FLASHPHOS

The complete thermochemical recycling of sewage sludge

CONCEPTUAL ENGINEERING

DATE OF THE DOCUMENT: 29/10/2021

DELIVERABLE VERSION: D4.1, V.01

DISSEMINATION LEVEL: PU

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[1] PU = Public

PP = Res Restricted to other programme participants (including the Commission Services)

RE = Restricted to a group specified by the consortium (including the Commission Services)

CO = Confidential only for members of the consortium (including the Commission Services)

DOCUMENT HISTORY

Project Acronym	FlashPhos
Project Title	The complete thermochemical recycling of sewage sludge
Grant Agreement No	958267
Project Coordinator	USTUTT
Project Duration	2025 / 4 years
Deliverable No.	D4.1
Diss. Level	Public
Deliverable Lead	USTUTT-IFK
Status	X Working
	Verified by other WPs
	Final version
Due date	31/10/2021
Submission date	29/10/2021
Work Package Number & Title	4.2.1 Conceptual Engineering
Work Package Lead	ARP
Contributing beneficiary(ies)	USTUTT-IFK, ARP, INERCO, SYSTEC
Deliverable Description (DoA)	Conceptual engineering of FlashPhos process and pilot plant

Date	Version	Author	Comment
DD/MM/YYYY	X	Name	Comment

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 958267.

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EXECUTIVE SUMMARY

The main objectives of conceptual engineering are defining a process flowsheet for the FlashPhos process including all unit operations and calculate pilot plant material as well as energy balances. This deliverable only contains a brief version of the conceptual engineering such as basic flowsheet and basic numbers of the FlashPhos process. A more detailed conceptual engineering is available to the project partners in a separate document that will be integrated in D4.2. “Design of key components”. In this deliverable “Conceptual engineering of the FlashPhos process and the pilot plant” USTUTT-IFK, ARP, INERCO and SYSTEC are involved.

Waste water treatment plants are the resource of sewage sludge, which is used as fuel for the FlashPhos process. For the FlashPhos process the different types of reactors are needed. In the first reactor, the so called FlashReactor, dried sewage sludge is gasified with air and oxygen. Reaction products are a gas with a higher heating value remaining and a flash slag. While the gas is combusted in a post-combustion chamber and cleaned by a gas cleaning system, the flash slag leaves the reactor. The Refiner is the second reactor, which is operated at reducing conditions with flash slag and coke as a reducing agent as input. In this reactor a refiner-gas is produced, which is injected into a phosphorous recovery unit. Beside phosphorous, heat can be recovered in this unit. The Refiner produces a slag, which can be used as an alternative cement binder after granulation. Using the FlashPhos process 0.026 kg of phosphorous and 0.27 kg of alternative cement binder can be produced per kg dried sewage sludge input.

This conceptual engineering is groundwork for basic and detailed engineering in the work packages 4.1 and 4.2.2, who will continue the engineering process by engineering technical drawings of the pilot plant.

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1 INTRODUCTION

Due to the fact that phosphorous is a critical raw material, the material recovery of phosphorous is getting into the focus of politics, industry and science. To produce climate friendly phosphorous in Europe the use of secondary raw materials, such as sewage sludge, is promising. Annually European wastewater treatment plants produce 9 million tons of sewage sludge (dry substance), of which ca. 68 % are disposed of mostly by soil spreading and the rest is mostly thermally treated by co-incineration[1]. Distributing contaminants in the environment and leaving valuable resources unused, this is both (i) a costly environmental disposal challenge, and (ii) an underexploited commercial opportunity as a source of secondary raw materials. The European sewage sludge contains enough phosphorous to cover the demand of P in the EU. Hence, the recycling of this secondary resource with a minimum of residues will contribute largely to a circular economy accepted by society. Furthermore, the EU will benefit through new employment and increased economic growth by adopting sustainable recycling.

In this project a new process is developed to recover P from sewage sludge. Therefore, a pilot plant will be engineered, designed and erected to demonstrate the new process. The results of this deliverable D4.1 consists of two different documents. The first document is this deliverable report and the second one is a spreadsheet “FlashPhos-Datasheet”. Due to confidentiality only the deliverable will be published, while the “FlashPhos-Datasheet”” is only accessible for partners within the consortium. This spreadsheet contains a detailed description of the overall FlashPhos process and a process for each unit, including mass and energy balances and a preliminary sizing of the key components. During the project duration, the consortium noticed, that some parts of the conceptual engineering are containing confidential content. Therefore, this deliverable provides only a general description of the FlashPhos process, whereas the detailed description in “FlashPhos-Datasheet” including mass and energy balances of each component will be transferred to deliverable “D4.2 Key components”.

