UNIVERSITAT DE BARCELONA

MASTER FINAL PROJECT
MASTER OF ENVIRONMENTAL ENGINEERING

Development of an air pollutant emission control system for the Fishmeal Industry in Peru

Author

Milagros del Carmen Bernales Muñoz

September 2020

Director/s

Dr. Carmen Sans Mazón

Chemical Engineering and Analytical Chemistry Department. University of Barcelona

UNIVERSITAT DE BARCELONA

INDEX

FIGURE INDEX

UNIVERSITAT DE BARCELONA

ABSTRACT:

Peruvian fishery is ranked among the 10 countries with the highest global fisheries production due to the abundance of marine biomass located on the Pacific coast. Therefore, it is a strategic resource for the country's economy, especially for anchovy fishing, the main marine resource for the production of fishmeal, for which 95% of the catch is destined and which ends up placing Peru as the leading producer of fishmeal in the world.

Since the 1950s, the evolution of the fishing industry has been constant, however, the fishmeal industry is one of the sources generating emissions of particulate matter (PM), nitrogen oxides (NOx), sulphur oxides (SO_x), hydrogen sulfide (H_2S), trimethylamine (C_3H_9N), mercaptans and ammonia (NH_3) in the country. These emissions are currently treated with atmospheric control techniques and have managed to comply with the maximum permissible limits established by Peruvian legislation. However, another polluting aspect not taken into account with so much pressure towards the industry is the pollution towards the population caused by the bad odors generated during the process.

In this research a review of the production process of fishmeal, the legislation established by the Peruvian state and the European Union was carried out, and of the different scientific studies focused on the control of odours produced by various industries and especially the fishing industry and fishmeal. With the available scientific information, an air pollutant treatment system has been developed to help reduce odors to 100%. This system includes the control techniques already used by the industry, such as, the use of cyclones, scrubbers with sea water, to which is added the addition of a biofilter as a new technique.

The selection of the biofilter for odor reduction was based on savings in installation and maintenance costs compared to incineration (thermal and catalytic), chemical absorption, water absorption and adsorption, by 84%, 58%, 57 % and 11% respectively. In addition to the high efficiency achieved in the elimination of hydrogen sulfide (H_2S), trimethylamine (C_3H_9N), mercaptans and ammonia (NH_3) in fishmeal plants, the food sector, sewage and waste treatment plants. It should be noted that the parameters of use of the biofilter are still under study, so there is no specific model for each industry.

1. INTRODUCTION

The Peruvian Sea is located in the Pacific Ocean through whose waters the Humboldt Current flows. The stream, which comes as a cold body of water that provides a lot of food and nutrients, produces more fish per unit area than any other region of the oceans in the world along the 3080 kilometres of the Peruvian coast [10]. This particularity places Peru among the 10 countries with the largest fishery production in the world [22]. This resource is considered as a strategic element for the Peruvian economy, since it is the largest source of foreign exchange after mining, representing 2% of the total gross domestic product [52], and the third most important resource at national level [31].

Among the different types of fishing that exist, the industrial pelagic fishery is the most developed and fastest growing. Since the beginning of fishing activity in the 1950s, it continues remain as a traditional technique used until today [21]. The main resource of pelagic fishing is anchovy (*Engraulis ringens*). This fish depends on several factors to maintain its biomass level or population abundance, such as; the level of extraction, the protection of spawning biomass and environmental factors that affect marine productivity, such as the El Niño and / or La Niña phenomenon [28]. Recent research estimates that the biomass of anchovy in the Peruvian sea is 8.340.000 tonnes, establishing a catch limit between the 2 annual seasons for the period 2019-2020 a total of 4.886.000 tonnes [44,45].

As anchovy is such an important resource. It is a species of rapid growth, short life, and with a longevity between 3 and 4 years, so, in order to protect the sustainability of the species, their capture takes place between 1 and 2 years of age when their height reaches between 10 and 18 cm of total length [46]. In addition, it is a fish that has properties with a high content of polyunsaturated fatty acids, such as eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) and that due to its characteristics as a fragile fish and its rapid deterioration, its storage and transportation options are limited [26].

Despite this, industry and government have invested large amounts of money to increase the direct human consumption of this resource, however, the projects have had a low impact, due to their distinctive and strong flavour, be unattractive to Peruvian cuisine compared to other fishery resources [26].Therefore, despite the efforts of the government and the industry to introduce anchovy as a fish for consumption, the important role it represents for the Peruvian economy is developed in the industrial part, and, having as its main axis the fishing sector, fishmeal production, equivalent to 50% of world farmed fish production [25].

Fishmeal serves as the main ingredient for the production of balanced feed for poultry, laying birds, pigs, ruminants, dairy cows, cattle, sheep and aquatic animals (shrimps, fish and others), representing a positive impact on global food security [25].

Considering the above, the classification of the world production of fishmeal is concentrated in 10 countries, being Peru the first world producer with a total of 890 tonnes produced in 2019. It is followed by Vietnam (460 tonnes), EU-27 (450 tons), Chile (360 tonnes), China (350 tonnes), Thailand (335 tonnes), United States (258 tonnes), Norway (230 tonnes), Japan (180 tonnes) and Morocco (170 tonnes), [12]. It should be noted that 95% of the anchovy catch is destined for its production, [14,15], and the 11th largest export [31]. Almost 80% of Peruvian exports went to China, while 5% and 4% went to Japan and Vietnam, respectively [23].

The production process of fishmeal, such as cooking and drying, generates significant sources of polluting emissions of particulate matter (PM), nitrogen oxides (NOx) and sulphur oxides (SO_x) and hydrogen sulfide (H_2S) respectively [51], added to high odor levels due to the presence of trimethylamine (C_3H_9N), [11]. Trimethylamine is a substance found naturally in the muscle tissue of fish, a volatile nature found in factory effluents that process fishmeal, causing problems due to bad air odors, reporting itself as an extremely flammable substance of toxic nature manifested by its irritant nature on the skin, eyes and upper respiratory tract [38].

Because of this, on May 16th, 2009, the Ministry of the Environment (MINAM) in Peru approved the Maximum Allowable Limits for Emissions (ALE) from the Fishmeal and Fish Oil Industry and Hydro Biological Waste Flour with Supreme Decree Nº011-2009-MINAM. The new legislation forced the fisheries sector to reduce emissions of hydrogen sulfide and sulfides to 5 mg/m^3 and particulate matter to 150 mg/m^3 [50]. Following the approval of the Maximum Allowable Limits for Emissions issued by the Peruvian State, the fishmeal industry as a whole decided to migrate from direct drying to indirect steam in order to reduce the emissions produced and to comply with the requirements of the Peruvian State. Within this order of ideas, we can still consider as an important factor in the fishmeal industry the presence of foul smelling vapours or gases in the air, which question whether the atmospheric control techniques necessary to provide the coastal population with an adequate quality of life.

2. OBJETIVES

The main objective of this project is to identify the processes of fishmeal production and detect the stages of the process where the polluting atmospheric emissions are produced and, accordingly, find the best control techniques available for the Peruvian industries dedicated to this activity.

The specifics objectives are:

- To describe the production processes of fishmeal.
- To identify the current gaseous emissions and control strategies used by the fishmeal industry in Peru.
- To review the approved Peruvian legislation on the maximum permissible emission limits imposed for the fishmeal industry and compare with other existing legislation.
- To select the best control techniques available for the fishmeal production process.
- To develop a system of atmospheric pollutant treatments for the fishmeal industry.

3. PROCESS DESCRIPTION

The fishing activity in Peru is made up of 393 industrial plants, 222 canned, frozen and cured producers, 52 destined for the production of residual flour and reuse of residues, while 119 industries are responsible for the production of fish meal [52]. As there are a large number of industries dedicated to the production of fishmeal, there is no specific production model to which all Peruvian industries adapt, however, this research will be considered the standard model that shows the high technology used.

3.1. Production process

In general terms, the basic operations will be mentioned according to the literature found by Sotomayor and Power [55], in their book "Clean technologies and the environment in the Peruvian industrial sector". This book collects information extracted from the Pisco Flour and Fish Oil Producers Association (APROPISCO) of a group of fishing industries, which is made up of 5 companies from the South coast of Peru (TASA, Fishing Diamante, Austral Group, CFG Investment and Prisco).

According to the information collected, the production process of fishmeal shall be described and divided into two lines, in accordance with the flowchart of *Figure1*: the solid phase, identifying each operation by letters, A, B, C, E, F, G and the liquid phase, identified by letters, H, I, J, K, marked in red. Thereafter, each operation shall be described step by step in Section 3.1.1 and 3.1.2 respectively. An illustration of all the production process of fishmeal explained is show in *Annex 1*.

