Nutrients recovery from marine aquaculture sludge through biodrying process

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1. INTRODUCTION

The aquaculture industry is currently one of the fastest-growing and promising food sectors worldwide, accounting for 46% of global fish production. However, the aquaculture activity generates large quantities of animal by-products (ABPs) such as dead fish, remains of animals not marketed (head, skeleton, fins, etc.). ABP also includes an important volume of under-valorised aquaculture sludge resulting from recirculating aquaculture systems which is mainly composed of fish faeces and feed. To be in line with the New European Circular Economy Plan this work aims to valorise aquaculture sludge, through an innovative technological approach (**Figure 1**), into high-added value products, such as bio-based fertilisers (BBFs) and improve the overall sustainability of the aquaculture sector. The treatment scheme proposed takes biodrying technology as a starting treatment and includes some downstream processes to improve the quality of the obtained product and maximise the recovery of nutrients and energy.

Biodrying is a biological aerobic process in which microorganisms consume organic matter in the sludge, producing heat that is then used, combined with the forced air, to remove the moisture present in it. Overall, the process is less energy-demanding and thus, cheaper than direct air drying due to the use of biologically produced heat. The biodried product obtained could be marketed either considered as a solid organic fertiliser, according to European Regulation EU 2019/1009, or as biomass fuel. In the first case, the obtained product was characterised following the requirements established in the mentioned regulation. If the phosphorus availability for plants was detected to be low, a P-chemical and biological solubilization was proposed to overcome this problem. In the second case, the organic amendment can be used as a biomass fuel as an alternative energy source in a biomass boiler, while the nutrients that remained in the ashes (mainly P) were recovered via acidic extraction.

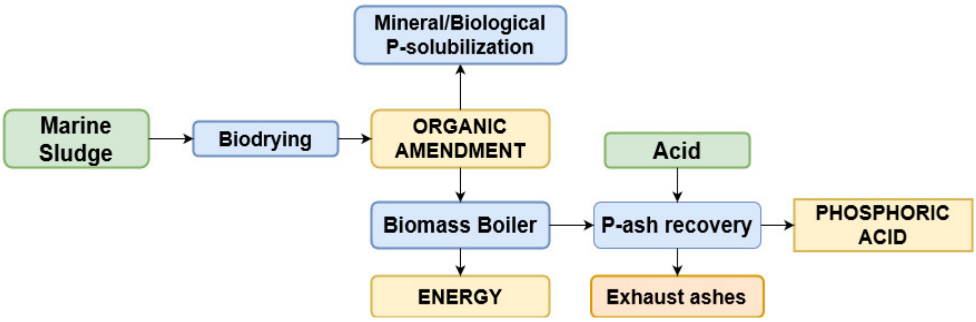

Figure 1. Biorefinery diagram for marine sludge valorisation. Input materials are in green, technologies proposed are in blue, products obtained in yellow and waste stream in orange.

2. MATERIALS AND METHODS

The biodrying unit consisted of a 100 L adiabatic cylindrical reactor. Air was supplied with an air compressor through a perforated plate located at the bottom of the reactor. The humidity of the inlet air, the weight loss and the temperatures of both the inlet air and the bulk mixture were regularly monitored.

In the biodrying unit, a mixture of solid fraction from fish sludge with bulking agent (wooden chips) in a 1:2.5 (v:v) ratio was employed to adjust the initial moisture content for the experiments (Villergas and Huiliñir, 2014). An air flow rate strategy was established according to previous studies (Guerra-Gorostegi *et al.,* 2021), depending on the initial volatile solids content of the sludge and the temperature of the bulk mixture during the experiment. The obtained biodried product was analysed to be used as an organic amendment for fertiliser formulation or as a biomass fuel. For the last valorisation route, ashes resulting from combustion were acid-treated to extract phosphorus. Three different extractants were tested (H_2SO_4, HCl and Aqua Reggia) at different concentrations ranging from 0.05-1 M, different extractant:ash ratios and extraction temperatures (50-135ºC). The phosphorus concentration was measured to determine the process efficiency. All the extractions were performed during 2 h in 0.1 L Erlenmeyer flasks.

