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Pilot plan for industrial wastewater treatment facilities in the objective of water reuse

Plan pilote pour les installations de traitement des eaux résiduaires industrielles en vue de la réutilisation de l'eau

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Contents

Page

Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 282, *Water reuse*, Subcommittee SC 4, *Industrial water reuse*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Climate change impacts on water availability have industries across the globe seeking ways to drought-proof their operations. One of the key water conservation methods is to implement water treatment and reuse practices, simultaneously reducing demands on potable water resources and on industrial wastewater effluent discharges, and associated residual contaminants, to the environment. The greatest challenge to this approach lies in the characteristics of industrial wastewater and the water quality requirements for reuse, which vary significantly between industries and processes and are unique for each industrial operation. This variation depends on the type of process, raw materials, reagents and additives used, all resulting in a unique set of circumstances for each location, even within one industry. Therefore, industrial wastewater often requires unique treatment approaches, as well as the development and implementation of novel and innovative water treatment technologies.

To overcome this challenge, following a review of source control measures and water treatment alternatives, industries can choose to evaluate novel technologies using a scale-up study to transition the research-based laboratory-scale or bench-scale proof-of-concept treatment process into a functional demonstration or full-scale process. The use of a pilot plan for testing and evaluation of a novel technology or process is the focus of this document.

Pilot plant/facility is a relative term in the sense that it is typically smaller than a full-scale production plant. Still, it is built in a range of sizes and does not necessarily infer a small-scale application as it could be conducted at demonstration-scale or full-scale and often involves a significant investment of financial, equipment and labour resources; therefore, the term 'pilot' is relative. For new water treatment technologies emerging from laboratory and bench-scale development, pilot-testing is the first opportunity to establish or demonstrate commercial potential.

Pilot-testing can be used to check, on a reduced scale, a water treatment process developed through laboratory research. The experience gained by operating a pilot plant/facility can assist in making a decision as to whether or not to proceed with the full-scale plant by determining the likelihood of a full-scale successful implementation. Furthermore, pilot-testing provides for more reliable capital and operational cost estimates, and all necessary inputs (e.g. chemicals, power, labour resources), as well as the ease of operation and maintenance of a given water treatment process. Other objectives can be fulfilled simultaneously and some definitive considerations for the decision to build the pilot plant/facility are possible.

An industrial wastewater treatment pilot plan is a specific case of a chemical, physical and biological processing pilot plan. However, this type of treatment poses many unique challenges that need to be covered by the pilot plan. For example, because some industrial wastewater characteristics vary seasonally or are based on changes in industrial processing and product generation, it could be necessary to adjust or test different operating conditions and control strategies and settings to achieve the highest efficiencies and determine the most suitable economic operating conditions.

The concept of serviceability limit state (SLS) could be useful to determine these stress conditions. To satisfy SLS criterion, a facility ought to remain functional for its intended use (subject to routine operation conditions) after achieving SLS. A typical range of a ratio between the critical parameter values characterizing SLS and routine operation conditions (e.g. concentration of treated target contaminants, flow of wastewater stream, stream temperature) is 1,2/2, although it could be significantly higher for the modern robust wastewater treatment technologies.

The transition from laboratory-scale to a pilot-scale study requires detailed knowledge about the critical design and operating parameters, which initially does not exist and could include assumption making within an iterative process of refinement. The inability to replicate laboratory-scale research findings is often caused by failure to adequately scale-up critical process parameters. It is necessary that the principles of similitude to correlate model and prototype behaviour are carefully observed. Hydraulic similitude, commonly based on the Froude Number Law, is important, as it affects physical attributes such as energy dissipation, as well as dimensional analysis, thus establishing the basic relationship of the physical quantities involved in the dynamic behaviour of the treatment process. The physical, chemical and biological behaviour of the pilot process can simulate, in a known manner, the behaviour of the laboratory or bench-scale prototype, and similarly the behaviour of the pilot process can simulate that of a full-scale application. All scalability criteria and specific similitude requirements ought to be carefully defined prior to pilot planning.

Similarity assessment: since the similarity concept implies checking if the laboratory results are to be applicable to the real-life situation, as a rule, the initial conditions for the simulation correspond to the conditions of the performed laboratory research, whereas the boundary conditions correspond to the expected 'typical' future conditions. In some cases, the boundary conditions also include design limit states [e.g. SLS, fatigue limit state (FLS)] defined as the boundary conditions beyond which the tested technology/process/system fails (or could fail) to perform the function that is expected of it[3].

This document, with some necessary modifications and adjustments, can be used for comparative testing and analysis of the suitability of existing and proven commercial solutions to specific sites and applications (given, for example, operational conditions or specific requirements).

By the nature of dealing with the unexpected, any pilot plan represents a big challenge. Even a successful pilot plan cannot fully guarantee future success of full-scale implementation of tested solutions in real industrial conditions, for the following reasons:

— partial relevance of pilot conditions and environment to real full-scale conditions and environment (e.g. scale-up effects);

— partial coverage of tested pilot conditions of a spectrum of all possible full-scale states;

— short-term pilot performance (long-term effects, such as progressive failures as well as equipment-degraded performance due to ageing or seasonal effects, could hardly be evaluated in the framework of a pilot plan);

— uncertainty of statistical conclusions derived from rather limited collected pilot data;

— it could be that testing conducted at a single site of specific conditions will not represent the entire range of possible conditions characterizing other sites.

