A Review: "Global Trends in Recovery of phosphorus by Different Techniques"

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Abstract Phosphorus deposits around the world are rapidly depleting, therefore phosphorus recovery methods are gaining more and more interest both in science and industry. This article presents the main methods of phosphorus recovery from sewage sludge. The described approaches are divided in two groups: phosphorus recovery from Orange waste, Waste water, Seawage sludge, and recovery of phosphorus from sewage sludge ashes. The latter seems to have more advantages connected with both ecological and economical aspects. The concept of comprehensive management of all solid residues after what is currently considered the most ecological process of sewage sludge incineration connected with phosphorus recovery based on acidic extraction, is described in the article. Solid residues after phosphorus recovery from sewage sludge ashes by means of acidic extraction can be stabilized with solid residues after sewage sludge incineration exhaust gas treatment. Such an approach may enable production of phosphoric raw material together with stabilized construction material. The aim of the paper is to provide information for the recovery of phosphorus from various waste by different techniques towards the environmental sustainability.

Key Words : Phosphorus recovery, Sewage sludge ash, Sewage sludge

Introduction

Phosphorus is an essential, often limiting, nutrient for growth of organisms in most ecosystems. The extensive industrial use of phosphates large amounts of phosphate-bearing wastes, discharged into municipal and industrial water effluent streams Phosphate discharged into surface waters can disturb organisms present in water and affect water quality, mainly through the depletion of the dissolved oxygen level as the algae decay. Depletion of the oxygen level in confined water lakes and pond causes eutrophication which, in turn, has a harmful effect[4] on fish and resulting in a reduction in biodiversity as well as unfavorable human environmental health. On the other hand, phosphorus resources are limited and there have been some alarming reports that deposits of high-grade phosphate ores are likely to be depleted in the next few decades. For the non-fertilizer sector of the phosphate industry, techniques for the extraction of impurities from green phosphoric acid are at an advanced state of development. But, inevitably, for every Cinderella stream of purified phosphoric acid there is an ugly sister metal-enriched stream. The disposal route for these metals is usually into fertilizers[12] but, with increasing pressure on the cadmium content, this route may not be available indefinitely. For those companies without a fertilizer sink there has been a need to develop alternative technologies to extract and isolate problematic metals in an environmentally safe form: but at a cost. Even without the additional burden of impurities from the purified acid sector, metal levels in fertilizers are under attack.

Three fundamental reasons why the phosphate industry should regard the *status quo* as unsustainable:

1. Phosphate rock resources are limited and declining both in quality and accessibility
2. Growth in the world population, particularly in areas with poor soils, will lead to an increase in phosphate fertilizer consumption, only partially offset by a declining rate of use in the historically over-fertilized temperate zones.
3. The pressure to remove heavy metals from all phosphate products (including fertilizers) derived from natural phosphate rock will lead to increasing raw material prices and escalating disposal costs.

Over three decades there has been persistent pressure on the non-fertilizer sector of the phosphate industry concerning the contribution of detergents to phosphorus levels in rivers and lakes. Increasingly this is also being felt by the fertilizer sector. Even farmers, traditionally a no-go area for environmental legislation, are beginning to feel the heat with respect to balanced fertilization, slurry spreading etc. European water legislation concerning nutrients is diffuse and, perhaps with the exception of the *Urban Waste Water* Directive and the *Nitrates* Directive has gone largely unnoticed. Where phosphorus removal is required by law, phosphorus recovery from sewage treatment systems may be an economically attractive alternative. Animal wastes also offer a potentially large source of phosphates for recovery. The technology of phosphate recovery is relatively straightforward and, as well as the value of the recovered phosphorus, there can be significant savings in both treatment costs and in the disposal of the residual sewage sludge.

Why phosphorus recycling strategies are required?

Spreading of sewage sludge and animal manures[4] onto agricultural land has always been, and will remain, the simplest strategy for recycling nutrients and the importance of this route has been recognised throughout history. Compelling archaeological evidence exists to show that rigid procedures existed for the gathering and re-application of manure (both human and animal) to farmed land. In English monasteries, by the Middle Ages, it was commonplace for contracts, governing the use of monastic lands, to contain a manure clause which permitted the farmer to graze his sheep, take away the wool, take away the meat, but the manure had to stay where it fell: on the field.

Things have changed, however. The growth of cities has resulted in the centres of consumption (and hence, human sewage production) becoming remote from areas of agricultural production This has led to logistical difficulties in restoring human waste to the land a problem, incidentally, made more difficult with the widespread introduction of sewage treatment. In recent years, the whole practice of sludge[2] spreading has been called into question with pressure on heavy metal content, pathogens, odour, nutrient losses to water etc.

Manure and slurry spreading might seem a comparatively homely and unproblematic practice. But here, too, problems have arisen due to the intensification of livestock production particularly pigs and poultry. This has resulted in large local excesses of manure production, far beyond the capacity of nearby farmland to absorb the output. In such situations, alternative disposal routes have to be found; incineration is amongst the options already being employed.

The excess of nutrients, currently from sewage treatment works but increasingly from animal wastes, will need to be prevented from reaching surface water if quality objectives are to be achieved and maintained. Hitherto, the strategy has been one of phosphorus removal, not recovery and this has been achieved via a variety of methods In all cases, however, where phosphorus is removed from waste waters it is transferred to sludge[3], either in an organic form, as in biological phosphorus removal, or as a chemical precipitate:usually in the form of an iron or aluminium salt. The majority of sewage works equipped with phosphorus removal in Europe use chemical precipitation, often simultaneous with secondary biological treatment, where the chemical precipitate is mixed into the organic sludge.

