MÁSTER EN INGENIERÍA INDUSTRIAL

# Project in collaboration with PSA

## Proposals to reduce water consumption and waste at the group's factory at Villaverde, Madrid

Group 4

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# 1. INTRODUCTION

The objective of this work is to study the feasibility of a water recovery system for industrial use at the Stellantis factory, which resulted from the merger of PSA Peugeot-Citroën and Fiat Chrysler Automobiles, and was formerly known as the PSA Villaverde factory.

The Madrid site is a pioneer factory in the Spanish automotive industry. However, in its 70 years of life, this factory needs certain improvements to adapt to modern times. There is a growing concern about not meeting Sustainable Development Goals within the Stellantis group, which has led them to study different sustainable projects, such as the installation of solar panels for the factory's self-consumption. In this line, the Stellantis group has contacted us to study the feasibility of installing a reverse osmosis plant for the recovery of water from the paint sector. In this way, the intention is to use this water as industrial water for the TTS to replace drinking water. For this purpose, a plant with a capacity of $10m^3/h$ should be installed.

However, this project will not be limited to the study of a single solution but will consider two other alternatives for the reuse of water for industrial use. These two options consist of the recovery of rainwater and the installation of a storm tank in collaboration with Canal de Isabel II.

# 2. THE FACTORY

The Villaverde factory, inaugurated in 1951, has a surface area of 750,000 m2, where the development of the automotive industry in our country has been forged. Today, its production capacity is focused on the new Citröen model, the C4 Cactus.

The factory is divided into two areas. In one of them, there is the general office building, where around 1,200 people work, and where the vehicles are delivered to the brands at the end of the assembly line. The second zone is where the industrial activity takes place. In this area the industrial building can be found, where the painting, bodywork, assembly, common services and spare parts warehouse are located. This warehouse has a surface area of 80,000 m2. In addition, there is a ring-shaped parking lot with an area of 100,000 m2, where the cars are waiting to be distributed.

The water supply to the factory comes from the Canal de Isabel II with a given pressure of 8 bar. The facility has a 3,500 m3 tank where this effluent is stored, ready to be pressurized again depending on the sector to which the water is destined. This tank allows the plant to continue operating in the event of a momentary cut or breakdown in the canal. In addition to this tank, there is also a direct intake from the Canal Isabel II. The average water consumption per vehicle manufactured is around 1 liter. The wastewater passes through an internal physical-chemical treatment system and is then returned to Canal de Isabel II, where it undergoes biological treatment.

# 3. REVERSE OSMOSIS SYSTEM

## *3.1 REVERSE OSMOSIS PROCESS*

Reverse osmosis is a water purification technology used to remove large particles and other ions and molecules with the help of a semi-permeable membrane. Reverse osmosis can remove many types of suspended elements in water, including bacteria, and is used both in industrial processes and to produce drinking water. In the process of reverse osmosis, the flow must be introduced in the semi-permeable membrane container at a pressure higher than the osmotic pressure of the supply water. In this way, the substances in the water are separated on one side of the membrane (concentrate) and a dilute solution low in dissolved solids (permeate) is obtained on the other side.

Reverse osmosis plants require pretreatment systems, feed pumping equipment for pressurized tanks that contain the membranes, chemical dosing equipment, etc. for them to work properly. Pretreatment of reverse osmosis systems is crucial to prevent scaling and to extend membrane lifetime and to obtain better performance in the reduction of dissolved solids. A typical treatment process is filtration. It is recommended to use filters that retain all particles larger than 5 microns. Disinfection is another pretreatment step used to prevent biological saturation of the membrane. It is of utmost importance to verify that the membrane material and the disinfecting agent are compatible since many of them can permanently damage the osmosis membrane.

## *3.2 USE OF RO IN PAINT WASTE*

The use of reverse osmosis systems for the treatment of paint waste is a technique that is still underdeveloped in the industry, so a more detailed study with the data obtained in the analysis of the wastewater samples is necessary to know the viability of the process and if necessary, add pretreatment stages in order to eliminate chemicals that may affect the reverse osmosis membrane preventing its proper functioning or reducing its performance.