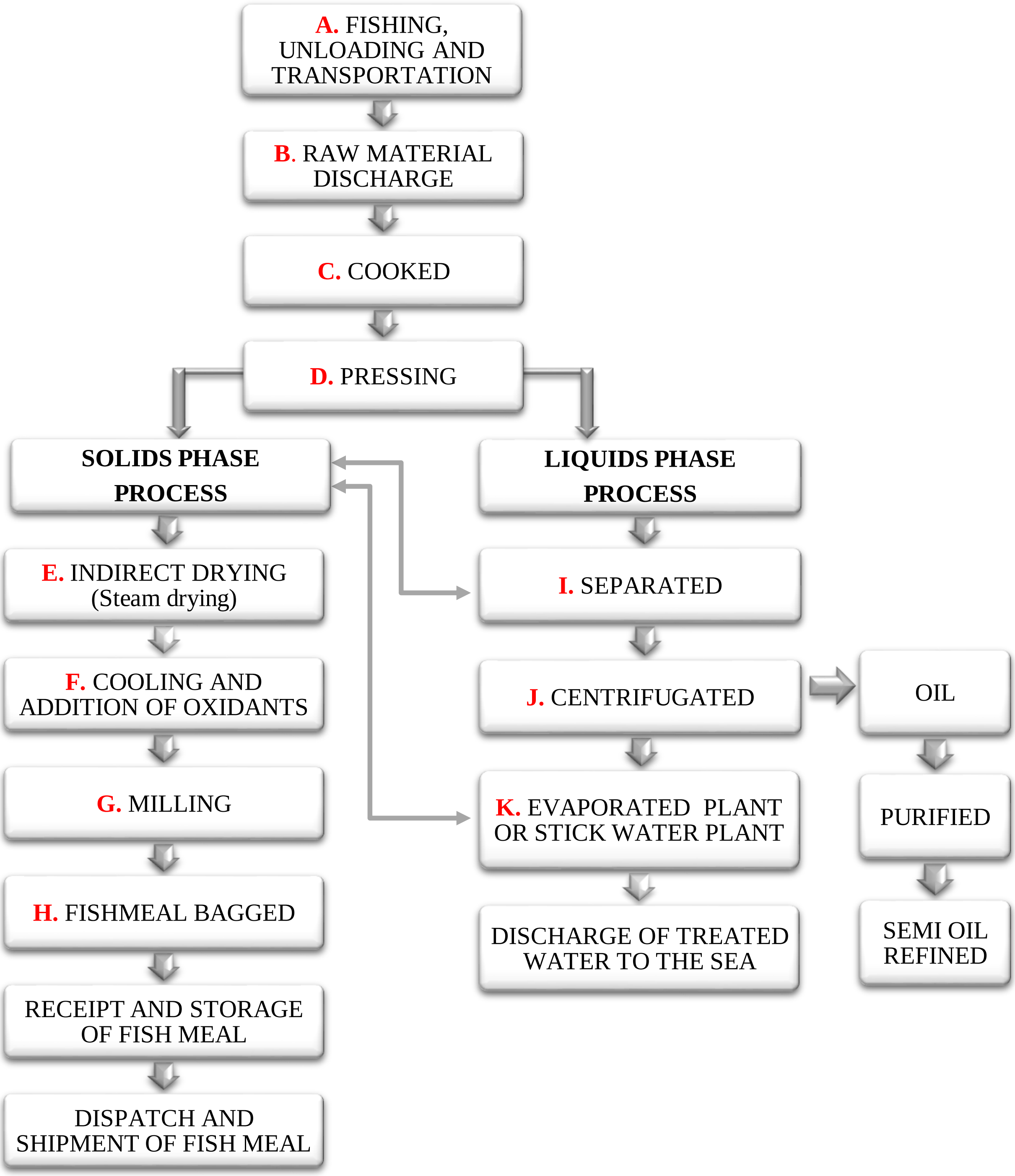

Figure 1. *Flowchart of the fishmeal production process (Own elaboration)*

A. Fishing, unloading and transportation to the port

Fishing for anchovy is carried out by 411 companies, which together form a fleet of 782 vessels fishing for anchovy [53]. However, a fundamental part of this capture process is the subsequent conservation of this raw material. It is very important to maintain the freshness of the fish, due to their rapid decomposition at normal temperatures. The raw material must be properly conserved to avoid the different types of degradation caused by bacterial and enzymatic action, which accelerate the decomposition of lipid and protein fractions, contributing to the general loss of fish quality [47]. The enzymatic and bacterial decomposition of fish forms highly unpleasant substances such as trimethylamine (C_3H_9N), ethylmercaptan (C_2H_6S) and hydrogen sulfide (H_2S). The human nose is so sensitive that it can detect the odor of trimethylamine in concentrations up to 0.0002 ppm [20]. To prevent bacterial and enzymatic degradation, there are methods that help preserve fish, such as: reduce storage temperature and apply cold water. Both to prevent bacterial and enzymatic degradation and to prolong the life of the fish until its arrival at the processing plant. During the cooling period, the temperature is reduced until the ice melts: 0 ºC (32 ºF), ice being the most common form of cooling. For cold water, liquid ice mixtures are mixed with cold sea water (AMR) or salt water recirculation (RSW). It should be noted that prolonged storage under fish conditions with seawater results in a high salt content in fishmeal. To maximize the benefits of refrigeration, it is essential to keep temperatures low during all fish handling operations [39].

B. Raw material discharge and reception (drainage and weighing)

Once the fishmeal industry has received the raw material (anchovy) in the plant, it proceeds to the respective drainage and weighing. Then, it goes to the laboratory of the quality control zone that is in charge of carrying out the analyses that will validate the quality of the product and protein available for the production process [8]. These analyses consist of determining the degree of freshness of the raw fish that evaluate the TVN (total volatile nitrogen). This quality criterion is the most important, since it has trimethylamine (TMA) and ammonia (NH_3) as its main components, therefore, the amount of TVN increases while the fish remains unfrozen, promoting bacterial growth and reducing the quality of the final product [32].

C. Cooked

Fresh fish properly separated after going through the quality control process is subjected to the steam cooking machine, where the heat is transferred indirectly [55]. Fresh fish is submitted to a temperature that varies between 90 and 100 ºC depending on the industry, for 15 to 20 minutes

[47,55]. This procedure seeks to sterilize fish, in order to stop the bacterial and enzymatic activity that causes the degradation, in addition, coagulates the proteins in the solid phase, allowing cell membranes to disintegrate and facilitating the separation of oil and soluble residues [33].

D. Pressing

The cooked raw material goes to the stage of mechanical pressing (screw press) with which it will be checked whether a good cooking has been carried out. Prior to pressing, a pre-pressing (pre-strainers) is necessary in order to drain the percentage of fat and humidity [33]. The objective of the pressing is to separate the liquid phase or press liquor through grids, from the solid phase also called press cake in the industry and reduce the amount of humidity in it [8]. Subsequently, before moving to the optimal drying conditions, it is necessary to divide the material into smaller pieces to facilitate the escape of water vapor, for this the press cake must go through a wet milling to avoid adhesion and formation of lumps in drying followed by good mixing [55].

3.1.1. Solid phase process

E. Indirect drying

The objective of drying is to convert the wet and unstable mixture considered as a press cake into a dry and stable mixture necessary for the production of fishmeal [8]. This means that the mixture must contain a low humidity level to limit the growth of microorganisms, being in a lower range of 5% and 12%. On the other hand, the temperature undergoes a controlled increase that achieves a faster drying that should not exceed 90 – 100 ºC to avoid reducing the quality of the protein, especially not deteriorating the nutritional values [7,47,55]. Indirect drying is currently the most used because it complies with Peruvian legislation, however it requires more operating time. Its mechanism is to dry the press cake and the stick water concentrate when it comes into contact with steam heated elements such as coils, tubes, discs, etc., air is injected to accelerate water removal and heat transfer by which it can exceed 30 minutes of operation [55].

F. Cooling and addition of antioxidants

After drying, the flour gets the desired humidity, but at a temperature not suitable for bagging. For this reason, the flour is cooled, to decrease the temperature until it reaches the appropriate temperature by means of the rotating drum while it is being transported or with the addition of air [8]. In general, fishmeal, being a hygroscopic product, absorbs humidity, absorbs oxygen and also has a tendency to combustion due to the oxidation of polyunsaturated fatty acids [9]. To avoid these characteristics, the product is cold-bagged and stabilized with antioxidants such as Ethoxyquin, which is the most effective, Butylated Hydroxytoluene (HBT) or Butylated Hydroxyanisole (BHA), these are added to the conveyor screw to achieve homogeneous mixing while the product is transferred to the factory [47,55].

G. Milling

The aim of the milling is to reduce the size of the particles according to the needs of the customer, as well as to facilitate their homogeneous incorporation in the food that will be manufactured from it [55]. Well-ground flour has an attractive appearance, avoids clumping and facilitates homogeneous mixing in the proportions of food that require appropriate combinations and mixtures [33].

H. Fishmeal Bagged (receipt, storage, dispatch and shipment)

After complying with the basic cooling parameters and adding antioxidants, we proceed to the bagging stage, where the flour is placed in bags according to the needs of each customer, usually of polypropylene [8]. When the flour is placed in the bag, it remains reactive and not stabilized, so it must oxidize for a period of 28 days. For this purpose, the bags are placed on the ground in single or double rows, depending on the end of the stabilisation period. After that, it is dispatched and shipped [55].

3.1.2. Press fluid process

I. Separated

Once the liquids are separated from the liquid press and the pre-pressing, which contain, in addition to water, a greater concentrated portion of fish oil with dissolved proteins, salts and solid particles, they are separated by decanters. The remaining cake or solid part of the separation is added to the solid phase (press cake), while liquid phase is sent to another separation machine [55].

J. centrifuged y purified

To finish the oil process, the liquid part or stick water plus oil is separated again by a centrifugal machine, and the oil is directed to the polishers or purifiers to obtain the fish oil that will be stored for marketing [8,55].

K. Evaporated or Stick water plant

The remaining centrifugal fluid, or stick water, still contains a small amount of fat and solids. It is estimated to contain: digestible dissolved protein, minerals, vitamins and fats, which is sent to the evaporator plant to eliminate the amount of water and recover the solid that will be sent to the press cake (solid phase). The effluents of the stick water are treated and then dumped into the sea through an underwater emitter complying with the regulations [55].

4. CURRENT EMISSIONS AND CONTROL OF POLLUTING EFFLUENTS FROM FISHMEAL INDUSTRY IN PERU

The fishmeal industry is the main source of concentrated gas with bad odors and particulate emissions from the various production processes [18]. There is limited evidence to show that odorous emissions from fishmeal plants cause serious risks to people's physical health. However, they, can cause irritation in the eyes, nose, throat, headaches, drowsiness, stress, nausea and aggravating allergies such as asthma and bronchitis [35]. In the United States, the distances from fish processing plants are usually a few kilometres from urban areas so that the population is not affected [58]. Unlike in Peru where the fishmeal industry is located along the entire coast and close to urban areas [42]. Data on the characterisation of air emissions produced by this industry mention the presence of the following pollutants: nitrogen oxides (NO_X), sulphur oxides (SO_X), particulate matter (PM), carbon monoxide (CO), carbon dioxide (CO_2), hydrogen sulfide (H_2S), trimethylamine (C_3H_9N), water vapour, fugitive fumes [43]. Updated information in the latest Air Quality Guides specifically details the most common air pollutants which includes: particulate matter (PM_{10} and $PM_{2,5}$), ozone (O_3), nitrogen dioxide (NO_2), and sulphur dioxide (SO_2), hydrogen sulfide (H_2S). This demonstrate the negatives effects of the aforementioned pollutants on health and their relative importance in the regions belonging to the Health Organization [36,37].

The Peruvian State based on the OMS air quality guidelines, which aim to provide guidance on how to reduce the health effects of air pollution and to mitigate air pollution from fishing activities, have established environmental protection policies, monitoring and control tools through the *Maximum Permissible Limits in the legislation* [48].These state initiatives will also lead to better quality products and greater competitiveness on the international market [43]. The last provision addressed by the Ministry of the Environment of Peru to fishmeal and fish oil and fish meal waste plants is specified in *Supreme Decree Nº. 011-2009-MINAM* and *Ministerial Resolution Nº. 621-2008-PRODUCE.*

Figure 2, summarizes the critical points of pollutant emissions, pollutants and the current emission control system used in the fishmeal production process. After that the description of each.

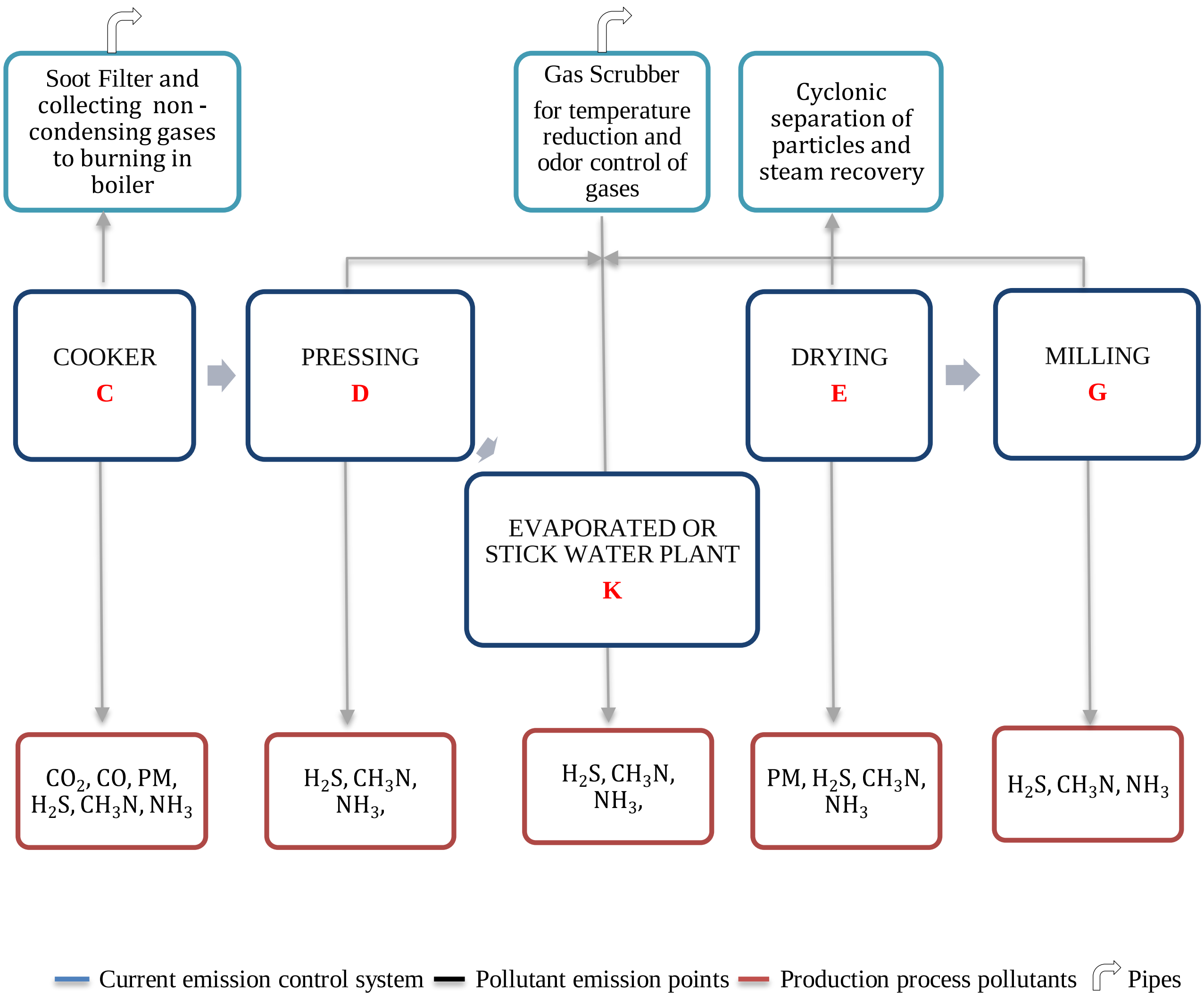

Figure 2. *State of art of gaseous emissions and employed control techniques identified in the fishmeal production process (Own elaboration)*

4.1. Emission critical points

- **Cooked**

An important part of the fishmeal production process is the fuel for the start-up of the all processes. The burning of fuels previously used by industry generated high concentrations of NOx, SOx, PM, H_2S, CO_2 and CO. Currently the fuel used to feed boilers and dryers by the fishing industry is Natural Gas, which replaced the use of coal or petroleum type R500 [48].However, despite state regulations, the use of R-500 as fuel continues to be considered for boiler operation in emergencies due to the lack of natural gas supply at the plant [40].