Effective phosphorus removal requires higher concentrations of precipitation chemicals than actually combine with the available phosphorus and, without exception, these methods result in a large (around 40%) increase in sludge production. The resulting sludge is of dubious agronomic value and presents its own disposal problems.
Recovery of phosphorus for recycling, rather than its transfer into sewage sludges, may offer economic and environmental rewards for the water industry. For the phosphate industry it holds out the promise of a significant, if only partial, source of sustainable raw material, which is comparatively free from heavy metals. These benefits must be compared with the investment and running costs of phosphorus recovery installations.

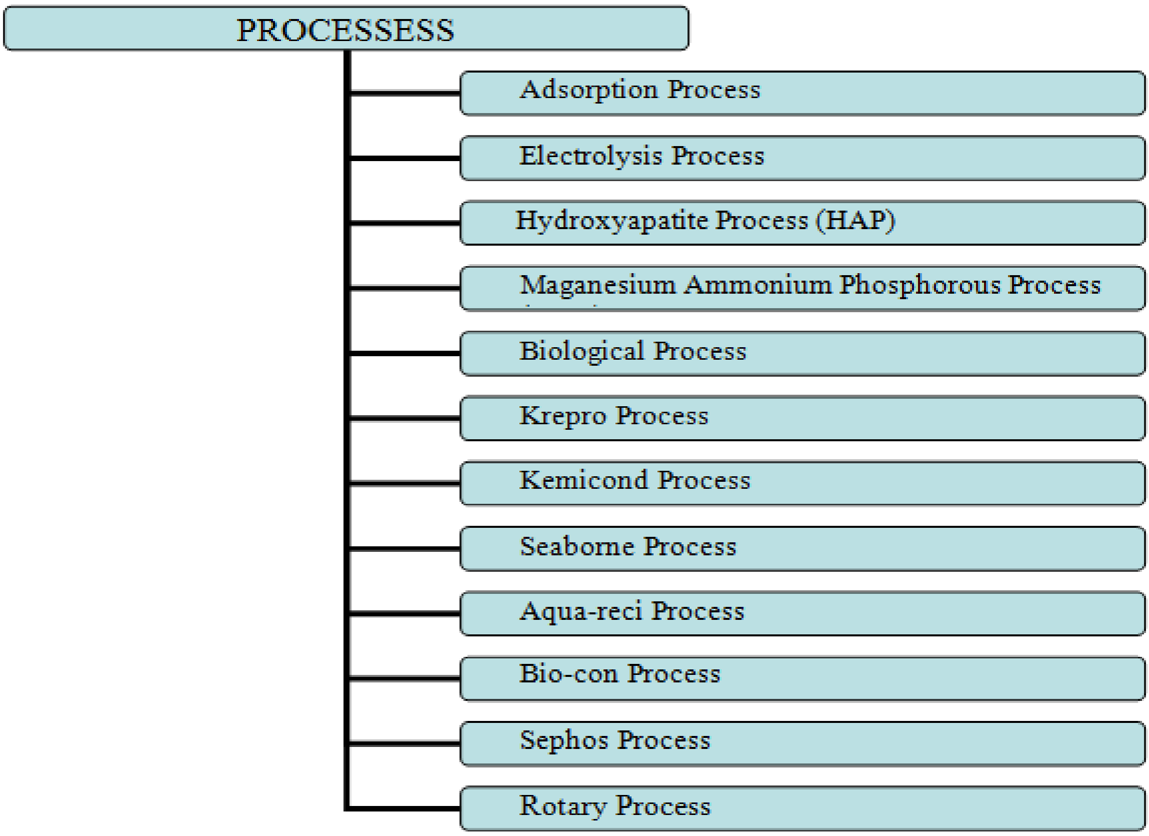

Figure 1 : Process Selection For Phosphorus Removal from:(A) Orange waste[11] (b) Waste water (c)Seawage sludge[1]

(A)Recovery from Orange Waste[1]

The bio-waste material investigated in this study is an industrial waste generated in orange juice factories. Orange waste contains around 10% pectin which exists in the cell wall as an intercellular cementing material. Pectin is a polysaccharide in which pectic acid is partly esterified by methyl groups. It is easily converted into pectic acid by saponification with alkalis such as calcium hydroxide.

Preparation of Orange Waste Gel[11]

The preparation of the SOW Gel is been discussed in following ways:

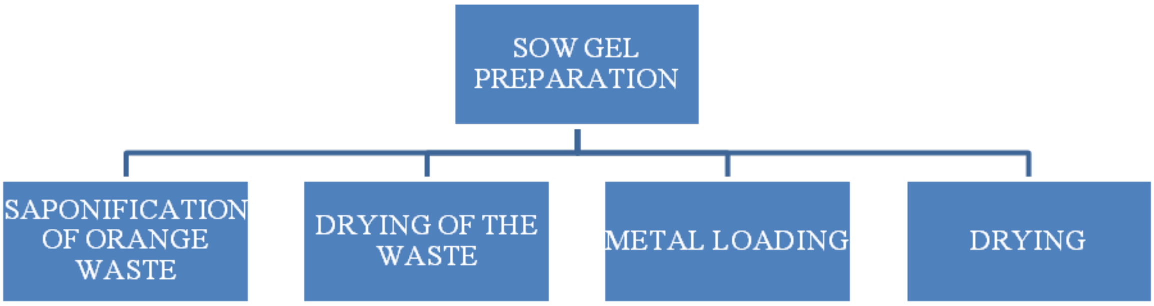

Figure 2 : Preparation of Orange Waste Gel

1) **Saponification Of Orange Waste:** About 100 g of orange waste was taken along with 8 g of $Ca(OH)_2$ and crushed into small particles to make[5]. The mixture was then transferred into a beaker and, after adding a substantial amount of deionized water, the suspension was stirred for 24 h at about 200 rpm at room temperature in order to facilitate the saponification. The pH of this suspension was maintained constant at around 12.5 by adding sodium hydroxide solution.

