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Review Article

Projects for the Desalination of Brackish Water and Seawater at the Bilbao School of Engineering

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Abstract

Desalination of brackish water and seawater is a process in constant development and improvement that needs to be taken into account nowadays in order to provide fresh water for different uses. Students that have studied the specialty of Hydraulic Engineering at the Bilbao School of Engineering in University Master in Industrial Engineering are qualified to design and/or improve these kinds of facilities. These students have developed several projects in collaboration with top companies of the sector in the recent years. This work summarizes the main contributions of these projects focusing on the advances and improvements obtained for the desalination process.

Keywords: Desalination; Degree; Master; Energy efficiency; Hydraulic simulation; Hydraulic transient; Water hammer; Desalination plant

Introduction/Background

The educational offer at the Bilbao School of Engineering in Bilbao includes the University Master in Industrial Engineering where the Specialty of Hydraulic Engineering with 30 ECTS credits can be studied [1]. The world of fluids implies many disciplines that are difficult to bring together. Figure 1 shows a brief summary of the possible applications of the Hydraulic Engineering.

That specialty was developed for the Industrial Engineering degree in order to work on the most relevant issues of the water sector (Management, Operation, Pipeline Networks and Hydroelectric Power Plants [2, 3]), together with some other disciplines related to the operation such as Computational Fluid Dynamics (CFD), Hydraulic Power or Pneumatics. This specialty is a unique case in Spain among all the Master's degrees offered in Industrial Engineering.

More than 90 % of the world water is brackish water and seawater. Therefore, it is necessary to take into account this kind of water as a resource. In this sense, among the specialty subjects, one of them called Management of Hydraulic Resources and Hydroelectric Power Plants [4] with 6 ECTS credits is studied during the 1st academic year of the master. When developing this subject, desalination techniques for brackish water and seawater are explained to the students in order to be able to adapt them to the different uses of fresh water (domestic, for agricultural-livestock use or for industrial use).

Figure 1: Hydraulic Engineering Applications.

In relation to hydraulic machinery, which is a fundamental part of these kind of facilities (pumps, for example, are the most used type of machine after engines), there is a compulsory subject that analyzes Fluid Facilities and Machinery, with 4,5 ECTS credits also during the 1st academic year of the master.

The knowledge gained by the students in this subject in relation to the desalination processes is then applied when carrying out their Master's Thesis.

Students need to get the competences by carrying out alternative activities, based on the innovation. After passing the subjects, they are ready to incorporate to the job market. An Educational Cooperation Program sets the students in the path of the job market for the first time, where they can develop their Master´s Thesis in situ. Often, after finishing their studies at the university, they end up working in the same companies. The university teaching encompasses a curriculum of a degree that enables the practice of the Industrial Engineering profession with regulated professional assignments [5]. Among the competences, the following are included: design, test and analysis of fluid machinery and design and development of projects for fluid facilities.

The Basque Country is not an area that has a specific need of brackish water or seawater desalination, which can be a critical issue in the Canary Islands, Balearic Islands or in the southeast of the Iberian Peninsula. However, the top companies of the sector Acciona [6], Suez [7], Ferrovial-Cadagua [8], and so on, are located in the Basque Country and the students develop these topics in a satisfying way in collaboration with these companies.

The final objective is to get the students into the job market within the hydraulic area such as desalination. The covered academic path will be described in the following sections.

Discussion and Results

In order to study in the specialty of Hydraulic Engineering, students have previously had to complete the Bachelor's Degree in Engineering in Industrial Technology or have had to take additional training in order to access the Master's Degree in Industrial Engineering at the Bilbao School of Engineering.

In the Degree in Engineering in Industrial Technology, and in practically all degrees in Engineering, Fluid Mechanics needs to be studied. The basic principles are focused in that subject in order to be able to develop advanced skills for the specialty. This means that any student from an engineering degree would not have to take additional training in this area to access the Master in Industrial Engineering and therefore the specialty in Hydraulic Engineering.

