
**Sludge recovery, recycling, treatment
and disposal — Information on
the processes and technologies for
inorganic substance and nutrient
recovery**

*Valorisation, recyclage, traitement et élimination des boues — Guide
sur les procédés et les technologies de récupération des substances
inorganiques et des nutriments*

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Published in Switzerland

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Foreword

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This document was prepared by Technical Committee ISO/TC 275, *Sludge recovery, recycling, treatment and disposal*.

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

Inorganics and nutrient recovery is necessary to build a sustainable society; there are many studies and plants all over the world that demonstrate this concept. Above all, phosphorus recovery systems to produce fertilizer material are increasingly common and other nutrients recovery systems are now being developed.

This document provides a selected overview of various technologies and is based on country standards and guidance documents already in existence or under preparation, and documents provided by private organizations.

As inorganics and nutrient recovery knowledge and technology is developing rapidly, this document will therefore be reviewed regularly to reflect the advancing nature of the industry and technology.

[Annex A](#) provides examples of sewage sludge composition, which can help determine which element(s) can be recovered. [Annex B](#) provides case studies of nutrient recovery, including practical and emerging ones.

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Sludge recovery, recycling, treatment and disposal — Information on the processes and technologies for inorganic substance and nutrient recovery

1 Scope

This document provides information on the processes and technologies for inorganic substance and nutrient recovery from sludge.

This document is applicable to sludge and products from urban wastewater collection systems, night soil, wastewater treatment plants for urban and similar industrial waters. It includes all sludge that can have either similar environmental or health impacts, or both.

Hazardous sludge from industry and dredged sludge are excluded from this document.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

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

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

3.1

ammonia stripping

method that removes ammoniacal compounds from water by making it alkaline and of aeration

3.2

calcium phosphate

salts that consist of calcium ions and phosphate ions

Note 1 to entry: Hydroxyapatite (HAP) is a form of calcium phosphate.

3.3

centrate

liquid product from a centrifugal dewatering device

3.4

hydroxyapatite

HAP

sparingly soluble salt that is generated from phosphate and calcium ions

Note 1 to entry: The general chemical formula of HAP is $\text{Ca}_{10}(\text{OH})_2(\text{PO}_4)_6$.

3.5

incineration ash

residue of combustion

3.6

nutrient

element required by living organisms throughout the course of their lives in small quantities for a range of physiological functions

3.7

seed crystal

crystal employed as a nucleus to generate and grow crystals in the crystallization process

3.8

struvite

compound which is precipitated by magnesium addition to water with high concentration of phosphate and ammonium ions

Note 1 to entry: The chemical formula of struvite is $MgNH_4PO_4 \cdot 6H_2O$.

4 Methods of nutrient recovery from sludge

There are four methods for nutrient recovery from sludge, which are whole use, cleaning, separation and extraction.

- a) **Whole use:** Whole use of sludge is a simple use method in which sludge, which is typically aerobically or anaerobically treated (e.g. compost), is directly applied to land as fertilizer or soil improver. This method can minimize the loss of the nutrients in the treatment process and can achieve the highest potential of utilizing the nutrients in sludge.
- b) **Cleaning:** Cleaning is the process in which sludge has contaminants such as plastics or heavy metals removed by mechanical treatment or chemical extraction. The cleaned sludge can be handled in the same way as whole use.
- c) **Separation:** Separation is the process in which sludge is divided into two or more different parts. Sludge is separated by physical or chemical parameters such as size, shape, specific gravity difference and chemical affinity. All or only the least contaminated part of separated sludge can then be utilized. In this method, sludge contains various nutrients.
- d) **Extraction:** Extraction is the way in which only the target element is taken out as a compound using chemical actions. Fewer nutrients in sludge are made available or utilized through extraction processes than in whole use, cleaning and separation methods. However, the process has some advantages:
 - reduces the storage volume of the nutrient;
 - prevents contamination of the recovered material by hazardous elements;
 - stabilizes the recovered materials as a chemical compound;
 - improves the value of the recovered materials.

Precipitation, including stripping processes, can decrease the volatile nutrient content.

This document is focused on nutrients which can be recovered by extraction.

5 Phosphorus recovery

5.1 General

Phosphorus is an essential element for plant growth and is an important ingredient of chemical fertilizer products. The dry solid contents of sludge normally include more than 1,0 % phosphorus and it can reach 5,0 % of sludge under certain operating conditions, such as biological dephosphorization or anaerobic-anoxic-oxic processes.

On the other hand, the supply of phosphate ore in the global market is strongly influenced by political and economical issues and often gets unstable, as it is quite unevenly distributed globally. Therefore, studies and commercialization of phosphorus recovery from sludge is the most progressive area in inorganic and nutrient material recovery.

Phosphorus can be recovered from sludge using various chemical compounds. The phosphorus recovery process that is described in [Clause 5](#) is summarized in [Figure 1](#).

For case studies, refer to [Clauses B.1](#) to [B.11](#).

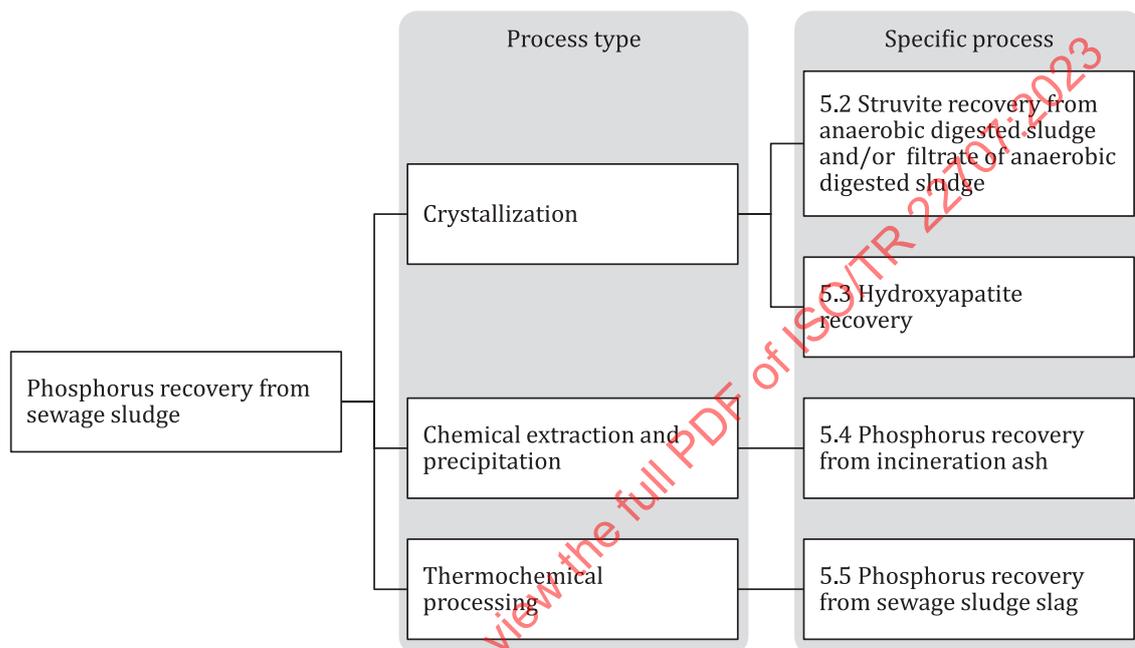


Figure 1 — Summary of phosphorus recovery process

5.2 Struvite recovery from either anaerobic digested sludge or filtrate of anaerobic digested sludge, or both

5.2.1 Principle

The principle of the struvite recovery process are based on the chemical precipitation carried out in a crystallizer followed by particle separation. The chemical reaction for struvite is:



This reaction is the same as the scale formation which is frequently observed in anaerobic sludge treatment facilities. The difference of struvite recovery from scale formation is well-controlled chemical dosing, pH control and particle separation. After the application of this process, much less scale formation is likely to occur in treatment facilities.

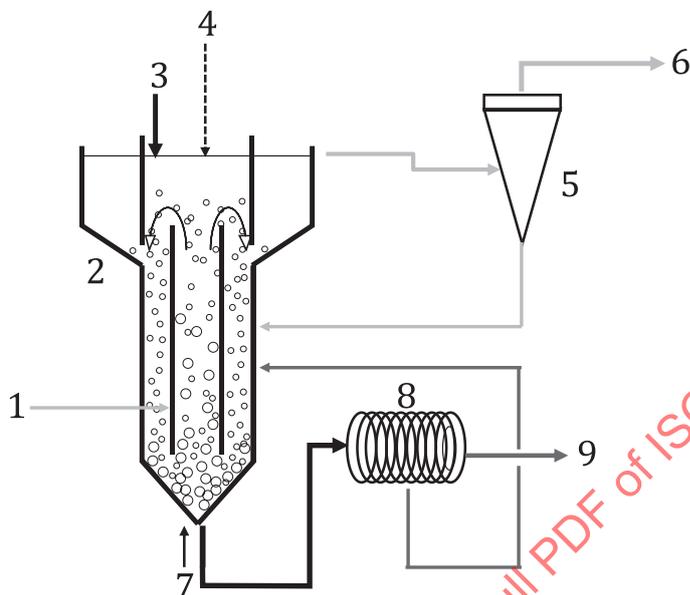
Recovered struvite can be used as delayed release fertilizer because of its low solubility.

