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# Demonstrated Advantages and Considerations of a Beta Nucleated Polypropylene Piping System Versus a Stainless Steel Piping System

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**ABSTRACT**

A polymer is a thermoplastic material that crystallizes in three forms: α (monoclinic), β (trigonal) and γ (orthorhombic). These forms have characteristics that provide specific physicochemical properties in the same formulation. The α crystalline form is found in higher proportion and is the most stable and simplest to produce. However, the raw material of the beta-nucleated polypropylene and PR (pressure resistant), monolayer pipes and PR fiber polypropylene pipes are processed to produce β structures in ways where it would be easier to have α crystals, since this process favors the formation of a stable, fine hexagonal crystalline structure and a homogeneous size distribution. These attributes derive in an optimization of the mechanical performance of the system, in which a mixture of these forms (α and β) will provide a very optimal thermo-mechanical property.

**Keywords:** PP-R (polypropylene random copolymer); transfer; biocidal product; austenitics; biofilm.

## INTRODUCTION

American inventor John Hyatt created celluloid, a plastic material whose composition consists of a solution of carbohydrate from plants, cellulose and a mixture of ethyl alcohol and camphor; it is also known as “thermoplastic material” due to its ability to be molded and softened when exposed to heat (Concha, 2014).

Later, in 1907, Leo Baekeland invented Bakelite, which was described as the first thermoset or thermosetting plastic, that is, moldable, when melted. By 1930, polyethylene (PE), a thermoplastic resulting from the polymerization of ethylene gas under pressure and heat, was manufactured for the first time in England. Around 1950, the same process applied to propylene was used to create polypropylene. At present, this partially crystalline thermoplastic is classified as a polyolefin and is used extensively for multiple applications (Concha, 2014). Based on its properties, industrial applications are more associated with the use in the transport of acids and bases, even at high temperatures (Concha, 2014).

The beta nucleated polypropylene pipe system is one of the best choices for the manufacture of pipes intended for the transfer of fluids such as drinking water. The pressure and temperature working range of PP-R (polypropylene random copolymer) of the beta nucleated polypropylene piping system is fully compatible with treatments to prevent Legionella contamination during pipeline maintenance such as thermal shock.

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This means that Legionella prevention is under constant scrutiny and, consequently, undergoes periodic changes. This issue is more relevant in countries where there is a relationship between disease development and the country's industry. Such relationship is not apparent in other countries, either because of the lack of analysis or because Legionella contamination is not frequent. Indeed, continuous monitoring, new strategies and evaluation result in a good prevention of contracting diseases such as Legionellosis. It is a fact that the maintenance of equipment and the conditions of its environment are important; however, in urban areas, the disease is caused as a result of poor building design, inadequate construction and neglect of water quality control of the facilities (Gea, Mezones, & Haro, 2012).

In summary, the PP-R of the beta nucleated polypropylene pipe system complies with Decreto Supremo No. 031-2010 (2010), which imposes regulations on the management of water quality for human consumption, in order to ensure its safety, avoid risks to human health and maintain population health.

$ClO_2$ is not recommended for drinking water disinfection.

Historically, metals have always been the first choice for plumbing materials. However, as we have seen, technical polymers have been replacing them. Contrary to what its name specifies, stainless steel is not stainless. The reason it has this name is that, compared to normal steel, it can withstand much longer under the same working conditions before showing signs of wear. Not all stainless steels, however, have the same properties and, consequently, qualities.

Austenitic stainless steels are the most commonly used, of which the 300 series is the largest subgroup and, within this, AISI 304, followed by AISI 316, are the two most common types, whose high chromium and nickel content increase their resistance to corrosion. In addition, manganese, phosphorus, sulfur and silicon are also integrated into its chemical composition, which, in general, is iron (Goodfellow, n.d.a; Goodfellow, n.d.b). Some differences between the two alloys can be significant, depending on the structure, the most notable being the molybdenum content in AISI 316, which improves corrosion resistance with respect to AISI 304 in saline environments or environments exposed to chloride solutions, which are the most detrimental to stainless steel.

The aim of this research is to raise awareness among professionals in all branches of engineering (designers, contractors, owners, consultants, etc.) regarding the fact that there is an alternative to design or build a project that meets all the technical requirements and even exceeds them, since beta nucleated polypropylene pipes last for many years, unlike a stainless steel pipes that will nevertheless deteriorate.

