Course book *Operation & Maintenance of Wastewater Treatment Plants*

World Water Academy

Foreword

This textbook corresponds to the module *Operation & Maintenance of Wastewater Treatment*, the fourth and last module of the course *Wastewater treatment for Process Controllers*. The course is developed as one of the projects of the Centre of Expertise in Durban. This Centre is a joint innovative of the Netherlands and South Africa to implement innovative methods and experiences in Southern Africa.

The course focus on the responsibilities, roles and tasks of the process controller in normal conditions and in emergency situations. The differences between normal operation & maintenance and troubleshooting are discussed. The organisation and procedures are put central and the behavior of the process controller is discussed. The course includes the data collection and recording for a good quality. Sampling, logs, LIMS and ICT are discussed and demonstrated. The participants become aware of the importance of good operation & maintenance and troubleshooting at the wastewater treatment plant.

To make the course as effective as possible for you, we hope that you will share your knowledge and examples, that you feel free to ask explanations. Please let us know if you have any comments, because with your comments we can improve the training!

We hope you will enjoy the training and wish you lots of success.

Best regards,

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Content

1 Introduction

1.1 Importance

Every service provider in wastewater treatment has the objective to produce effluent and sludge meeting the requirements for the intended use at low costs.

This is not possible without well maintained equipment, relevant information, clear procedures, appropriate health and safety management and most of all good educated and well trained staff, such as process controllers.

These aspects, which are not all specific to wastewater treatment, are covered here.

1.2 Maintenance

The primary goal of maintenance is to avoid or mitigate the consequences of failure of an equipment or installation. It is aimed at preventing the failure before it actually occurs. It is designed to preserve and restore equipment reliability by replacing worn components before they actually fail.

Preventive maintenance

Regular or preventive maintenance has fixed intervals, which are recorded in the maintenance logbook. For example, this interval is after a certain number of hours in service or at a fixed interval of time, such as every three months. The time period can be made shorter or longer, depending on the wear or defectiveness determined during preventive maintenance.

Daily maintenance involves ensuring the correct functioning of an installation. Some important examples of daily maintenance are listed below:

- Lubrication and checking oil levels;
- Changing oil, checking for leakage, unblocking pumps, pipelines, etc.;
- Simple maintenance work, such as fixing minor problems, replacing defective light bulbs, levelling tiled pavements, checking pump shaft seals, cleaning level floats, etc.;
- Cleaning, checking and touching up paint work;
- Calling in specialized assistance;
- Updating maintenance logbooks and reporting breakdowns;
- Inspection.

With the preventive maintenance, the installation is returned to its original condition. This reduces the likelihood of breakdowns and increases the service life of the installation.

Corrective maintenance

Corrective maintenance is aimed to identify, isolate, and rectify a fault, so that the failed equipment, machine, or system can be restored to the normal operational conditions. Corrective maintenance must be avoided as far as possible by the conduct of regular maintenance and inspection.

Corrective maintenance also includes the introduction of modifications or attention to minor matters so as to:

- Improve effectiveness;
- Simplify maintenance work;
- Reduce the likelihood of breakdowns.

In this regard one might think of such work as the changing or relocation of level meters and fitting the bearings of a check valve with grease nipples. These actions are taken because the designer cannot think of everything in advance, or because one is working with trade parts, which the fitter can only supply with such extras at a high cost.

It is particularly important that this maintenance is well reported, since both the designers and other users can make good use of such information.

2 Organisational aspects

2.1 Organisation structure

An organisational chart, also called organogram, is a diagram that shows the structure of an organisation and the relationships and relative ranks of its parts and positions/jobs. It typically illustrates relations between people within an organisation. Such relations might include managers to sub-workers, directors to managing directors, chief executive officer to various departments etc..

Organogram

In wastewater treatment, the organogram shows if e.g. more treatment plants are combined within one part of the organisation and have the same manager or if the maintenance is performed by one or more separate parts of the organisation.

The organogram shows also the responsibilities and communication; who is responsible for the management of e.g. a wastewater treatment plant and to which higher manager must be reported.