1.1 PURPOSE AND TARGET GROUP

In this deliverable the concept of the pilot plant is engineered. Therefore, all necessary components of the plant have to be selected and preliminary sized. The target groups of this deliverable are the work packages 4.2.2 and 4.2.3, in which the basic and detailed engineering is performed on basis of conceptual engineering. In this work package the required measurement strategies for measurements of the plant performance in work package 6 have to be taken into account during the engineering process.

[1] https://ec.europa.eu/eurostat/tgm/table.do?tab=table&plugin=1&language=en&pcode=ten00030

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1.2 CONTRIBUTIONS OF PARTNERS

Table 1 Contributions of partners

PARTNER SHORT NAME	CONTRIBUTIONS
USTUTT	Conceptual Engineering
ARP	Advisory role
INERCO	Advisory role
SYSTEC	Advisory role
ITALMATCH	Technological supervisor

2 OBJECTIVES AND EXPECTED IMPACT

The overall objective in the work package 4 is to engineer, design and erect a new pilot plant to recover phosphorous from sewage sludge. The engineering process is divided into three main task: conceptual, basic and detailed engineering. In this deliverable the conceptual engineering is in focus, while other steps will be addressed in pending deliverables.

2.1 OBJECTIVES

The objective of conceptual engineering is to define a process flowsheet for the pilot plant. Based on this flowsheet mass and energy balances for each unit will be calculated. The calculations results are needed for selecting the most suitable technological elements and unit operations. Preliminary sizing of the main components and the definition and location of auxiliary equipment are also part of the conceptual engineering. At last a preliminary layout of the pilot plant is developed within this work package.

2.2 EXPECTED IMPACT

For the work packages 4.2.2 “Basic engineering” and 4.1 “Design and construction of pilot plant key components” the results of the conceptual engineering are the groundwork for its actions. As mentioned in the introduction the results of the conceptual engineering consist of this deliverable report and a spreadsheet “FlashPhos-Datasheet”, which is postponed to deliverable D4.2 due to confidentiality. Based on the defined process flowsheet, the mass and energy balances and preliminary sizing of the key components in work package 4.1, the detailed engineering of pilot plant key components is performed. For sizing the components of the pilot plant material throughput and energy consumption is mandatory. In work package 4.2 a basic engineering of the pilot plant will be performed, in which the results of the conceptual engineering and detailed engineering of the key components will be merged.

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3 DESCRIPTION OF TECHNICAL/SCIENTIFIC ACTIVITIES

The leader for the conceptual engineering is USTUTT-IFK supported by ARP, INERCO and SYSTEC. In the subtask “Conceptual engineering” with the work package 4 “Process Development and Pilot Plant Design and Construction” ITALMATCH has a supervisor role of technological aspects, especially in designing the Refiner. During the process of conceptual engineering the following task have to be solved:

- Definition of the process flowsheet
- Selection of most suitable technological elements and operation units
- Calculation of plant material and energy balances
- Preliminary sizing of main components
- Definition and location of auxiliary components
- Calculation of energy needs
- Develop of a preliminary layout

To complete these tasks, it is necessary to have a closer look at the used sewage sludge as resource.

3.1 SEWAGE SLUDGE

As mentioned in the introduction the used resource for the FlashPhos process is sewage sludge. The quality and chemical composition of sewage sludge varies much due to different treatments in waste water treatment plants. For the conceptual engineering various calculations were performed, which are based on the sewage sludge composition given in Table 2. To guarantee acceptable handling of the sludge and reducing the energy demand for the gasification, the water content of the sludge is fixed to 15 mass-%.

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Table 2 Sewage sludge composition

COMPONENTS	MASS-%
C	23.24
H	3.18
N	3.41
S	0.94
Cl	0.1
O	15.73
H_2O	15
Ash	38.43

The sewage sludge almost consists of approximately 39 mass-% of inorganic ash. Beside the inorganic ash and water, sewage sludge contains organic components like carbon, hydrogen, nitrogen, sulphur, chlorine and oxygen. The ash of the sewage sludge contains phosphorus. Therefore a composition of the main components of the produced ash is given in Table 3 Sewage sludge ash composition

Table 3 Sewage sludge ash composition

COMPONENTS	MASS-%
SiO_2	29.66
CaO	22.50
P_2O_5	20.41
Al_2O_3	11.70
Fe_2O_3	10.61
MgO	2.94
K_2O	2.17

The concentration of P_2O_5 in the sewage sludge ash, which has the highest value of the process, is approximately 20 mass-%. The total amount of phosphorous during the production of the pilot plant depends on the quality and phosphorous content of the provided sewage sludge.