This document is not oriented towards a specific type of industrial process; use of raw materials, reagents and additives; or to a particular kind of wastewater. Rather, it provides comprehensive general guiding principles for pilot planning and performance to verify laboratory-scale findings and potential for commercialization. This document includes the critical considerations, methods, criteria and processes which need to be a part of every pilot plant study, from the initial planning through to the post-pilot analysis of the data collected during the pilot study.

A decision about performing a pilot plan ought to be made directly by all relevant stakeholders and interested parties. This document is therefore intended to provide the critical guidelines and considerations for successful implementation of a pilot plan.

Pilot plan for industrial wastewater treatment facilities in the objective of water reuse

1 Scope

This document provides the fundamental principles and guidelines for industrial wastewater treatment technology pilot studies.

It does not address laboratory research and development, study or testing of a given technology. It does not cover reuse applications or operations, such as irrigation.

This document applies to a wide range of industrial water treatment systems for the purposes of reuse.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 20670, *Water reuse — Vocabulary*

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 20670 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1.1
pilot plan
plan
programme
small (reduced) representative scale preliminary study, or a trial implementation and testing of a proposed solution (technology/process/processing chain), limited by some timeframe and conducted in predefined special conditions, in order to evaluate feasibility, effectiveness, efficiency, compliance and sustainability of this solution in an attempt to reveal all possible deficiencies and address them prior to performance of a full-scale project

Note 1 to entry: A pilot plan is a framework in which verification can be executed.

Note 2 to entry: For the purposes of this document, the terms *pilot plan*, *plan* and *programme* are used interchangeably.

3.2 Abbreviated terms

BoD	base of design
CSP	continuous sampling plan
DCS	distributed control system
DoE	design of experiments
DR	design review
FLS	fatigue limit state
FMEA	failure mode and effect analysis
HLD	high-level design
HSE	health, safety and environment
IQ	installation qualification
IT	information technology
LLD	low-level design
LLI	long lead items
NDCS	non-distributed control system
OQ	operational qualification
P&I	piping and instrumentation
PMBoK	project management body of knowledge
PMI	project management institute
PQ	performance qualification
QA	quality assurance
QC	quality control
RFP	request for proposal
R&R	repeatability and reproducibility
SLS	serviceability limit state
SOP	standard operating procedure
WBS	work breakdown structure

4 Lifecycle of a pilot study

4.1 General

To achieve the desired objectives, a pilot study requires a substantial investment, often including a long-term operation. A thorough analysis of the intended objectives and potential outcomes should be carried out before pilot-testing is carried out. The appropriate cost of constructing, operating and maintaining the pilot system should be weighed against the expected advantages to be gained in completing and meeting the pilot plan's objectives.

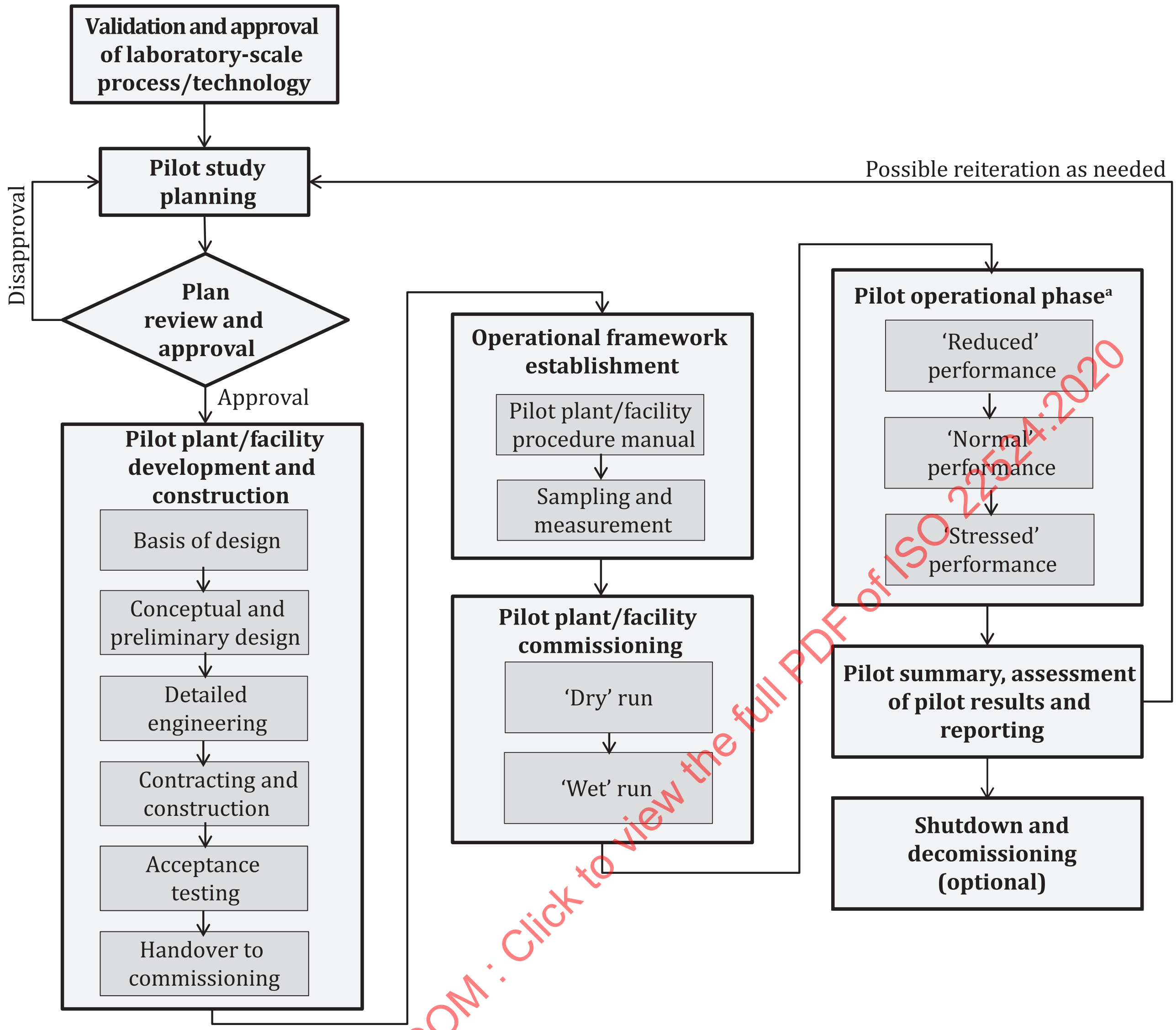
The decision about the performance of a pilot plan should be made directly by all relevant stakeholders and interested parties.

