the Palestinian Water Authority (PWA) in managing and coordinating training in the Palestinian Water Sector.

The revised 11th edition of the book "Wastewater Engineering in Question and Answer" aims at providing knowledge and practical experience to university students trainers and to enable technicians and vocational staff to carry out responsible tasks independently and to give master technicians increased competence in leadership and management.

This English-language edition covers the main areas of wastewater discharge, wastewater treatment, sludge treatment, sampling and analysis. It comprises two parts: a task part and a solution one, while the diversity of the wastewater engineering subjects is given the widest cover.