After the changes established and the use of natural gas as fuel, the generation of these pollutants has decreased, due to the composition and lower working temperature [40]. For the control of PM, the industry has chosen to use soot filters, located at the outlet of the boilers and pipes, which have the main function of trapping and collecting the particles generated by incomplete combustion [55].

The high concentrations of odor-generating substances come from cooking, pressing and drying operations, therefore, in order to facilitate their treatment, the emission flows should be kept to a minimum. This will increase the value of waste heat recovery [20]. The bad odors generated during the cooking of fish at high temperatures indicate the production of H_2S, C_3H_9N and mercaptans. As a control measure, these gases are collected and burned in the boiler to mitigate odors. It is therefore important that the raw material of the fish is as fresh as possible before entering the process. The fishing industry continues to make the effort to reduce catch times (TDC) and shorten the arrival of raw materials to the plant, but they fail to meet the desired goal [40].

- **Pressing**

During the pressing process, the vapours generated emit bad odors at high temperatures. Non-condensing vapours are treated of gas scrubber with seawater that help to reduce temperature and odor, while condensable vapours are transported to the stick water plant [40].

- **Drying**

Like the cooking process, the use of carbon and petroleum as fuel in the drying process generated emissions of NOx, SOx, PM, H_2S, CO_2 and CO. In accordance with state regulations, the industry had to innovate not only in the fuel change but also in the direct drying system, through other measures that allowed compliance with the legislation, such as; indirect steam drying, hot gas recirculation drying and drying systems, including efficient gas treatment and particle recovery [48]. An important factor in drying is temperature control, to avoid abrasion of fine fishmeal particles and increased odors [20].

For these provisions, there are industries that have opted for the installation of cyclonic separation system at the exit of the dryers, which are responsible for recovering the fishmeal particles [55]. As a result of drying, water vapour containing NH_3, C_3H_9N and H_2S is generated with bad odors that are the subject of complaints from neighbouring communities or populations. Therefore, these vapours are treated with a gas scrubber with seawater, which precipitate and are sent to the stick water plant and the air coming out of the gas scrubber goes towards the atmosphere [49].

- **Milling**

The gases produced by milling are gases with low concentrations of odorous substances [20]. The state establishes that vapours emissions must be eliminated from the basic and complementary equipment of the process, by means of an adequate condensation system [48].

- **Evaporated or Stick Water Plant**

The stick water plant requires a lot of energy, so the state establishes the use of drying vapours as an energy source [20]. In addition, the large quantity of odor emissions in the plant are treated with a gas scrubber with sea water injection, which will allow the temperature to be lowered, condense the gases and precipitate the small particles that will then be collected and taken to the solid pass [55].

5. PERUVIAN AND SPANISH LEGISLATION COMPARISON

In order to prevent and control industrial emissions based on the concept of maximum allowable limits and Best Available Techniques, Peruvian and European legislation develop a regulatory framework presented below:

5.1. Peruvian Legislation

The current Peruvian regulations are established within the regulatory framework for fishing activities, with the aim of protecting and preserving the terrestrial and atmospheric maritime environment.

- Law Nº 28611, General Law of the Environment.
- Decree Law Nº 25977 - General Law of Fisheries.
- Ministerial Resolution Nº 621-2008-PRODUCE, they lay down provisions for headlines of fishmeal, fishmeal and fishmeal plants to carry out technological innovation to mitigate their emissions to the environment.
- Ministerial Resolution 242-2009-PRODUCE, it amends R.M. Nº 621-2008-PRODUCE, by means of which it was established that the owners of industrial fishing establishments for fishmeal and fish oil and hydrobiological resources are obliged to carry out technological innovation in order to mitigate their emissions to the environment.
- Supreme Decree Nº 011-2009-MINAM, Approves Maximum Permissible Limits for Emissions from the Fishmeal and Fish Oil Industry and Hydrobiological Waste Meal.

5.1.1. Summary of the Regulation

Peruvian legislation is headed by *Law 28611*, in which *article 76* promotes that industrial activities adopt environmental management systems according to the nature and magnitude of their field of operation. *Decree-Law 25977* describes the regulatory framework for fishing activity and its compliance with the protection and conservation of the environment by adopting the necessary measures to control the environmental impacts that may occur.

Ministerial Resolution 621-2008-PRODUCE, concerning the mitigation of atmospheric emissions from the fishmeal and oil industry. It is amended by *Ministerial Resolution 242-2009-PRODUCE* on technological innovation in the industry and which sets out the complementary arrangements for industry compliance with respect to the replacement of direct drying by indirect drying, the use of drying vapours as an energy source in waste water plants, the elimination of fugitive emissions of process start-up gases and fumes and ancillary equipment, and the switching of the fuel system from waste oil to natural gas. Likewise, *Supreme Decree 011-2009-MINAM*, which approves the emission limits for this industry, setting the values of hydrogen sulfide, sulfides equivalent to concentrations of 5 mg / Nm^3.

5.2. European Legislation

The European regulations are governed by the Council of the European Union in the first instance and subsequent to it, each member country transposes and implements the ruled provisions. Industry legislation also covers the fishmeal industry.

- Directive 2010/75/EU of The European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control).
- Commission Implementing Decision (EU) 2019/2031 of 12 November 2019 establishing best available techniques (BAT) conclusions for the food, drink and milk industries, under Directive 2010/75/EU of the European Parliament and of the Council.

5.2.1. Spanish State Legislation

- Law 34/2007 of 15 November on air quality and protection of the atmosphere.
- Law 5/2013, of 11 June, amending Law 16/2002, of 1 July, on integrated pollution prevention and control and Law 22/2011, of 28 July, on contaminated waste and soil.
- Decree 833/1975 of 6 February implementing Law 38/1972 of 22 December on the protection of the atmospheric environment.

- Royal Decree 100/2011, of 28 January, updating the catalogue of potentially polluting activities in the atmosphere and laying down the basic provisions for its implementation.
- Royal Decree 815/2013, of 18 October, approving the Regulations on industrial emissions and on the implementation of Law 16/2002, of 1 July, on integrated pollution prevention and control.
- Royal Legislative Decree 1/2016, of 16 December, approving the consolidated text of the Law on Integrated Pollution Prevention and Control

5.2.2. Summary of the Regulation

At European Level, the *Directive 2010/75/EU* is partially transposed into national law by *Law 5/2013, Law 22/2011* and *Royal Decree 815/2013*. The aim of this Directive is to establish a regulatory framework setting out the conclusions of the *Best Available Techniques (BAT)* at European level, as set out in the BREF (Best Available Techniques Reference) documents of the main industrial activities, for the prevention and control of emissions to air, water and soil, waste management, energy efficiency and accident prevention. The Decision framing BAT for the activities of the food industry within which the production of fishmeal is situated is *Decision 2019/2031/EU,* section 6 where details the conclusions on BAT for the processing of fish and shellfish, specifically in *BAT 26* on air emissions in order to reduce controlled air emissions of organic compounds from fish smoking. Among the techniques described for the control of atmospheric emissions, the following can be considered for the control of odors: biofilter, thermal oxidation, non-thermal treatment of plasma and, wet scrubber, as described in point *14.2*.

At Spanish level, *Law 34/2007*, focused on reducing air pollution, adopts a comprehensive approach to control potentially polluting activities. Likewise, this law repeals *Annex II of Decree 833/1975*, referring to the catalog of the various unspecified industrial activities, and which continues to apply to certain activities and facilities, including emission values, now located in *Annex IV, number 27 of Law 34/2007*. As an example, the hydrogen sulfide emission levels equivalent to 10 mg / Nm^3 are mentioned. These activities have been updated more recently by *Royal Decree 100/2011*, where the food industry, the manufacture of animal feed or meal are located. Likewise, *Law 5/2013* with a legal character, focused on the "polluter pays" principle, aims to reduce, prevent and eliminate pollution caused by industrial activity before the origin of the same, while *Royal Decree 815/2013* of a more technical nature, establishes a legal regime applicable to industrial emissions, as well as authorizations identifying each pollutant emission source in the atmosphere.

5.3. Comparison of legislation

The difference between Peruvian and European legislation is due to the large industry that represents the production of fishmeal in Peru with respect to Europe therefore greater emphasis on regulations. On the other hand, Europe has a technological advantage over Peru for the implementation of mechanisms that help mitigate atmospheric emissions.

Chart 1. *Comparative summary*

Description	Peruvian Legislation	European Legislation
Specific legislation for the fishmeal industry	x	
Supplementary provisions to mitigate polluting emissions produced by the fish industry	x	x
Best available techniques to control odors and other emissions		x
Hydrogen sulfide emission levels	5 mg / Nm^3	10 mg/Nm^3

6. BEST AVAILABLE TECHNIQUES FOR ODOR CONTROL FOR FISHMEAL INDUSTRY

There is very little public information available in the media and by the Peruvian industry itself, indicating other odor control techniques used in the production process of Fishmeal. However, according to *Sotomayor & Power* [55] and *Becerra* [3], the current control measures is, the reduction of the time of capture and arrival of the fish to the processing plant, which represents a challenge to the present time, in addition to the use of gas scrubbers with atomized water (sea water), which does not present the desired results so far and which remains a concern for the risk to the health and quality of life of the population.

The concern for smelly gases produced by the Fish Processing Industry has led governments worldwide to consider the implementation of the best available odor control techniques, For example, the *Food and Agriculture Organization of the United Nations* [20] establishes as odor control techniques, the cleaning of effluent gases, chemical inactivation, combustion at high temperatures, catalytic combustion and adsorption by activated carbon. In the United States, *The Environmental Protection Agency* [17] mentions thermal oxidation and chemical inactivation. The European Union through *Decision 2019/2031/EU* on BAT for fish processing considers biofilter, thermal oxidation, non-thermal plasma treatment and wet scrubber as the best available techniques, while in Peru the industry itself has adopted the gas scrubbing system in accordance with the provisions taken by the state. Taking into account the different control techniques that it can be applied, it has been reviewed studies that help select the best available technique for odor control of the fishmeal industry in Peru, which are presented below.

6.1. Absorption

The *Decision 2019/2031/EU*, states that wet scrubber is the removal of gaseous or particulate pollutants by transferring the mass to a liquid solvent, which can generally be water or an aqueous solution. Likewise, it can be associated with an acid or alkaline chemical reaction and in certain cases the solvent can be recovered. *Figure 3* shows the system.