There are two types of crystallizer processes: agitation by air or mechanical agitation.

Both methods of crystallization are employed in commercial operations. Wastewater employed for this process is a filtrate of anaerobically digested sludge (ADS) or ADS itself and industrial wastewater containing phosphate and ammonium. Under optimum operating conditions, dissolved phosphorous recovery can reach more than 80 % using this process.

5.2.2 Schematic diagram

Schematic diagrams for an air fluidized crystallizer and a mechanical agitator are shown in Figures 2 and 3. An influent such as a filtrate of ADS, and/or ADS, is mixed in the reactor with magnesium (Mg) salt and struvite granules (as seed crystal). Alkalisising chemicals such as sodium hydroxide solution can be added for pH control.

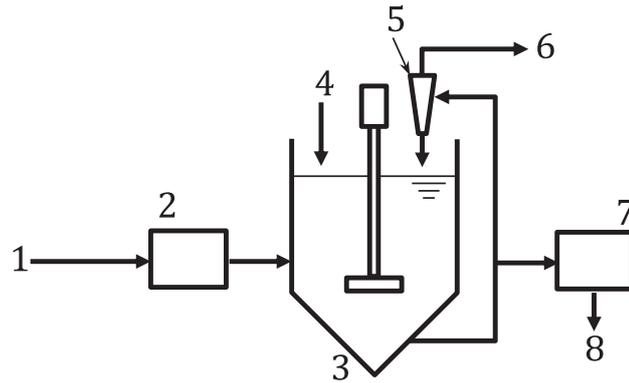


Key

- | | |
|---------------------|----------------------------|
| 1 ADS or ADS liquor | 6 treated sludge or liquor |
| 2 phosnix reactor | 7 air |
| 3 $Mg(OH)_2$ | 8 rotary sieve |
| 4 NaOH | 9 struvite |
| 5 liquid cyclone | |

SOURCE Reference [1]. Reproduced with the permission of the authors.

Figure 2 — Schematic diagram of a fluidized bed reactor

**Key**

1	digested sludge	5	struvite separator (cyclone)
2	trash removal equipment	6	treated sludge
3	crystallization reactor	7	washing/drying equipment
4	Mg(OH) ₂	8	recovered struvite

SOURCE Reference [7]. Reproduced with the permission of the authors.

Figure 3 — Schematic diagram of a stirred tank reactor

5.2.3 Operating conditions

The key factors influencing struvite recovery rates are inflow concentrations of phosphate and ammonium, the dosing rate of magnesium ions, alkalinity and pH.

The concentration of phosphate needs to be higher than 50 mg/l of P, preferably over 100 mg/l of P and ammonia over 300 mg/l of N. From an economical point of view, the pH needs to remain in the range of 7,5 to 9,0. Various Mg compounds can be used as a source of Mg including, Mg(OH)₂, MgCl₂ and MgSO₄. Seawater can also be used as a source of Mg.

5.2.4 Characteristics of recovered products

Recovered struvite is crystalline with few impurities. Its shape depends on the above discussed operating conditions, including pH, temperature, agitation and the retention time of struvite particles in the crystallizer.

5.3 Hydroxyapatite recovery

5.3.1 Principle

The principle of hydroxyapatite (HAP) recovery process is based on chemical precipitation carried out in a crystallizer followed by particle separation. The chemical reaction for HAP is:



HAP recovery systems require well-controlled chemical dosing, pH control and particle separation.

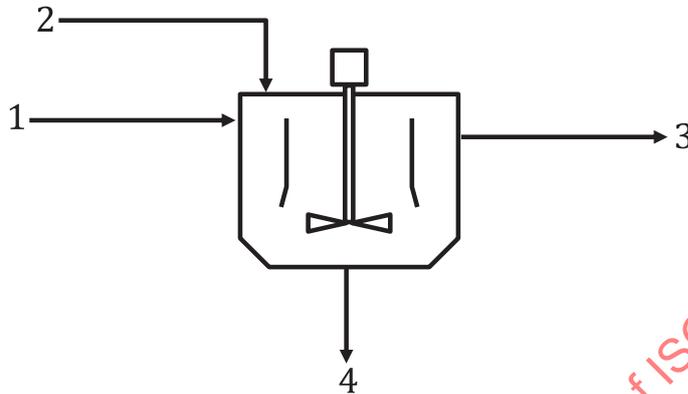
Recovered HAP can be used as raw material for fertilizers.

A crystallizer is a type of mixing reactor employed in commercial operations. The applicable wastewater for this process will be black water (human faeces and urine), industrial wastewater containing phosphate and filtrate from sludge treatment processes.

Under general operating conditions, dissolved phosphorous recovery can reach 70 % through this process.

5.3.2 Schematic diagram

A schematic diagram for a crystallizer is shown in [Figure 4](#). Influent such as filtration liquid, calcium chloride and HAP granules (as seed crystal) are mixed in the mixing reactor. Sodium hydroxide solution is added for pH control.



Key

- | | | | |
|---|-------------------|---|----------|
| 1 | filtration liquid | 3 | effluent |
| 2 | calcium chloride | 4 | HAP |

Figure 4 — Schematic diagram for HAP recovery

5.3.3 Operating conditions

The key factors influencing HAP recovery are inflow concentrations of phosphate, carbonate ion, the dosing rate of calcium ions, alkalinity and pH.

The concentration of phosphate is required to be around 50 mg/l of P. From an economical point of view, the pH needs to remain in the range of 7,5 to 9,0.

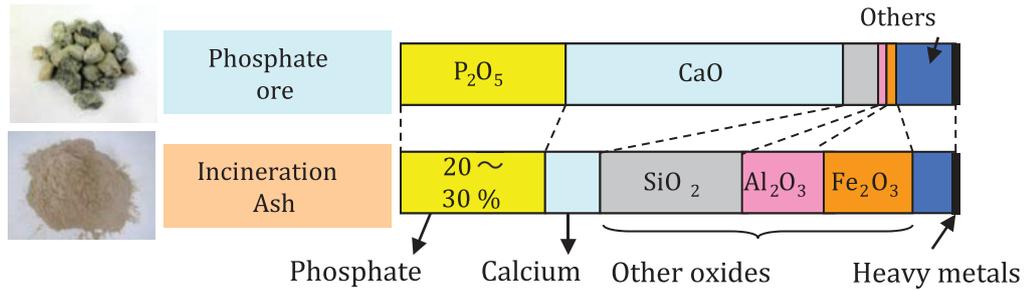
5.3.4 Characteristics of recovered products

Recovered HAP is a crystalline structure with few impurities. Its shape depends on the above discussed operating conditions including pH, temperature, agitation and the retention time of HAP particles in the crystallizer.

5.4 Phosphorus recovery from incineration ash

5.4.1 Principle

When advanced wastewater treatment technologies have been employed, phosphorus tends to increasingly concentrate in sludge. As a result, incineration ash from sewage sludge contains almost the same concentration of phosphorus as that of natural phosphate ore, shown in [Figure 5](#). Sewage sludge ash is expected to be one of the alternative sources of phosphorus for depletion in the future.



SOURCE Reference [9]. Reproduced with the permission of the authors.

Figure 5 — Composition comparison between phosphate ore and incineration ash

Phosphorus recovery from incineration ash can be achieved by means of a chemical reaction, which is leaching and precipitation. Leach is performed under both alkaline and acidic condition.