All students taking the master's degree in Industrial Engineering at the Bilbao School of Engineering will have to study the Fluid Facilities and Machinery subject. This subject is designed so that students who do not choose the specialty of Hydraulic Engineering develop at least some basic notions of these machines, while those of the specialty can increase their knowledge about them in the subjects of the specialty through practical applications.

In addition to the skills of the degree [5], by taking this specialty, students will acquire the following skills:

- IH1. Design, operate and maintain hydraulic systems.
- IH2. Project, calculate, design and manage hydraulic resources and hydroelectric plants.
- IH3. Project, calculate and design fluid networks and oleopneumatic components.
- IH4. Have knowledge and advanced capabilities of calculation methods in fluid mechanics.
- IPCC4. Knowledge and skills to project and design electrical and fluid facilities, lighting, air conditioning and ventilation, energy saving and efficiency, acoustics, communications, home automation and smart buildings and security facilities.
- IPCC6. Knowledge and skills to perform verification and control of facilities, processes and products.
- IT5. Knowledge and skills for the design and analysis of heat engines and machines, hydraulic machines and industrial heat and cold installations.
- TI8. Ability to design and project automated production systems and advanced process control.

Concretely, with the subject of Management of Hydraulic Resources and Hydro-Electric Plants, the student will be provided with an elementary theoretical base to solve specific problems, typical within engineering, in the management of hydraulic resources and hydroelectric facilities.

Among the theoretical or practical contents of that subject, the following contents need to be highlighted:

- ✓ Water and hydrology.
- ✓ History of hydraulic planning. Scope.
- ✓ Water management in the world. Applications.
- ✓ The balance between uses and resources.
- ✓ Necessary endowments of use.
- ✓ The management of the demand.
- ✓ Water cycle. Precipitation.
- ✓ Surface water. Watersheds.
- ✓ Stochastic analysis of hydrological information.

So, seawater desalination and the reuse of water are explained in this topic.

Before finishing the studies, students can do External Practices subject that correspond to 9 ECTS credits during the 2nd academic year of the master. An Educational Cooperation Program allows getting the first job, passing the subject and developing their Master´s Thesis in situ.

Master´s Thesis must be carried out during at least 600 hours of personal work, which corresponds to 24 ECTS credits during the 2nd academic year of the master.

As long as some of the most important companies of the water sector operate in the surroundings of the Faculty, the desalination of brackish water and seawater is a topic for their Master´s Thesis.

Different type of Master´s Thesis in relation with brackish water and seawater have been presented:

- Design a new desalination plant in the island or Mediterranean coast
- Improvement of an existing facility
- Use of renewable energy in a desalination plant (solar thermal or wind energy)
- The typical structure of these type of Master´s Thesis is the following:
- Brief abstract in Spanish, Basque and English
- Introduction considering water resources (characteristics of the water quality, percentage of water used for activities, and salinity)
- Objectives and scope
- Description of a typical desalination facility and its fundamental parts
- Analysis of studied facility checking the hydraulic machinery (for example, the point of operation of the pump)
- Description of the different methods of energy recovery from reject
- Design and description of the improvement proposal
- Economic calculation of the proposed solution implementation
- Planning of Master´s Thesis and economic cost
- Conclusions
- Bibliography

In order to pass satisfactorily the Master´s Thesis, students have to write a memory and present it in an oral communication during15 minutes. The cover page of one Master´s Thesis is shown in Figure 2.

During the development of their Master´s Thesis, students are encouraged to analyse the water needs of the area. Then, they also check the available water resource of the region (saline and/or brackish) before studying the types of desalination plants that can be implemented. They usually focus on plants based on reverse osmosis as long as they are more widespread and all the stages of the process are analysed. In general, the critical step in terms of energy consumption, that consequently makes the process more expensive, is the high pressure pumping. This phase is usually studied it in detail, trying to find cheaper but equally effective alternatives with the aim of improving the energy recovery system

according to the latest existing developments in the market. In the past, the solution for that problem was choosing one of the several types of turbines (Pelton, Francis, and so on), but at this moment the new designs of energy recuperators are being implemented, such as ERI [9-15].