2). Drying Of Solution: After stirring, the suspension was repeatedly washed with deionized water until neutral pH and finally filtered to obtain a wet gel, which was dried in a convection oven for about 48 h at 70 ^{0}C to produce a dry gel.

3). Metal Loading: The SOW gel was modified by loading with Zr to facilitate the exchange adsorption of phosphate. Approximately 3 g of SOW gel was equilibrated with 500 ml of a 0.1 M zirconium solution at pH 2.11 for 24 hrs.

4). Drying: The gel was then dried naturally for adsorption. This phenomenon was to remove moisture from gel.

(B)Phosphorous removal processes from waste water

The removal of phosphorous from wastewater involves the incorporation of phosphate into TSS and the subsequent removal from these solids. Phosphorous can be incorporated into either biological solids (e.g. micro organisms) or chemical precipitates.

(i)By precipitation:

Chemical precipitation is used to remove the inorganic forms of phosphate by the addition of a coagulant and a mixing of wastewater and coagulant. The multivalent metal ions most commonly used are calcium, aluminum and iron.

Use of Calcium:

It is usually added in the form of lime $Ca(OH)_2$. It reacts with the natural alkalinity in the wastewater[3] to produce calcium carbonate, which is primarily responsible for enhancing SS removal.
As the pH value of the wastewater increases beyond about 10, excess calcium ions will then react with the phosphate, to precipitate in hydroxylapatite. Because the lime and the alkalinity of the wastewater, in general independent of the amount of phosphate present. It will depend primarily on the alkalinity of the wastewater. The lime dose required can be approximated at 1.5 times the alkalinity as $CaCO_3$. Neutralisation may be required to reduce pH before subsequent treatment or disposal. Recarbonation with carbon dioxide (CO_2) is used to lower the pH value.

Use of Aluminium and Iron:

Alum or hydrated aluminium sulphate is widely used precipitating phosphates and aluminium phosphates ($AlPO_4$).Reaction is deceptively simple and must be considered in light of the many competing reactions and their associated equilibrium constants and the effects[4] of alkalinity, pH, trace elements found in wastewater[3]. The dosage rate required is a function of the phosphorous removal required. The efficiency of coagulation falls as the concentration of phosphorous decreases. In practice, an 80-90% removal rate is achieved at coagulant dosage rates between 50 and 200 mg/l. Dosages are generally established on the basis of bench-scale tests and occasionally by full-scale tests, especially if polymers are used. Aluminium coagulants can adversely affect the microbial population in activated sludge, especially protozoa and rotifers, at dosage rates higher than 150 mg/l. However this does not affect much either BOD or TSS removal, as the clarification function of protozoa and rotifers is largely compensated by the enhanced removal of SS by chemical precipitation. Ferric chloride or sulphate and ferrous sulphate also know as copperas, are all widely used for phosphorous removal, although the actual reactions are not fully understood. Ferric ions combine to form ferric phosphate. They react slowly with the natural alkalinity and so a coagulant aid, such as lime, is normally add to raise the pH in order to enhance the coagulation.

Table 1 - Metals used for Chemical Phosphorus Removal (Techobanoglous et al. 2014)[9].

Name	Metal ion	Basic precipitation reaction
Aluminum	Al^{+3}	$Al^{+3} + H_nPO_4^{3-n} \rightarrow AlPO_4 + nH^+$
Iron	Fe^{+3}	$Fe^{+3} + H_nPO_4^{3-n} \rightarrow FePO_4 + nH^+$
Calcium	Ca^{+2}	$10Ca^{+2} + 6PO_4^{3-} + 2OH^- \rightarrow Ca_{10}(PO_4)_6(OH)_2$

Strategies Required:

The main phosphate removal processes generally requires following steps:

Step-1: Treatment of raw/primary wastewater.

The first process is included in the general category of chemical precipitation processes. Phosphorous is removed with 90% efficiency and the final P concentration is lower than 0.5 mg/l. The chemical dosage for P removal is the same as the dosage needed for BOD and SS removal, which uses the main part of these chemicals. As mentioned above lime consumption is dependent on the alkalinity of the wastewater: only 10% of the lime fed is used in the phosphorous removal reaction. The remaining amount reacts with water alkalinity, with softening. To determine the lime quantity needed it is possible to use diagrams: i.e. the lime used to reach pH 11 is 2-2.5 times water alkalinity.

Step-2: Treatment of final effluent of biological plants (post-precipitation).

The post-precipitation is a standard treatment of a secondary effluent, usually using only metallic reagents. It is the process that gives the highest efficiency in phosphorous removal. Efficiency can reach 95%, and P concentration in the effluent can be lower than 0.5 mg/l. Post-precipitation gives also a good removal of the SS that escape the final sedimentation of the secondary process. Its advantage is also to guarantee purification efficiency at a certain extent even if the biological process is not efficient for some reason. The chemical action is stronger, since the previous biologic treatment transforms part of the organic phosphates in orthophosphates. Disadvantages are high costs for the treatment plant (big ponds and mixing devices) and sometimes a too dilute effluent. Using ferric salts there is also the risk of having some iron in the effluent, with residual coloration. The metallic ions dosage is about 1.5-2.5 ions for every phosphorus ion.