**Corrosion in Stainless Steel**

Steel tends to rust when exposed to the environment, since it comes into contact with oxygen and water vapor present in the air, which cause the formation of iron oxides and hydroxides on its surface. If left unchecked, oxidation penetrates through the entire thickness of the metal until it corrodes it completely; for this reason, there are a myriad of strategies to prevent this from happening.

Stainless steel tends to undergo passivation before corrosion penetrates its wall, so that a thin film of chromium oxide forms, making it more resistant to corrosion. This film of chromium oxide, when removed, re-forms upon contact of the chromium with oxygen. Nonetheless, as discussed above, stainless steel is still vulnerable to corrosion, which can occur as a result of a number of different mechanisms:

a. ***Intergranular Corrosion***

   Inadequate treatment (including both the temperatures used during steelmaking and the heating procedures during welding) can produce high carbon-concentration lattices, which promote intergranular corrosion. Under these conditions, the surface allows the metal to oxidize and reduces its service life in many relatively light environments.

b. ***Galvanic Corrosion***

   Galvanic corrosion occurs locally and under different conditions. The most common is when two dissimilar metals are in direct contact (as in the case of threaded joints with brass valves and stainless steel or copper pipes); corrosion increases when exposed to humid environments or submerged in electrolyte solutions.

   In a corrosive environment, this situation is exponentially aggravated, resulting in the dissolution of the anode, while the cathode remains unchanged. The factors that influence the galvanic couple to a greater extent are:

   - Fluid connectivity

- Difference of reduction potentials of metals in direct contact
- Polarization
- Relative areas of cathode and anode in geometric relation between contact surfaces

*c. **Differential Aeration Corrosion***

A semi-embedded particle on the surface may be sufficient to remove the protective chromium oxide layer. Even after the particle has been removed, its attack on the surface continues, since a durable electrolytic cell has formed between the attacked portion of the anodic surface and the vast cathodic area.

*d. **Pitting Corrosion***

Chloride solutions often cause pitting corrosion on the surface in contact with stainless steel, which is virtually attacked by pitting where electrolytic cells can develop.

Acid chlorides, such as iron (III) chloride and sodium chloride, are two of the most common compounds responsible for this type of corrosion, although any chloride in a significant concentration can cause pitting corrosion. Chlorides are often the critical factor in situations where stainless steel corrosion would not be expected.

*e. **Fatigue Corrosion***

Although the average user may not be aware of its existence, fatigue corrosion is another factor that often leads to corrosion in stainless steel piping. Almost all metals and alloys can experience failure by cracking at the microscopic level under conditions involving stresses in a mildly oxidizing environment. Also in this case, chloride solutions are one of the most detrimental agents.

*f. **Microbiology Influenced Corrosion (MIC)***

Based on the evidence, it has become firmly argued that many of the cases, where thermodynamic processes did not explain the cause of corrosion, may be caused by biofilms in the so-called Microbiology Influenced Corrosion (MIC). Currently, it is the subject of multiple studies on different fronts.

Depending on the bacteria responsible and the final morphology of the metal surface, there are several causes for the propagation of biological material in this type of corrosion. For example, $Fe^{2+}$, an ion commonly considered a biocide, tends to attract iron-reducing bacteria which, on the other hand, use it in their metabolism.

Upon creation of the biofilm, which is composed mainly of water, the environment is radically modified; thus, the biofilm acts as an electrolyte and can alter known and controlled reactions, or cause reactions that would not take place without the biological presence.

Clearly, corrosion is the main cause of failure in stainless steel. Polymers, on the other hand, are completely immune to this process due to their nature.

Many projects in Peru use stainless steel pipes, either to transport fluids such as aseptic water or other fluids that could be corrosive. Although stainless steel pipes prevent corrosion, there are some disadvantages, such as:

- They are very expensive.
- They are very heavy, which can overload the structure of a building.

As stated above, the use of this type of piping presents many disadvantages, but there are alternatives. In this paper, we propose the use of polypropylene pipes as an option with multiple advantages, such as:

- It does not corrode.
- It is asceptic.
- It is lighter.
- It is less expensive.
- Its installation is easier and faster.

Further research is required on the research topic, as it is not very popular in the country; stainless steel pipes are still being used, despite the fact that they are more expensive. Stainless steel pipes are also widely used in the mining sector for the transport of corrosive water, even though these steel pipes tend to corrode, and polypropylene pipes would be the most appropriate for this task.