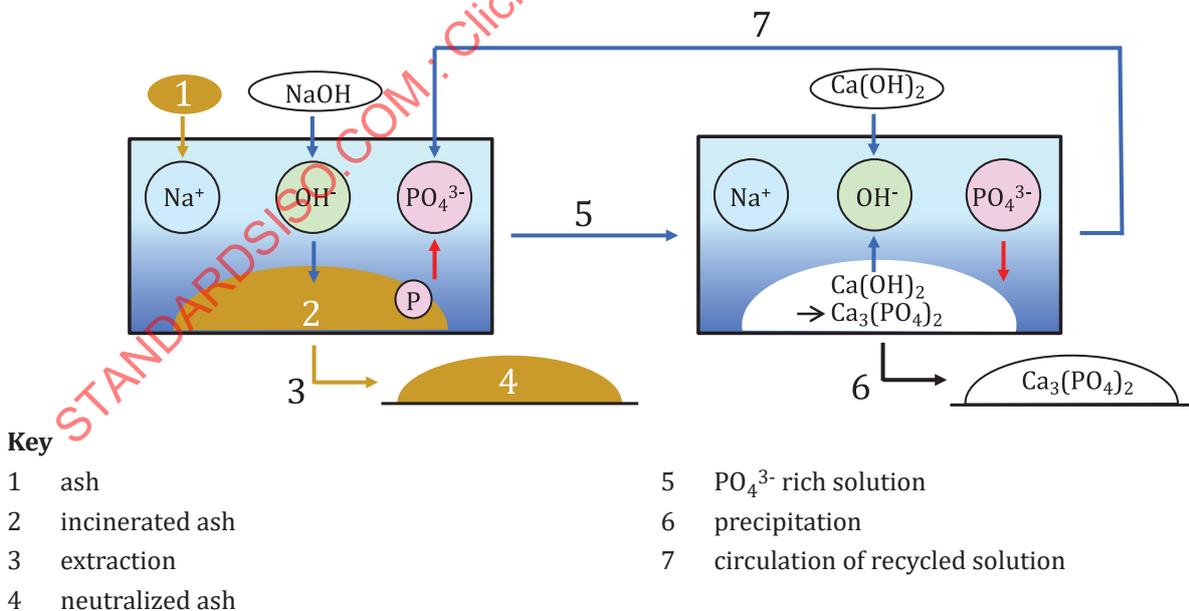
Sewage sludge ash can be used directly as a P fertilizer. This direct utilization, however, is only possible for sewage sludges with a low level of contamination. See [Clause B.8](#).

5.4.2 Alkaline treatment

5.4.2.1 Schematic diagram

A schematic diagram of the phosphorus recovery process from incineration ash is shown in [Figure 6](#), which consists of two reaction tanks.

In the first reactor, phosphate is extracted from the incineration ash by using alkaline solution. In the second reactor, phosphorus-rich sediment is precipitated by adding slaked calcium ($\text{Ca}(\text{OH})_2$) into a solution taken from the first reactor. The solution after collecting phosphorus-rich sediment is recycled and returned into the first reactor.

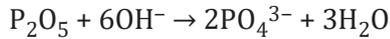


SOURCE Reference [9]. Reproduced with the permission of the authors.

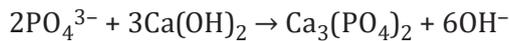
Figure 6 — Schematic diagram of phosphorus recovery from incineration ash

5.4.2.2 Operating conditions

In the first reactor, phosphate in the incineration ash is extracted into the solution by controlling the pH at more than 13, adding sodium hydroxide, maintaining the temperature between 50 °C and 70 °C, and the retention time between 5 min and 30 min. The chemical reaction is:



In the second reactor, $\text{Ca}(\text{OH})_2$ is added in a solution from the first reactor and the substances that contain a lot of phosphate are precipitated by controlling temperature between 20 °C to 50 °C, and a retention time between 6 h and 18 h. The hydroxide ion that is consumed by phosphorus extraction is replenished by using $\text{Ca}(\text{OH})_2$ as a calcium source. The chemical reaction is:



5.4.3 Acidic treatment

Acidification is possible to extract more phosphoric acid and metal components such as iron and aluminium than alkaline treatment, which can be recovered by precipitation. However, it is necessary to pay attention to simultaneous extraction of heavy metals. In many cases, sulfuric acid or hydrochloric acid is used as acid. Many studies on this concept are carrying out.

5.4.4 Characteristics of recovered products/residues

Phosphorus recovery technology from incineration ash can produce the two products, recovered phosphorus and neutralized ash.

The recovered phosphorus from this technology is a mixture of HAP and calcium phosphate. The concentration of phosphorus is approximately 30 %. After dewatering and drying, it can be utilized as a raw material of fertilizer for agriculture, gardening, etc.

Neutralized ash contains fewer amounts of heavy metals than untreated incineration ash because it is chemically treated for reducing and minimising solubility of heavy metals. After washing and drying, it can be easily utilized for many applications like cement material, soil rehabilitation, etc.

5.5 Phosphorus recovery from sewage sludge slag

5.5.1 Principle

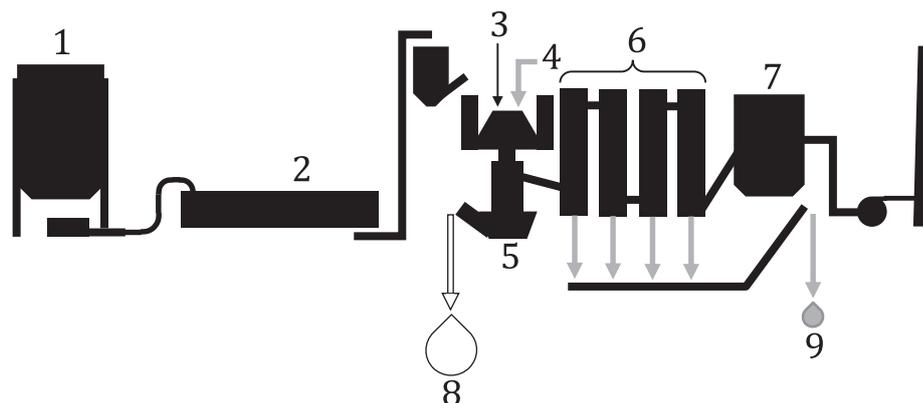
Melting is a thermochemical process for separating and refining target materials under high temperature and altered atmospheric conditions. Hazardous heavy metals such as lead, cadmium and mercury that have lower boiling points than the temperature in the furnace, are evaporated.

Phosphorus generally volatilizes under high temperature and reducing atmospheric conditions. The melting technology, however, makes it possible to recover phosphorus in the slag in the form of phosphorus oxide by controlling the air supply into the furnace to maintain oxidation conditions. Ca and Fe in the sludge effectively influence to fix phosphorus into the slag.

5.5.2 Schematic diagram

A schematic diagram of the phosphorus recovery process from sewage sludge into slag is shown in [Figure 7](#).

Dewatered sludge, after drying, is supplied to the furnace. Recovered heat from exhaust gas is used for preheating of the drying and the combustion air. The gas treatment system neutralizes acidic gases and separates heavy metals from gas as fly ash.

**Key**

1	sewage sludge storage tank	6	heat recovery system
2	dryer	7	gas treatment system
3	melting furnace	8	P-rich slag (recovered phosphorus)
4	air	9	fly ash (heavy metals)
5	water bath		

SOURCE Reference [3]. Reproduced with the permission of the authors.

Figure 7 — Schematic diagram of phosphorus recovery as slag

5.5.3 Operating conditions

The correct operating temperature in the melting furnace is between 1 250 °C to 1 350 °C. Air levels in the melting zone in the furnace before secondary combustion is approximately 1,0 %.

If the low heat value (or net calorific value) of dried sludge is high enough, there is no need to supply fuel in the melting furnace. This results in the following process. In the case of raw sludge with higher high heat value, sludge is dried to a lower dryness in a dryer in order to achieve self-thermal combustion in the melting furnace. In the case of digested sludge with lower high heat value, sludge is dried to higher dryness in a dryer.

5.5.4 Characteristics of recovered products

Based on the above process, the melting process for sewage sludge generates slag which is equivalent to 90 % to 95 % of ash content in the sludge, and approximately 90 % of phosphorus in the sludge is recovered in the slag. The main components of the slag are silicon, calcium, phosphorous, iron and aluminium. The phosphorous concentration in the slag is nearly equal to phosphorous concentration in sludge incineration ash. Performance data shows that phosphorus concentration in the slag ranges from 20 % to 30 % of dry P_2O_5 .

Slag is a kind of amorphous material. Approximately 90 % of phosphorous in the slag is citric acid soluble. Heavy metal concentration in the slag is low enough to be used as a fertilizer or raw material fertilizer.

5.6 Other technologies for phosphorus recovery

Other than the processes and technologies discussed in this subclause, additional processes and technologies are available, including:

- the reductive melting process, a technology for yellow phosphorus recovery from sludge incineration ash where yellow phosphorus is evaporated from melting ash under reductive atmosphere;

- the heating process, which solubilizes excess sludge by heating and where eluted phosphate is precipitated in the adsorption step;
- the adsorption process, which employs specific adsorbent to recover phosphorus with high selectivity from centrate.

5.7 Summary

Table 1 shows a summary of high-level technologies for phosphorus recovery. It is noted that processes and results can vary considerably depending on many conditions, such as the wastewater source, the wastewater treatment process and sludge quality. The table therefore is read assuming all input factors are the same.