Step-3:Treatment contemporary to the secondary biologic reaction (co-precipitation).

The co-precipitation process is particularly suitable for active sludge plants, where the chemicals are fed directly in the aeration tank or before it. The continuous sludge recirculation, together with the coagulation-flocculation and adsorption process due to active sludge, allows a reduction in chemical consumption. Moreover the costs for the plant are lower, since there is no need for big post-precipitation ponds. In this process the chemical added are only iron and aluminium, lime is added only for pH correction. Lower costs and more simplicity are contrasted by a phosphorous removal efficiency lower than with post-precipitation (below 85%). The phosphorous concentration in the final effluent is about 1 mg/l. Another disadvantage is that biological and chemical sludge are mixed, so they cannot be used separately in next stages. Mixed sludges need bigger sedimentation tanks than activated sludge.

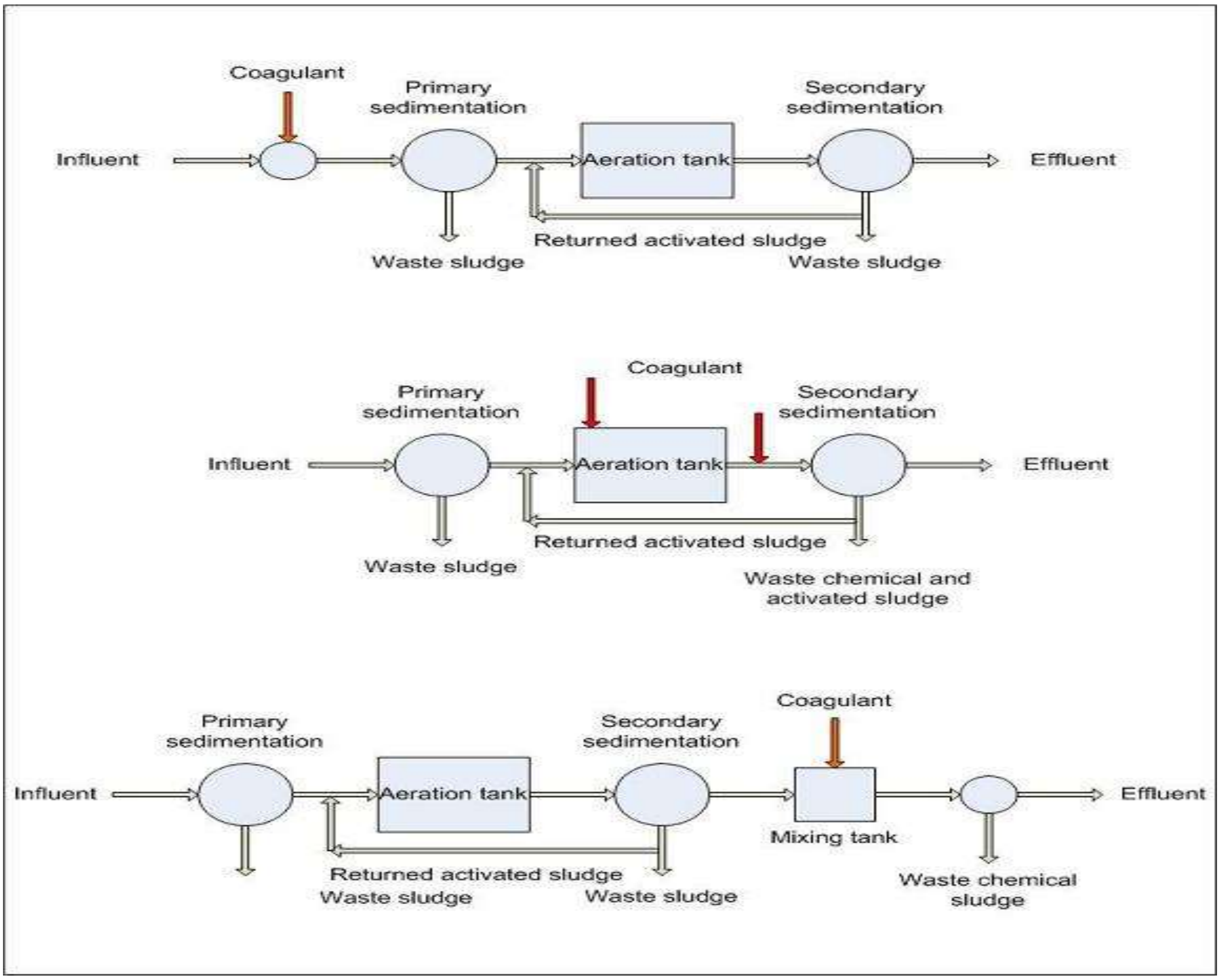

Figure 3: Treatment contemporary to the secondary biologic reaction

(ii)By Biological processes:
Over the past 20 years, several biological suspended growth process configurations have been used to accomplish biological phosphorous removal. The most important are shown in the following picture.