The knowledge and the experience obtained during performance of a pilot plan can be used for the design of full-scale water treatment systems and commercial products, as well as to identify further research objectives and to assist in reducing technical and financial risks associated with investment decisions. Pilot-testing of reclaimed water processes can also be used to demonstrate the effectiveness and robustness of the technology in protecting public and environmental health and safety and can also be useful in gaining public support for new technologies. They can also be used to train personnel for a full-scale plant.

4.2 Pilot plan lifecycle phases

4.2.1 General

In its lifecycle, a pilot plan may go through some or all of the phases depicted in Figure 1.



[a] Refer to 11.2, 11.3 and 11.4 for an explanation of the terms 'reduced', 'normal' and 'stressed' performance.

Figure 1 — Block-diagram of pilot plan phases

4.2.2 Statement of pilot plan goals

Pilot plan goals, scope and boundaries may be stated, based on the laboratory R&D outcomes, industrial wastewater characteristics and analysis of all relevant regulatory requirements, technology needs and constraints.

4.2.3 Pilot study programme

A pilot study (experiment) comprehensive programme may be established to ensure that the pilot plan results can be extrapolated and used for full-scale design purposes while minimizing the potential for process failure.

As an extension to laboratory research, the pilot plan should start with a study of the laboratory research findings and recommendations, and the process parameters determined during lab testing, with particular emphasis on critical aspects that have a significant impact on capital and operating costs.

This includes, but is not limited to, consideration of the following questions:

— Which aspects of the process need to be verified and optimized?

— Which parameters should be measured or assessed and how will the collected data be analysed, processed and ultimately used?

— Which range of operating conditions have to be covered by the pilot plan?

— Which experiments and tests have to be performed?

— What is the scope for each experiment and how can it be determined when the objectives of each experiment have been reached?

— How long should each experiment be, and what should be the overall duration of a pilot study, taking into account possible temporal variability?

— What sequence of tests should be carried out?

— From which locations should samples be collected to account for special and common variability?

The answers to all these questions strongly depend on many factors, including the specific pilot plan (customized solution), the tested technology, the relevant regulatory requirements, the available equipment and the environment. The guiding principle should be based on cost-effectiveness considerations; the pilot plan should be as effective and comprehensive as reasonably practicable.

Important characteristics for consideration in establishing a pilot study programme are volume, physical, biological and chemical properties, and constituent concentrations of the wastewater which often vary significantly over time. If possible and relevant, the pilot testing plan should cover or simulate the seasonal changes in wastewater flow, such as flowrates, concentrations and temperatures. As it is often not practical to carry out lengthy testing during which such variations can be experienced, it can be necessary to create extreme characteristic conditions as stress tests or stress conditions as part of the pilot testing plan. A pilot plan should determine all pre-treatment and post-treatment requirements (e.g. removal of floatables).

Prior to programme finalization, all implicit and explicit assumptions should be exposed, clarified, documented and carefully examined (their correctness and possible impact on pilot results). The guiding principles of the pilot programme should correspond with the concepts and principles of DoE statistical methodology[12].

4.2.4 Pilot plant/facility design and construction

The pilot plant/facility should be designed and constructed taking into consideration the operating environment, for example the area available for pilot plant/facility, site feasibility and the possible need for site adaptation, access to this area and operating conditions. This includes deciding whether the pilot-testing will comprise the whole system of unit processes or separate unit process operations within the system, as well as the size and capacity of the pilot plant/facility.