MÁSTER UNIVERSITARIO EN
INGENIERÍA INDUSTRIAL

TRABAJO FIN DE MÁSTER

ANÁLISIS DE LOS DISTINTOS MÉTODOS DE RECUPERACIÓN DE ENERGÍA DEL RECHAZO DE UNA PLANTA DESALADORA

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Curso académico 2017-2018

Bilbao, 5, Septiembre, 2018

Figure 2: Cover page of one Master´s Thesis.

Also new membranes for reverse osmosis are been considered [16-19].

Table 1 shows some information about the Master´s Thesis related to desalination facilities of the recent years. Three types of Master´s Thesis have been identified: Design (D) / Implement (I) / Renewable Energies (RE).

Table 1: Important information about the Master´s Thesis.

Academic Year	Type	Title
2010/2011	RE	Reverse Osmosis Desalination with Thermal Solar Energy
2012/2013	D	Reverse Osmosis Desalination Plant
2013/2014	RE	Applying Wind Power to a Desalination Plant
2014/2015	I	Improving the Energy Efficiency of Adeje-Arona's EDAM
2017/2018	I	Taking advantage of the Rejection of the Son Tugores Salty Water Plant
2017/2018	D	Analysis of the different Methods of Energy Recovery from the Rejection of a Desalination Plant
2019/2020	I	Energy Revaluation of the El Atabal Salty Water Plant
2022/2023	I	Computational Simulation using the AFT IMPULSE program of the steady and transient states of a high pressure manifold of the MIRFA 2 desalination plant
2022/2023	D	Study of Desalination and development of algorithm for the sizing of Brine unloading stations

A brief summary of these Master´s Thesis will be provided in the next paragraphs:

Master´s Thesis 1: Reverse Osmosis Desalination with Thermal Solar Energy

The objective of this final master's project is to carry out an analysis and a design of a desalination system using reverse osmosis of seawater in which the main energy consumption of the reverse osmosis process is provided by a solar thermal system. It is intended to be able to desalinate 15000 m^3 of seawater to supply a population of 50000 inhabitants. The study of 3 possible sites on the southern desert coast of Peru (Arequipa, Moquegua and Tacna) has been carried out in order to obtain 300 l/d.

Unlike what happens with photovoltaic solar energy and wind energy, practical experiences regarding the coupling between reverse osmosis desalination systems and solar thermal technologies are very scarce. And there are no examples of commercial direct steam generation (DSG) generation plants.

In the case of solar technologies for DSG, by means of parabolic collectors, it is remarkable to note that, despite being an advanced technology, up to now it does not meet expectations due to its high costs and low yields. However, with the development of new materials this situation could change.

Master´s Thesis 2: Reverse Osmosis desalination plant

The objective is to carry out a reverse osmosis desalination plant on the island of Ibiza so that the amount of drinking water produced can be increased and, thus, supply the demand, especially in populations where there is still no total coverage.

The desalination plant will provide 5500 m^3/d so that the amount of drinking water obtained by this system will increase from the current 44500 m^3/d, to 50000 m^3/d.

The phases of the plant are:

- Catchment: necessary to capture and displace the feed water at the foot of the plant.
- Physical and chemical pre-treatment: in order to leave the water in appropriate conditions before coming into contact with the membranes in the core of the process.
- Reverse osmosis core: where the physical phenomenon of reverse osmosis takes place and where most of the energy consumption of the global process is concentrated.
- Brine flow rate or rejection: it will be sent to an energy recovery system in which it gives much of its energy back to the feed flow.
- Post treatment: to adapt the water product in relation to some of its physical-chemical characteristics and make it suitable for consumption.
- Pumping system: to move desalinated water from the point of production to the storage or consumption point.