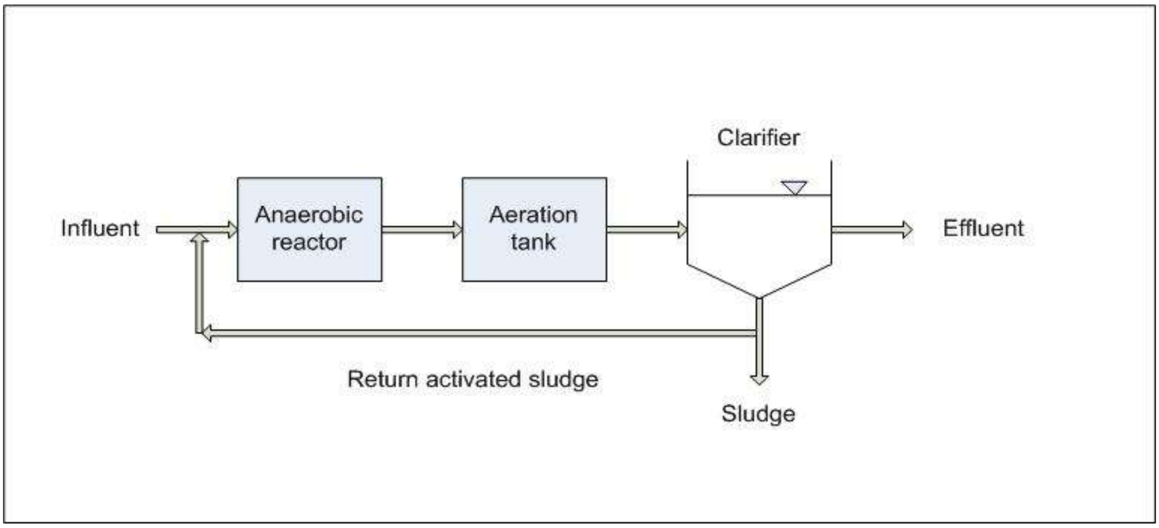

Figure 4 : Biological processes

The principal advantages of biological phosphorous removal are reduced chemical costs and less sludge[8] production as compared to chemical precipitation.
In the biological removal of phosphorous, the phosphorous in the influent wastewater is incorporated into cell biomass, which is subsequently removed from the process as a result of sludge wasting. The reactor configuration provides the P accumulating organisms (PAO) with a competitive advantage over other bacteria. So PAO are encouraged to grow and consume phosphorous. The reactor configuration in comprised of an anaerobic tank and an activated sludge activated tank. The retention time in the anaerobic tank is about 0.50 to 1.00 hours and its contents are mixed to provide contact with the return activated sludge and influent wastewater.

In the anaerobic zone:
Under anaerobic conditions, PAO assimilate fermentation products into storage products within the cells with the concomitant release of phosphorous from stored polyphosphates. Acetate is produced by fermentation of COD, which is dissolved degradable organic material that can be easily assimilated by the biomass. Using energy available from stored polyphosphates, the PAO assimilate acetate and produce intracellular polyhydroxybutyrate (PHB) storage products. Co-current with the acetate uptake is the release of orthophosphates, as well as magnesium, potassium, calcium cations. The PHB content in the PAO increases as the polyphosphate decreases.

In the aerobic zone:
Energy is produced by the oxidation of storage products and polyphosphate storage within the cell increases. Stored PHB is metabolized, providing energy from oxidation and carbon for new cell growth. Some glycogen is produced from PHB metabolism. The energy released from PHB oxidation is used to form polyphosphate bonds in cell storage. The soluble orthophosphate is removed from solution and incorporated into polyphosphates within the bacterial cell. PHB utilisation also enhances cell growth and this new biomass with high polyphosphate storage accounts for phosphorous removal. As a portion of the biomass is wasted, the stored phosphorous is removed from the bio treatment reactor for ultimate disposal with the waste sludge. The amount of phosphorous removed by biological storage can be estimated from the amount of COD that is available in the wastewater influent. Better performance for BPR systems is achieved when COD acetate is available at a steady rate.

(C)Recovery of Phosphurus from sewage sludge and sludge ashes [20]

Phosphorus (P) is an essential nutrient, which can not be substituted by any other element. Extrapolating the current consumption, the depletion of low-contaminated phosphate ores will become a severe problem within the next 100 years. This fact implies the necessity to use recycled phosphorus in the future. Therefore, wastewater treatment plants (WWTP) as important phosphate sinks should be considered not only for phosphorus removal, but also for phosphorus recovery. During the wastewater treatment 40 - 95 % of the incoming phosphorus load is transferred into the sewage sludge[22] depending on the technology applied. One way to recycle the nutrients of the sludge is the direct use as a fertiliser in agriculture. However, as every substance which is eliminated from the water phase during different wastewater treatment processes remains either in the sludge or is transformed into the gas phase (e.g. CO_2, Methane, N_2), the sludge contains both, most of the removed nutrients but also the harmful contaminants such as heavy metals or endocrine substances. Therefore, as in many other European countries its agricultural re-use is discussed controversially in Germany and might be more and more restricted because of the potential harm of the sewage sludge. Thus, it seems to be worthwhile to develop methods for a phosphorus recovery from sludge, or taking into account the future development towards sludge incineration. The advantage of the latter is a complete destruction of all organic compounds like germs and odour. All processes for a recovery of phosphorus from sewage sludge and sewage sludge ashes include a chemical or thermal treatment, respectively, whereby phosphorus and the contaminants is re-transferred into an aqueous phase prior to the separation of phosphorus from the pollutants. Alternatively, phosphorus can be recovered from phosphorus-rich process waters from sludge disintegration or partial flow of the return sludge in WWTPs by using methods, such as the crystallisation of apatite (calcium-phosphate)[7] or the precipitation of magnesium ammonium phosphate (MAP/Struvite)[8]. This article will give an overview of technology developments and applications especially in Germany and Northern Europe regarding phosphorus recovery from sewage sludge.