The first step in a pilot plant/facility design should be the preparation of a block diagram, consisting of a series of connected rectangular blocks, each representing a unit process component, and connected by arrows in order of flow sequence. Such a diagram can be a useful tool in the initial stages of pilot programme planning, as it provides an overview of the stages and can incorporate external inputs such as flocculants, coagulants and anti-scaling chemicals.

Consideration should also be given to whether the process is to be batch or continuously fed. In conjunction with the preparation of the block diagrams during the design phase, the different streams that enter or leave the process can be used to prepare preliminary mass and energy balance diagrams.

Particular attention should be paid to flexibility in the design of a pilot plant/facility, which is critical for adapting the pilot facility operation to different field circumstances.

Potential modifications should be considered at the stage of the pilot plant/facility design such that changes can be made during testing, in relation to uncertain aspects or elements of the process being tested.

The plant should be designed taking into consideration that changes in equipment might be required or that new components could be introduced. For example, if the expected results of a particular unit process are not achieved, or the component is found ineffective, then it is possible that an alternative component needs to be installed.

The scale-up factor from the pilot plant/facility to a commercial plant should be carefully considered. A larger pilot plant/facility will provide more reliable information and reduce technical and associated financial risks for the project, but will be more expensive to build and operate. Alternatively, controlling flow rates and chemical feed rates can be difficult in a small plant/facility and result in process failures and pipe blockages. The pilot plant/facility layout should be compact and simple, allowing sufficient space in the operating area for access to operate and maintain the plant.

Once the block diagrams are complete, a process diagram, including all relevant equipment in a particular process section, should be prepared for each block, typically omitting pipes and electrical details which are, instead, addressed through the preparation of P&I diagrams.

A basic engineering document should then be produced to establish the criteria for the project, taking into consideration physical, chemical and microbiological processes, civil engineering, mechanical engineering, instrumentation and electrical engineering aspects of the design. This should then be used to prepare detailed engineering project documents, including drawings for construction purposes.

4.2.5 Operation and maintenance procedures and protocols

The pilot plant location should be considered. It should also be decided if raw water for treatment is to be directly fed to the pilot plant in the field or transported to a laboratory that can offer more controlled operating conditions (e.g. a cold room to evaluate climate conditions on operation).

Operations should also include consideration for siting and the supply of water and electricity, as well as overall facility access. This is of particular concern where the pilot plant/facility is to be operated in a country with limited infrastructure.

4.2.6 Action planning

Capital and operation budgets, programmes and schedules should be planned for the pilot-testing programme.

Programming and scheduling as well as tracking whether the data collection has addressed the intended objectives will minimize the time required for testing and, inherently, reduce costs. This includes referencing and tracking the experimental design and appropriate statistical analyses to determine when a hypothesis has been sufficiently investigated to arrive at a conclusion for the set objective. Properly established experimental design and selection of appropriate statistical analyses will reduce the effects of human bias, identify when a line of testing has reached a conclusion or dead end, eliminate less productive experimentation and generate maximum information at minimum cost. Appropriate statistical tests belonging to either parametric or non-parametric statistics should be used for examination of all underlying statistical assumptions related to the measures of central tendency and spread[13].

4.2.7 Pilot plant/facility commissioning

Pilot plant/facility commissioning should be performed to ensure that all systems and components of the pilot facilities (e.g. equipment, instrumentation, control systems) as well as infrastructure systems and elements are designed, installed, tested, operated and maintained according to the operational requirements.

Pilot plant/facility commissioning should include the following:

— inspections during construction;

— supervision of installation and testing unit components;

— overall process to establish that the pilot facility functionality is as designed.

4.2.8 Pilot plant/facility operation and management

Depending upon the size and extent of the pilot plan's objectives, its management may range from an informal to a relatively complex organizational structure.

Management functions should include planning, staffing and controlling of the operation. The operation should follow a set routine of field measurements, sample collection and equipment maintenance, including sensor calibration and an overall QA/QC programme.

Depending on the operating environment and size of the operations group, ongoing training could be required throughout the testing programme, particularly where there are rotating shifts.

Schedule delays caused by equipment malfunctions and breakdowns, or other mechanical problems, are the most frequent causes of exceeding budgets and cost overruns, and should thus be considered.

The availability of spare parts and an effective programme of preventive/predictive maintenance should be taken into account to control costs and budget.

4.2.9 Sample collection plan

A sample collection plan includes appropriate use of grab samples and time or flow proportional composite samples, field measurements and calibration protocols, sampling design, QA/QC samples, field treatments and preservation, sample handling and delivery, sample storage times, analytical procedures and resolution requirements, and analytical laboratory coordination.

Laboratory test results may be used to establish design and operating parameters for the project. While the parameter values established by laboratory or bench-scale testing (e.g. reaction times, reagent doses, temperatures) should be considered, basic values and adjustments should be evaluated to determine the most favourable values for the process.

The pilot plant/facility design and construction should have adequate flexibility to allow for possible modifications of these parameters, whereby every stage should be similarly analysed.

4.2.10 Pilot plan summary

Data analysis, pilot plan summary and reporting should be made to capture whether the tested technology/process/facility could be recommended for use in industrial wastewater treatment facilities in the objective of water reuse.

A pilot plan report should present estimations of the uncertainty associated with all data-based critical conclusions concerning pilot plan results for a chosen confidence level (by default, a confidence level of 95 % is used).