As a novel feature, a power recovery system based on PX (Pressure Exchanger) devices will be applied. These devices consist of a rotating positive displacement pump that recovers energy from the reject jet, with 98 % efficiency and almost no maintenance.

The site of the plant will be in the vicinity of the town of Vista Alegre (south of Ibiza), which is located in the municipality of San José, the only one that does not have its own source of drinking water.

The operation of the plant will be carried out by a company that provides the drinking water supply service.

Master´s Thesis 3: Applying Wind Power to a Desalination Plant

Motivated by the field of sustainability in the energy and water sector, the objective of the project aims to introduce the concept of water sustainability and desalination in particular.

The site chosen to develop the application, consisting of a self-tested desalination by a wind farm is the Canary Islands. Firstly, because the Islands are a paradigm in everything that refers to the water-energy binomial. Having been able to adapt to the times, and innovate to take advantage, in the most efficient and exquisite possible way, of natural water resources. The second reason is that the demand for primary energy in them is currently almost entirely covered by petroleum-derived fuels, resulting in an energy-dependent, non-competitive model with large negative environmental impact.

In addition, it is necessary to take into account the uniqueness of the Canary electric system. This system consists of six electrically insulated and small subsystems. This makes quality of service and service stability more complicated than large interconnected systems. Therefore, it is important to be self-sufficient as much as possible in each of the islands. That is why renewable energy is one of the keys to regional energy policy, aimed at reducing energy dependence and reducing emissions.

Master´s Thesis 4: Improving the Energy Efficiency of Adeje-Arona's EDAM

The main objective of this project was to improve the energy efficiency of the processes that are carried out in the desalination plant, either in the osmosis area, or in the product water pumping area. This will reduce energy consumption per cubic meter of desalinated water. It will also reduce the maintenance costs of equipment today, when installing new ones, and improve safety. The energy saving target set is 0,3 kWh/m^3, as from that figure, the improvement becomes profitable.

Within the plant, improvement efforts are to focus on the membrane area, and on the product pumping area. The actions to be carried out in the elements are then being described in general.

In terms of electronic regulation and control in electric motors, speed drives will be incorporated, and motors will be replaced with more energy-efficient ones.

In relation to the pumps of the osmosis part, the impellers that are already installed will be replaced with others rectified by the same manufacturer, improving efficiency. In the product water pumping area, the old pumps will be replaced with new ones.

Energy recovery systems: Pelton turbines operating at the moment will be replaced by energy exchange systems, specifically ERI px models.

For the system to function properly, the pipe network will be redesigned, with its corresponding valves, transmitters, gaskets, and filters. The plant control system will also have to be adapted.

Master´s Thesis 5: Taking advantage of the Rejection of the Son Tugores Salty Water Plant

The water treatment plant of Son Tugores, in Palma de Mallorca, supplies around 30 % of the daily water needs of the Balearic capital, since it is the convergence point of all water resources capable of being suitable for human consumption which EMAYA has, "Municipal Water and Sewer Company" of Palma.

In 1995, the desalination plant was built, which purifies 30000 m^3/d, to solve the problem of salinization of the Na Burguesa and Pont d'Inca aquifers and to provide the city with water of high quality.

The plant was designed to treat water with a salt concentration between 2 and 10 g/L, but the values collected are between 5 g/L and 8 g/L. Thanks to the construction of desalination plants like this one, and thanks also to a good rainfall in the area, it has been possible to recover the aquifers in 15 years and reduce the salinity of the confined waters.

The work comprises the study carried out in this plant about the recovery of the water rejecting, which, at the moment, is drained to the sea without obtaining any benefit. Rejecting water will be used to produce more quantity of desalinated water without increasing the inflow to the plant and, through an energy recovery system, the specific consumption will be reduced. As a result, the cost per cubic meter of water produced will be lower.