3. RESULTS AND DISCUSSION

An example of the biodrying performance is depicted in **Figure 2**. After a 2-day lag phase, the mixture temperature reached up to 50ºC and maintained thermophilic conditions for 6 days. Then, the mesophilic-cooling phase started progressively decreasing to 30ºC. A great reduction of the sludge moisture content was achieved (from 73.9% to 45.4%) and a production ratio of 0.49 organic amendment: marine sludge was obtained. However, a 15% of the organic matter was consumed, which decreases the effectiveness of the biodried product to be applied as biomass fuel.

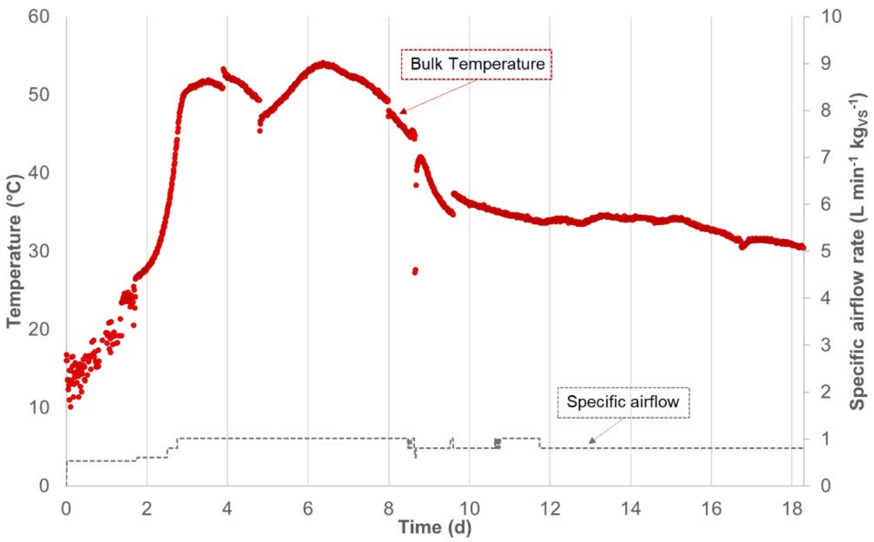

Figure 2. Bulk mixture temperature profile and specific airflow rate of the biodrying experiment.

The characteristics of the biodried product are shown in **Table 1**. The organic amendment is a fair source of phosphorus (10.9% in the form of P_2O_5). With this characteristic and the organic carbon content (11.9%), it could be categorised as solid organo-mineral fertiliser (PFC 1 (B)(I)) with one declared primary nutrient, according to EU Regulation 2019/1009. Further analysis will be performed to determine the phosphorus availability for plants, to evaluate the necessity of the P-solubilization step proposed in **Figure 1**.

Table 1. Total solids (TS), volatile solids (VS), nutrients content (total nitrogen, total phosphorus, and total potassium) of the obtained biodried product (n=3).

Parameter	Value
TS (g kg^{-1})	574.40 ± 2.50
C_{org} (g kg^{-1})	118.72 ± 1.98
TN (g kg^{-1})	15.21 ± 0.29
TP (g kg^{-1})	47.72 ± 0.67
TK (g kg^{-1})	0.63 ± 0.01

On the other hand, the obtained biodried product can be used as a source of biomass fuel. The lower heating value (LHV) was around 3.4 MJ kg^{-1} limiting the feasibility of the maintained combustion of the product by itself. Regarding the P-acidic extraction, **Table 2** reports the P extraction yields obtained in the initial screening of conditions. In general, temperature and the extractant: ash ratio seemed to be the most influencing parameters, rather than acid concentration, obtaining the best results with high temperatures (>100ºC) and/or high extractant: ash ratios (35). Additional experiments will be performed to optimize the acidic extraction to lower the economic costs in terms of energy and acid consumption.

Finally, the energy balance performed an estimated energy production of 468.1 kWh t^{-1} in the biomass boiler able to overcome the estimated energy consumption of the biodrying unit (100 kWh t^{-1}) and the acidic treatment of the combustion ashes (179.8 kWh t^{-1}), resulting in a net energy production of 188.3 kWh t^{-1}.

Table 2. Extraction results from the biodried product ashes using different extractant agents, temperatures and ratios.

Extractant	Concentration	Extractant:ash ratio	Extraction Tª (ºC)	P-extraction Efficiency
H_2SO_4	0.5	20	50	70.1%
			135	100%
		35	50	85.5%
	0.19	35	50	81.8%
HCl	0.5	50	115	100%

Aqua Reggia	-	20	135	100%

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