Despite this, there are examples of similar projects carried out in factories of companies in the sector such as Honda or Audi, the latter being capable of reducing wastewater by 40% in its factory in Ingolstadt, Germany. In both cases the use of additional systems to reverse osmosis is mentioned.

Reverse osmosis technology is well developed in water treatment and there are numerous manufacturers and models on the market that could be compatible with paint treatment, so if an adequate pretreatment is carried out, quality requirements could be met in the effluent.

## *3.3 INPUTS AND DESIRED OUTPUTS*

With the reverse osmosis plant, the objective is to reuse the effluent at the outlet of the physical-chemical treatment. Two uses can be given to this RO plant:

- To use it as demineralized water (ADR), replacing the current plant with a capacity of 7 m3/hour. For this purpose, the characteristics of the plant would be as follows:

| Inlet effluent | Lower Limit | Upper Limit |
|---|---|---|
| pH | 7 | 8.5 |
| Conductivity (uS/cm) | 1250 | 2500 |
| Outlet effluent | | |
| pH | 4,5 | 8 |
| Conductivity (uS/cm) | 0 | 20 |

*Table 1: Characteristics of the plant. Option 1*

- Use it as industrial water for the TTS (Surface Treatment) instead of drinking water for a continuous supply of 10 m3/h in the TTS tanks. For this purpose, the characteristics of the plant would be as follows:

| Inlet effluent | Lower Limit | Upper Limit |
|---|---|---|
| pH | 7 | 8.5 |
| Conductivity (uS/cm) | 1250 | 2500 |
| Outlet effluent | | |

| | | |
|---|---|---|
| pH | 7 | 7.6 |
| Conductivity (uS/cm) | 100 | 130 |

*Table 2: Characteristics of the plant. Option 2*

Since reverse osmosis systems are not capable of recovering 100% of the water introduced and the need of a secondary circuit to direct treated water to equipments, the second option is not feasible. Therefore, we will opt for the first option, for which we would need to recover at least 7 m3/h of water.

It is necessary to point out that it would be convenient and highly recommendable to carry out a more exhaustive analysis of the quality parameters of the feed water, both to achieve a correct operation of the plant and optimum results, and to prolong the lifespan of the equipment. However, laboratory analysis has not been provided to us for this study and the proximity of the delivery of the project does not allow sufficient time to request this data.

## 3.4 PROPOSED SOLUTION

Focusing on the first solution, it will be necessary to install a high-pressure pump with a capacity of 10 m3/h and pressure pipes between it and the container with the membrane in the stage prior to the osmosis process.

Based on data observed from multiple sources, typical design conversion values are around 55-65%. In this project, a conversion value of 65% is chosen, that is, of the 10 m3/h that are introduced into the reverse osmosis system, a permeate flow of 6.5 m3/h is produced from the input flow and a reject flow of 3.5 m3/h is discharged.

Therefore, to cover the capacity needed the new osmosis plant could be used both to treat waste from the painting process and to treat fresh water and obtain demineralized water when the plant is not working and no waste is being produced, thus replacing the old demineralized water plant. This old plant would be maintained to support the new osmosis plant when its capacity is at maximum or as a backup equipment when maintenance tasks are carried out. Equipment as bypasses, regulating valves, flow indicators and conductivity meters must be installed to ensure the quality needed is reached and the water flow can be directed depending to the needs of the moment.

The rejection produced in the reverse osmosis plant can be treated in the same way as the physical-chemical treatment sludge or a possible recirculation can be studied to improve the plant's yields.

## *3.5 FLOW DIAGRAM*

The Stellantis group provided us with a flow diagram in the area where they plan to install the reverse osmosis plant. This diagram details the physicochemical treatment of the water at the outlet of the discharge pond, with processes such as coagulation and flocculation. With all this, it is assumed that the pre-treatment for the reverse osmosis plant has been carried out correctly, and therefore, this part is left out of the scope of the study.