The study is composed of divided into several parts. In the first sections the current situation of desalination worldwide, at the level of Spain and the Balearic Islands, is described. Afterwards, the different types of desalination are explained, especially the process based on reverse osmosis as long as it is the most used and the one operating in this plant. Finally, the existing plant and the new reject recovery plant are described and the calculations made to design this new plant are detailed.

The study also consists of a planning of the proposed project and a budge, as well as a summary of the future operating costs of the plant. At the end of the document, several annexes are included in which the calculations carried out are developed and the plans of the new plant are presented, as well as an environmental impact study and specifications of the selected turbo-pump and the membranes.

Master´s Thesis 6: Analysis of the different Methods of Energy Recovery from the Rejection of a Desalination Plant

The aim of this Master´s Thesis is to analyse the different energy recovery methods of the brine flow in a Sea Water Reverse Osmosis plant (SWRO) located in Adeje (Canary Islands). Following the analysis, the plant's economic and technical viability is studied in order to determine whether the method currently used could be substituted with a more efficient one.

The desalination plant, with a 30 000 m^3/d capacity, covers the water supply of the Adeje-Arona region. Given that the plant started operating in 1998, its facilities and equipment are now less efficient than those currently available in the market. Therefore, the substitution or the replacement of the equipment currently installed in order to optimise the desalination process is a subject of great interest.

First, this work introduces desalination in a global context and explains the specificities of water needs in the Canary Islands, as well as the objectives, the scope and advantages of the project. Next, the desalination process and specifically the characteristics of the SWRO plant of Adeje-Arona are described. The different energy recovery alternatives are analysed, and an assessment is given as to the most adequate option. One of the systems, DWEER (Dual Work Exchanger Energy Recovery), that has been studied is shown in Figure 3.

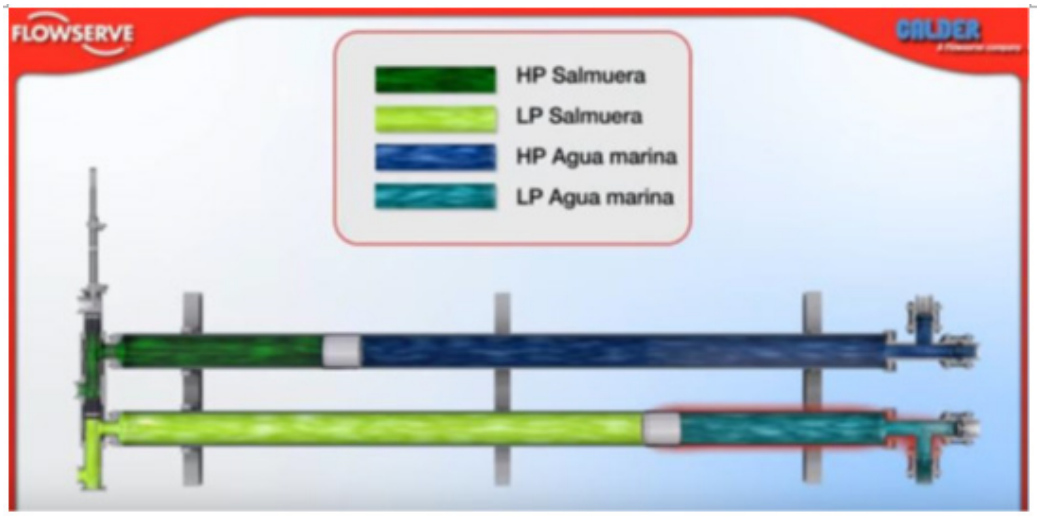

Figure 3: DWEER devices [11].

The planning of the project and final quotation are also included. Finally, the conclusions extracted from the completion of this project are outlined.