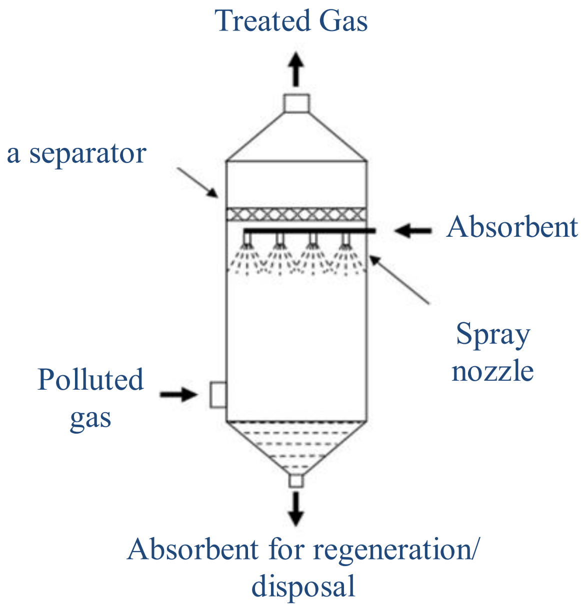

Figure 3. *Absorption system. (Adapted from Wysocka et al. 2019)*

According to *FAO* [20], hot gases enter from the bottom and cold water (fresh or seawater) from the top, to produce a large contact space gas - cooling water (see *Figure 3*) . Cooling condenses much of the water and other condensable vapours, reducing the volume of the gas with 40% efficiency. Vapors escaping from the washing tower are burned in the boiler. Likewise, the research of *Sotomayor & Power* [55], mentions that gas scrubbing by sea water flow currently used by the Fishmeal industry in Peru has not been an efficient method. Similarly, *Burgess et al.* [6] states that water washing obtains only efficiencies that reach 70% because non-condensable gases have a residual odor so it necessarily requires an additional deodorization system.

On the other hand, *FAO* [20] also suggests the use of gas-washing towers with chemical inactivation, that is, to contact gases with strong oxidizing agents, derived from chlorine or permanganate, which are applied in aqueous or gaseous state. Chlorine is considered the most economical oxidizer, however, the treated gases require a final wash to prevent the chlorine from escaping to the atmosphere, in addition to being very corrosive the equipment must be made of stainless steel or reinforced plastic. The efficiencies of the absorption towers with chlorinated water and sodium hypochlorite solutions are 80%. The *United States Department of the Interior Washington. D.C.* [58] points out that chlorine is not considered an oxidizing agent strong enough to fully oxidize odorous substances present in dry gases, therefore, it provides an efficiency between 50 to 80% by itself. While in more current research by the *Environmental Protection Agency* [17] points out that scrubbing gases with chlorine addition works for inlet gases at low temperatures, which must not exceed 93ºC. The efficiencies of this system have been tested at 95 to 99% for fresh fish. The research by *Wysocka et al.* [60] found that efficiencies with this system for odor control are between 50% to 75%, using substances such as ozone (O_3), chlorine (Cl_2), hydrogen superoxide (H_2O_2), sodium hypochlorite (NaOCl), dilute sodium hydroxide, dilute potassium hydroxide, sulphuric acid or chlorinated seawater. The advantage of this system is that it can eliminate smelly gases without the need for particle extraction.

Pendashteh et al. [41] in their study concerning a case of a fishmeal industry in Iran, processing 24 tons of Kilka fish/day, shows that using a 3-stage gas scrubbing system achieves trimethylamine removal efficiencies up to 100%. The first step of a wet water scrubber and the other two steps with oxidative scrubbers, with addition of sodium hypochlorite as a chemical oxidizer. Other studies by the *Environmental Protection Agency* [16] found that odorous waste gases from the fishmeal process contain 200 mg/m^3 of NH_3, 15 mg/m^3 of substances containing sulphur (H_2S and mercaptans), 5 to 10 mg/m^3 of carbonyl compounds and sulphur and organic acids up to 100 mg/m^3. These gases can be removed with high efficiencies in 3-stage gas scrubbers. These consist of a first stage in the washing tower the waste gas is cooled to - 30 ºC with water to reduce the concentration of organic compounds. The second tower, adding 2% NaOH and sodium bleach, and the third tower spraying 0.5% H_2SO_4. Likewise, they carried out another study in 2 stages. The first step is to spray the waste gas with a base (NaOH) and the second step is to spray it with diluted H_2SO_4. This two-stage washing method, along with the 1:1000 dilution effect of a high chimney was enough to eliminate the unpleasant odors of the fishmeal plant and at low cost.

The *Industrial Environmental Research Laboratory* [27] mentions the use of sulphuric acid as a means of absorption for gas washing of nitrogenous compounds, bearing in mind that reactions may be ineffective because they are not completely basic. For its part, *Poblet* [42] check the effectiveness of chemical inactivation with addition of the 5% HCL solution resulting in an average efficiency of 75% in trimethylamine removal at the outlet of the gases. The *Ministry for the Environment of New Zealand* [32] mentions the most common oxidizing agents used, mentions hypochlorite, chlorine gas, permanganate and ozone. It also points out as disadvantages of absorption, that scrubbers require regular maintenance, daily tests of active agents, pH control in some cases and due to the cleaning or absorption of wet gases with a liquid phase, there remains a liquid waste to dispose of if it cannot be recovered. Similarly, indicates *Higuchi* [24] strict management of the waste water treatment operation due to the chemical hazard and corrosion of waste water treatment equipment. *Chart 2* shows a summary of the most significant data found in the references.

Chart 2. *Research summary of the absorption process (Own elaboration)*

Nº	Liquid solvent	Inlet temperature °C	Odours Efficiency (%)	Observations
06	-	-	70	-
16	Water (-30ºC) (1), NaOH (2) , H_2SO_4 (3)	-	High	3 stages
16	NaOH (1) , H_2SO_4 (2)		High	2 stages
17	Chlorine	< 93	95 - 99	Requires final cleaning with sea water
20	Sea or Fresh Water	25	40	-
20	Derivatives of chlorine and permanganate	-	80	Requires final cleaning with sea water
24	-	-	-	Strict management of the waste water treatment operation due to the chemical hazard and corrosion of waste water treatment equipment.
27	H_2SO_4	-	Low	Low efficiency on its own, requires another compound
32	Hypochlorite, chlorine gas, permanganate and ozone	-	-	Equipment corrosion risk, requires treatment of wastewater, constant maintenance and pH control.
41	Water (1), NaClO (2 and 3)	-	100	3 stages
42	HCl	-	75	-
55	Sea Water	25	Low	-
58	Chlorine	-	50 - 80	-
60	Cl, O_3, H_2O_2, NaClO, NaOH, KOH, HCL and Chlorinated Sea Water	-	50 -70	-

Nº = Reference number (Bibliography)

6.2. Thermal oxidation or incineration

Decision 2019/2031/EU, defines thermal oxidation as the oxidation of odorous substances and the combustible gases present in a waste gas flow by heating the mixture of pollutants with air or oxygen above their point of self-ignition in a combustion chamber and keeping it high temperatures long enough to complete their combustion in carbon dioxide and water. *Figure 4* shows the system.

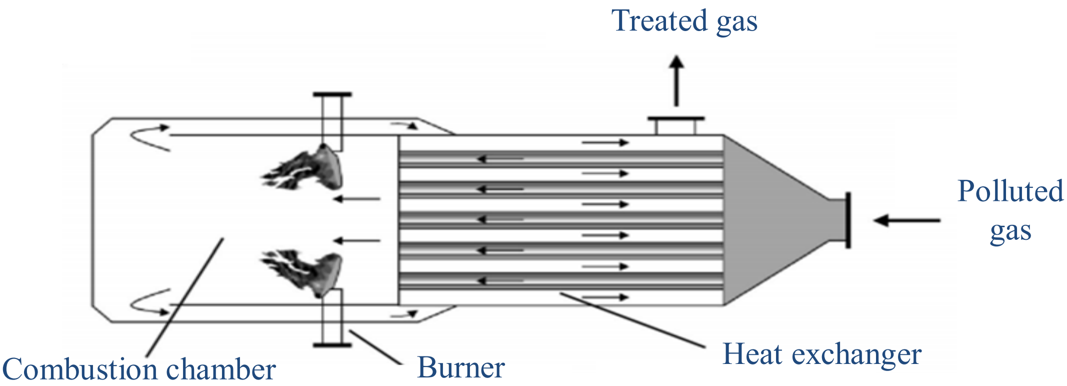

Figure 4. *Thermal oxidation system (Adapted from Wysocka et al. 2019)*

The *FAO* [20] recommends the use of this system for fish meal plants that operate with steam dryers. The high temperatures for the elimination of smelly substances must reach 750ºC for a second, to obtain good efficiencies. However, odorous gases with low intensity should be treated with some other method, such as chemical inactivation before dispersing through the pipe. *Higuchi* [24] also concludes that for the removal of VOCs work at 750 ºC for stable efficiency. Similarly, *Wysocka. et al.* [60] points to efficiencies greater than 95% for odorous organic removal, since combustion processes destroy the structure of the compound that generates odors and its aromatic properties.

In addition, the *Environmental Protection Agency* [16] considers thermal oxidation as an efficient method in the temperature range between 648 ºC and 926 ºC, when the temperature of the fishmeal processing is higher than 149ºC. High temperatures tend to burn the fishmeal particles and if they are large on the contrary tend to increase the concentration of odors instead of decreasing them, while, for fine particles is more efficient. While, *Alva* [2] indicates that the temperature suitable for thermal oxidation varies between 649 ºC and 760 ºC for a time of not less than 0,3 seconds in the incineration chamber. Similarly, the *Industrial Environmental Research Laboratory* [27] describes thermal oxidation as the most effective method for odor control of all kinds. The gases must be incinerated for at least 0,5 seconds at a temperature of

650ºC. Considering that, at lower temperatures, part of the compound may be partially oxidized generating an odor as unpleasant as the original compound.

Other research such as *Nicolay & Kristbergsson* [34] describe the importance of reducing the moisture content for gas streams entering at a temperature above 400ºC and reducing fuel consumption at incineration. The food and animal products industry uses this type of system the most. However, *Sotomayor & Power* [55] in its research on the fishmeal industry in Peru, found that the thermal flux in the boilers works a maximum temperature of 340ºC and then recirculated by means of hot air exchangers at a temperature below 300ºC at the entrance of the dryer so that after that it leaves at a temperature of 80 to 100 ºC.

According to *Mills* [30] and all the authors described above conclude that thermal oxidation is an efficient method for the removal of VOCs and odor problems, but primary and secondary heat recovery is important to ensure that the system is optimal and minimizes capital and operating costs, as hot exhaust gases return through heat exchangers to heat the incoming waste air. This method is suggested when sufficient water is not available in the plant. So it is advisable to incorporate this system in a new plant than in an existing plant. Also because of the cost of this system, it works continuously with chemical oxidation combined with purification to make it more economical. Thermal oxidation stands out as an efficient system for energy intensive plants, such as fish meal plants, meat, bones, etc. *Chart 3* shows a summary of the most significant data found in the references.

***Chart 3**. Research summary of the thermal oxidation process (Own elaboration)*

Nº	Temperature ºC	Incineration time (Sec)	Efficiency (%)	Investment costs
02	649 - 760	0,3"	*	*
16	648 - 926	-	*	*
20	750	1"	*	*
24	750	-	*	*
27	650	0,5"	*	*
30	-	-	*	*
34	400	-	*	*
55	340	-	*	*
60	-	-	95	*

Nº = Reference number (Bibliography)

* High efficiency and high investment costs

6.3. Catalytic oxidation or incineration

According to the *Environmental Protection Agency* [19] the operation of catalytic incineration is similar to thermal incineration, with the main difference that the gas, after passing through the combustion area, passes through a catalyst. The function of the catalyst is to increase the reaction rate of the oxidation process at lower temperatures, allowing for a smaller incinerator. They also point out that the catalysts commonly used for the incineration of VOCs are of metals such as platinum (Pt) and palladium (Pd). *Figure 5* shows the system.