4.2.11 Pilot plant/facility shutdown and decommissioning

Permanent pilot plant shutdown and decommissioning (total or partly) should be performed, for example disassembly of installations and equipment, cleaning and waste disposal.

5 Programme and project management

5.1 General

A pilot plan should be managed as a programme. 5.2 to 5.6 describe key components to make the pilot plan run properly and accomplish its goals.

5.2 Oversight committee

In relatively large and/or complicated projects, it is typical that an oversight committee is appointed, though it is not a compulsory requirement in every pilot plan. The oversight committee may also be referred to as a steering committee or an authorized committee.

A pilot plan oversight committee should be established for decision-making and follow-up on the pilot plan execution, from the approval of a pilot plan to its termination. The pilot plan oversight committee should summarize the pilot plan's intermediate and final results and present them to a superior authority.

In situations where a superior authority is required, the pilot plan oversight committee may occasionally deal with pilot plan decision-making escalated by the pilot team.

Whether an oversight committee is appointed or not, the following process owners should be involved in the preparation of the pilot plan:

— Investors: being the main stakeholders, investors should be represented in order to be sufficiently informed about opportunities and risks as the pilot plan proceeds, as well as to be part of critical decision-making during the pilot plan.

— R&D experts: as most pilot plans deal with new unproven technologies, it is especially critical that R&D experts are represented.

— Administrators: administrators should be represented to support all administrative pilot plan requirements.

— Engineers: engineers should be represented to provide the technological expertise, insight and support needed during the pilot.

— Operators (including QA operators): the operation and QA activities are a critical part of every pilot plan.

— Regulators: the involvement of a regulatory representative should be considered if the pilot plan is related to any regulatory requirements.

5.3 Pilot study team

5.3.1 General

A multidisciplinary team should be established to include representatives from all relevant departments (e.g. R&D, engineering, maintenance, human safety, environmental safety, quality). The team members should participate in, for example, the pilot planning, preparation, performance, data collection, results analysis and report preparation.

In some cases, independent third-party testing is favoured. Testing by a third-party team can contribute to robust and objective testing, and therefore should be considered.

5.3.2 Team members

As the pilot plan progresses, the roles and responsibilities of the pilot team should be clearly defined. The team members should be familiar with the pilot plan. They should be trained in the relevant areas and have all the relevant skills and experience. Requirements of the team members should be defined at the stage of pilot planning.

5.3.3 Team leader

A team leader (pilot plan manager) should be appointed and given the authority and responsibility to:

- ensure the technical quality of the testing programme;
- monitor and control project costs;
- ensure the project is safely completed on schedule.

The team leader should be skilled in a range of disciplines including engineering, financial management, human resources and training skills, have strong leadership skills and the ability to make the correct decisions in critical situations. The team leader should be responsible for the overall pilot plan activities, including pilot planning, pilot plan preparation, pilot plan initiation, transition to the next pilot plan phase, pilot plan stoppage, pilot plan changes (if needed) and repetitions in the course of pilot plan, and should have primary technical and administrative responsibility for the performance of the pilot facility.

5.3.4 Additional team members

The pilot plan should account for situations where team members have to leave the pilot due to some unforeseen reason (e.g. illness, moving onto another project or business). A list of potential additional team members (capable of substituting the team members if needed) should be prepared in advance.

5.3.5 Technical experts

Technical experts with specialized knowledge in certain areas may be requested to assist in critical situations or to solve complicated problems arising during pilot plan execution. Relevant technical experts should be readily available to assist the team. The pilot plan should be sent to all relevant technical experts prior to the pilot plan initiation and they should approve their potential assistance.

5.3.6 Team meetings

Periodical team meetings may be arranged during pilot plan execution, in accordance with the pilot team leader's directives in respect to meeting frequency, timing and duration. The first coordination meeting should be held before the initiation of the pilot plan.

5.4 Quality management system

The pilot plan should deploy best practices of quality management. QA and QC procedures should comply with a quality management system guideline and comprise both the concept and principles of three-stage process/system qualification:

- IQ: documented objective evidence that process equipment, measuring and control devices and ancillary systems have been provided and installed in accordance with the established specifications;
- OQ: documented objective evidence that the installed equipment operates within predetermined limits when used in accordance with its SOP;
- PQ: documented objective evidence that a process/system consistently produces the results meeting the predetermined specifications and requirements.

5.5 Risk management

The pilot plan should deploy best practices of risk management[2].

5.6 Schedule planning

5.6.1 General

A detailed pilot plan schedule and its WBS should be prepared. In a project, WBS visually breaks the scope down into manageable work segments that a project team can understand, as each level of the WBS provides further definition and detail. Assigned personal responsibilities for every pilot plan phase should be prepared. Boundaries of responsibility should be clearly defined.

5.6.2 Time reserve

A normal pilot plan schedule time reserve is between 10 % and 30 % of overall programme duration. These values are based on good engineering practice in the broad area of risk management, in the framework of different industrial projects[7][8][9][11]:

— 10 %: for a simple project (this amount of reserve is relevant when a 'used and proven technology/process' is being implemented/tested);

— 30 %: for a riskier project characterized by large uncertainty (this amount of reserve is relevant when a 'major technology breakthrough' is being implemented/tested).