Master´s Thesis 7: Energy Revaluation of the El Atabal Salobre Water Plant

The El Atabal desalination plant in Malaga, with a nominal production of 165000 m^3/d, supplies most of the region's needs. In 2002, the old ETAP (Drinking Water Treatment Station) was modified to add a desalination process to the old water treatment plant and, therefore, solve the problem of water scarcity that plagued the area.

The plant was analyzed to treat water with a concentration of up to 8 g/L. the values collected so far ranged between 0,8 g/L and 6,5 g/L, far from the recommendation of values less than 0,5 g/L for human consumption.

Thanks to the construction of desalination plants like this one and to the technological advances in desalination, it has been possible to recover the country's aquifers in 15 years and reduce the salinity of confined waters.

This work deals with the study carried out in the aforementioned plant on the energy recovery of rejection waters, which, today, pose as an obsolete energy recovery system based on a turbopump that does not take advantage of energy capacity that this flow has. It is intended, on the one hand, to propose an improvement that allows increasing the production of the plant, and, on the other hand, to develop an alternative to the current energy recuperator that allows obtaining specific lower energy consumption, that is, reducing the cost per cubic meter of produced water.

The study carried out consists of a memory divided into several parts. It begins by explaining the basic concepts of desalination and the current situation of the technique worldwide, at the national level in Spain and in the Málaga area. The different types and techniques of desalination currently used are described below, with greater emphasis on the reverse osmosis process, which is most used and used in this plant. Finally, the existing plant is described in detail, a series of alternatives is proposed and the necessary calculations and explanations are carried out to justify the solution adopted to solve the goals.

The study is complemented by planning the proposed project and a budget divided into different parts, ending with an extensive analysis of the operating costs of both the current plant and future solution in order to calculate its profitability.

At the end of the document, there are several annexes that include the hydraulic calculations, pumps set points, as well as specifications of both the membranes and the equipment selected for the energy recovery system.

Master´s Thesis 8: Computational Simulation using the AFT IMPULSE program of the steady and transient states of a high-pressure manifold of the MIRFA 2 desalination plant

Throughout this study will model and simulate the stationary and transient state of a high-pressure collector of the desalination plant MIRFA 2 using the AFT Impulse software. The work has been developed in educational cooperation with the company ACCIONA Agua, being part of the hydraulic team in charge of performing the hydraulic calculations in the company's various projects. The work presented here will simulate a high-pressure collector that supplies the reverse osmosis racks of the desalination plant. This high-pressure section will be modelled following industry standards and adopting widely used simplifications to obtain a simulation that yields results extrapolatable to the reality of the nominal steady state and the transient state caused by the sudden stop of the pumps.

Master´s Thesis 9: Study of Desalination and development of algorithm for the sizing of Brine unloading stations

During the execution of the internship agreement in the IDOM company, the task of this Master's thesis has been coordinated with the development of the conceptual analysis of the Sabha desalination plant, located in the area of just 12 km of coastline that Israel, between Egypt and Jordan, has with the Red Sea. This facility supplies water to the city of Eilat and the surrounding area for domestic, industrial and agricultural needs. The facility was commissioned in 1978 with the first plant and due to the increasing demand for drinking water and also seawater it was decided to expand the facility with a new desalination plant with additional infrastructure to cover these needs, the Sabha D module, to add 20 million m^3 /year of product water. To achieve this purpose a complete new infrastructure had to be designed, fragmented into the raw water intake, the pumping facility, the water conveyance, the reverse osmosis based desalination plant, the effluent treatment and the brine discharge. This work focuses, on the one hand, on deepening the knowledge about water, about the concept of osmosis and reverse osmosis, and about the application of the latter phenomenon to the operation of desalination plants, addressing and explaining each of the sub-processes that must take place within the general process of obtaining permeate water in a correct way. On the other hand, the work emphasizes the study of the transient regime caused in the brine discharge station when starting or stopping the operation of the plant. This is achieved by implementing the differential equations that define this transient state in an Excel macro, and by solving the problem with the fourth order Runge-Kutta numerical method, in order to simulate real operating and dynamic situations that occur in the unloading stations, thus being able to correctly dimension these stations for the correct operation and maintenance of the plant

The Master´s Thesis can be written in Spanish, Basque or English. As long as the subject of the Hydraulic Engineering speciality is explained in Spanish, all of the Master´s Thesis related to desalination are written in Spanish.