2.2 Operational Procedures

There are different rules and systems in place on a waste water treatment works. These rules dictate how and when duties are to be completed safely including what needs to be done when things may go wrong in the form of process control and failure response plans. There are also procedures in place to manage the information and data produced on the plant. Other procedures include methods to be followed in the case of repairs and maintenance on the plant. Together, all these procedures ultimately ensure the production of good quality water or final product discharge to the receiving environment.

2.3 Process controllers

The tasks and responsibilities of the process controllers on a wastewater treatment plant are to control the treatment processes within operational limits and to produce effluent and sludge meeting the requirements. Low costs of treatment is an important objective as well.

The requirements for process controllers are established in Regulation 17.

3 Information

3.1 Information management

Process control is not possible without information about the status of the process. Process information is the key tool for Process Controllers.

Information differs from 'data'. Data are figures describing process parameters at a certain moment. The following example illustrates this difference: *If it is required to determine the mean value of nitrogen concentration in the effluent as an average value per week and the effluent is sampled and analysed every day, there are seven samples analysed. These seven values are the raw data, because there is no relation between them. The calculated average value of the seven daily values is information.*

Information management is used to convert raw data into information. For a wastewater treatment plant there are four different sources of raw data:

1. Visual inspection
2. Sampling
3. Log sheets
4. SCADA

Information will increase when different sources of raw data are combined. For example COD concentration of the water after the PST (in mg/l) and influent flow at the head of works (in m^3/d) can be combined to calculate the COD loading rate of the activate sludge process in kg/d COD.

Information will increase when information is presented in readily understandable form. For example a graph over time is more clear than the same data in a list. Combining graphs in the same figure may give an even better overview of the information, e.g. the loading rate of a decanter and the resulting solids content of the dewatered sludge.

The information management is combining the raw data of different sources, execution of calculations and presenting the results which exceed what is performed by SCADA and LIMS. Dedicated software is required.

Visual inspection

On a wastewater treatment plant many phenomena can be seen, such as the colour of activated sludge, the smell of digested sludge, the clogging of a screen etc. Usually the observations are only recorded in a logbook when they are different from the normal situation.

Sampling

Sampling is based on a sampling and analysing program that is specific for a WWTP. Sometimes extra samples are taken and analysed e.g. for research or troubleshooting. The samples are transported to the laboratory and analysed. The resulting values are stored in the LIMS (Laboratory Information and Management System). These values are raw data.

Log sheets

Plant log sheets are used to log operational data from the plant. Log sheets contain readings of on-site measurements. The readings are collected on a routine basis.

KINGSBURGH WASTEWATER TREATMENT WORKS				LOGSHEET: 1
PLANT LOGSHEET	DATE:		DAY:	

H.O.W HAND SCREENINGS REMOVAL	
Estimated Volume (m^3)	

GRIT REMOVAL	
Estimated Volume (m^3)	
SKIPS REMOVAL	
No. of skips removed	
Date Skips Removed	
CHEMICAL LIME USAGE	
No. of lime bags used	
kg lime used	
CHEMICAL ALUM USAGE	
Dosing rate (litres/hr)	
Volume used (litres/day)	
Total Alum Used (litres/day)	

DAILY FLOWS (m^3/day)	Totalizer Start	Totalizer Stop	Difference (m^3)
H.O.W Inflow Meter			
Volume of Sludge wasted			
Portable Water Meter			
Second class meter			
Power Usage (kWh)			

PLANT OPERATIONAL TESTS		PROCESS CONTROL TESTS	
Imhoff Cone test (ml/l)		Ammonia (NH_3)	mg/l
1/2 Hour Settlement (ml/l)		Nitrates (NO_2)	mg/l
Dissolved Oxygen (mg/l)		pH	

WEATHER	
Weather	
Rainfall (mm)	
Temperature Minimum (°C)	
Temperature Maximum (°C)	