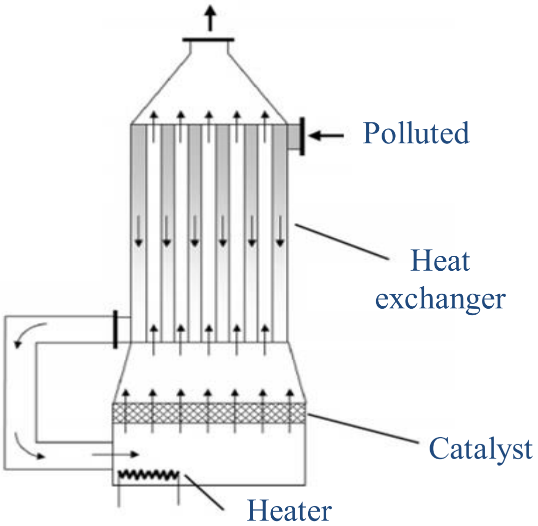

Figure 5. *Catalytic oxidation system (Adapted from Wysocka et al. 2019)*

The *Industrial Environmental Research Laboratory* [27] describes that the temperature range for the oxidation process is between 315 ºC to 425 ºC, thus reducing the fuel consumption to be burned in the incinerator. Similarly, *Alva.* [2] mentions that the temperature for catalytic oxidation must be at 316 ºC and 427 ºC and with the use of catalysts such as platinum (Pt) or palladium (Pd). Meanwhile, *Higuchi* [24] in its research on odor control techniques in Japan, points out that high efficiencies in pollutant degradation require temperature ranges around 250 ºC and 350 ºC. For its part, the *FAO* [20], indicates use as catalysts, platinum alloys (Pt) and metal oxides at temperatures between 350 ºC to 400 ºC.

On the other hand, *Wysocka et al.* [60] found that efficiency with the use of catalysts can reach up to 100% depending on the type of catalyst. For example, precious metals such as platinum, palladium, ruthenium, iridium and rhodium or others such as copper oxide (Cu), chromium (Cr), vanadium (Va), cobalt (Co), tungsten (W), manganese (Mn), zinc (Zn), nickel (Ni) and iron (Fe). In the investigation of *Scirè & Liotta* [54], noble metals such as platinum (Pt), palladium (Pd), silver (Ag) and gold (Au), alloyed to other metals such as osmium, are the best performing. In addition, gold in iron oxides and nickel ferrites shows a high oxidation activity due to its affinity with nitrogen. With respect to operating costs *Nicolay & Kristbergsson* [34], *Higuchi* [24] and *Mills* [30], point out that catalytic oxidation reduces the amount of energy, fuel costs compared to thermal oxidation. However, if a comparison is made between thermal oxidation and catalytic oxidation or regenerative thermal oxidation (RTO), the advantage of the former is the destruction of VOCs and odors with better efficiency, without the risk of fouling, wear, obstruction or poisoning of the catalyst, which represents a high cost to the catalytic oxidation system. On the other hand, as mentioned by *Wysocka et al* [60], the costs of catalysts are quite high, therefore, attempts have been made to use catalysts from solid waste as ash from wood incineration to reduce costs.

In addition to the above, for *Scirè & Liotta* [54] *and Alva* [2], catalytic combustion in addition to reducing energy costs, is a process that works with low flow rates compared to other gas treatment processes with a limit of 40,000 Nm^3/h, at low concentrations of Trimethylamine between 0.1 and 10 g/Nm^3. The oxidation of trimethylamine at temperatures below 100 °C over $Au/NiFe_2O_4$ mainly produces N_2 and CO_2, while over the catalysts of palladium (Pd) and platinum (Pt) it produces N_2O at higher temperatures. *Chart 4* shows a summary of the most significant data found in the references.

Chart 4. *Research summary of the catalytic oxidation process (Own elaboration)*

Nº	Oxidation Temperature °C	Suggested Catalyst	Efficiency (%)	Observations
02	316 - 427	-	-	-
02,54	-	-	High efficiency for small flow rates	-
19	-	Pt, Pd	-	-
20	350 – 400	Pt, metal oxides	-	-
24	250 - 350	-	-	-
24,30,34	-	-	-	Reduction of the amount of energy and operating costs. risk of catalyst fouling, wear, clogging or poisoning
27	315 - 425	Pt, Pd	-	-
54	-	Pt, Pd, Ag, Au, Os, Fe_2O_3	-	-
60	-	Pt, Pd, Ru, Ir, Rh, CuO, Cr, V, Co, W, Mn, Zn, Ni, Fe	100	High costs

Nº = Reference number (Bibliography)

6.4. Biofilter

Decision 2019/2031/EU states that, in the biological treatment of waste gases, the flow passes through a bed of organic material which may consist of roots, tree bark, compost, wood, combinations of other materials or some inert material such as activated carbon, clay and polyurethane. These organic or inorganic components in some cases by the action of microorganisms naturally present in these materials are transformed into water, carbon dioxide, biomass and other metabolites. *Figure 6* shows the system.

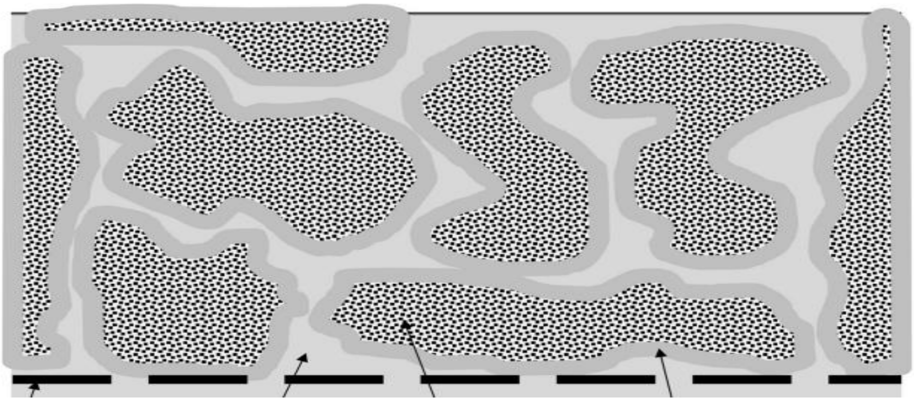

Figure 6. *Biofilter system (Adapted from Wysocka I. et al.2019)*

According to *Mills* [30], mentions that biofilters are formed from large natural beds, with large surfaces and suitable conditions for acclimatization to compounds and concentration, facilitating the reproduction of bacteria, these can be made of materials such as peat or heather, as well Likewise, the compounds to decompose are usually acidic, so the filters require continuous water washes in small volumes to maintain neutral conditions. The *Ministry for the Environment of New Zealand* [32] agrees that the filling material for the biofilter can be soil, bark, compost and that it must be replaced completely every 5 years depending on its operation. Likewise, regarding the microorganisms they have to be cultivated as a film on the surface of the support which can be plastic rings, slag or pumice, with recirculation of water, to maintain the filter bed in aerobic conditions. *Bolcu* [4] recommends the use of bacteria such as *Pseudomonas* and *Nocardia* for their ability to degrade small and more complicated organic molecules respectively.

Brennan et al. [5] describes that biofiltration is used to treat odors of hydrogen sulfide and other organic compounds, halogenated hydrocarbons can also be treated, however, the process is less effective due to the inhibition of biological activity. The concentrations in the gas stream to be treated can vary from 1 ppm to 1000 ppm, achieving higher efficiencies from 90 to 99%

in odor control. Similarly, *Wysocka et al.* [60] found efficiencies for odors of up to 90%, like, *Dorado* [13] in its study for the elimination of VOCs, in a municipal solid waste treatment facility, evaluated TMA efficiency greater than 90%. *AINIA* [1] found efficiencies up to 95%, indicating that the biofilter requires high initial investments, up to 120 m^3/h are low maintenance costs. *Higuchi* [24] points out that the installation costs of the biofilter in Japan are low due to the fill used. This method is the main one for odor control, due to its high effectiveness, for odor control produced by hydrogen sulfide, sulfur reducing compounds, ammonia and the control of VOCs. The advantage of this system is energy saving and secondary non-contamination. However, the treatment for biological control continues to represent an unknown factor, especially for the control of gaseous contamination, the gas-biomass ratio, the sorption capacity and the biological activity for the degradation of contaminants due to the high sensitivity to factors. external. Likewise, the operating conditions for biofiltration are not established. Research by *Ying et al.* [61] *& Ying et al.* [62] on the bioremoval of trimethylamine (TMA) in 2 biofilters of 3-stage of a compost filter and a sludge filter, both operated for 67 days. Achieved elimination efficiencies of trimethylamine at 100% before day 15, presenting better disposal capacity in the compost medium for the growth of nitrifying and degrading bacteria that accelerate the biodegradation and transformation of TMA. *Chart 5* shows a summary of the most significant data found in the references.

Chart 5. *Research summary of the biofilter process (Own elaboration)*

Nº	Filling	pH	T°	Nutrients	H°	Inoculum	E (%)	VL $m^3/m^2/h$	Qv (m^3/h)	Depth (m)	R.T
01	-	-	-	-	-	-	95	-	-	-	-
04	-	6,5 -7,5	20-40	C: N: P (100:5:1 - 200:10:1)	95	*Pseudomonas* and *Nocardia*	50-90	200	40.000	-	20
32	Soil, bark, compost	4-8	20-35	C, N,.P	100	-	-	50-100	-	0,8-1,2	-
13	-	-	-	-	-	-	90	-	-	-	-
24	Soil, bark, compost	-	-	-	-	-	-	-	-	-	-
60	-	-	-	-	-	-	90	-	-	-	-
Nº	**Filling**	**pH**	**T°**	**Nutrients**	**H°**	**Inoculum**	**E (%)**	**Cc (ppm)**	**Q (m^3/h)**	**Gas Vel. (m/s)**	**Stage**
05	-	-	-	-	-	-	90 -99	1 -1000	120	-	-
30	Peat or Heather	-	-	-	-	-	-	-	-	0.01 - 0.03	-
61, 62	-	-	-	-	-	-	100	-	-	-	3

Nº = Reference number (Bibliography)
E = Efficiency // H° = Humedad // Temperature // R.T = Retention Time // VL = Volumetric Loads // Qv = volumetric flow rate // Cc = concentration // Gas Vel. = Gas Velocity

6.5. Adsorption

The *Industrial Environmental Research Laboratory* [27] defines adsorption with active carbon as a more effective method for odor control than absorption, this is because the former does not depend on the water solubility of the material being absorbed. *Figure 7* shows the system.

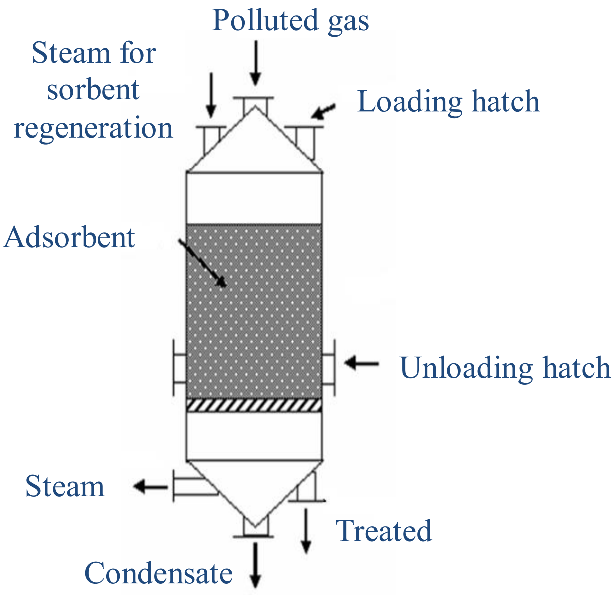

Figure 7. *Adsorption system (Adapted from Wysocka I. et al. 2019)*

The most commonly used adsorbents according to *Wysocka. et al.* [60] *and the Ministry for the Environment of New Zealand* [32] are, activated carbon, aluminum oxides, silica gels and zeolites (molecular sieves, with regular structures), as well as the *Ministry for the Environment of New Zealand* [32] *and the Industrial Environmental Research Laboratory* [27], point out that these adsorbents can be regenerated by incineration or desorption with another gas or liquid. Surface area is a key factor in increasing the amount of adsorbed compound.