When the Master´s Thesis has the approval of the director, an exposition of 15 minutes has to be done by the student. The tribunal of the defence has to evaluate the written memory and the oral presentation, completing an evaluation sheet provided by the School of Engineering [20,21]. Figure 4 shows the sheet used for the evaluation.

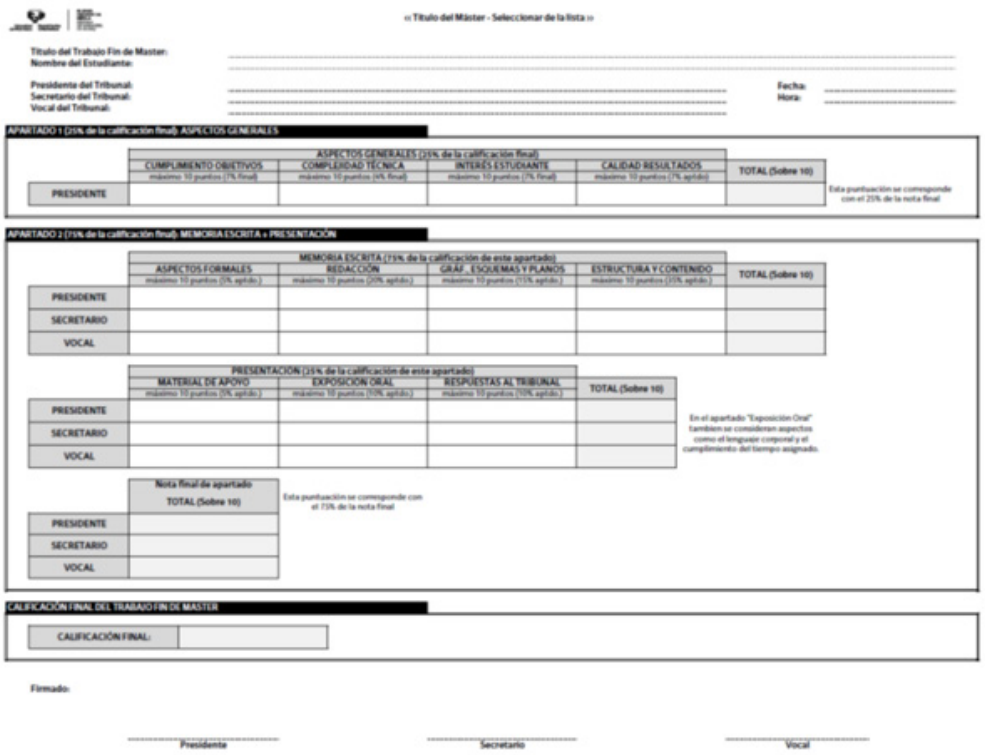

Figure 4: Evaluation sheet [21].

The qualifications obtained for the described Master´s Thesis related to desalination systems show a very positive evaluation with an average value of 8,5 over 10 points. These results bring to light the high level of knowledge developed in the Hydraulic Engineering specialty.

Summary/Conclusions

Students who take the subject of Management of Hydraulic Resources and Hydroelectric Power Plants (specialty of Hydraulic Engineering, University Master in Industrial Engineering at the Bilbao School of Engineering) acquire the concepts and skills to be able to develop their Master´s Thesis on the subject of desalination in an efficient way. This way, these students will be prepared to join the labour market by designing or improving facilities of this kind.

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Conflict of Interest

There is no conflict of interest.

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