Before the installation of any P recovery system, consideration of capital expenditure (CAPEX) and operating expense (OPEX) is undertaken to ensure installation is financially viable. Financial viability is highly dependent on the condition of the existing facilities and the circumstances.

Table 1 — Summary of phosphorus recovery

	Process type			
	Crystallization		Chemical extraction and precipitation	Thermochemical processing
Input material	Filtrate of ADS, ADS	Filtrated liquid, return sludge	Ash	Ash, dried sludge
Characteristics of recovery system				
Input material	Soluble P	Soluble P	Solid P	Solid P
Recovered material	Struvite	Hydroxyapatite	Ca salt	Slag
Use of recovered P	Fertilizer	Fertilizer	Fertilizer	Fertilizer
Comparative recovery ratio of input P	Low	Very low	High	High
Dosing chemicals^a	Mg compounds	Ca compounds ^b	Ca compounds ^b	None
Comparative amount of dosing alkali for pH control	Low	Low	High	Nil
Installation in sludge process flow	Need an anaerobic treatment system	Need a filtration system	Need an incinerator	Need a melting facility
Advantages	Anti-scaling Less moisture content of dewatering sludge	Anti-scaling	Decrease waste	Decrease waste
Disadvantages	Need excess ammonium ion	High temperature dependence	Requires attention on heavy metals in sludge	Requires attention on heavy metals in sludge
Implementation^c	Most	Most	Less	Least
^a Compounds which release Mg or Ca ions. Appropriate chemical can be selected depending on the process. ^b The necessity of Ca compounds depends on the process or plants. ^c Refer to Reference [12].				

6 Recovery of other nutrients

6.1 General

Sludge include various nutrients which is needed of growth of microorganism. A lot of recovery technologies of these are still undergoing research and are not yet in commercial operation.

6.2 Nitrogen

Nitrogen (N) is an important nutrient for plants and fertilizer to increase the level of a crop's production. Sludge includes large amount of nitrogen and can reach 3 % on average and, in some cases, even more. Studies for nitrogen recovery systems are underway and there are a few recovery plants in the world. However, composting is much more economically effective than inorganic nitrogen recovery at present.

An ammonia stripping system is sometimes applied for centrate, industrial wastewater, etc. Recovered ammonia is absorbed in acid liquids such as sulfuric acid and used as raw material for chemicals. However, recovered ammonia can be released to the air as nitrogen gas after it is broken with a catalyst under high temperature.

6.3 Sulfur

Much of organic matter includes sulfur (S) and sulfate is one of the most common acids used by industry. Sludge can include 2 % to 3 % of sulfur.

Some researchers have studied a sulfur recovery process using bacteria from wastewater including sulphide.^[4]

Contacted bacteria can oxidize sulphide to sulfur with aeration under controlled pH and ORP. However, almost all sulfur is produced as a by-product of removing sulfur-containing contaminants from fossil fuel and mine ore.

6.4 Potassium

Potassium (K) is one of the basic elements for plant growth, which is used as chemical fertilizer and pesticide, etc. There are fewer studies developing potassium recovery from sludge as there is currently no shortage of the resource.

Sludge can include 0,2 % to 0,5 % of potassium.

Potassium can be recovered as $MgKPO_4$ from wastewater with high concentration of potassium and phosphate dosing Mg salts under pH 11. This high alkalinity can strip ammonia from liquid to air and prevent the generation of $MgNH_4PO_4$.

7 Recovery of other inorganics

7.1 General

Wastewater collecting system can gather not only wastewater but a lot of elements, which can be considered a resource. Nowadays, sludge is being considered the urban mine of various elements.

7.2 Metals

Sludge is being considered the municipal mine of various metals, like Ag, Mg, Al and Fe. Much research on metal recovery has progressed in the light of the circular economy principle, but they are currently only emerging technologies.

On the other hand, there are some examples of metal recovery which generally happen as a by-product. One example is gold recovery in a particular area in Japan. It is thought that trace amounts of gold, which

comes from hot spring water and plating industrial wastewater, can be accumulated in incineration ash of sludge.

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Annex A (informative)

Sewage sludge composition

[Table A.1](#) shows typical inorganic composition of sewage sludge.

Table A.1 — Inorganic composition of sewage sludge

Element	Composition ^a			
	% of dry solids			
	China ^b	Finland ^c	Germany ^{d[5]}	Japan ^{e[6]}
Nitrogen (N)	2,96 (0,84 – 5,03)	4,0 (2,6 – 5,5)	5,0 (0,2 – 14,7)	5,67 (3,61 – 8,43)
Sulfur (S)	No data	No data	No data	0,858 (0,50 – 1,81)
Potassium (K)	0,583 (0,14 – 1,22)	0,15 (0,08 – 0,5)	0,26 (0,00 – 2,45)	0,353 (0,188 – 0,558)
Phosphorus (P)	2,22 (0,6 – 3,74)	3,0 (1,9 – 3,8)	2,5 (0,05 – 5,2)	2,75 (1,69 – 4,14)

^a Values are shown as an average (minimum minus maximum).

^b Samples come from sludge of 98 municipal sewage treatment plants (almost none of industrial wastewater included). The wastewater treatment process includes activated sludge process, anaerobic-anoxic-oxic process, anaerobic-oxic process and membrane bioreactor (MBR).

^c The number of samples is in the several hundreds. The samples are mainly dewatered sludge cake by centrifuge, dry solid (DS) about 20 %. These data are from research reports, written in Finnish. The wastewater treatment processes are based on activated sludge process in Finland.

^d The number of samples is 704. The samples are municipal sewage sludge for agricultural utilization (2017/2018). Data have been queried in the federal states of Germany which have to report the quality of agricultural utilized sewage sludge annually. Some data are obviously implausible or runaway values.

^e The number of samples is 32. The samples include sludge cake dewatered by centrifuge, screw press, multidisc screw press, belt press or rotary press. The wastewater treatment process includes activated sludge process, anaerobic-anoxic-oxic process, anaerobic-oxic process, modified Ludzack-Ettinger (MLE) process, step-feed MLE process and oxidation ditch process.

Annex B (informative)

Case studies

B.1 Phosphorus recovery from centrate 'Phosnix'

For information on phosphorus recovery from centrate 'Phosnix'¹⁾, see Table B.1, and [Figures B.1](#) and [B.2](#).

Table B.1 — Technical overview

General data	
Type of process	Crystallization
Input material	<input type="checkbox"/> Filtration liquid, <input type="checkbox"/> Dewatered sludge, <input checked="" type="checkbox"/> ADS, <input checked="" type="checkbox"/> Filtrate of ADS, <input type="checkbox"/> Incineration ash, <input type="checkbox"/> Dried sludge, <input checked="" type="checkbox"/> Industrial wastewater, <input type="checkbox"/> Others ()
Product	<input checked="" type="checkbox"/> Phosphorus: <input checked="" type="checkbox"/> Struvite, <input type="checkbox"/> HAP, <input type="checkbox"/> CaPO ₄ , <input type="checkbox"/> Others() <input type="checkbox"/> Nitrogen, <input type="checkbox"/> Metals (), <input type="checkbox"/> Others ()
Type of plant	Wastewater treatment plant (WWTP) with P removal with coagulant and anaerobic digestion
T-P recovery rate	—
Dissolved P recovery rate	60 % to 70 %
P-concentration of product	27 % P ₂ O ₅ of dry matter (DM)
Average total electricity demand	(2,5 to 4,0) kWh/kg-P _{recovered}
Average chemical demand (as 100 % concentrate)	(2,5 to 3,0) kgMg(OH) ₂ /kg-P _{recovered} (0,8 to 1,1) molar ratio Mg:P _{recovered} (0,8 to 1,2) molar ratio Mg:P _{dissolved}
Reference	
Raw materials for recovery	<input type="checkbox"/> Filtration liquid, <input type="checkbox"/> Dewatered sludge, <input type="checkbox"/> ADS, <input checked="" type="checkbox"/> Filtrate of ADS, <input type="checkbox"/> Incineration ash, <input type="checkbox"/> Dried sludge, <input type="checkbox"/> Industrial wastewater, <input type="checkbox"/> Others ()
Reuse of recovered materials	<input checked="" type="checkbox"/> Fertilizer <input type="checkbox"/> Raw material of chemicals <input type="checkbox"/> Others ()
Country	Japan
Background	In order to keep the water body quality of Lake Shinjiko, the local government must decrease total phosphorus discharge of STP. Along with the global demand for sustainable society, phosphorus recovery from the sewage sludge had been started.
Objective	Resource recovery and improvement of sewer effluent quality
Result	Amount of recovered struvite: 0,6 kg/m ³ -centrate Effluent of T-P: 1 mg/l → 0,4 mg/l without coagulant dosing into water treatment process

1) Phosnix is an example of a suitable product available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of this product.