Wypych. [59] describes the use of activated carbon, metal oxide (magnesium oxide) and aluminosilicate as a binder is used as an excellent filter for odorous compounds and for the removal of odors produced by hydrogen sulfide as well as research by *Mills* [30]. For their part, *Cartellieri et al.* [9] verified better efficiencies for the elimination of ammonia and trimethylamine , with the impregnation of carbon with phosphoric acid to improve selectivity and improve adsorption properties. The efficiencies found by the Ministry for the Environment of New Zealand [32], are between 95% and 98% for VOCs input concentrations in a range of 500 to 2000 ppm. While *Wysocka et al* [60] have achieved efficiencies greater than 90%.

Higuchi [24] mentions from the experience in Japan, that this system uses the activated carbon as adsorbent of the pollutants which is regenerated or exchanged for the saturation of pollutants. It is easy to operate and is a compact system. However, contaminants must enter at low concentrations to prevent the adsorbent from regenerating. Wastewater treatment is only necessary if the absorber is regenerated by chemicals. The *FAO* [20] also points out that this method is used for the removal of gases with low odour intensity and that its usefulness depends on the economic factors of the industry due to the reactivations of the charge of the activated coal. *AINIA* [1] for its part, mentions that the cost of installing the adsorption system with activated carbon for the control of odours is not very high and that the costs of maintenance depend on the amount of times the coal regenerates. *Wypych et al.* [59] states that the adsorption with activated carbon represents the technology with high costs compared to the biofilter, filter biotickling and chemical purifier, because the lifetime and cost of activated carbon account for 66 per cent of overall operating costs.

The *Industrial Environmental Research Laboratory* [27] and the *Ministry for the Environment of New Zealand* [32], describe as disadvantages part of the costs of regeneration that this method is best adapted to ambient temperature and without water vapour saturation, the disadvantages arise from the high temperatures and the high water vapour content of the contaminated gas stream to be adsorbed. According to *Wysocka et al.* [60] this method is sensitive to pollutants with solids present in gases, because it has a large amount of pores that can be easily blocked, as well as the poisoning of the same by substances of difficult elimination that block the active center of the adsorbent. *Chart 6* shows a summary of the most significant data found in the references.

Chart 6. *Research summary of the adsorption process (Own elaboration)*

N°	Oxidation Temperature °C	Suggested Catalyst	Efficiency (%)	Observations
01	-	-	-	Low cost depending on maintenance
09	-	-	-	Removal of ammonia and trimethylamine
20	-	-	-	High efficiency at low concentrations
24	-	-	-	
27	-	Active carbon	-	High costs
30	-	-	-	Removal of hydrogen sulfide
32	25	Activated carbon, aluminum oxide, silica gels and zeolites	95 - 98	High efficiency at low concentrations
59	-	activated carbon, metal oxide and aluminosilicate	-	High costs
60	-	Activated carbon, aluminum oxide, silica gels and zeolites	90	Sensitive to pollutants with solids

N° = Reference number (Bibliography)

7. SELECTION OF THE TREATMENT TO IMPROVE THE EMISSIONS PRODUCED BY THE FISHMEAL INDUSTRY IN PERU

According to all the information gathered regarding the description of the process, state of the art, legislation, the best available control techniques and based on the air pollution control techniques already implemented by the Fishmeal Industry in Peru, described by Sotomayor & Power [55] through the information collected by APROPISCO, the treatment system best suited to industry shall be proposed with a view to reducing the malodorous gases produced during processing.

The design of the proposed system is shown in *Figure 8*, which describes the current particulate and odour control system (red box), the addition of the new design technique (yellow box), efficiencies, temperatures, fans, etc.

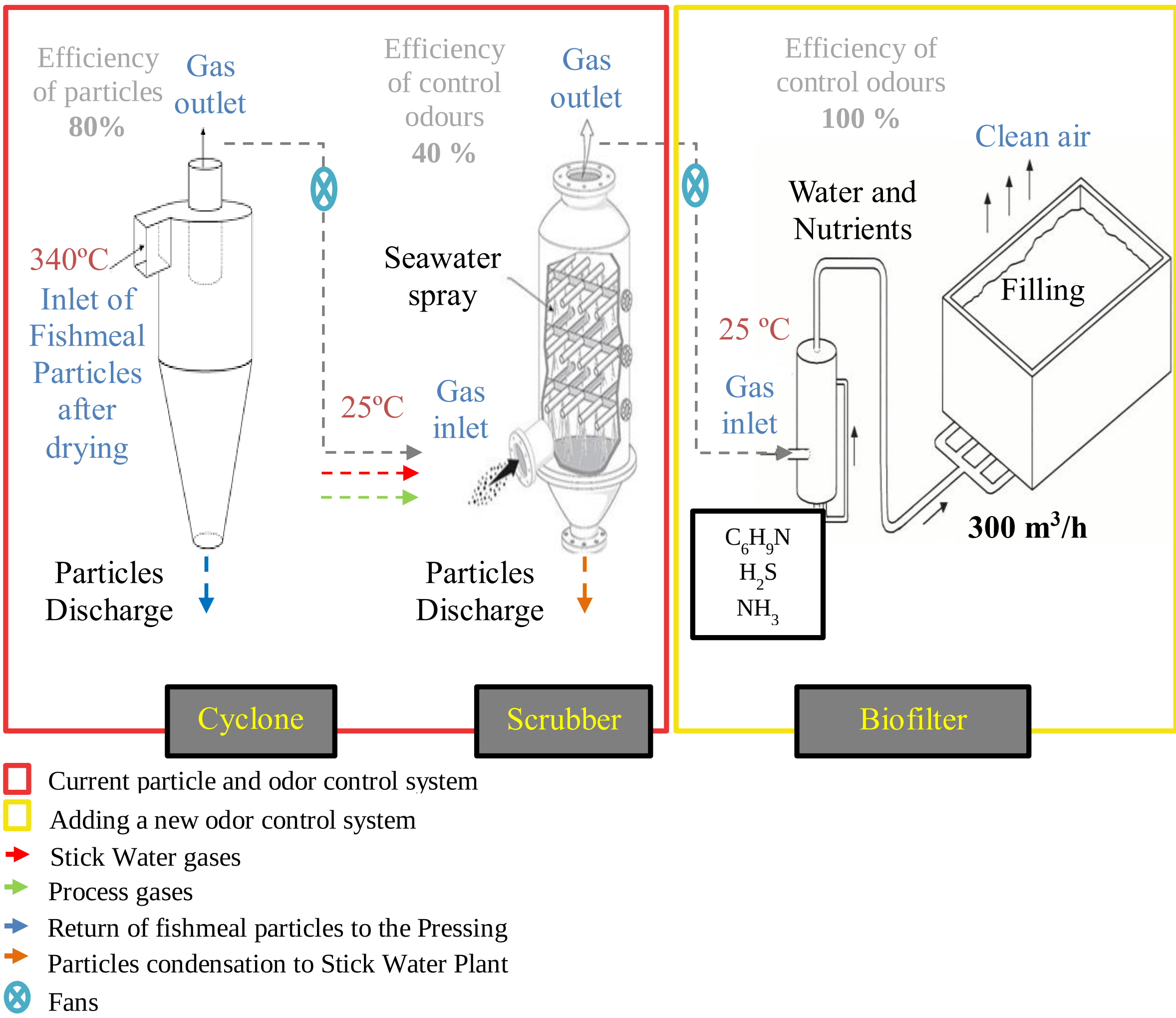

Figure 8. *Treatment proposal of air pollution control techniques for the fishmeal industry (Own elaboration)*

The *Figure 8* shows 2 stages; the current system of atmospheric emissions, consisting of cyclones for the recovery of fishmeal particles produced during the drying process. These collected particles are returned to the pressing cake, while the smelly gases and unrecovered particles are piped to the absorption towers along with the gases from the drying processes, pressing, milling and evaporating plant of stick water, which will be sprayed with flow of sea water to decrease the temperature and odors, obtaining efficiencies of 40 %.

Due to low efficiencies, it is necessary to implement an additional system that helps to improve smelly emissions. From the revised and summarized literature in *chart 7* (*Annex 3*) on Best Available Control Techniques, the following can be concluded:

The amount of information found on absorption shows that it is one of the most recommended and used techniques for odour control including relatively low costs. However, selection for this industry is discarded, as it is a technique currently used. In addition, the incorporating of chemical absorbers to improve efficiency would require wastewater management and treatment due to chemical risk and equipment corrosion.

On the other hand, the efficiency of thermal incineration is quite high, despite this, it is discarded by the high costs of installation and fuel, added to the high entry temperatures that do not fit the Peruvian industry.

Catalytic incineration is also considered an efficient technique for odour control and is better suited to industrial working temperatures. However, it is ruled out because the gases entering the process must be completely clean to avoid risks of poisoning and wear of the catalyst, which increases maintenance costs, in addition to being more efficient for small flows.

Similarly, there is adsorption, which has the same disadvantages as catalytic incineration, with respect to efficiency for low flows, problems of regeneration and removal of adsorbents and sensitivity to solid contaminants in gases due to catalyst poisoning, resulting in an additional cost in maintenance.

Finally, after studying all the techniques described, it can be concluded that the technique that best adapts to the reality of the Peruvian industry, is the biofilter. The proposal is supported by the fact that the biofilter represents a lower economic cost to the industry in relation to the other control techniques, due to the low costs of investment, operation, energy use and maintenance (*Chart 9 and 10, Annex 4*). Taking into account the information presented on the maximum average capacity of the volume of air sent to the atmosphere and which needs to be treated by the fishmeal industries is 300 m^3/h, and according to the literature up to 120 m^3/h of air treated volume the initial and maintenance costs are low, can be considered relatively low costs for Peruvian industry. In addition, the experience in Japan with biofilters shows that the costs of installing biofilters with air volume treated of 834 m^3/h are equivalent to 11,038 EUR approximately (443,330.94 PEN). Therefore, it has high efficiencies to treat large amounts of air with low amount of contaminants, work at ambient temperatures in the mesophilic range, it is able to eliminate of trimethylamine, VOCs, H_2S and NH_3, in addition to the absence of polluting discharges or difficult disposal.

It should be taken into account that the use of biofilters requires strict parameters that guarantee biological activity and high gas flow fluctuations. Likewise, the studies mention that the oxidation of H_2S and NH_3, produces H_2SO_4 and HNO_3 respectively, which are final products that do not degrade in a next reaction therefore accumulate in the filter bed causing acidification, which can be solved with watering periods of the filter package. On the other hand, the large spaces they occupy and the time losses in the replacement of the filling can represent a disadvantage factor, which have been solved with the use of stacked systems in stages.

In summary, a biofilter model recommended for the fishmeal industry is shown in *chart 7*. It should be taken into account as mentioned in the literature that the operating conditions of the biofilter are not yet established and are still under study, so it is difficult to describe a standard structure. However, it is considered a technique that is adapted depending on the industry to which it will be applied.