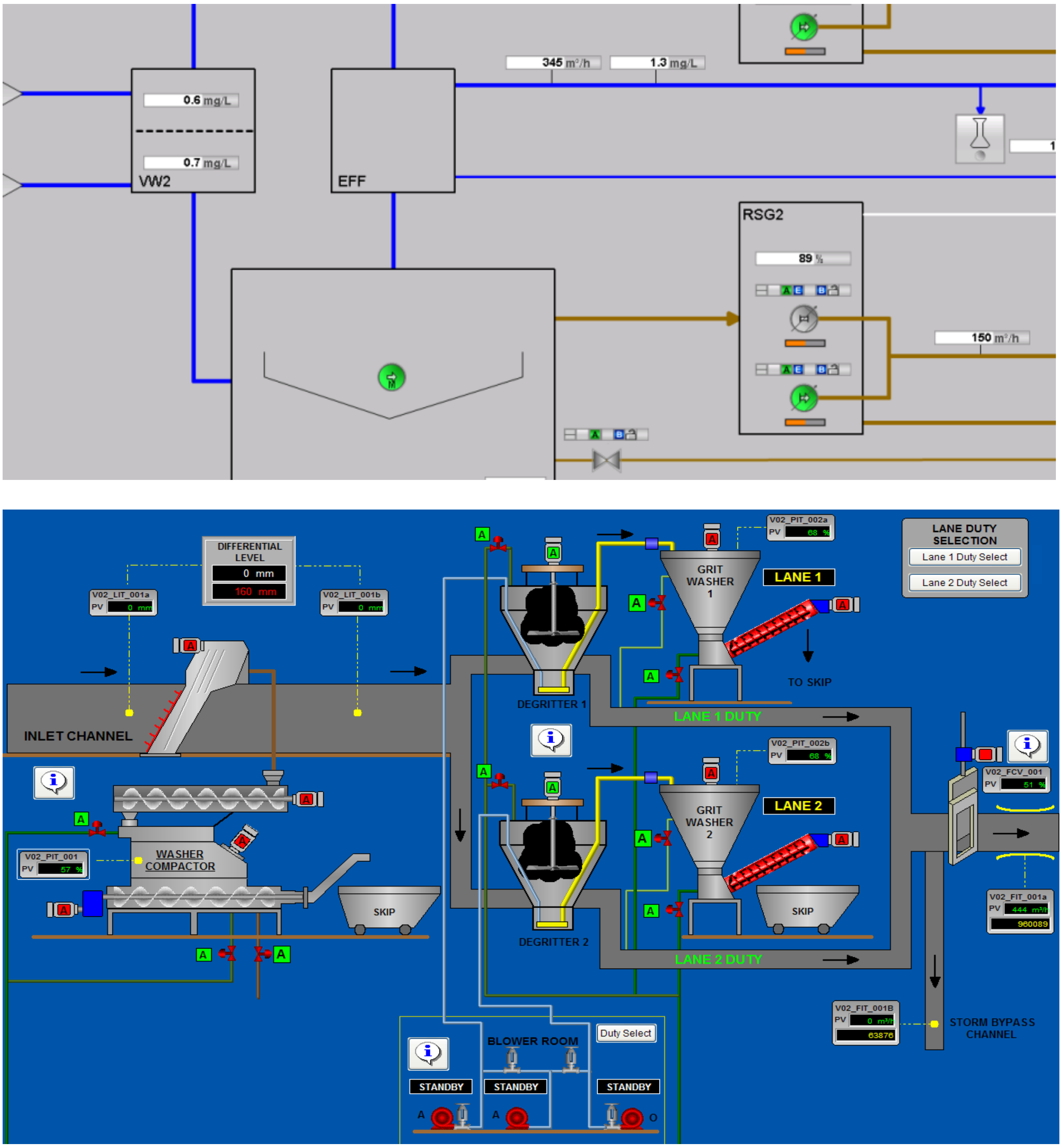
CHLORINATION	08h00	14h00
Residual Chlorine		
Chlorine Dosing rate (kg//hr)		
Chlorine Used (kg/day)		
Chlorine Left (kg)		

EQUIPMENT CHECKLIST	START	FINISH	TOTAL HOURS	AMPS	STATUS
Mechanical screen motor					
Raw Sewage Pump					
Anoxic Mixer					
Aerator Motor					
Anaerobic digester Mixer					
Clarifier Bridge Motor					
Clarifier Bridge Motor					

Log sheet example.