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3.2 PROCESS FLOWSHEET

The main task in this work package is the definition of a process flowsheet with all necessary components for the pilot plant in the most suitable order. This includes the core FlashPhos process and additional equipment, for example gas cleaning and phosphorous recovery. To define a technical feasible and suitable process flowsheet, ARP, MIT, SYSTEC, ITALMATCH TUGRAZ and AMC were consulted These consultations included component and potential issues with the components.

3.3 MASS AND ENERGY BALANCE

Based on the process flowsheet mass and energy balances have been calculated with the simulation software FactSage by CRCT – ThermFact Inc. & GTT-Technologies. The simulations are performed as chemical equilibrium calculations with minimization of the Gibbs energy. For each unit of the FlashPhos process an individual mass and energy balance is calculated, on what basis preliminary sizing of the components is performed.

4 RESULTS AND DISCUSSION

In this chapter the results of the work package are presented. This includes process flowsheets of the FlashReactor and Refiner, followed by a mass balance of the FlashPhos process.

4.1 PROCESS FLOWSHEET

As there are two main reactors part of the FlashPhos process, two process flowsheets were created and are presented in the following chapters. Starting with the FlashReactor (Figure 1) followed with the Refiner (Figure 2). In both figures input streams are coloured white and output streams in blue.

4.1.1 FLASH REACTOR

Due to the fact, that sewage sludge is delivered by the waste water treatment plant with a water content of 75 mass-% and a needed water content for the FlashReactor of 15 mass-%, a dryer is the first process step of the FlashPhos process. During the drying process the sewage sludge particles were grinded to a diameter of $d_{80} = 300\ \mu m$. The dried and grinded sewage sludge is mixed with a slagging agent for example CaO, before entering the FlashReactor. This mixture is fed into the FlashReactor were it is gasified in under stoichiometric conditions in the presents of air.

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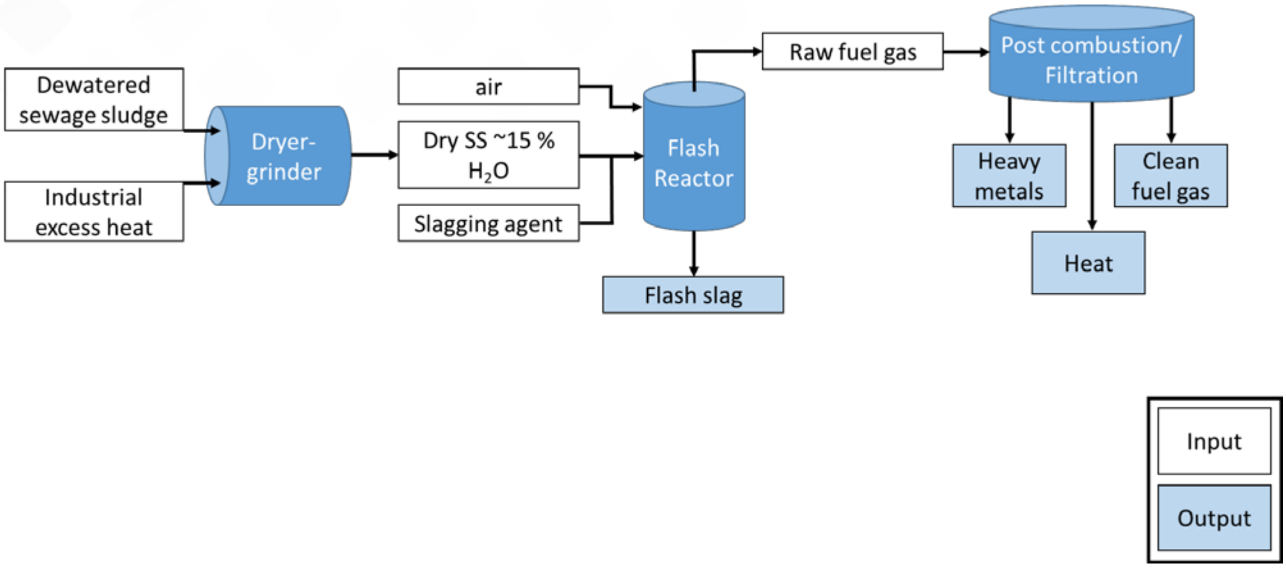