Chart 7. *Recommended model of biofilter (Own elaboration)*

Parameters	**Description**
Model	Open filter
Filling	Roots, tree bark, compost, wood, etc.
Inoculum	*Pseudomonas and Nocardia*
Stage	1
Humidity (%)	100 (use of humidifiers)
Temperature (C°)	20 – 40
Nutrients	C : N : P // 100:5:1 - 200:10:1
pH	4 - 8
Residence Time (seconds)	10 – 30
Gas volume/area ratio (m3/m2/h)	200
Depth (m)	0,8 – 1,2

8. CONCLUSIONS

- A review was made of the production processes of sugar flour to facilitate the analysis of emissions and the search for the best solution for the control of bad odors.
- The current gaseous emissions of hydrogen sulfide (H_2S), trimethylamine (C_3H_9N), mercaptans and ammonia (NH_3) and the control strategies used by the fishmeal industry in Peru were identified, such as the use of cyclones for collection and recovery of flour particles and seawater gas scrubber for odor control.
- Peruvian legislation passed on the permissible emission ceilings imposed on the fishmeal industry was reviewed and compared to European legislation, finding that by Supreme Decree Nº 2009-MINAM, which approves the emission limits for this industry, establishes the values of hydrogen sulfide, sulfides equivalent to concentrations of 5 mg/Nm^3 and by European legislation through Annex II to Law 34/2007, detailing the emission levels of hydrogen sulfide equivalent to 10 mg/Nm^3.
- The best odor control techniques were selected, which were absorption, adsorption, biofilter, thermal oxidation and catalytic oxidation and the description was made, as well as the advantages and disadvantages of each one.
- The biofilter was selected as the best available odor control technique to be incorporated into the air pollution control system of the industry.
- A system of treatments of air pollutants for the fishmeal industry has been developed with the use of biofilter, which was selected, because it represents a lower economic cost in which can be seen 84%, 58 %, 57% and 11% savings in installation costs compared to incineration (thermal and catalytic), chemical washing, water washing and adsorption, in addition to high efficiencies in the fishmeal industry by achieving up to 100% trimethylamine removal, VOC, H_2S and NH_3.

9. APPENDIX

Annex 1. Scheme illustrative of the fishmeal production process.

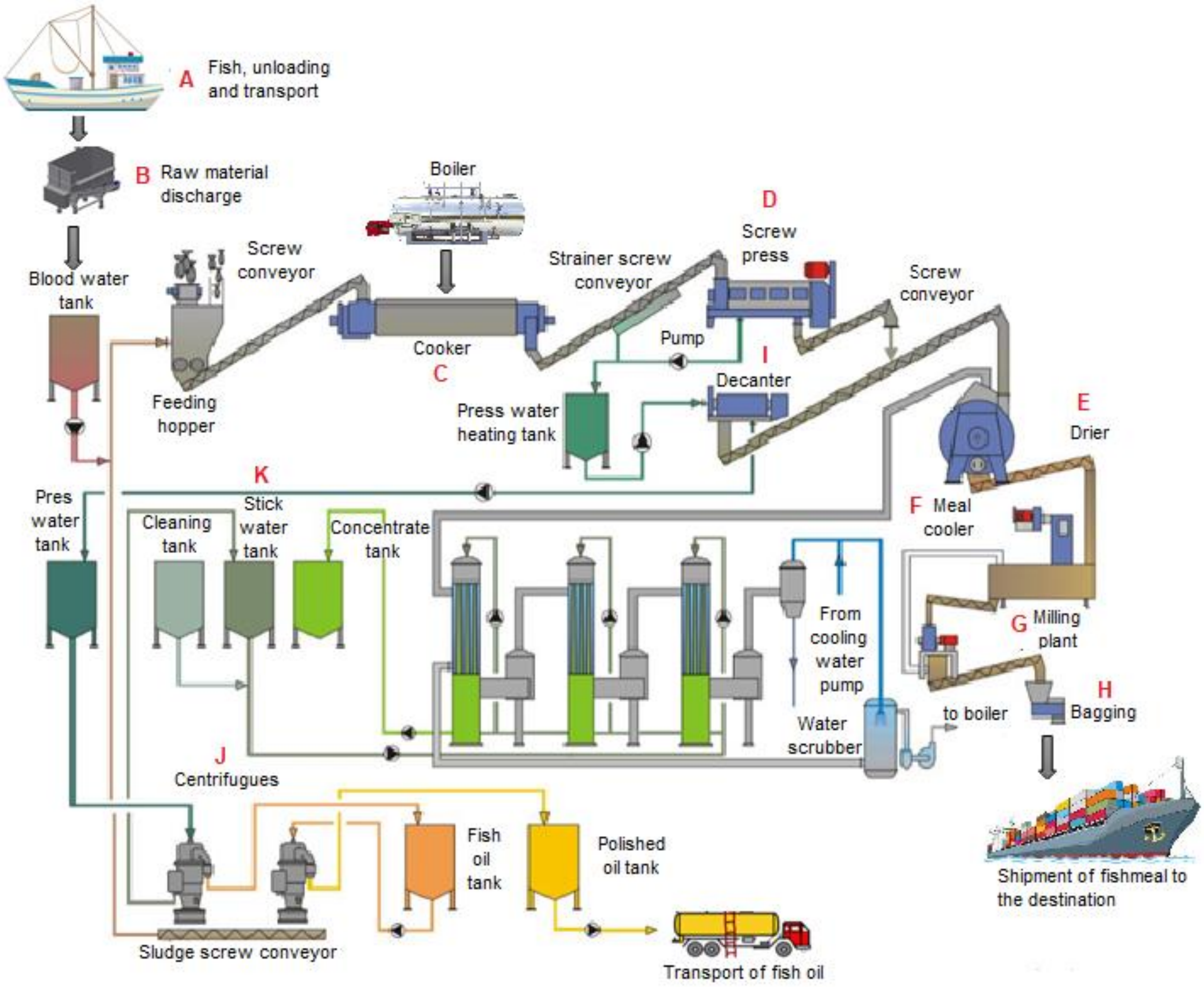

Figure 9. *Scheme illustrative of the fishmeal production process (Adaptation of Stord Process As,2020)*

Annex 2. Design of air pollution control techniques for the fishmeal industry.

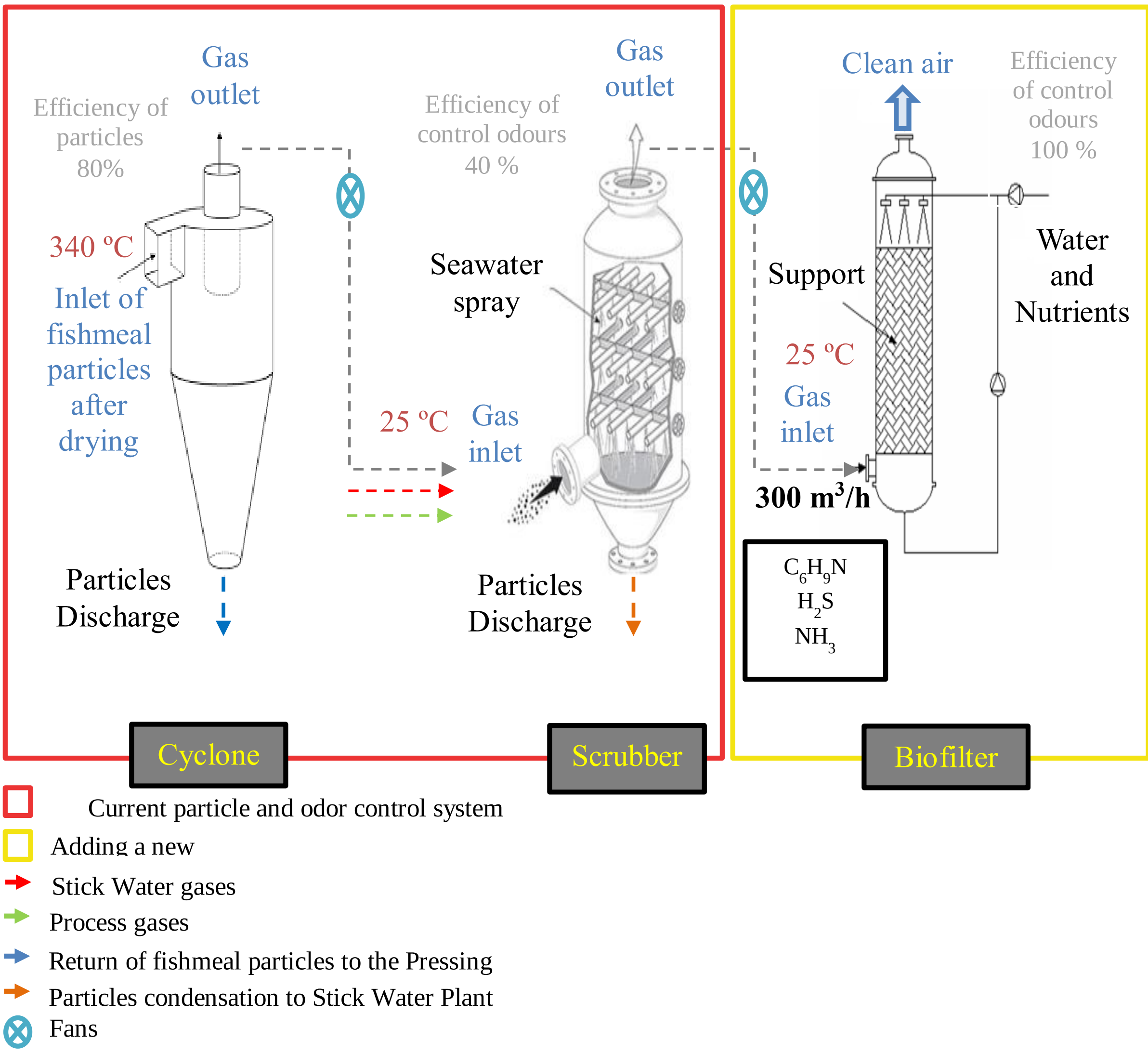

Figure 10. *Design of biofilter option 2. (Own elaboration)*

Annex 3. Advantages and disadvantages of the best control odor technology

Odor System	Advantages	Disadvantages
Absorption	Low investment cost. Low operating costs. Treatment for high concentrations. Possibility to recover absorbed compounds. Particles and gases can be treated simultaneously.	Equipment corrosion. High pumping costs. Use of additional and contraband chemicals. Risk of secondary emissions. The air problem becomes the water problem.
Adsorption	High efficiencies for odor control.	High costs depending on the type of catalyst and maintenance. Problems of regeneration or removal of adsorbents. Risk of catalyst poisoning. Sensitive to solid contaminants. Low flow rates.
Biofilter	Effective for biodegradable substances. Low operating and investment costs. Low maintenance costs. Versatility for gas combinations. Absence of polluting discharges or difficult to remove.	Not used for toxic substances. Large installation area.
Oxidation catalytic	Low energy consumption. Lower operating cost.	Risk of catalyst poisoning. Sensitive to solid contaminants. Low flow rates.
Thermal Oxidation	Zero waste. Simple installation design.	High operating costs. High energy consumption.