SCADA

A process automation system controls processes within a WWTP automatically. It analyses process units automatically with sensors and meters placed at representative points within the units. Usually this system is associated with a SCADA (supervisory control and data acquisition) system. SCADA is a system that obtains data (from those sensors) through signals and provides an automated control on equipment based on the incoming data. It is a programmable industrial control system that stores all data in a linked database. This is an advanced system that is able to monitor and control processes in real time. Parameters that can be measured include flow rates, temperature DO, nitrates, ammonium, phosphates, TSS, energy consumption and turbidity. These sensors should be calibrated frequently to avoid faults in the process. The lab analyses should be compared to that of the automated system to insure that all measurements are accurate (available quick tests kits on site are useful for on-site analyses).



Examples of a computer interface that depicts a process automation system

3.2 Sampling

The objective of sampling is to obtain a small, representative amount of the material, to be analysed. In this case the material to take a sample from is wastewater or sludge. Analysis of this sample should provide the best possible information about the composition of the water or sludge concerned. Usually the samples are taken at fixed intervals per sample, e.g. every hour, three times a week on Monday, Wednesday and Friday at noon, every month on the first Wednesday etc.

A sample can be obtained in the following ways:

- By a spot check, i.e. a sample is withdrawn at a certain moment in the day. Single spot sampling only gives information that is valid around the sampling time. The analysis of a relatively large number of spot samples will give a more complete picture;
- A number of spot samples are taken during the day and are collected together in a drum. At the end of the day the content of the drum is mixed and an average daily sample is withdrawn;
- The last method described above can be automated by using a sampling apparatus to withdraw equal sample quantities at fixed intervals and depositing them in a collecting drum. This is called ‘Time proportional sampling’;
- Sampling equipment is used to take equal sample quantities, depending on the wastewater outflow. The samples are collected in a drum. This is called ‘Flow proportional sampling’.

Spot sampling is usually too inaccurate for wastewater analysis. It is only desirable when the wastewater has to be analysed for volatile substances that undergo (rapid) changes over time. Spot sampling is often satisfactory for the analysis of activated and digested sludge. By contrast, it is less suitable for the analysis of primary sludge due to the frequent changes in its composition, however it is common practice.

It should be remarked that the most favourable sampling site is located where the wastewater or the sludge is fully mixed. Areas with high turbulence and/or an upward flow direction are most suitable for easy sampling resulting in high quality samples.

Sampling effluent (example)

Hand sampling

This method is most commonly used for taking spot samples, and sometimes when a combined sample is required for a particular analysis. It is highly recommended to use good, easily used aids, such as extendable sampling rods with a robust bottle holder, carrying baskets and suchlike.

Automatic equipment

Automatic equipment is used to take continuous or periodic samples from the wastewater stream for deposition in a collecting drum. After a pre-set period of time has elapsed, a sample is taken from the well-stirred collecting drum for further analysis. Especially when the collecting drum contains sediments, it is difficult to stir, shake and sample the collecting drum in such a way that a homogeneous sample is obtained.

The next sampling period commences after the collecting drum has been emptied. As has been mentioned, the best results may be expected from flow-proportional sampling. This is especially true for the influent. Suitable equipment thus often has the sampling equipment coupled to the volumetric flow meter which transmits a signal to the sampling equipment after a pre-set, measured flow (in m3) so that a partial sample is obtained and deposited in the collecting drum.

Frequent use is currently made of vacuum sampling equipment for influent sampling. While there are many designs, the basic principles of such equipment are practically universal.

A sampling cycle consists of the following stages.

- Outlet valve is closed; pressurized air blows suction line clear;
- Air is withdrawn from the sampling flask, allowing a fresh quantity of liquid to flow into the flask;
- Suction line cleared with pressurized air;
- Outlet valve is opened and sample deposited.