Thus, the flow diagram including the pumping equipment is as follows. As it can be seen, an additional pressurized water intake has been added to the reverse osmosis plant from the Canal Isabel II. In this way, it will be possible to treat the discharge or to produce demineralized water from drinking water. Finally, the treated water must be collected in a storage tank.

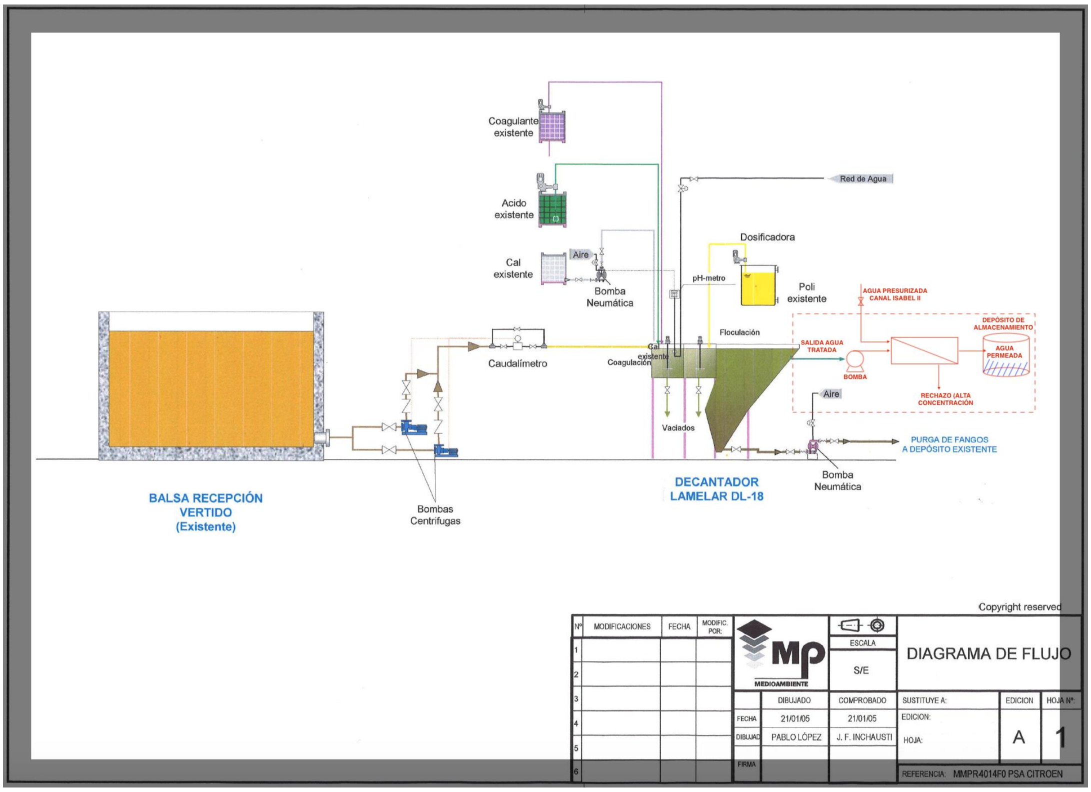


*Figure 1: Flow diagram*

## 3.6 SYSTEM LOCATION

The new reverse osmosis plant could be located in the area where the physical-chemical treatment plant is located, to whose effluent outlet it will be connected.

There are containerized complete systems on the market that are easy to install, without the need for major works, and that could be a good solution when it comes to reducing installation space and time.

*Figure 2:Possible location of the new RO plant*

## 3.7 *ECONOMIC VIABILITY*

After a thorough investigation of market prices, we have taken as a reference a technical-economic proposal for the installation of a reverse osmosis plant in a food company. The costs of this project, for a reverse osmosis plant with a capacity of 15 m3/h, are broken down as follows:

| Description | Price (€) |
|---|---|
| Labor costs, technical assistance and analytical control | 12,332 |
| Costs of chemicals and other consumables | 6,359 |
| Reverse osmosis plant costs (includes high pressure pump) | 65,769 |
| **Total** | **84,460** |

Currently, the company has an agreement with the Isabel II Canal for the latter to carry out biological treatment of the discharges. The water discharged per year at a rate of 10 m3/h is 35,000 m3. The contracted price per m3 of water is 2.44 €.