Table B.1 (continued)

Description (differentiation from others)	This plant is the one of the earliest commercialized plants in the world for phosphorus control and recovery from STP. One reactor system for crystallization and solid separation make small footprint. Application of magnesium hydroxide as chemical can reduce operation cost. Not only centrate but sludge can be treated in almost same process.
Main components and specification	[Project outline] Location: Shinjiko East STP (Shimane) Capacity: 1 150 m ³ -centrate/day Operation start: 1998 [Main equipment] Crystallizer/fluidized bed: $\varnothing 3,6$ m /1,42 m \times H 7 m Struvite separator: $\varnothing 300$ mm \times l 1 000 mm
Source	See Reference [1]
Contact details	Organization: Japan Sewage Works Agency Email: js-international@jswa.go.jp

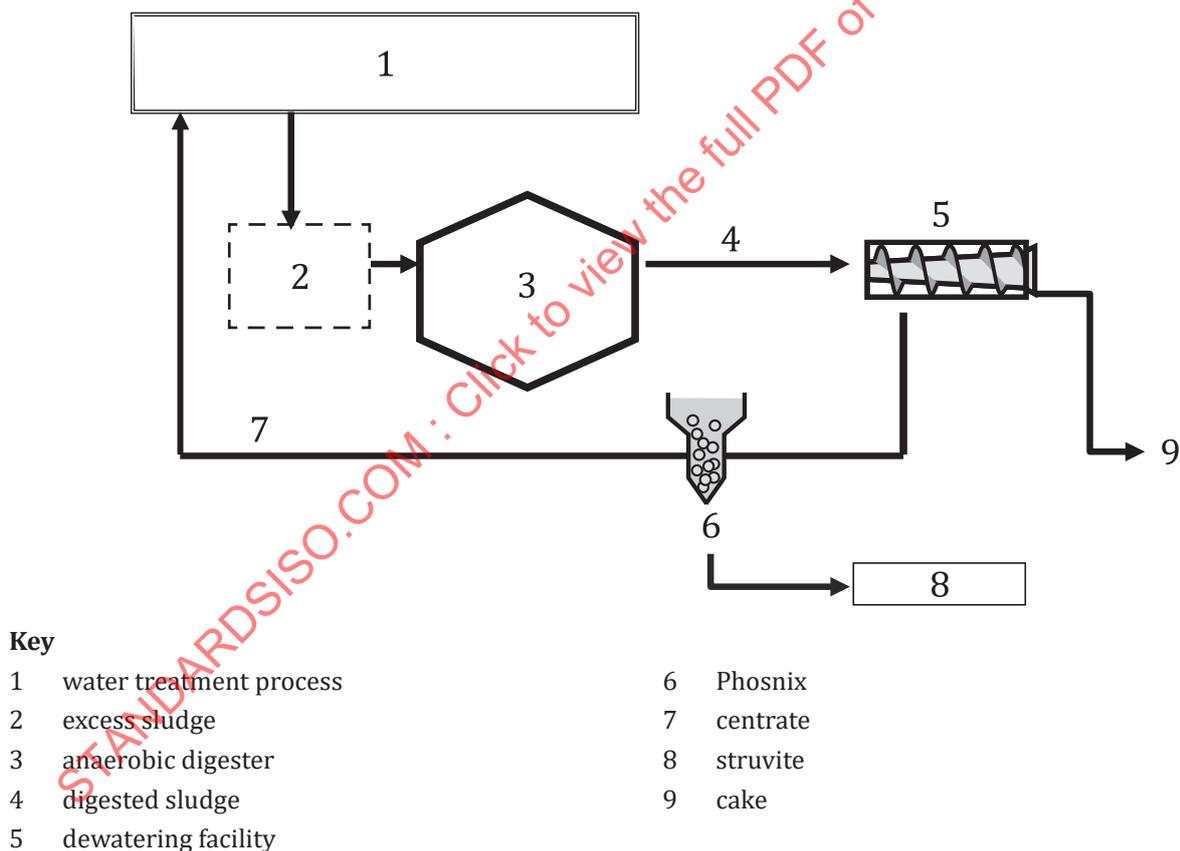


Figure B.1 — Process flow diagram



Figure B.2 — Commercial plant in Shimane

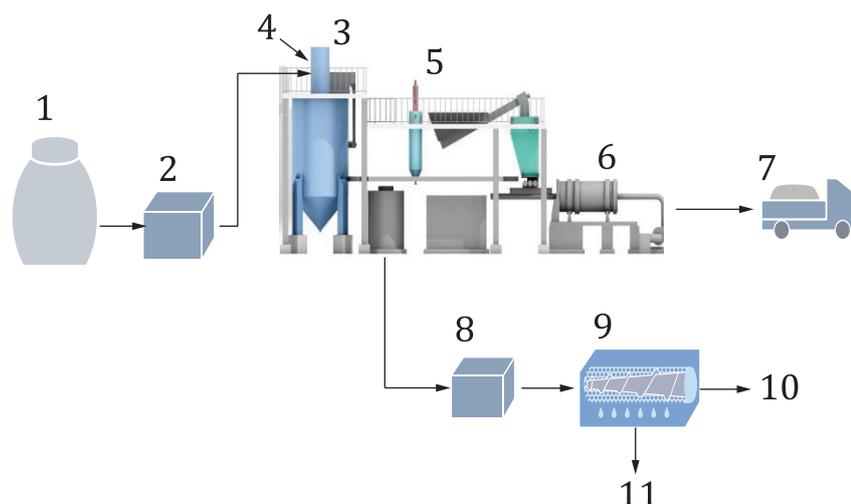
B.2 Struvite recovery from digested sewage sludge

For information on struvite recovery from digested sewage sludge, see Table B.2, and [Figures B.3](#) and [B.4](#).

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Table B.2 — Technical overview

General data	
Type of process	Crystallization
Input material	<input type="checkbox"/> Filtration liquid, <input type="checkbox"/> Dewatered sludge, <input checked="" type="checkbox"/> ADS, <input type="checkbox"/> Filtrate of ADS, <input type="checkbox"/> Incineration ash, <input type="checkbox"/> Dried sludge, <input checked="" type="checkbox"/> Industrial wastewater, <input type="checkbox"/> Others ()
Product	<input checked="" type="checkbox"/> Phosphorus: <input checked="" type="checkbox"/> Struvite, <input type="checkbox"/> HAP, <input type="checkbox"/> CaPO ₄ , <input type="checkbox"/> Others() <input type="checkbox"/> Nitrogen, <input type="checkbox"/> Metals (), <input type="checkbox"/> Others ()
Type of plant	WWTP with P removal with coagulant and anaerobic digestion
T-P recovery rate	30 % to 40 %
Dissolved P recovery rate	More than 80 %
P-concentration of product	26 % P ₂ O ₅ of DM
Average total electricity demand	Not detected (ND)
)Average chemical demand (as 100 % concentrate)	ND
Reference	
Raw materials for recovery	<input type="checkbox"/> Filtration liquid, <input type="checkbox"/> Dewatered sludge, <input checked="" type="checkbox"/> ADS, <input checked="" type="checkbox"/> Filtrate of ADS, <input type="checkbox"/> Incineration ash, <input type="checkbox"/> Dried sludge, <input checked="" type="checkbox"/> Industrial wastewater, <input type="checkbox"/> Others ()
Reuse of recovered materials	<input checked="" type="checkbox"/> Fertilizer <input type="checkbox"/> Raw material of chemicals <input type="checkbox"/> Others ()
Country	Japan
Background	Removal and reuse of phosphorus are very important theme in sewerage treatment. Therefore, a more effective phosphorus recovery process from digested sewage sludge has been developed.
Objective	Removal and reuse of phosphorus in sewage
Result	T-P removal from the returned water: more than 85 % Quantity of struvite: more than 1,4 times than a conventional method
Description (differentiation from others)	This technology can recover more phosphorus from the digested sludge than struvite recovery methods applied to the filtrate of anaerobic digested sludge.
Main components and specification	[Project outline] Location: Higashinada WWTP (KOBE) Capacity: 239 m ³ /d (digested sludge) Operation start: 2013 [Main Equipment] Crystallization reactor/Completely mixing: Capacity 239 m ³ /d × 1 Struvite scrubber × 1 Struvite dryer × 1
Source	See References [7] and [9]
Contact details	Organization: Japan Sewage Works Agency Email: js-international@jswa.go.jp



Key

- | | |
|------------------------------|----------------------|
| 1 anaerobic digester | 7 recovered struvite |
| 2 receiving tank | 8 buffer tank |
| 3 crystallization reactor | 9 screw press |
| 4 Mg(OH) ₂ dosing | 10 dewatered sludge |
| 5 struvite scrubber | 11 filtrate |
| 6 struvite dryer | |