PHOSPHORUS RECOVERY PROCESSES:

In the course of all recovery processes described below, chemical or thermal digestion takes place. All processes are under development, and have not yet been tested on a large technical scale.

a. The Krepro Process :

The Krepro Process developed by Kemira Kem water, and the operator of the Helsingborg's WWTP allows a separation of sewage sludge into four fraction:
(i)Iron phosphate (ii) highly calorific organic sludge (iii)precipitation chemicals and (iv)a carbon-rich centrate.

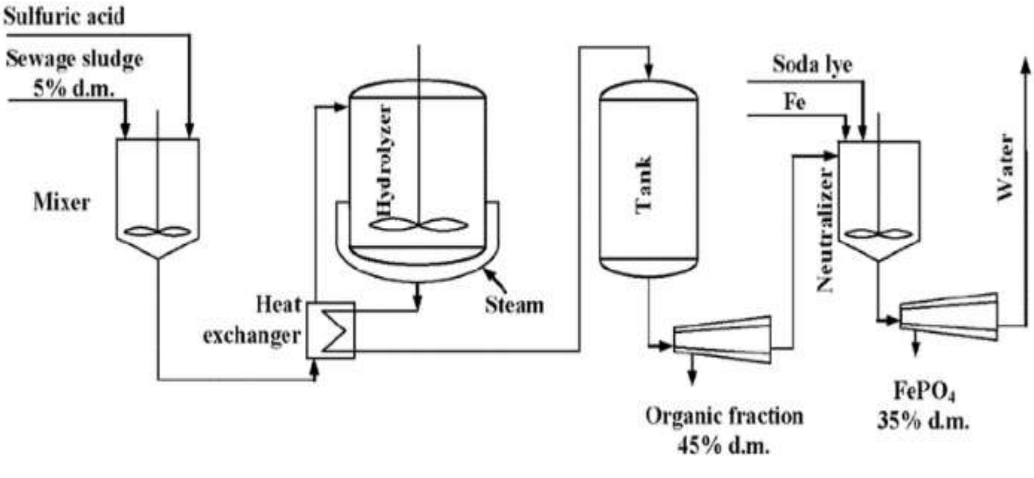

Figure 5 : Krepro Process[17]

Phosphorus is recovered as iron phosphate. In the first step, as shown in Figure 4, the sludge is passed on to a hydrolysis reactor, where it remains for 0.5 to 1.0 h at a pH of 1.5, a temperature of up to 150°C, and a pressure of 4 bar. Under these conditions, about 40 – 60 % of the organic substance and, depending on the precipitant used, about 75 % of the phosphorus are dissolved. The non- dissolved fraction is then dewatered to about 45 % DS in a centrifuge. Due to this high DS concentration of this fraction, the sludge is suited for combustion. The reaction is conducted in that way, that a large part of the heavy metals remains undissolved and can be separated with the sludge. The concentrate contains the dissolved organic substances and part of the nitrogen, the dissolved phosphorus as well as ferrous iron ($Fe^{2+)}$. Upon the addition of ferric iron ($Fe^{3+)}$ as precipitant and a stepwise increase of the pH-value, iron phosphate (Fe_3PO_4) is precipitated and separated from the liquid phase by means of a centrifuge. Residual water with a high concentration of COD and the precipitant remains. This water can be used in the sewage treatment plant as a carbon source for denitrification and due to the Fe^{2+} content as precipitant .It has to be taken into account that the technology was developed for Swedish conditions, e. g. more precipitants were applied, mainly iron-based coagulants. The main advantage of this process is the significant reduction of sewage sludge volume. Though, the long- term fertilising properties of the low-contaminated products were promising. The Krepro process has been tested on a pilot scale for about 3 years in sewage treatment plant.

b. Kemicond Process:

The Krepro process was modified by Kemira in 2003. The Kemicond process for sludge conditioning consists of a chemical treatment by sulphuric acid and hydrogen peroxide followed by a two stage dewatering unit (Figure 4). It is shown that the chemical treatment can facilitate the dewatering, resulting in much higher solid concentrations compared to untreated sludge. Furthermore the bacterial counts indicate that the germs are reduced to an extend similar to pasteurisation. With some modifications the process offers the possibility of phosphorus recovery and a reuse of precipitants. A large scale plant is planned for the WWTP.

c. The Seaborne Process:

The Seaborne process serves to treat organic substances, among others sewage sludge and has been developed by the Seaborne Environmental Research Laboratory in Germany. The entire process consists of several individual modules that are linked with each other in terms of the mass flows. Apart from the recovery of phosphorus and nitrogen in the form of mineral fertilisers, a discharge of heavy metals and digester gas cleaning shall take place. Following an increase in the pH value by the addition of disodium carbonate, nitrogen and phosphorus are precipitated in the form of MAP from the heavy metal-depleted liquid phase. In a drying/degasification process, NH_3 gas is produced from MAP. Together with the magnesium hydrogen phosphate, it may be used for the production of fertilisers. In this drying/degasification process, di-sodium carbonate is formed from sodium hydrogen carbonate under separation of CO_2 that is also used for the synthesis of fertilisers. Sodium hydrogen carbonate may be produced by the reaction of NaCl and CaO with the CO_2 of the digester gas. During this process, methane gas and $CaCl_2$ salt arise. The advantages of Seaborne are the closed cycles, the synthesis of different fertilisers such as mono-ammonium phosphate, di-ammonium phosphate or di-ammonium calcium phosphate as well as the production of methane. Since 2000, a pilot plant has been operated in Owschlag (Schleswig-Holstein). The first large-scale plant shall be tested at the sewage treatment plant. There, modifications and simplifications of the complex process have been recently considered regarding economy and mass balances.