6 Statement of pilot plan goals, scope and boundaries

6.1 Goals

The primary goal of every pilot plan should be to prove either that a technology has merit for commercialization or that a particular commercial unit process or a system of unit processes can achieve the required overall water treatment objectives [e.g. reclaimed water quality for the intended industrial use(s)]. The pilot plan should provide reasonable confidence that the full-scale implementation of the technology will perform acceptably, demonstrating consistency and stability of both the process and effluent quality, i.e. effluent concentrations for specific wastewater quality parameters. Treatment performance should be measured by removal efficiencies for these parameters, calculated through the difference between the influent and effluent concentrations divided by the influent concentration ("relative difference"). Other critical aspects that should be positively demonstrated during a pilot plan are safety (for humans and for the environment), compliance and sustainability, operability and economic viability, as described in 6.2 to 6.5, as well as the establishment of the key design and scale-up factors for a successful full-scale implementation.

6.2 Safety

Installation, operation, maintenance and disassembly of a full-scale industrial facility should not result in physical harm to humans, direct facility personnel, other organization employees or members of the surrounding community, and it should also prove to be safe for the environment.

6.3 Sustainability

The design of the full-scale industrial facility should allow adaptation to relevant regulation, law, standard and different/additional customer requirements that could apply.

For the purpose of sustainability, two types of characterizations may be made for a given pilot plan, depending on the treated wastewater:

a) Regulated/non-regulated water: does the treated effluent need to comply with any regulation?

b) Indoor/outdoor reuse: who is the intended user of the effluent; is it the same body that treated the wastewater or another that will establish regulatory requirements?

In either of the above cases, it has to be taken into consideration that regulatory considerations can apply to other aspects of the treatment process, such as disposal of sludge.

The ability for sustainable and eco-friendly operation (and decommissioning, if needed) of the facility should be considered as part of the criteria for success, by which the technology will be evaluated.

6.4 Effectiveness

A full-scale industrial facility should perform all its intended functions, yielding the intended results, while avoiding any adverse effects on the system and the environment.

6.5 Efficiency

A full-scale industrial facility can require a reasonable amount of resources, such as raw materials, water, reagents, energy, labour and any other related cost drivers. An efficiency consideration should also take into account sustainable operation costs related to the fully complying processes of waste disposal and environmental rehabilitation, if and where needed.

7 Pilot plan study programme

7.1 General

The pilot plan study programme should be the cornerstone of the entire pilot plan. The pilot plan study programme should be the most fundamental document, defining the principles for the pilot plan. As the pilot plan study programme has a critical impact on all phases of the pilot plan, the purpose of all pilot plan activities, technical effort and expertise should be to serve it.

The pilot plan study programme should define which experiments should be performed, why these experiments are important, how they should be planned and designed as well as in which order they should be performed. The priority of these experiments should also be established. The pilot plan study programme should define guidelines for the duration of each experiment and all aspects of measurement and sampling, including sampling frequencies and sizes. Success/failure criteria for all experiments should also be defined.

A pilot plan study programme should take into account the consequences of all experiment requirements, so as to allow allocation of resources for development and operation, which can involve considerable investment. The pilot plan requirements should be carefully reviewed by multiple parties to make sure all requirements are justified and reasonable. A technical authority, such as a process engineer, should participate in the planning and the review of the experimental programme to ensure that its requirements are tailored in accordance with the 'real-life' constraints.

Modern methodologies should be applied in experiment planning, such as DoE and principles of Taguchi Robust Design[12], to ensure the most efficient programme is being developed.

NOTE 1 DoE is a statistical methodology using a systematic way to study the effects of experimental factors on response variable of interest. DoE implies:

— preliminary planned change(s) of the system under investigation;

— statistically assessing the effect of such change(s) on the system;

— comparative analysis – all assessments of the effects are made against some prescribed standard.

NOTE 2 Taguchi Robust Design is an approach developed by Genichi Taguchi, Japanese engineer and statistician, in the early 1980s for designing products and processes which are insensitive to unavoidable variation of uncontrollable factors (so-called noises) such as raw materials, manufacturing processes, operating and environmental field conditions (usually the biggest source of variation).

7.2 Pilot plan study programme contents and structure

7.2.1 General

The contents and structure of the pilot plan study programme should be as described in 7.2.2 to 7.2.5.

7.2.2 Background and pilot plan goals and objectives

A brief background (project description) as well as a statement of clear and achievable pilot plan goals should be presented. Comparative importance of all defined goals and objectives should be explained.

7.2.3 Prior project history, current project state and post-pilot-plan planned activities

The pilot plan study programme should include:

— a brief description of the performed lab research/feasibility study and a summary of its results;

— project activities performed in parallel with the pilot plan that could affect or be affected by the pilot plan execution results;

— post-pilot decision-making, process adjustments, plans and activities dependent on pilot plan results.

7.2.4 Pilot plan scope (within/beyond)

The pilot plan coverage should be clearly defined, i.e. it should be explained which critical issues will be covered (investigated/checked/tested/analysed) during the pilot plan ('within pilot plan's issues') and which issues will not be covered ('beyond pilot plan's issues') with a brief explanation of why they are excluded (irrelevant/insignificant/postponed issues).