Figure 1 Process flowsheet FlashReactor

Reaction results of the flash gasification in the FlashReactor are a slag and a raw fuel gas. The produced fuel gas is injected into a post combustion chamber and burned in over stoichiometric conditions. Filtering the fuel gas separates a solid heavy metal fraction from the clean fuel gas. During the post combustion and filtration system heat can be recovered.

4.1.2 REFINER

Slag and coke as a reducing agent are fed into the Refiner, which is strictly operated at high temperatures and under reduction conditions. Reaction products of the Refiner are a Refiner slag and gas. The produced slag is getting granulated to an alternative cement binder and the Refiner gas is injected into a phosphorous recovery unit. In the phosphorous recovery unit, the phosphorous is separated from the produced syngas. During this process heat is accessible for further usage.

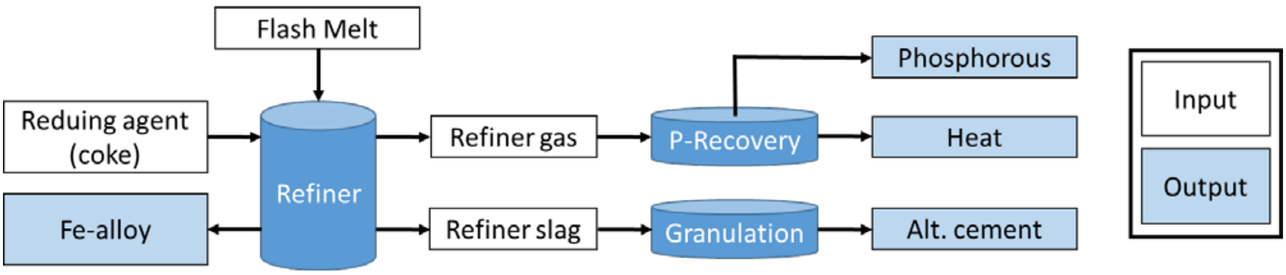

Figure 2 Process flowsheet Refiner

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4.2 MASS BALANCE OF THE FLASHPHOS PROCESS

Based on the process flowsheet a mass balance of the process is calculated, which is shown in Figure 3. The given numbers in the figure are normalized to 1 kg sewage sludge with a water content of 15 mass-%. As described during the process description the sewage sludge is delivered from a waste water treatment plant with a water content of 75 mass-%. To reach 1kg sewage sludge feed for the FlashReactor with 15 mass-% of water, a raw sewage sludge input of 3.3 kg sewage sludge is required. During the drying process 2.3 kg of water is separated from the raw sewage sludge. 0.03 kg of CaO additive and 0.06 kg coke with a particle size of $d_{coke} = 0.5$ mm as a reducing agent have to be added per kg dried sewage sludge to the FlashPhos. To ensure a gasification of the sewage sludge 2.24 kg of air have to be injected into the process as gasification medium. By feeding 1kg dried sewage sludge, 0.026 kg of phosphorous can be produced by the FlashPhos process. Another process product is 2.97 kg of fuel gas with a lower heating value of $LHV = 1.57$ MJ/Nm³. 0.27 kg of alternative cement binder is a valuable by-product of the process. As by-products of the FlashPhos process 0.04 kg of iron alloy and 0.0025 kg of a heavy metal concentrate are produced.