Besides the requirements necessary for satisfactory sampling, the following aspects should be born in mind when locating sampling equipment:

- The equipment needs regular maintenance; collection drum, sampling equipment, inlet and outlet hoses must be periodically well cleaned and/or replaced;
- The equipment must be readily accessible. This means that there must be sufficient space around the equipment for the easy disposal of collected sample remains, that the suction hose in particular (preferably permanently attached) can easily be cleaned. The sampling equipment should preferably be located indoors. This affords the best protection against undesired influence by the weather and direct sunlight.
- The space in which the sample collecting drum stands should preferably be cooled to a constant temperature of 4 ^{o}C., e.g. in a household refrigerator. This restrains biological degradation as far as possible, which gives accurate values for the parameters depending on it (BOD, Kjeldahl nitrogen, NO2 and NO3);
- In connection with biological degradation, the samples should be analysed in the laboratory as soon as possible (the samples should in any case be stored under refrigerated conditions and they should be analysed within three days) .

Water and sludge analysis

Analysis can start after the water and sludge samples have been obtained. In many cases the analysis will be performed in the (central) laboratory, using standard procedures for each parameter. The resulting data may be stored in and transferred by a LIMS (Laboratory Information and Management System).

Besides that, some simple tests are often done at the treatment plant. These include a number of laboratory tests, as well as the determination of control or signal parameters, such as oxygen content, acidity and turbidity. These parameters are measured continuously in larger plants, using permanently installed sensors.

4 Troubleshooting

Troubleshooting is a form of problem solving, often applied to repair failed products (e.g. effluent) or processes (e.g. digestion). It is a logical, systematic search for the source of a problem so that it can be solved, and so the product or process can be made operational again. Troubleshooting is needed to develop and maintain complex systems where the symptoms of a problem can have many possible causes

4.1 Normal operation versus troubleshooting

Troubleshooting differs from normal operation. During normal operation the usual process control results in processes and products within the usual limits. Troubles arise when the normal control procedures do not give usual results for products and processes, e.g. the effluent standards are no longer met or the digestion process fails.

In this case the normal control procedures are no longer leading and troubleshooting must start.

4.2 Guidelines

Once a failure causes troubles, troubleshooting has the highest priority. The sooner the troubleshooting starts, the easier and cheaper it will be to solve the problems and to go back to normal operation eventually.

It is important that all available knowledge is used (ask colleagues and experts for help) and consider upscaling the problem (information to the management) from the very start if there are any doubt in easy, cheap and quick solving of the problem.

4.3 Troubleshooting steps

Troubleshooting can be divided in four different steps:

5. Detection: how is a failure detected
6. Analysis: what caused the failure (more than one cause at a time possible)
7. Solving: how to solve the failure (urgent measures / back to normal operation)
8. Prevention: how to prevent this failure from happening again

Detection

It is not always easy to detect a failure in a complex system like wastewater treatment, because a failure may show the first effects a long time after the failure started. Signals of a failure can be:

- Visual - unusual colours (e.g. grey instead of light brown), unusual bubble patterns in aeration tanks, unusual gas bubbles rising to the surface, unusual sedimentation tank and thickener overflow etc.
- Process data – unusual high or low values for parameters such as oxygen content in aeration tanks, COD, nitrogen, phosphorus, Ecoli etc in effluent, solids content of all types of sludge, digester gas production, pH etc.
- Plant data – unusual high or low values for plant data such as polymer consumption, energy consumption, use of chlorine etc.
- Trends – Trends (graphs) of process and plant data are very usefull to recognize slow phenomena that may cause a failure in future.

Especially when more of the signals occur at the same time, special attention shoudl be given to possible failures. Checking all available information may result in still unnoticed signals that may contain the clue for troubleshooting.

Analysis

Once a failure has been detected, the root cause, the real cause of the failure, should be investigated. It may be very difficult to find the root cause as many unusual values are the result of the same cause.

Analysis requires the co-operation of all staff. Especially process controllers with their specific knowledge of the plant history and lay-out, but also engineers and plant management must be mobilized to make a proper analysis.

Solving

Once the analysis is successfully done, the problems can be solved. In general two stages in problem solving can be identified:

- Urgent measures – the measures that have to be taken immediately to prevent worse, e.g. bypassing of processes such as transporting liquid sludge to another treatment plant to be processed there instead of sludge dewatering, bypassing failed thickeners or other relevant measures, depending on the root cause.
- Back to normal operation – a program to restore normal operation over time. This may consist of emptying, cleaning and recommissioning of tanks. In some cases a total new start-up of a process will be more effective than time consuming attempts to restore normal operation without much effort.