With these data, it is easy to perform an economic analysis to study the feasibility of the project. For this purpose, it will be assumed that the total cost of a 10 m3/h osmosis plant, smaller than in the reference taken, is around 70,000 €, which is a conservative value.

**Total money saved over a one-year period:**

**Savings** = [Recovered water] * [Biological treatment price] = 35,000*0.65*2,44 = 55,510 €

**Payback Period** = [Cost of investment] / [Cash inflows] = 70,000 / 55,510 = 1,26 years

It is thus determined that the money saved by installing the reverse osmosis equipment would mean recovering the investment at the end of the first quarter after the first year.

In addition, a second, less optimistic case is analyzed for the assumption that the price of the investment rises considerably. A 50% increase in costs up to 105,000 € is assumed. Repeating the same formulas as above, we obtain the following:

**Payback Period** = [Cost of investment] / [Cash inflows] = 105,000 / 55,510 = 1,89 years

In case of a large deviation from baseline, the payback period would still be less than 2 years.

# 4. RAINWATER SYSTEM

## *4.1 POSSIBLE USES OF RAINWATER*

The first option to be evaluated is the installation of a rainwater harvesting tank to try to satisfy a demand.

The characteristics of the rainwater make it possible to adapt its use to the use of water in the cooling towers, the irrigation system, car washes and firefighting systems of the factory. The demand will be estimated at 27,000 cubic meters per year.

In the case of cooling towers, which consume most of the water, 20,000 cubic meters per year, a biological and bactericidal pretreatment must be installed to avoid cases of legionella. According to Royal Decree 865/2003, of July 4, 2003, which establishes the hygienic-sanitary criteria for the prevention and control of legionellosis, "the use of water that does not come from a public or private distribution network will require the mandatory administrative concession for the use of the resource, issued by the competent authority for the management of the public water domain".

## *4.2 COLLECTING SURFACE*

We will use the existing rainwater harvesting system to collect the rainwater through collectors located on the sides of the parking lot with the form of a ring.

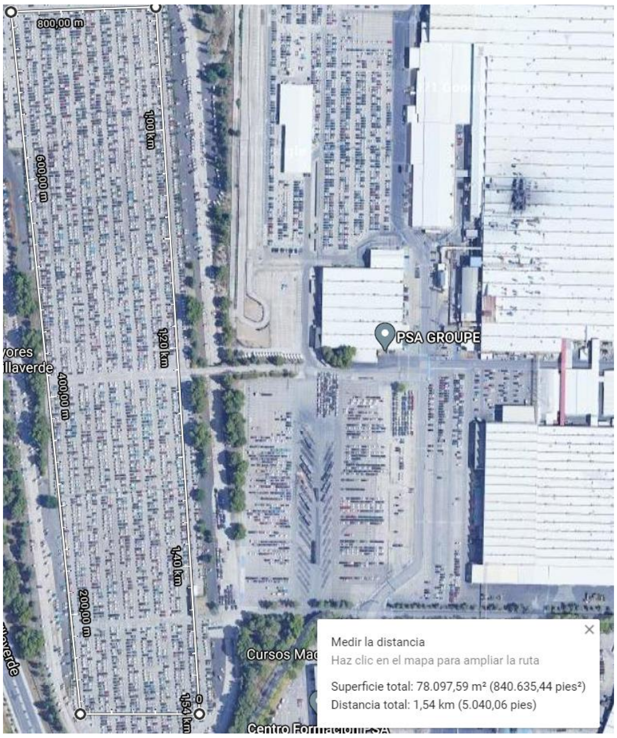


*Figure 3: AvailabLe collecting surface*

As can be seen, we have an area of 80,000 square meters available, which we will use to size the water collection tank.

## 4.3 HYDROGRAPHIC STUDY

Madrid's climate is slightly continental, with moderately cold and relatively rainy winters, and very hot, dry and sunny summers.