Figure B.3 — Process flow



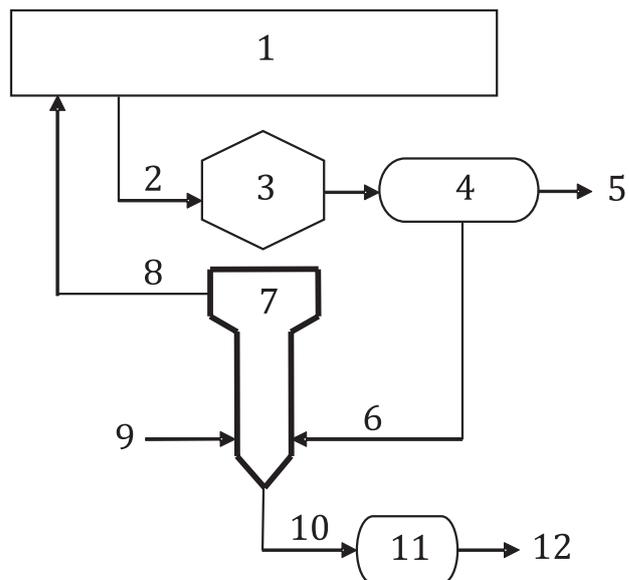
Figure B.4 — Commercial plant in Kobe

B.3 Phosphorus recovery from centrate using seawater as a magnesium source

For information on phosphorus recovery from centrate using seawater as a magnesium source, see Table B.3, and [Figures B.5](#) and [B.6](#).

Table B.3 — Technical overview

General data	
Type of process	Crystallization
Input material	<input type="checkbox"/> Filtration liquid, <input type="checkbox"/> Dewatered sludge, <input type="checkbox"/> ADS, <input checked="" type="checkbox"/> Filtrate of ADS, <input type="checkbox"/> Incineration ash, <input type="checkbox"/> Dried sludge, <input type="checkbox"/> Industrial wastewater, <input type="checkbox"/> Others ()
Product	<input checked="" type="checkbox"/> Phosphorus: <input checked="" type="checkbox"/> Struvite, <input type="checkbox"/> HAP, <input type="checkbox"/> CaPO ₄ , <input type="checkbox"/> Others () <input type="checkbox"/> Nitrogen, <input type="checkbox"/> Metals (), <input type="checkbox"/> Others ()
Type of plant	WWTP with P removal with coagulant and anaerobic digestion
T-P recovery rate	60 % to 80 %
Dissolved P recovery rate	70 % to 80 %
P-concentration of product	27 % P ₂ O ₅ of DM
Average total electricity demand	1,4 kWh/kg magnesium ammonium phosphate (MAP)
Average chemical demand (as 100 % concentrate)	No need of chemicals because of using only seawater
Reference	
Raw materials for recovery	<input type="checkbox"/> Filtration liquid, <input type="checkbox"/> Dewatered sludge, <input type="checkbox"/> ADS, <input checked="" type="checkbox"/> Filtrate of ADS, <input type="checkbox"/> Incineration ash, <input type="checkbox"/> Dried sludge, <input type="checkbox"/> Industrial wastewater, <input type="checkbox"/> Others ()
Reuse of recovered materials	<input checked="" type="checkbox"/> Fertilizer <input type="checkbox"/> Raw material of chemicals <input type="checkbox"/> Others ()
Country	Japan
Background	To recover phosphorus from centrate of dewatering machine as struvite and to reduce chemical costs is one of problems.
Objective	Check the effectiveness of seawater as Mg source for struvite recovery
Result	Dissolved phosphorus (D-P) recovery is more than 70 %. Chemical cost using seawater is much reduced compared to use MgCl ₂ or Mg(OH) ₂ as Mg source.
Description (differentiation from others)	Seawater contains 1 250 mg/l Mg ²⁺ . Only pumping cost is needed to use seawater as Mg source. By feeding the sidestream which was 50 mg/l to 110 mg/l in D-P and above 7,8 in pH together with 9 % to 10 % flow of seawater into the reactor and by reacting for 29 min, D-P recovery was achieved more than 70 % without pH control.
Main components and specification	[Project outline] Location: Hiagari WWTP (Kitakyushu city) Capacity: 38 m ³ /day (Pilot plant) Operation: 1996 - 1997 [Main Equipment] Struvite reactor/fluidized bed: φ1 200 mm × 3 700 mmH × 1 Struvite dryer: 1,060 mm × 800 mm × 1,650 mmH × 1
Source	See Reference [8]
Contact details	Organization: Japan Sewage Works Agency Email: js-international@jswa.go.jp



Key

- | | | | |
|---|------------------------------|----|-----------------------|
| 1 | wastewater treatment process | 7 | struvite reactor |
| 2 | mixed sludge | 8 | effluent |
| 3 | digestion tank | 9 | seawater |
| 4 | dewatering machine | 10 | struvite particles |
| 5 | dewatered cake | 11 | struvite dryer |
| 6 | centrate | 12 | recycle as fertilizer |

Figure B.5 — Process flow diagram



Figure B.6 — Pilot plant in Kitakyushu

B.4 Struvite precipitation with fluidized bed reactor "Phosphogreen™"

For information on struvite precipitation with fluidized bed reactor "Phosphogreen™²⁾", see Table B.4, and [Figures B.7](#) to [B.10](#).

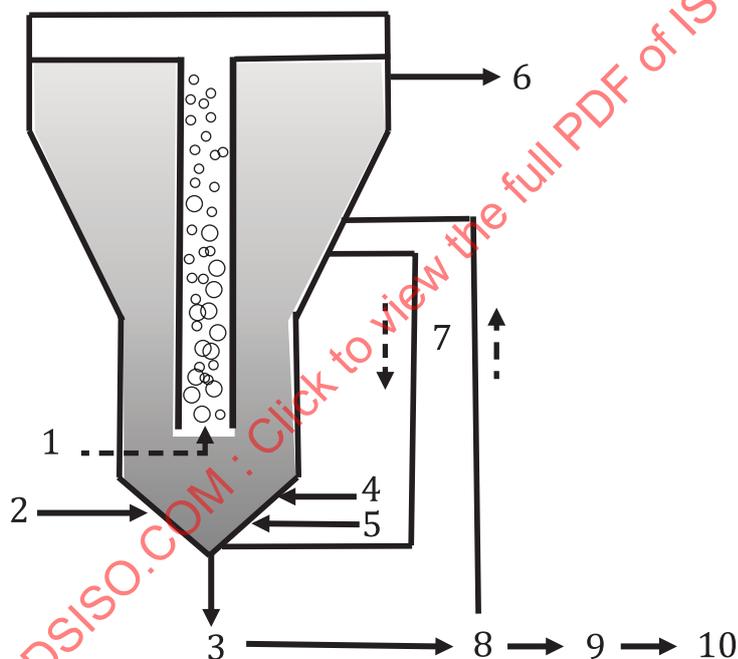
Table B.4 — Technical overview

General data	
Type of process	Crystallization
Input material	<input type="checkbox"/> Filtration liquid, <input type="checkbox"/> Dewatered sludge, <input type="checkbox"/> ADS, <input checked="" type="checkbox"/> Filtrate of ADS, <input type="checkbox"/> Incineration ash, <input type="checkbox"/> Dried sludge, <input type="checkbox"/> Raw sewage, <input checked="" type="checkbox"/> Industrial wastewater, <input type="checkbox"/> Treated water, <input checked="" type="checkbox"/> Others (thickening filtrate)
Product	<input checked="" type="checkbox"/> Phosphorus: <input checked="" type="checkbox"/> Struvite, <input type="checkbox"/> HAP, <input type="checkbox"/> CaPO ₄ , <input type="checkbox"/> Others() <input type="checkbox"/> Nitrogen, <input type="checkbox"/> Metals (), <input type="checkbox"/> Others ()
Type of plant	WWTP with biological P removal and anaerobic digestion
T-P recovery rate	—
Dissolved P recovery rate	80 %
P-concentration of product	Phosphorus mass fraction of 12,2 %
Average total electricity demand	—
Average chemical demand (as 100 % concentrate)	(0,8 to 1,2) molar ratio Mg:P _{dissolved}
Reference	
Raw materials for recovery	<input type="checkbox"/> Filtration liquid, <input type="checkbox"/> Dewatered sludge, <input type="checkbox"/> ADS, <input checked="" type="checkbox"/> Filtrate of ADS, <input type="checkbox"/> Incineration ash, <input type="checkbox"/> Dried sludge, <input type="checkbox"/> Raw sewage, <input type="checkbox"/> Industrial wastewater, <input type="checkbox"/> Treated water, <input checked="" type="checkbox"/> Others (Thickening filtrate)
Reuse of recovered materials	<input checked="" type="checkbox"/> Fertilizer <input type="checkbox"/> Raw material of chemicals <input type="checkbox"/> Others ()
Country	Denmark + France
Background	The client Aarhus Vand wanted to resolve operating problems (struvite in pipes...) and produce a value from the WWTP.
Objective	The objective was to produce a clean fertilizer to be sold as pellets and recover about 80 % of phosphorus.
Result	Phosphorus recovered was between 80 % to 85 %; struvite is homologated and sold as a fertilizer.
Description (differentiation from others)	Low use of sodium hydroxide. pH modification is made by stripping of CO ₂ . Total phosphorus recovery on plant is around 35 %.
Main components and specification (1)	[Project outline] Location: plant of Aaby (Denmark) Capacity: 84 000 PE - 105 kg/d P _{tot} at inlet of Phosphogreen™ Operation start: 2013 [Main equipment] Fluidized bed reactor
Main components and specification (2)	[Project outline] Location: plant of Herning (Denmark) Capacity: 150 000 PE - 240 kg/d P _{tot} at inlet of Phosphogreen™ Operation start: 2015 [Main equipment] Fluidized bed reactor

2) Phosphogreen™ is an example of a suitable product available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of this product.