7.2.5 Pilot plan success/failure criteria

The pilot plan study programme should include a definition of the qualitative (pass/fail) or quantitative (measurable) success criteria, derived from the relevant regulatory requirements and/or appropriate references, for decision-making in the course of pilot plan execution and at its termination. Criteria should be approved by the oversight committee, if such a committee has been appointed.

7.3 Description of technology and facilities

The pilot plan study programme should include a brief description of the purpose and abilities of the used technology, equipment, instrumentation, control systems, P&I diagrams, process flow diagrams, drawings and layout diagrams.

7.4 Description of pilot facility environment and site

The pilot plan study programme should include a description of a selected site for pilot facility and a detailed influent wastewater characterization covering all critical parameters for a given wastewater treatment process (e.g. flowrate, pH values, chemical composition, temperature) and their average, peak and minimum values. Its environment should also be described (if relevant).

7.5 Pilot plan correctness and coverage

A comprehensive pilot plan should be capable of verifying and validating the application of all posed requirements, evaluating both effectiveness and efficiency of the proposed solution and revealing all possible deficiencies in the design of the proposed technology/process.

If possible, the pilot plan should address deficiencies during the pilot plan before time and resources are expended on a large-scale facility/plant.

7.6 Pilot plan flexibility

Due to an inherent uncertainty of all pilot plans, a pilot plan should have enough resilience to allow changes in response to problems occurring in the course of the pilot plan's execution. Moreover, the plan should imply the programme tracking and feedback (when it is needed).

7.7 Plan review

As any pilot plan tests an unproven process/technology and/or site-specific application of an established process/technology, it is normally involved with some uncertainties which could affect its performance. The pilot plan should therefore be reviewed before finalization and approval, to allow for an early identification and analysis of all possible risks in the course of pilot plan execution.

The FMEA technique may be used for risk identification and characterization.

NOTE FMEA is one of the well-known risk-assessment methodologies. The main purpose of FMEA is to examine possible failure modes and determine the impact of these failures on a product (Design FMEA – DFMEA) or a process (Process FMEA – PFMEA). FMEA procedure implies ranking and prioritization of the relative risks associated with the specified failures as well as development of risk reduction/mitigation plan for most critical issues.

7.8 Statistical measures, tools and techniques

The pilot plan testing programme should include a description of all statistical measures, tools and techniques for an analysis of results in a pilot plan summary format. This should include pilot plan description and deviations from plan during performance, events and their root causes, pilot plan results, conclusions and recommendations.

Adequate budget and time allowances are required to ensure sufficient data were collected to draw valid conclusions using appropriate and valid statistical techniques.

7.9 Pilot plan study programme approval

The oversight committee, if such a committee was appointed, should approve the pilot plan study programme. Once the study's experimental programme has been approved, the pilot plant/facility development phase may be initiated. The approved experimental programme, including its key elements, such as success/failure criteria, should be considered a binding document from this point onward and set the criteria for the interpretation of later findings.

8 Pilot plant/facility development and construction

8.1 General

A pilot plant/facility development should be considered a development project and follow best practices, such as the PMI guidelines for project management, the PMBoK and other supporting guidelines[6].

NOTE The PMBoK is a collection of processes, best practices, terminologies, and guidelines accepted as standards within the project management industry.

As a development project, the pilot facility should follow the following phases, which are part of the basic components of every development project:

— basis of design;

— conceptual and preliminary design;

— detailed engineering;

— contracting and installation (construction);

— acceptance testing;

— handover to commissioning and operational team.

8.2 Basis of design (BoD)

As a first step of pilot plant/facility development and construction, established objectives and technical requirements should-be converted into a technical document incorporating all the information that needs to be used as input to the team that will work on the conceptual and preliminary design. This BoD file should be a comprehensive document addressing all relevant aspects of design.

8.3 Conceptual and preliminary design

In the conceptual and preliminary design phase, a design team should prepare an early, non-detailed version of the proposed design (HLD). This version should include the design approach and concept that will conform to all terms and requirements defined in the BoD. It should include, but not be limited to, the following:

— industrial services and infrastructure (e.g. power, water, steam);

— instrumentation;

— control philosophy (control approach based on either DCS or NDCS: DCS implies a large number of control loops, in which autonomous controllers are distributed throughout the system, whereas NDCS use the centralized controllers usually located at a central control room or within a central computer);

— containment of wastewater that may have escaped the process;

— IT, control, instrumentation, communication.

The final product of the conceptual design step should be a design package that will typically be reviewed by an oversight committee before being released. Review by an overseeing committee should be performed to detect any potential deficiencies of the conceptual design that could risk achieving the pilot plan goals. To facilitate such review, a multidisciplinary team is needed. The key members of an oversight committee that may review the conceptual design are detailed in Clause 5.

8.4 Detailed engineering design

A full, high-resolution design process (LLD) may either be performed by internal engineering departments within the organization or outsourced to an independent engineering body.

The final product of the high-resolution design process should be an approved full-scale pilot facility design package that can be used for RFPs or any other bidding and contracting process. However, detailed engineering design can also be relevant in cases where the pilot system is of a smaller scale, such as a demonstration scale pilot system.