Rainfall is not abundant, amounting to 415 millimeters per year (average 34.58 mm per month) and, in fact, the landscape is arid, especially in the summer months. However, rainfall is quite frequent from October to April. In May and more rarely in the summer, in the afternoon some thunderstorms may break out, but generally from June to August it almost never rains.

Winter, from December to February, is quite cold. Rainfall, caused by Atlantic disturbances, is quite frequent, but generally not abundant. In general, snowfall in Madrid is rare and not abundant. However, snow is slightly more frequent in the northern districts of the city, which are at higher altitudes. Light snowfalls can be observed every year or almost every year, but significant accumulation is rare. The January 2021 snowfall, when snowfall reached half a meter, was the heaviest since November 1904.

| | January | February | March | April | May | June |
|---|---|---|---|---|---|---|
| Precipitation (mm) | 41 | 34 | 40 | 47 | 39 | 16 |
| Rainy days (days) | 5 | 4 | 4 | 6 | 5 | 3 |
| | July | August | September | October | November | December |
| Precipitation (mm) | 6 | 8 | 22 | 61 | 55 | 46 |
| Rainy days (days) | 1 | 2 | 3 | 5 | 5 | 5 |

*Table 3: Madrid climate table*

## 4.4 RAINWATER COLLECTION

As we are in a case of water collection through a concrete floor, we have proceeded to multiply the collection surface by a factor called runoff coefficient or impermeability factor in the case of rainfall. With this factor we assume that it will not be possible to collect all the water in a parking lot with a gravel/concrete floor. The factor is between 90% and 95% as the water is also encountered with vehicles after precipitation. For this reason, we will use the factor for the most adverse conditions, estimated at 90%.

Applying the maximum area available for rainwater collection mentioned before (80000$m^3$), we obtain the following table, Table 1.2, which shows the maximum amount of water per month that can be collected.

| | January | February | March | April | May | June |
|---|---|---|---|---|---|---|
| Available water ($m^3$) | 2878 | 2387 | 2808 | 3299 | 2738 | 1123 |
| | July | August | September | October | November | December |
| Available water ($m^3$) | 421 | 562 | 1544 | 4282 | 3861 | 3229 |

*Table 4: Availability of water by month*

We obtain a total of 29133 $m^3$/year. Calculating the maximum output that can be extracted each month, based on the data provided by Stellantis of 220 working days per year and two work shifts, it is obtained that up to 2428 m3/month on average could be extracted, which would correspond to an input of 7.6 m3/h.

With this output, a table can be made to measure the filling level of the tank, and it is observed that at the end of the summer months the total water in the tank would have been used, while in the autumn and winter months this capacity would be recovered.

| | January | February | March | April | May | June |
|---|---|---|---|---|---|---|
| Water in tank ($m^3$) | 4539 | 4499 | 4879 | 5750 | 6060 | 4756 |
| | **July** | **August** | **September** | **October** | **November** | **December** |
| Water in tank ($m^3$) | 2749 | 883 | 0 | 1854 | 3288 | 4089 |

*Table 5: Water in tank by month*

## 4.5 DEPOSIT SIZING

Finally, we calculate the size of the deposit needed from the annual demand volume and the available volume of rainwater by applying the following formula:

$$V = \frac{volume\ to\ be\ collected\ + water\ demand}{2} x \frac{45d\ (reservation\ period)}{365}$$

Substituting the values, we arrive at the following expression:

$$V = \frac{29133 + 27000}{2} x \frac{45}{365} = 3461 m^3$$

## *4.6 ECONOMIC VIABILITY*

We assume that at a price of 2.44 euros per cubic meter and with a demand of 27,000 cubic meters per year, we have a budget of 66,000 euros in one year to meet the payback period of the project for this situation.

It has been decided to compare our starting situation with projects of rainwater collection tanks of similar characteristics in order to achieve an extrapolation of the results due to the difficulty of estimating costs for civil works of this magnitude.

Our tank, which has been dimensioned for 3500 cubic meters, has been compared with a tank of 1000 cubic meters installed in the province of Ciudad Real.