Table B.4 (continued)

General data	
Main components and specification (3)	[Project outline] Location: plant of Marselisborg (Denmark) Capacity: 200 000 PE Operation start: 2018 [Main equipment] Fluidized bed reactor
Main components and specification (4)	[Project outline] Location: plant of Villier Saint Frederic (France) Capacity: 40 000 PE Operation start: 2020 [Main equipment] Fluidized bed reactor
Source	See Reference [10]
Contact details	Organization: SUEZ Email: math.delahaye@suez.com



Key

- | | |
|-----------------------------|-----------------------|
| 1 air | 6 water outlet |
| 2 water inlet (concentrate) | 7 water recirculation |
| 3 struvite extraction | 8 washing |
| 4 NaOH | 9 drying |
| 5 MgCl ₂ | 10 packaging |

Figure B.7 — Phosphogreen™ reactor



Figure B.8 — Aaby plant



Figure B.9 — Herning plant



Figure B.10 — Marselisborg plant

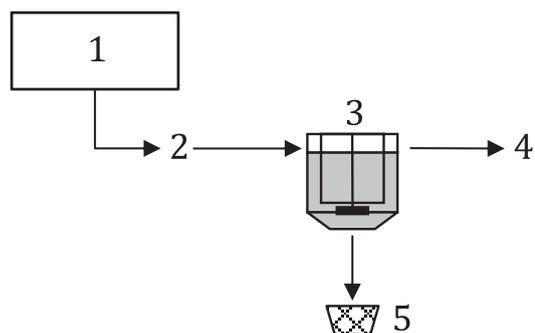
B.5 Phosphorus recovery from filtrate 'HAP system'

For information on phosphorus recovery from filtrate 'HAP system', see Table B.5, and [Figures B.11](#) and [B.12](#).

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Table B.5 — Technical overview

General data	
Type of process	Crystallization
Input material	<input checked="" type="checkbox"/> Filtration liquid, <input type="checkbox"/> Dewatered sludge, <input type="checkbox"/> ADS, <input type="checkbox"/> Filtrate of ADS, <input type="checkbox"/> Incineration ash, <input type="checkbox"/> Dried sludge, <input checked="" type="checkbox"/> Industrial wastewater, <input type="checkbox"/> Others ()
Product	<input checked="" type="checkbox"/> Phosphorus: <input type="checkbox"/> Struvite, <input checked="" type="checkbox"/> HAP, <input type="checkbox"/> CaPO ₄ , <input type="checkbox"/> Others() <input type="checkbox"/> Nitrogen, <input type="checkbox"/> Metals (), <input type="checkbox"/> Others ()
Type of plant	WWTP for night soil
T-P recovery rate	ND
Dissolved P recovery rate	70 %
P-concentration of product	30 % P ₂ O ₅ of DM
Average total electricity demand	(1,5 to 3,0) kWh/kg- <i>P</i> _{recovered}
Average chemical demand (as 100 % concentrate)	(3 to 5) kgCaCl ₂ /kg- <i>P</i> _{recovered} (4 to 8) molar ratio Ca: <i>P</i> _{recovered} (2 to 4) molar ratio Ca: <i>P</i> _{dissolved}
Reference	
Raw materials for recovery	<input checked="" type="checkbox"/> Filtration liquid, <input type="checkbox"/> Dewatered sludge, <input type="checkbox"/> ADS, <input type="checkbox"/> Filtrate of ADS, <input type="checkbox"/> Incineration ash, <input type="checkbox"/> Dried sludge, <input type="checkbox"/> Industrial wastewater, <input type="checkbox"/> Others ()
Reuse of recovered materials	<input checked="" type="checkbox"/> Fertilizer <input type="checkbox"/> Raw material of chemicals <input type="checkbox"/> Others ()
Country	Japan
Background	Human waste can be good source of phosphorus thanks to its higher concentration of that than sewage. The Ministry of Environment of Japan has fund subsidies for the plant which has resource recovery system since 1997.
Objective	Phosphorus recovery from human waste and reduction of the processing cost
Result	Amount of recovered HAP: 0,26 kg/m ³ -human waste Chemical consumption for post coagulation and related sludge generation has been reduced.
Description (differentiation from others)	This plant is the first human waste treatment plant to recover phosphorus as HAP in Japan. Now, five HAP recovery plants are working in Japan. After growing up particle size, HAP product is easily dripping water without mechanical dewatering.
Main components and specification	[Project outline] Location: Senboku city (Akita) Capacity: 60 m ³ /day Operation start: 2009 [Main equipment] Crystallizer: φ2,6 m × H 2,8 m HAP recovery tank: flexible container
Source	See Reference [9]
Contact details	Organization: Japan Sewage Works Agency Email: js-international@jswa.go.jp



Key

- 1 human waste treatment process
- 2 filtration liquid
- 3 crystallizer
- 4 coagulation
- 5 HAP

Figure B.11 — Process flow diagram



Figure B.12 — Commercial plant in Akita

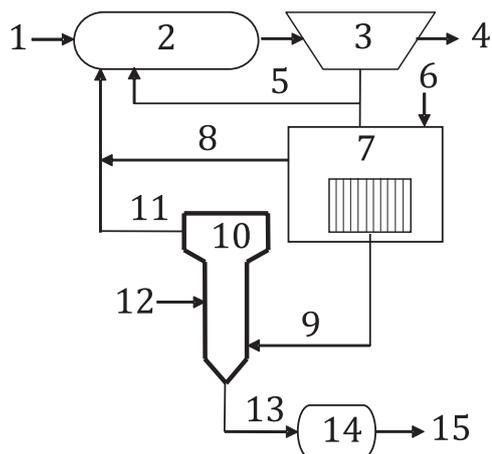
B.6 Phosphorus recovery from sewage by PhoStrip process

For information on phosphorus recovery from sewage by PhoStrip³⁾ process, see Table B.5, and [Figures B.13](#) and [B.15](#).

3) PhoStrip is an example of a suitable product available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of this product.

Table B.6 — Technical overview

General data	
Type of process	Crystallization
Input material	<input checked="" type="checkbox"/> Filtration liquid, <input type="checkbox"/> Dewatered sludge, <input type="checkbox"/> ADS, <input type="checkbox"/> Filtrate of ADS, <input type="checkbox"/> Incineration ash, <input type="checkbox"/> Dried sludge, <input type="checkbox"/> Industrial wastewater, <input checked="" type="checkbox"/> Others (Return sludge)
Product	<input checked="" type="checkbox"/> Phosphorus: <input type="checkbox"/> Struvite, <input checked="" type="checkbox"/> HAP, <input type="checkbox"/> CaPO ₄ , <input type="checkbox"/> Others() <input type="checkbox"/> Nitrogen, <input type="checkbox"/> Metals (), <input type="checkbox"/> Others ()
Type of plant	WWTP with anaerobic membrane bioreactor
T-P recovery rate	60 % to 80 %
Dissolved P recovery rate	70 % to 80 %
P-concentration of product	30 % P ₂ O ₅ of DM
Average total electricity demand	8 kWh/kg- <i>P</i> _{recovered} to 10 kWh/kg- <i>P</i> _{recovered}
Average chemical demand (as 100 % concentrate)	3 kgCaCl ₂ /kg- <i>P</i> _{recovered} 5 kgCaCl ₂ /kg- <i>P</i> _{recovered} 2 kgNaOH/kg- <i>P</i> _{recovered} to 3 kgNaOH/kg- <i>P</i> _{recovered}
Reference	
Raw materials for recovery	<input checked="" type="checkbox"/> Filtration liquid, <input type="checkbox"/> Dewatered sludge, <input type="checkbox"/> ADS, <input type="checkbox"/> Filtrate of ADS, <input type="checkbox"/> Incineration ash, <input type="checkbox"/> Dried sludge, <input type="checkbox"/> Industrial wastewater, <input checked="" type="checkbox"/> Others (Return sludge)
Reuse of recovered materials	<input checked="" type="checkbox"/> Fertilizer <input type="checkbox"/> Raw material of chemicals <input type="checkbox"/> Others ()
Country	Japan
Background	Activated sludge ingests phosphorous in sewage under aerobic condition and excretes the phosphorous under anaerobic condition. Then, calcium is added to concentrated phosphorus liquid to immobilize phosphorus as HAP. HAP is crystalized, recovered and used as fertilizer.
Objective	P-Concentration of the treated effluent <1 mg/l P-recovery efficiency ~80 %
Result	Sewage T-P 3 mg/l to 5 mg/l, effluent T-P 0,5 mg/l to 1 mg/l T-P recovery efficiency: 75 % to 80 %
Description (differentiation from others)	1) Reducing treated sewage P-concentration to a low level. 2) Recovering the high pure HAP as fertilizer. 3) Reducing low P-concentration in the excess sludge. 4) Stable facility operation.
Main components and specification	[Project outline] Location: Urabandai WWTP (Fukushima prefecture) Capacity: 3 400 m ³ /d Operation start: April 2007 [Main equipment] Stripper tank: 4,7 m × 7,9 m × 5,0 mH × 2 sets Crystallizer/Fluidized bed: φ4,6 m (settler) /φ2,0 m (reactor) × 7,3 mH
Contact details	Organization: Japan Sewage Works Agency Email: js-international@jswa.go.jp