Chart 8. *Summary of advantages and disadvantages (Adapted from Higuchi T. 2004 & Wysocka I. et al. 2019)*

Annex 4. Cost analysis between odor control systems

Method	Treated air volume (m^3/h)	Normal single installation cost (EUR)
Incineration	2.418	193.550
Chemical scrubber	2.100	73.470
Water scrubber	1.812	72.680
Adsorption	1.008	34.760
Biofiltration	834	30.810

Chart 9. *Estimation of flow rates and costs on odor control systems (Adapted from Higuchi T. 2004)*

Costs	Thermal and catalytic oxidation	Absorption	Adsorption	Biofiltration
Initial cost	Moderate	Low	Low	High
Operating cost	High	High	High	Low
Maintenance cost	High	High	High	Low

Chart 10. *Comparison costs on odor control systems (Adapted from Wysocka I. et al. 2019)*

10. BIBLIOGRAPHY

1. AINIA. (2007). Mejores técnicas Disponibles para la Industria de Aprovechamiento de Subproductos de Origen Animal. España: Instituto Tecnológico Agroalimentario. Retrieved Junio 2020
2. Alva, E. (2003). Control de Contaminación de aire producido por el proceso de secado de la Harina de Pescado Tipo Estandar. Universidad Nacional de Ingeniería, Facultad de Ingeniería Química y Textil, Lima, Perú.
3. Becerra, W. (2020, Abril). Proceso de Producción de la Harina de pescado. Técnicas de control de olores. Comunicación personal / Jefe del área ambiental de APROPISCO. Pisco, Perú.
4. Bolcu Ozcan, E. (2006). State of the Art of Biofiltration. In Agriculture Waste Products as Filter Media and as Cover Materials in Biofilters for Mediterranean Countries (p. 72). Sttutgar. Germany: Alle Rechte vorbehalten.
5. Brennan, B., Donlon, M., & Bolton, E. (1996). Peat Biofiltration as an Odor Control Technology for Sulphur-Based Odors. In C. I. (CIWEM), Water and Environmental Journal. Promoting Sustainable Solutions. (pp. 190-198).
6. Burgess, G., Cutting, C., Lovren, J., Waterman, J., & Atkinson, K. (1979). El pescado y las industrias derivadas de la pesca. Harina y aceite de pescado. España: Zaragoza Acriboa.
7. Cabello, A., García, A., Figuera, B., Yoli, H., & Vallenilla, O. (2013). Calidad Físico - Química de la Harina de Pescado Venezolana. (U. d. Venezuela, Ed.) SABER. Revista Multidisciplinaria del Consejo de Investigación de la Universidad de Oriente, 25(4), 10. Recuperado el Abril de 2020.
8. Cárdenas de la Cruz, A. (2015). Mejoramiento de la etapa de prensado en el proceso de elaboración de harina de pescado mediante un sistema automizado de con control de la humedad en la empresa JASA S.A. Universidad Nacional de Trujillo. Facultad de Ingeniería. Escuela de Ingeniería Mecatrónica, Chimbote.
9. Cartellieri, A. et al. (2005). Development of a basic procedure to design sorption processes. ScienceDirect, 9.
10. Chavez, F., & Arnaud, B. (2008). The northern Humboldt Current System: Brief history, present status and a view towards the future. ELSEVIER, 11.
11. Contreras, S. (2011). La contaminación heredada: diferentes realidades, distintas soluciones. Lex, 14.
12. Department of Agriculture of the United States. (2020). IndexMundi. Obtenido de www.indexmundi.com/agriculture/?commodity=fish-meal.
13. Dorado, A. et al. (2013). Inventory and treatment of compost maturation emissions in a municipal solid waste treatment facility. ScienceDirect, 8.
14. El Peruano. (2013, Febrero 13). El Peruano Diario Oficial del Bicentenario. Retrieved Abril 2020, from El Perú se afianza como primer abastecedor de Harina de Pescado:
15. El Peruano. (2016, Febrero 13). El Peruano Diario Oficial del Bicentenario. El Perú se afianza como primer abastecedor de harina de pescado.
16. Environmental Protection Agency. (1972). Control Methods. En U. E. Agency, Odors and Air Pollution (pág. 262). North Carolina. United States.
17. Environmental Protection Agency. (1973). Air Pollution Engineering Manual. Air Pollution Control District Country of lo Angeles. Fish Canneries and Fish Reduction Plants. Air Pollution Control Equipment. Los Angeles, United States.
18. Environmental Protection Agency. (1977). Fish Processing. Standards Compilation of Air Pollutant Emission Factors: Third Edition (págs. 211-214). United States.
19. Environmental Protection Agency. (2016). Air Pollution Control Technology Fact Sheet. United States: EPA-452/F-03-018. United States.
20. FAO. (1986). The production of fish meal and oil. Pollution Abatement. Pollution from Emission of Malodors. Rome, Italy: Food and Agriculture Organization of the United Nations.
21. FAO. (2010). Visión General del Sector Pesquero Nacional Peru. Organización de las Naciones Unidas para la Agricultura y la Alimentación.
22. FAO. (2018). El estado muncial de la pesca y la acuicultura. Roma: Organización de las Naciones Unidas para la Alimentación y la Agricultura.

23. FAO. (2019). GLOBEFISH - Información e Análisis Comercial en Pesquerias. Organización de la Naciones Unidas para la Alimentación y la Agricultura.
24. Higuchi, T. (2004). The Trend of Odor Control Techniques in Japan. ResearchGate. Ritsumeikan University, 6.
25. IFFO & SNP. (2017). The Marine Ingredients Organisation. Recuperado el Abril de 2020, de Anchoveta Peruana ¿Por qué es utilizada para el alimento balanceado y no como alimento?.
26. IFFO. (2018). Informe Anual. La Organización de Ingredientes Marinos, China.
27. Industrial Environmental Research Laboratory, (1979). Section 3. Air Control Problems. Odor Emissions and Control. En Overview of the Environmental Control Measures and Problems in the Food Processing Industries (págs. 11-20). California: EPA-600/2: Issue 79, Parts 8-13.
28. IMARPE. (2014). Análisis poblacional de la pesquería de anchoveta en el ecosistema marino peruano. Ministerio de la Producción, Instituto del Mar del Perú, Lima.
29. Lückstädt, C., & Kühlmann, K.-J. (2010). Fresh fish for high quality fish meal. Aqua Culture Asia Pacific Magazine, 23.
30. Mills, B. (1998). Review of methods of odor control. ScienceDirect, 6.
31. MINCETUR. (2019). Reporte Mensual de Comercio. Reporte, Ministerio de Comercio Exterior y Turismo, Dirección General de Investigación y Estudios sobre Comercio Exterior, Lima.
32. Ministry for the Environment of New Zealand. (2016). Good Practice Guide for Assessing and Managing Odor.
33. Neira, R. (2015). Análisis de la aplicación de sistema de frío en la captura y transporte de anchoveta (Eugraulis ringens) y su influencia en los parámetros de procesamiento de la harina de pescado. Tesis , Universidad Nacional de San Agustín de Arequipa, Facultad de Ciencias Biológicas - Escuela Profesional de Ingeniería Pesquera, Arequipa.
34. Nicolay, X., & Kristbergsson, K. (2006). Odors Treatment. Physicochemical technologies. In Odors in the Food Industry (pp. 117-118). Brussels, Belgium: Springer.
35. Odor Control Task Force 1998. Control of odor emissions from animal operations. A report from the Board of Governors of the University of North Carolina, NC State University, USA.
36. OMS. (2003). Hydrogen Sulfide: Human Health Aspects. World Health Organization, Geneva.
37. OMS. (2005). Guías de calidad del aire de la OMS relativas al material particulado, el ozono, el dióxido de nitrógeno y el dióxido de azufre. Ginebra, Suiza: OMS.
38. Padilla, J. (2009). Evaluación de los niveles de Trimetilamina en el aire en la ciudad de Chimbote-Ancash Perú. Biotiempo, 3.
39. Paredes, C. A. (2014). Mejoramiento del estadio de conservación del pescado mediante un sistema de recirculación por agua de mar refrigerada en una embarcación de la Empresa Pesquera Austral. Tesis Universitaria, Universidad Nacional del Callao , Facultad de Ingeniería Mecánica - Energía, Lima.
40. Pesquera Diamante. (2009). Avances en la industria pesquera para mitigar la contaminación del aire. Presentación , Pisco. Recuperado el Abril de 2020
41. Pendashteh, A., Fathi, H., Niazmehr, F., & Rahmaninezhad, S. (2015). Odor Removal from a Fish Meal Plant by Oxidative Scrubber (a pilot study). ResearchGate, 10.
42. Poblet, L. (2019). Desodorización de la Harina de Pescado por el método de Inactivación Química. Universidad Nacional Federico Villareal, Lima, Perú.
43. PRODUCE. (2010). Protocolo para el Monitoreo de Emisiones Atmoféricas y de Calidad de Aire de la Industria de Harina y Aceite de Pescado y de Harina de Residuos Hidrobiológicos. Resolución Ministerial Nº 194 - 2010 - PRODUCE, Ministerio de la Producción, Lima.
44. PRODUCE. (2018, Noviembre 9). Autorizan el inicio de la Segunda Temporada de Pesca del recurso anchoveta y anchoveta blanca en la Zona Norte - Centro del Perú. El Peruano, p. 3.
45. PRODUCE. (2019, Abril 25). Autorizan inicio de la Primera Temporada de Pesca 2019 del recurso anchoveta y anchoveta blanca en área del dominio marítimo, el Límite Máximo Total de Captura Permisible de la Zona Norte - Centro del Perú. El Peruano, p. 3.

46. Saetersdal, G., & Valdivia, J. E. (1964). Un estudio del crecimiento, tamaño y reclutamiento de la Anchoveta (Engraulis ringens J.). Boletín, Instituto de Investigación de los Recursos Marinos, Lima.
47. Sandbol, P. (January de 1993). Nueva Tecnológia en la Producción de Harina de Pescado para piensos: Implicaciones sobre la Evalución de la Calidad. ResearchGate, 28.
48. SENACE. (2008). Establecen disposiciones dirigidas a titulares de plantas de harina y aceite de pescado y de harina residual de pescado, a fin de realizar la innovación tecnológica para mitigar sus emisiones al medio ambiente. RESOLUCION MINISTERIAL Nº 621-2008-PRODUCE, Servicio Nacional de Certificación Ambiental para las inversiones Sostenibles, Ministerio de la Producción.
49. Serna, B. (2009). La Industria de Harina de Pescado y El Ambiente. Perú. Obtenido de https://es.scribd.com/doc/16463905/La-Industria-de-Harina-de-Pescado-y-El-Ambiente
50. SINIA. (2009). Decreto Supremo N° 011-2009-MINAM. Aprueba Límites Máximos Permisibles para las emisiones de la Industria de Harina y Aceite de Pescado y Harina de Residuos Hidrobiológicos. El Peruano, pág. 3.
51. SINIA. (2011). Guía para el suministro de información al Registro de Emisiones y Transferencia de Contaminantes - Industria de Harina de Pescado. Sistema Nacional de Información Ambiental, Lima.
52. SNP. (2014). Relevancia del Sector Pesquero en la Economía Peruana. Aportes al debate de pesquería, Sociedad Nacional de Pesquería, Lima.
53. SNP. (2019). Aportes al debate en pesquería. ¿Existe concentración en la pescada de Anchveta? Sociedad Nacional de Pesquería, Lima.
54. Scirè, S., & Liotta, L. (2012). Supported gold catalysts for the total oxidation of volatile organic compounds. ScienceDirect, 25.
55. Sotomayor, A., & Power, G. (2019). Tecnologías limpias y medio ambiente en el sector industrial peruano (Vol. Primera Edición). Lima, Perú: Fondo Editorial.
56. Stord Process As. (Abril de 2020). Stord As. Obtenido de www.stord-as.com/
57. United States Department of Agriculture. (2019). Index Mundi. Retrieved Abril 2020, from Fish Meal Production by Country in 1000 MT: https://www.indexmundi.com/agriculture/?commodity=fish-meal
58. United States Departmento of the Interior Washington. D.C. (1952). Odor Control in Fish Processing Plants. Review of Developments and news of the fishery industries prepared in the branch of commercial fisheries. En Commercial Fisheries Review (pág. 879). Fish and Wildlife Service. United States Deparment of the Interior.
59. Wypych, G. (2017). Methods of Odor Removal. En Handbook of Odors in Plastic Materials (Second Edition) (págs. 171-200). ScienceDirect.
60. Wysocka, I., Gębicki, J., & Namieśnik, J. (2019). Technologies for deodorization of malodorous gases. National Center for Biotechnology Information (NCBI). Environmental Science and Pollution Research., 26.
61. Ying, D., Ji-Yan, S., Wei-Xiang, W., Jun, Y., & Ying-Xu, C. (2006). Trimethylamine (TMA) biofiltration and transformation in biofilters. ScienceDirect. ELSEVIER, 8.
62. Ying, D., Weixiang, W., Zhiying, H., & Yingxu, C. (2007). Correlation of reactor performance and bacterial community composition during the removal of trimethylamine in three-stage biofilters. ScienceDirect.ELSEVIER, 11.