Prevention

Once the root cause has been investigated it should be considered which measures should be taken to prevent this specific failure from happening again.

This may lead to better detection, better equipment, upgraded processes, more sensors, more awareness, other procedures etc.

A failure is a free advice for improvement!

4.4 Equipment failures

Wastewater treatment plants show many common equipment failures that have effect on processes. The failures belong to three categories:

1. Mechanical – such as pumps (clogging, breakdown), valves (actuators, blockage), travelling bridges (wheels, bearings), gearboxes (breakdown)
2. Electrical – such as power supply (interrupted, broken cables, short circuiting, fuses)
3. Control – such as sensors (failure, calibration), control software (bugs), safety systems (interlocked equipment)

4.5 Systemthinking

The effect of failures is not limited to the process were the failure exists. Wastewater treatment is a complex process with many interactions between the different processes. Because of recycle flows failures can not only spread to downstream processes, but also upstream processes may be affected. This is called the domino-effect.

Examples of the domino-effect are:

- Screen breakdown – this causes screenings to enter the PST. The screenings go with the sludge to the thickeners and afterwards to the digester. The screenings in the digester will cause blocking of the overflow on the long run. This is a domino-effect several processes downstream. This problem is identified as a too high sludge level in the digester.
- Polymer dosing sludge dewatering – overdosing or underdosing in the dewatering will cause less solids recovery in dewatering e.g. 95% > 85%. This causes transport of more digesting sludge to the head of works and the PST. The thickener will also receive more digested sludge and this will result in less thickening due to increased septic conditions (gas bubbles) and consequently more sludge is pumped to the digester and afterwards the dewatering. This higher loading leads to a worse recovery again. This type of failure shows a strong domino-effect since the effect becomes stronger over time. This problem is identified as too low solids content of the thickened sludge without the possibility to increase the solids content.

Screen breakdown

Screenings downstream (because of failing screens)

When a failure occurs at a wastewater treatment plant, the whole system should be considered. The root cause may be present upstream, but also downstream from where the problems are identified.

5 SHEQ

5.1 Safety and health

Safety in the workplace is one of the most important operating standards. Health and safety measures must be implemented and controlled in any working environment by a health and safety representative (Occupational Health and Safety Act, No. 85 of 1993, as amended, 2008). For all operational and maintenance activities safe standard operating procedures must be in place.

There are many disease and injury causing hazards present on a WWTP that must be prevented or mitigated. Identifying these hazards can aid in the design and implementation of preventive measures. All hazards on a WWTP, whether they are due to human error or mechanical failure, can be divided into 3 main groups: biological, chemical and physical.

Biological hazards include diseases from bacterial, viral and parasitical origin. Raw, untreated wastewater is contaminated with many pathogens that occur in human faeces and agricultural runoff. As a preventive measure all employees should wash their hands with disinfecting soap after having completed any task on site. Regular medical checkups are advised for the monitoring of the health of the staff.

Chemical hazards may include a variety of adverse effects, including:

- burns and irritation of the skin due to exposure to certain chemical substances, such as acid and alkaline solutions;
- irritation of the mucous membranes through the inhalation of vapour, such as hydrogen sulphide (H_2S);
- poisoning or suffocation through the ingestion or inhalation of certain chemicals;
- damage of the eyes when in contact with acid or alkaline solutions;
- physical explosions as a result of methane (CH_4) ignition.

Physical hazards comprise of a variety of incidents, some of which are:

- electrocution due to (partly) uninsulated or unearthed cables;
- falling into or off a reactor;
- falling over objects/falling objects from elevated areas;
- crushed fingers or toes as a result of incorrect handling of machinery;
- slipping on wet and slippery surfaces;
- weather circumstances may cause physical injury, such as very hot or cold weather, storms and winds;
- UV exposure causing damages to skin cells;
- exposure to certain noisy machines;
- back or other injuries as a result of overexertion.

All these situations can be prevented and/or mitigated with a good safety programme. Safety protective equipment wear should be worn by all personnel in the field and there should always be extra available on site. Safety wear includes:

- safety shoes/boots;
- safety helmets;
- chemical resistant clothing;
- safety goggles;
- hearing protectors;
- gas masks;
- H_2S sensors;
- gloves.