d. The Aqua Reci Process:

The Aqua Reci process is a wet oxidation process for sewage sludge, which is run in the supercritical range of water (Figure 4). Under these conditions, pure oxygen is added for a complete oxidation of all sludge constituents to take place within a residence time of 60 seconds in the reactor. The heat generated during oxidation allows for an auto-thermal mode of operation, such that thermal energy is required for the start-up of the process exclusively. The accrued sludge is considerably depleted inorganic compounds. From the remaining inorganic sludge, phosphorus may be separated by the addition of base in terms of calcium phosphate. Using base, the heavy metals will not be dissolved; however, its use is not always promising . The amounts of chemicals required for this purpose are far below those necessary for the dissolution of phosphorus from sewage sludge ashes. Known problems associated with this process are the formation of deposits, especially in the range of the heat exchangers, as well as corrosion. Pilot plants for supercritical wet oxidation are operated in the USA and Japan. Since 1998, a pilot plant has been run in Sweden.

(D)Processes for Phosphorus Recovery from Sewage Sludge Ashes:

a. The Bio-Con Process:

The BioCon process has been developed by PM Energi A/S in Denmark. The process consists in a modular concept for sewage sludge treatment[8], comprising the three modules of drying, incineration, and phosphorus recovery by ion exchange. The description below shall be restricted to the third module (recovery). Following combustion, the ashes are crushed. In a mixing reactor, sulphuric acid (pH ~ 1) and water are added to the pulverised ashes (Figure 5). This leads to the partial dissolution of phosphorus compounds and heavy metals. Subsequently, the remaining mineral constituents such as iron chloride, potassium hydrogen sulphate, and phosphoric acid as well as heavy metals can be separated by several ion exchangers that are connected in series. However, ion exchange is assumed to be not economic due to the considerable ion concentration. It requires numerous regenerations. Furthermore, the separation of phosphorus is probably reduced in the acid medium in comparison to sulphate.

b. The SEPHOS-Process:

The SEPHOS (sequential precipitation of phosphorus) process is under development by the Institute WAR of the TU Darmstadt and the Ruhrverband (Germany): Sludge ash is treated with sulphuric acid (pH < 1.5), the residual solids (mostly sand) are separated (Figure 6). In the filtrate, the pH value is then stepwise increased with caustic soda to pH 3.5 to separate phosphorus and heavy metals. The precipitate product is an aluminium phosphate, which can be used as raw material in the electrochemical phosphate industry . It is also feasible to produce calcium phosphate, which could be reused as a fertiliser by inserting a further process step: The amphoteric elements, especially aluminium and phosphorus of the aluminium phosphate are dissolved by an elution with a base (pH 12 – 14), the insoluble residuals (heavy metals) are separated. The dissolved phosphorus can then be precipitated as calcium phosphate by the addition of calcium ions, potentially also by crystallisation[7]. The dissolved aluminium can be recycled as coagulant for the wastewater treatment (advanced SEPHOS process). In a further research project of the TU Darmstadt, this process will be optimised and evaluated in economic and ecologic terms.

c. The Rotary Furnace Process:

An interesting new process principle concerning phosphorus recovery from sewage sludge ashes has been developed in laboratory scale by the BAM in Berlin, Germany (Kley et al., 2003) - the rotary furnace process . Prior to the thermal treatment in the rotary furnace (~ 1050 °C) a preliminary mono-incineration of the sludge is performed to remove the organic substances. Due to the supply of 35 – 40 % alkali and/or earth alkali chloride solutions such as KCl and $MgCl_2$ in molar surplus compared to the heavy metal concentrations, heavy metals are released as gaseous chlorides which are scavenged by wet deposition during gas treatment and have to be disposed as hazardous waste. The generated products are low-contaminated organic-free potassium and magnesium phosphates which seem to be similar to commercial fertilisers concerning also the plant availability. However, the process still has to be optimised from the economic point of view regarding the considerable energy consumption.

CONCLUSION:

Phosphorus is an essential, yet limited resource, which cannot be replaced by any other element. This is why there are increasing efforts to recycle phosphorus contained in wastewater. It involves the recovery of phosphorus and, normally, the separation of phosphates from harmful substances. Phosphorus can be recovered from wastewater, sewage sludge, as well as from the ash of incinerated sewage sludge, and can be combined with phosphorus removal in most cases. The phosphorus recovery rate from the liquid phase can reach 40 to 50% at the most, while recovery rates from sewage sludge and sewage sludge ash can reach up to 90%. There are various methods which can be applied for phosphorus recovery. Up to now, there is limited experience in industrial-scale implementation. The costs for recovered phosphate exceed the costs for phosphate from rock phosphate by several times. For German conditions, the specific additional costs of wastewater treatment by integrating phosphorus recovery can be estimated at euro 2-6 per capita and year.

FUTURE SCOPE:

As well as the further work on the economic aspects of recovery, a number of research priorities have been identified including: a better understanding of chemical and physical reaction conditions which promote crystallisation of phosphates; a clearer picture of the segregation of heavy metals in sewage treatment regimes; the role of organic materials in precipitation or crystallisation processes; the role of different seed materials (sand, calcite) in promoting recovery; a better knowledge of the solubility phases of different calcium phosphates; the agricultural value of struvite and the need to study its dissolution behaviour (nutrient release) in soils and accessibility for crops; a better understanding of the conditions for nucleation and growth of struvite under real sewage treatment works conditions. More important than all of these, however, is the need to create a will to make phosphorus recovery happen. The non-fertilizer phosphate industry is convinced that the future lies in phosphate recycling and considers that within a decade up to 25% of phosphates used in detergents and other high-grade applications could be recovered from sewage and animal wastes. But the industry cannot make this happen on its own. A partnership is required between the industry and the water treatment sector to begin to recover and, just as important, begin to create a market for recovered phosphate materials. It is needed to provide the leadership and the policy stimulus, to make phosphorus recovery a reality.