The execution of this tank has been divided into the following points with an associated cost:

-TOTAL CHAPTER 01 LAND PREPARATION 5.800,17€

-TOTAL CHAPTER 02 FOUNDATIONS 31.582,10€

-TOTAL CHAPTER 03 CONDUITS 19.612,76€

-TOTAL CHAPTER 04 PREFABRICATED RESERVOIR 87.477,58€

-TOTAL CHAPTER 05 OPERATING CHAMBER AND CHLORINATION EQUIPMENT 8.132,20€

-TOTAL CHAPTER 06 MARSH PUMPING INSTALLATION 18.176,80€

-TOTAL CHAPTER 07 MISCELLANEOUS 8.747,72€

-TOTAL CHAPTER 08 HEALTH AND SAFETY 1.989,45€

After adding General Expenses (13%), Industrial Profit (6%) and VAT (16%), the total amount was 250,568.53 €. The breakdown of prices shows that the largest disbursement of money comes from the prefabricated concrete cover of 1000 cubic meters with a cost of 23,541.12 €, within the chapter 04 PREFABRICATED RESERVOIR.

To this price estimate should be added in our case the exceptional situation of installing pipes to each cooling tower in addition to the modification of the old system of collection and transport of water from the factory.

It is for these reasons that our system will not only not meet the PSA demand of the return time but also that the investment would be between half a million euros and 750,000 euros to treat only a volume of water of 27,000 cubic meters, a small volume compared to the total water consumption of the factory.

Finally, this option has been discarded due to the high cost associated with it.

# 5. STORM TANK

The possibility of an agreement with the "Canal de Isabel II" and the City of Madrid is proposed for the execution of a joint project for the construction of a storm tank that joins the canal network and that helps to store the first rainwater and regulate the flow that arrives to the purification stations.

## *5.1 CONCEPT AND EXISTING NETWORK*

Storm tanks are huge underground tanks created to store the first rainwater, which is also the most polluting - even more than sewage - because they carry all the dirt accumulated in the streets and on the asphalt. In this way, the tanks keep the treatment plants from reaching their full flow capacity and having to discharge the excess untreated into the receiving channels on days of heavy rainfall.

The water is directed to the storm tanks through huge collectors and before reaching the tanks, the water passes through a series of filters that allow it to retain solid pollutants such as plastic bottles or other types of objects. Many of the solid objects that arrive with the rainwater remain accumulated at the bottom of it. Later they are removed by means of different cleaning systems.

Currently, the Canal de Isabel II has 65 storm tanks that reserve rainwater before being treated and that allow to control that the dirt and objects that the rain carries end up in the Manzanares River.

## *5.2 LOCATION*

The storm tank could be located under the logistics parking lot and could have dimensions of around 80,000 m2 while its use is maintained after the necessary works.


*Figure 4: Possible location for the storm tank*

## 5.3 BENEFITS

If the "Canal de Isabel II" and the Madrid city council were interested in the project, they would just bear all the construction and maintenance costs, in addition to receiving an economic compensation for the execution time of the works. For a similar project such as the one carried out by "Club de Campo Villa de Madrid" and "Canal Isabel II", according to the company's report, it received a consideration of 4.444.604 euros in 2009 [13] for the construction of the Arroyofresno storm tank.

In addition to the economic considerations, a project in collaboration with the "Canal de Isabel II" would mean an improvement in relations with the water supply company that could lead to possible reductions in the contracted rates and an improvement in the environmental evaluation of the water treatment in the factory. The realization of a complementary project could be studied for the creation of an industrial water circuit that can take the water collected in the storm tank and be used for car wash, fire-fighting systems, irrigation or cooling towers, reducing the consumption of fresh water in the factory by about 27,000 m3 per year[4.1].

In order to study the viability of this project, it would be necessary to estimate the losses caused by the transfer of the stored vehicles and the relocation of this logistics headquarters to another factory owned by the company or the rental of a suitable space during the execution time of the work. In addition, this project could involve changes in the value of the land that could affect future sales.

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# APPENDIX I – FLOW DIAGRAM