Safety gear required on a WWTP

Smoking or the use of any machinery that may cause a spark (e.g. a string trimmer) must be prohibited near any installation that contains a flammable gas (e.g. a digester). If a gas leak occurs a spark may result in an explosion. Areas surrounding flammable gas containers have to be clearly labeled as such.

When performing certain tasks on a WWTP, especially pertaining to maintenance, it is wise to employ the buddy system. In this way, if something were to go wrong, there is an available person to help in the situation or to call for help, if necessary. At the same time any personnel performing a task must be aware of any dangerous situations. If a dangerous situation is identified the appropriate steps to eliminate that situation must be taken immediately before finishing the task, unless otherwise specified by a health and safety representative.

However the buddy system does not always guarantee safety. In case one person gets unconscious in a confined space, the buddy should not enter that space without relevant protection against poisonous gasses and extra help. Otherwise he will fall next to the victim.

Example danger signs

Material Safety Data Sheets (MSDS) should be kept on site for all chemicals that are present on the premises. These sheets form a critical part of occupational safety and health as they provide personnel with the handling procedures of substances. All known (safety) information of a substance is included in a MSDS, which includes physical properties of the substance, health effects, first aid, toxicity, disposal, reactivity, and handling of the substance.

Functioning emergency showers and eyewash stations must be present on site. The first few seconds after exposure to a hazardous substance are critical. On-site facilities provide quick decontamination of biological or chemical substances and can prevent serious injuries.


Warning signs at taps

Warning signs at dangerous locations

Other warning signs

The signs and procedures are necessary for your own healthy, and for your colleagues. In case procedures are not clear or signs are damaged, repair it or communicate within the organisation. The example below shows in Zulu ‘drinkable’ instead of ‘undrinkable’. The ‘un’ in Zulu has been dropped off.

Damaged warning signs

All above mentioned safety precautions should be applied when operating any process unit. Good housekeeping and best practice should always be applied on a plant.

5.2 Environment

The WWTP will continuously have impact on the direct surroundings, while as a result of a calamity the environment may be affected adversely.

Incidental pollutions to the environment may be caused by:

- spills to water and/or soil of water, sludge, oil, chemicals etc.
- emissions of gases (biogas, chlorine): air

Note that all detrimental environmental effects that may occur during a calamity must be communicated to the applicable authority and mitigated appropriately (as stated in environmental legislation). An example of such a calamity includes chemical or contaminated wastewater spills, which may leach into the subsurface and contaminate the groundwater or may give rise to dangerous situations (emissions of biogas or chlorine).

Issues concerning nuisance or danger in the vicinity of the wastewater treatment plant are:

- Odours - by far the most important issue is spreading of odours to nearby residential areas. However some temporary odour nuisance is (financially) unavoidable, but by means of good housekeeping odour emission can be reduced. Important measures are:
    - avoiding of raw and digested sludge or septic water to be stored in open basins or tanks
    - closing of hatches in covers used for odour emission
    - flaring of biogas rather than just discharging into the atmosphere
- Noise - noise may spread well into nearby residential areas. Avoiding nuisance may be accomplished by closing doors in buildings where noise is produced, e.g. compressor

rooms. Small noise producing equipment may be equipped with noise insulating or reflecting materials.
- Danger for people – wastewater treatment plants are potentially dangerous to people who are not familiar with the dangers. The whole plant should be fenced in order to hold back persons, especially playing children, from entering into the plant.

5.3 Quality

The word quality has many meanings, depending on the context in which the word quality is used. Quality management in wastewater looks at:

- Process quality - the process control is on a level that guarantees that the processes are within limits and the resulting products meet the specifications as required for the intended use, e.g. effluent for discharge in the river and sludge for use in agriculture.
- Quality of equipment - keep equipment in good condition and increase lifespan on assets
- Quality of documentation – documentation helps monitor systems compliance and helps identifying shortfalls

For process controllers quality management means that they are aware of their important contributions to and responsibility for the quality management of the entire wastewater treatment plant.

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