References:

[1] Aage, H. K., B. L. Andersen, A. Blom & I. Jensen (1997) The solubility of struvite. *J Radioanal Nucl Chem*, **223**(1-2**)**, 213-215.

[2] Adam, C., B. Peplinski, M. Michaelis, G. Kley & F. G. Simon (2009) Thermochemical treatment of sewage sludge ashes for phosphorus recovery. Waste Management, 29(3), 1122-1128.

[3] Adam, C. (2008) Sustainable and Safe Re-use of Municipal Sewage Sludge for Nutrient recovery Retrieved from http://www.susan.bam.de/

[4] Bauer, P. J., A. A. Szogi & M. B. Vanotti (2007) Agronomic Effectiveness of Calcium Phosphate Recovered from Liquid Swine Manure . Agron. J., 99(5), 1352-1356.

[5] Battistoni, P., R. Boccadoro, F. Fatone & P. Pavan (2005) Auto-Nucleation and Crystal Growth of Struvite in a Demonstrative Fluidized Bed Reactor (FBR). Environmental Technology, 26(9), 975-982.

[6] Benefield, L.D., Judkins, J.F. , Weand Jr. B.L. , 1982. Process Chemistry foe water and Wastewater Treatment, prentice hall inc,Englewood cliffs, New jersey.pp.202-204

[7] Berg, U., G. Knoll, E. Kaschka, V. Kreutzer, D. Donnert, P. Weidler & R. Nüesch (2005) P-RoC-Phosphorus recovery from wastewater by crystallisation of calcium phosphate compounds. Proceedings of Conference on Management of Residues Emanating from Water and Wastewater Treatment, pp. 9-12.

[8] Bergmans, B. (2011) Struvite recovery from digested sludge - At WWTP West. Faculty of Civil Engineering. TU Delft.

[9] Bhargava, D.S,Sheldarkar, S.B 1993 use of TNASC in phosphate adsorption studies and relationship , literature,Experimental methodology,Justification and effects of process variable water Res.27(2) ,303-312

[10] Biplob K. Biswas, Katsutoshi Inoue *, Kedar N. Ghimire, Hiroyuk Harada, Keisuke Ohto, Hidetaka Kawakita. Department of Applied Chemistry, Saga University, Honjo 1, Saga 840-8502, Japan

[11] Biswas, B.K., Inoue, K., Ghimire, K.N., Ohta, S., Harada, H., Ohto, K., Kawakita, H., 2007. The adsorption of phosphate from an aquatic environment using metalloaded orange waste. J. Colloid Interface Sci. 312, 214–223.

[12] . Bridger, G. L., M. L. Salutsky & R. W. Starostka (1962) Micronutrient Sources, Metal Ammonium Phosphates as Fertilizers. Journal of Agricultural and Food Chemistry, 10(3), 181-188.

[13] Britton, A. (2009) Fertilizer products from the crystallisation from waste water: OSTARA Crystal Green (struvite). BALTIC 21 - Phosphorus Recycling and Good Agricultural Management Practice. Berlin.

[14] Cabeza, R., B. Steingrobe, W. Römer & N. Claassen (2011) Effectiveness of recycled P products as P fertilizers, as evaluated in pot experiments. Nutr Cycl Agroecosyst, 91(2), 173-184.
[15] Chen, X., H. Kong, D. Wu, X. Wang & Y. Lin (2009) Phosphate removal and recovery through crystallization of hydroxyapatite using xonotlite as seed crystal. Journal of Environmental Sciences, 21(5), 575-580.
[16] Cordell, D., A. Rosemarin, J. Schröder & A. Smit (2011) Towards global phosphorus security: A systems framework for phosphorus recovery and reuse options. Chemosphere, 84(6), 747-758.
[17]Cornel, P. & C. Schaum (2009) Phosphorus recovery from wastewater: needs, technologies and costs. Water Science & Technology, 59(6), 1069–1076.
[18] Dockhorn, T. (2009) About the economy of phosphorus recovery. International Conference on Nutrient Recovery from Wastewater *Streams*, pp. 145-158. IWA Publishing, Vancouver, Canada.

[19] Donnert, D. & M. Salecker (1999) Elimination of phosphorus from waste water by crystallization. *Environmental Technology,* **20**(7)**,** 735-742.
[20] El Diwani, G., S. El Rafie, N. N. El Ibiari & H. I. El-Aila (2007) Recovery of ammonia nitrogen from industrial wastewater treatment as struvite slow releasing fertilizer. *Desalination,* **214**(1–3)**,** 200-214. 36
[21] Giesin, a. (1999). Crystallisation process enables environmental friendly phosphate removal at low costs. Env Techn. 20(7), 769-776
[22] Phosphorus recovery from waste - methods review - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/The-scheme-of-KREPRO-process_fig1_244754844
[23] Piotr Konieczka, (2017). A review of phosphorus recovery methods at various steps of wastewater treatment and sewage sludge management. The concept of "no solid waste generation" and analytical methods. Journal of cleaner production. Vol. (142) Part 4, 1728-1740
[24] Tchobanoglous, G., M. Abu-Orf, G. Bowden & W. Pfrang (2014) Wastewater Engineering: Treatment and Resource Recovery. McGraw-Hill Education, New York.