Key

- | | | | |
|---|-----------------------------|----|-----------------------|
| 1 | sewage | 9 | filtrate |
| 2 | oxidation ditch reactor | 10 | crystallizer |
| 3 | final settling tank | 11 | supernate |
| 4 | effluent | 12 | Ca |
| 5 | return sludge | 13 | HAP particles |
| 6 | sewage | 14 | HAP dehydrator |
| 7 | stripper tank with membrane | 15 | recycle as fertilizer |
| 8 | sludge | | |

Figure B.13 — Process flow diagram

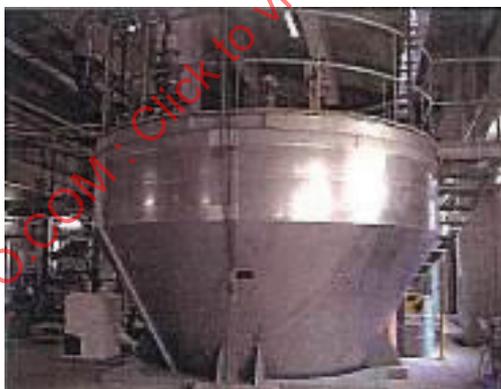


Figure B.14 — Crystallizer

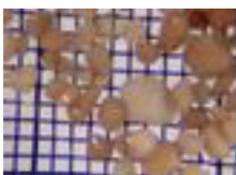


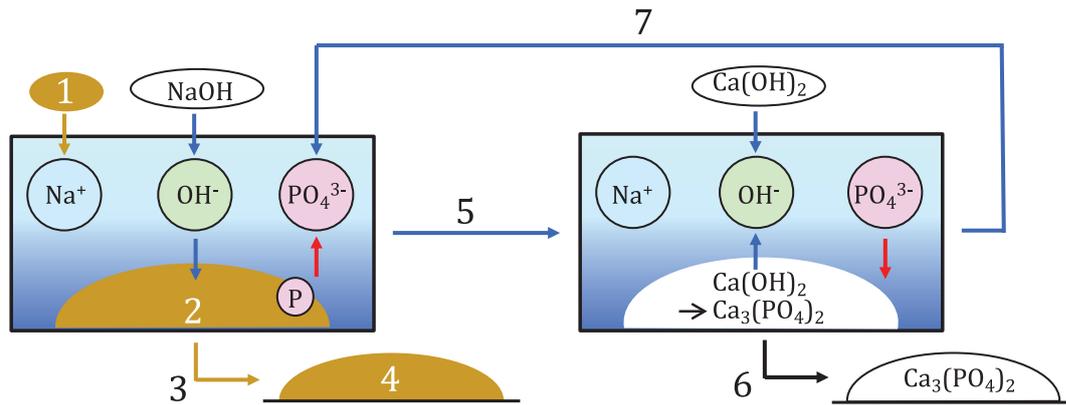
Figure B.15 — Recovered HAP

B.7 Phosphorus recovery system from incinerated ash

For information on phosphorus recovery system from incinerated ash, see Table B.7, and [Figures B.16](#) and [B.17](#).

Table B.7 — Technical overview

General data	
Type of process	Chemical extraction and precipitation
Input material	<input type="checkbox"/> Filtration liquid, <input type="checkbox"/> Dewatered sludge, <input type="checkbox"/> ADS, <input type="checkbox"/> Filtrate of ADS, <input checked="" type="checkbox"/> Incineration ash, <input type="checkbox"/> Dried sludge, <input type="checkbox"/> Industrial wastewater, <input type="checkbox"/> Others ()
Product	<input checked="" type="checkbox"/> Phosphorus: <input type="checkbox"/> Struvite, <input checked="" type="checkbox"/> HAP, <input checked="" type="checkbox"/> CaPO ₄ , <input type="checkbox"/> Others() <input type="checkbox"/> Nitrogen, <input type="checkbox"/> Metals (), <input type="checkbox"/> Others ()
Type of plant	WWTP without digestion
P-concentration of product	Approximately 30 % P ₂ O ₅ of DM
Average total electricity demand	(19 to 32) kWh/kg- <i>P</i> _{recovered} NOTE This value includes the necessary electricity demand for the neutralized ash treatment (dewatering, drying, etc.)
Average chemical demand (as 100 % concentrate)	(5,6 to 6,9) kgCa(OH) ₂ /kg- <i>P</i> _{recovered} (2,3 to 2,9) molar ratio Ca: <i>P</i> _{recovered} , (1,6 to 2,4) molar ratio Ca: <i>P</i> _{dissolved} (1,7 to 5,0) kgNaOH/kg- <i>P</i> _{recovered} (2,3 to 6,7) molar ratio Na: <i>P</i> _{recovered} , (2,3 to 4,3) molar ratio Na: <i>P</i> _{dissolved}
Reference	
Raw materials for recovery	<input type="checkbox"/> Filtration liquid, <input type="checkbox"/> Dewatered sludge, <input type="checkbox"/> ADS, <input type="checkbox"/> Filtrate of ADS, <input checked="" type="checkbox"/> Incineration ash, <input type="checkbox"/> Dried sludge, <input type="checkbox"/> Industrial wastewater, <input type="checkbox"/> Others ()
Reuse of recovered materials	<input checked="" type="checkbox"/> Fertilizer <input type="checkbox"/> Raw material of chemicals <input type="checkbox"/> Others ()
Country	Japan
Background	Phosphorus, widely used for fertilizer and animal feed, is in a great concern of shortage of natural phosphate ore as well as the price increase due to export control in the international resource market.
Objective	Recycling CaPO ₄ and dephosphorized ash ("de-P ash")
Result	Production of 1,1 tons of CaPO ₄ and 4,3 tons of de-P ash out of 5 tons of incinerated ash
Description (differentiation from others)	The incinerated ash from sewage sludge is turned into 2 recycled products through the wet processing; calcium phosphate and de-P ash, focusing on the high concentration (20 % to 30 %) of phosphate in the ash. The recovered phosphate is sold to ZEN-NOH, a national agricultural organization, reformed into a real fertilizer and retailed. The de-P ash can be for a raw material of cement industries, etc. All the necessary heat is supplied by the surplus heat from an incinerator, as the operation temperature is just 50 °C to 70 °C. The operation cost is also reduced because of the circulation of solution.
Main components and specification	[Project outline] Location: Gifu-hokubu wastewater treatment plant (Gifu) Capacity: 5 tons-ash/day Operation start: April 2010 [Main equipment] P-extractor: 4 m ³ , P-precipitator: 15 m ³ × 2, Rinse tank: 3 m ³ × 3, P-dryer: 2 m ²
Source	See Reference [9]
Contact details	Organization: Japan Sewage Works Agency Email: js-international@jswa.go.jp



- Key**
- 1 ash
 - 2 incinerated ash
 - 3 extraction
 - 4 neutralized ash
 - 5 PO_4^{3-} rich solution
 - 6 precipitation
 - 7 circulation of recycled solution

Figure B.16 — Process flow



- Key**
- 1 incinerated ash
 - 2 recycled phosphate
 - 3 dephosphorized ash

Figure B.17 — Commercial plant in Gifu