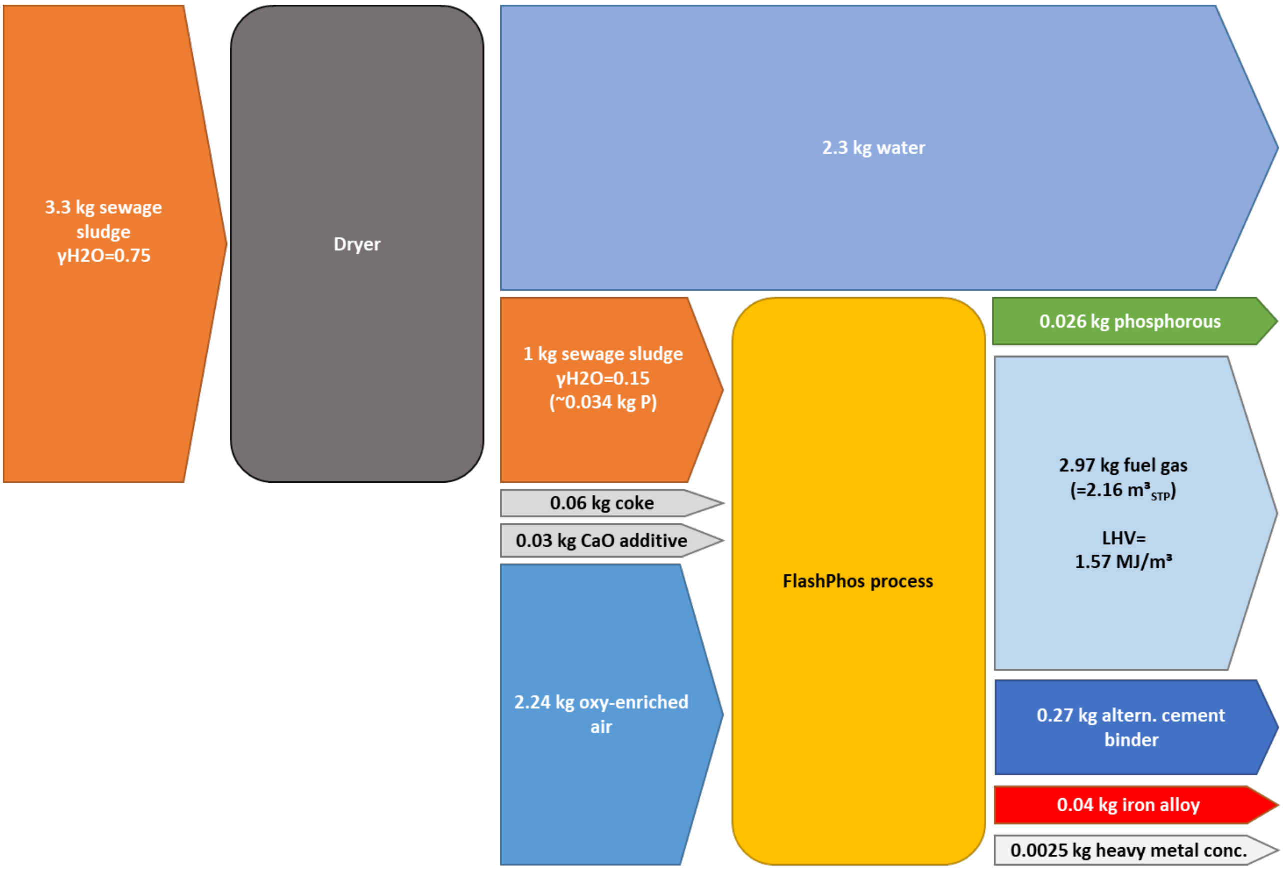

Figure 3 Mass balance FlashPhos process

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5 LINKS WITH OTHER WPS

The results of the conceptual engineering are groundwork for work packages 4.2.2 “Basic engineering” and 4.1 “Design and construction of pilot plant key components”. The results are distributed to the consortium in two separate documents, a publishable deliverable and a confidential “FlashPhos-Datasheet”. This spreadsheet contains detailed description of the functionality of every process unit, mass and energy balances and preliminary sizing of the main components of the FlashPhos process. Between the work packages 4 to 2 “Modelling and Simulation” and 4 to 3 “Component testing and pre-experiments” an iterative data exchange during the engineering process is necessary.

6 CONCLUSIONS AND RECOMMENDATIONS

In this deliverable the main results of the conceptual engineering are presented. These results include a process flowsheet for the FlashReactor and the Refiner as well as a mass balance of the overall process. It shows, that 0.026 kg of phosphorous can be recovered per kg dried sewage sludge. This amount of phosphorous can be recovered assuming the reactions are in chemical equilibrium and with the sewage sludge composition of Table 2. The main loss of phosphorous is ferrophosphorus in the Refiner.

As follow-up action, the work of basic and detail engineering can be mentioned, which are performed within the work packages 4.2.2 and 4.1.

7 BIBLIOGRAPHY

1 https://ec.europa.eu/eurostat/tgm/table.do?tab=table&plugin=1&language=en&pcode=ten00030; [last review: 09.08.2021]

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