The high-resolution design can be a lengthy process that requires some control and management. DRs may be used to ensure an effective and efficient design process.

8.5 Contracting and construction

This phase should include all activities related to erecting the facility on site. A contractor should be nominated for the installation of the project by tender/bid or RFP. Once the contractor is nominated, the process of construction may proceed.

Statutory and licensing processes, for example building permits, operating license, budgeting and ordering of LLIs and other actions which can be handled by the owner, should be completed at the very beginning of the project.

Following the completion of this phase, a facility may be installed and be considered ready for testing.

8.6 Acceptance testing

To ensure that the nominated contractor has delivered a conforming facility in all aspects of its specified scope, an acceptance testing stage should take place. The acceptance testing may involve some completion and correction tasks given to the contractor.

The acceptance testing should also include a performance test and a verification covering reliability and availability testing. This testing phase should be completed before the pilot plan is progressed to the next phase.

The last check of system readiness should be its activation, which should include checking and ensuring installation is as per design and specifications, and a visual inspection of all pilot facilities and equipment. Special attention should be given to all rotating equipment, piping, vessels, instrumentation, infrastructure (including IT), control systems, needed materials and lubricants. All deficiencies and defects should be carefully reported and fixed. Approval of wavers by the team leader or oversight committee (for serious wavers) should be conditioned by an engineering analysis of their effect on pilot plan execution.

All pilot plan documentation (e.g. diagrams, drawings, specifications, checklists, instructions) should be checked at this phase. The pilot team training should be completed at this phase.

8.7 Handover to commissioning and operational team

Once the facility has been approved, it may be handed over to the operational team. In some cases, mainly big and complex projects, the commissioning team is a separate team. In most ordinary pilot plans, the operational team will undertake the commissioning process. After this phase, no further involvement of the construction contractor is needed, although the construction contractor should be available for technical service/troubleshooting and any service covered by the warranty.

9 Operational framework establishment

9.1 General

The operational framework should include all necessary organizational infrastructure and resources that are not part of the physical equipment, infrastructure and machinery of the pilot facility. This should include:

— organizational chart, staffing, roles and responsibilities, job definitions;

— SOPs;

— emergency procedures and plans;

— maintenance policy, procedures and plans;

— reporting and communication scheme;

— training and qualification requirements and programme;

— procedures related to collaboration or services given by external contractors and suppliers.

9.2 Pilot plant/facility procedure manual

9.2.1 General

A pilot plant/facility manual should be prepared before the initiation of the pilot plan. The pilot plant/facility study procedures presented in the pilot facility manual should be:

— brief and concise;

— geared to the educational level of the user;

— expressed in the appropriate language (understandable by the pilot team).

9.2.2 List of procedures

The list of pilot plant/facility procedures should include, but not be limited to, the following:

— Process monitoring and control procedures covering all critical parameters for a given wastewater treatment process (e.g. flowrate, pH values, chemical composition, temperature), usage rates and concentration of all used chemicals during pilot plan study and power consumption.

— Sampling and analysis procedures: all procedures used for sampling, sample preparation and analysis should be carefully defined. If some analyses and/or tests are to be performed by an external laboratory, its procedures and tools should be presented as well. All these procedures should be validated prior to the initiation of the pilot plan.

— Industry standard techniques and procedures, for example, USEPA (United States Environmental Protection Agency) Standard Methods for the Examination of Water and Wastewater, should be used for the samples collection, labelling, preservation, storage, transportation and analysis[4][5].

— Safety instructions: since a pilot plan should be carried out without any incidents, all issues related to the safety instructions coverage and correctness should be implemented.

— Washing procedures should be included in the pilot plant/facility manual (special attention should be devoted to the solutions used for facilities washing).

— Maintenance procedures should be included in the pilot plant/facility manual. It should be specified how maintenance procedures and check-ups should be performed in the safest, most efficient and effective way in the course of the performance of the pilot. Format for the maintenance event reports should be presented while providing full traceability (date, time, operating conditions, event description, name of person completing the work and report, work performed and the results of the work).

— Pilot plan logbook defining data logging and analysis: the procedures of data collection and reporting, as well as statistical tools and techniques used for ongoing analyses, should be described.

— Procedures for calibration of instruments and sensors.

— Troubleshooting guide: a list of possible (expected) troubles/problems and recommended solutions providing prompt response to these troubles/problems should be presented. Every recommended solution should potentially solve a notable problem; it should not create new problems and it should be feasible under the existing constraints of, for example, HSE considerations, regulatory requirements, resources availability, budget limitations, required time for its implementation and quality and reliability requirements.

9.3 Sampling and measurement

9.3.1 Sampling and analysis planning

The sampling and analysis plan should completely correspond to the pilot plan execution at every phase. During pilot planning it should be taken into account that sampling, sample preparation and laboratory load during pilot plan execution will usually be three to four times more than the normal routine operating. Increased sampling is typically carried out once the pilot system has attained pseudo steady-state conditions, after a defined period of time following a change in applied process conditions (i.e. for a representative characterization of process performance at the applied process conditions), in accordance with an experimental plan.

NOTE CSP developed by H.F. Dodge in the 1940s represents a recommended basis for sampling procedures planning[10].