The purpose of this study is to encourage the use of propylene pipes instead of stainless steel pipes, since although the use of the former is more important due to their resistance to corrosion, they are expensive and heavy; also, they are more difficult to transport compared to polypropylene pipes. Moreover, propylene pipes have been developed and improved with the help of engineering so that their qualities are similar to those of stainless steel pipes and can compete with the latter.

## HYPOTHESIS

Propylene pipes are more cost-effective and environmentally friendly than stainless steel pipes.

## METHODOLOGY

Why choose polypropylene pipes instead of stainless steel pipes?

The beta nucleated polypropylene pipe system has advantages over the physicochemical properties of stainless steel pipes.

### The evolution from polypropylene pipes to beta nucleated polypropylene pipes

The remarkable improvement of materials and learning about their mechanical and physical properties has led to tremendous and obvious progress in all fields. In plumbing, metals were the most commonly used materials until a few decades ago due to their mechanical strength. However, as time went by, these materials have presented many drawbacks (Serrano, 2017).

According to Serrano (2017), the following advantages of polypropylene pipes, which solve the problems posed in metallic structures, can be highlighted:

- 100% corrosion resistance
- Minimum thermal conductivity
- Acoustic absorption
- High resistance to chemical agents (inert material to chloride solutions)
- Viability
- Fully recyclable, contributes to environmental sustainability
- Shorter installation time
- Reduced structure weight.

A major consideration, however, is the increasing use of chlorine in hot water distribution systems for high-impact disinfection of materials that many companies are forced to carry out. The beta nucleated polypropylene pipe system resulted from the need to deal with cases of thermo-oxidative degradation caused by this factor.

### Improvement of Thermo-Mechanical Characteristics

Borealis RA7050 polymer, a random copolymer polymer with modified crystallinity and high temperature resistance (PP-R, type 4), offers improved mechanical characteristics over the years in structures that transport high-temperature fluids, thus ensuring durability at higher pressure.

Figure 1 shows the differences between the reference curves for the expected strength of both PP-R type 3 and PP-R type 4. As can be observed, PP-R type 4 has a lower slope, which means that it has an excellent performance at high temperatures compared to PP-R type 3.

For a deeper analysis of this aspect, we can compare the ranges of beta nucleated polypropylene pipes with those of RP single-layer polypropylene pipes and RP polypropylene fiber pipes with respect to their mechanical strength characteristics at high temperatures, considering their expected service life. Thus, the beta nucleated polypropylene pipe has a higher mechanical performance due to its SDR and additivation, since the formulation of its raw material is slightly higher than that of PP-R RP (Italsan, 2017).

### Resistance to Disinfection Processes

As established in the disinfection treatment protocols of Decreto Supremo No. 031-2010-SA (2010) as well as Real Decreto 865/2003 (2003), chemical compounds, such as free chlorine, should always be used separately from treatments involving temperature increase, such as thermal shocks.

This is specified, among other reasons, because disinfectant compounds have an oxidizing nature and become very aggressive agents as temperature increases. This happens both in plastic or metal pipe systems, including copper and stainless steel AISI 316; it also occurs in other parts of the system, such as accumulators, heat exchangers and valves.

The beta nucleated polypropylene piping system is made of a raw material capable of enduring a higher concentration of chlorine at a higher temperature, bearing in mind that the system is always under pressure. It was rated CL3 according to ASTM F876 20B (American Society of Testing Materials, 2020) in tests carried out by the prestigious Exova laboratory, accredited to perform such operations. According to ASTM F2023 (American Society of Testing Materials, 2015), pipes must be subjected to the following specifications:

- 4.3 ppm sodium hypochlorite

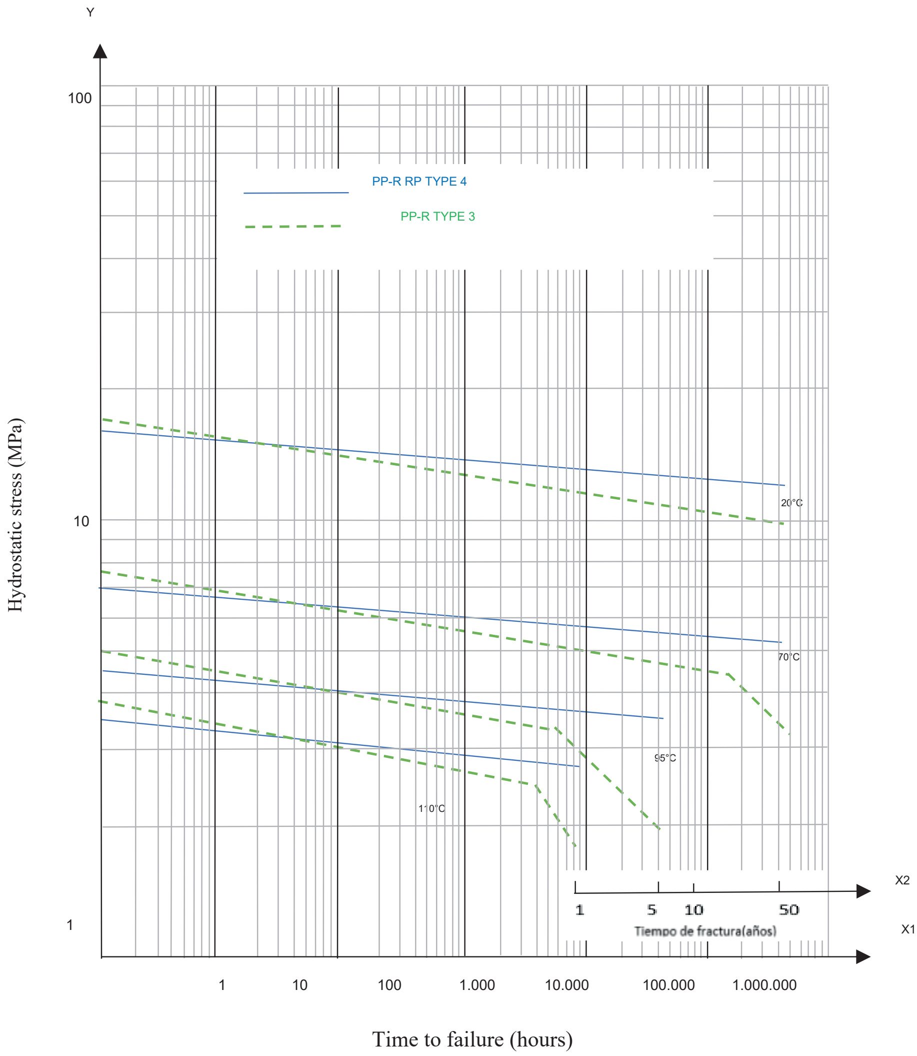


***Figure 1***. Reference curves for the expected strength of PP-R (Type 3) and PP-R (Type 4).

Source: Italsan, 2017.

- pH 6.8
- Temperatures of 115 °C, 105 °C and 95 °C.

The very high resistance to thermo-oxidative degradation shown in the results proved the superiority of the beta nucleated polypropylene pipe system over PP-R and PP-R RP pipes; therefore, its use in high temperature and pressure piping systems with transfer of fluids with high sodium hypochlorite content was certified.

Internal tests showed that, compared to other pipe types on the market, the beta nucleated polypropylene pipe samples had 40% higher oxidation induction times (OIt) when exposed to 4.5 ppm of free chlorine, 95 °C and 5 bar pressure.

The importance of using a beta nucleated polypropylene piping system lies on the technical and economic advantages it offers, since it is an innovative material when compared to stainless steel, due to its low cost and benefits when implementing a system, as it allows for a quick and easy installation. It should be noted that it will also mean less weight added to the civil structure being installed.

## RESULTS

### Physical Characteristics Directly Related to Energy Efficiency

Being manufactured with PP-R, polypropylene piping systems are 100% corrosion resistant, both inside the pipe and on its surface, making it totally immune to increases in electrical conductivity caused by the presence of electrolytes or chlorides. In comparison with a stainless steel pipe system, polypropylene:

- does not require any protective measures regardless of the surrounding environment,
- its impact is directly proportional to the energy efficiency.

A specific analysis is performed in this second section, evidencing that the radical reduction of probable deposits and fouling and the absence of corrosion reduce consumption in the pumping systems during the entire service life of the system, thus reducing energy consumption and increasing the efficiency of the system.

Head loss in steel piping varies depending on the degree of corrosion of the pipes. Figure 2 shows the results obtained by Rahmeyer (2009, as cited in Italsan, 2015), where the increase in head losses in a steel pipe is related to its corrosion state.

## HYPOTHESIS TESTING

An analysis of the data shown in Figure 2 is made in order to test the efficiency of a beta nucleated polypropylene pipe system versus a stainless steel pipe system; the head drop of the steel pipes due to corrosion is clearly observed. Upon observing the corrosion state of both materials, it is noticeable the total corrosion resistance property of the beta nucleated polypropylene pipe system, as well as the limited corrosion resistance of the stainless

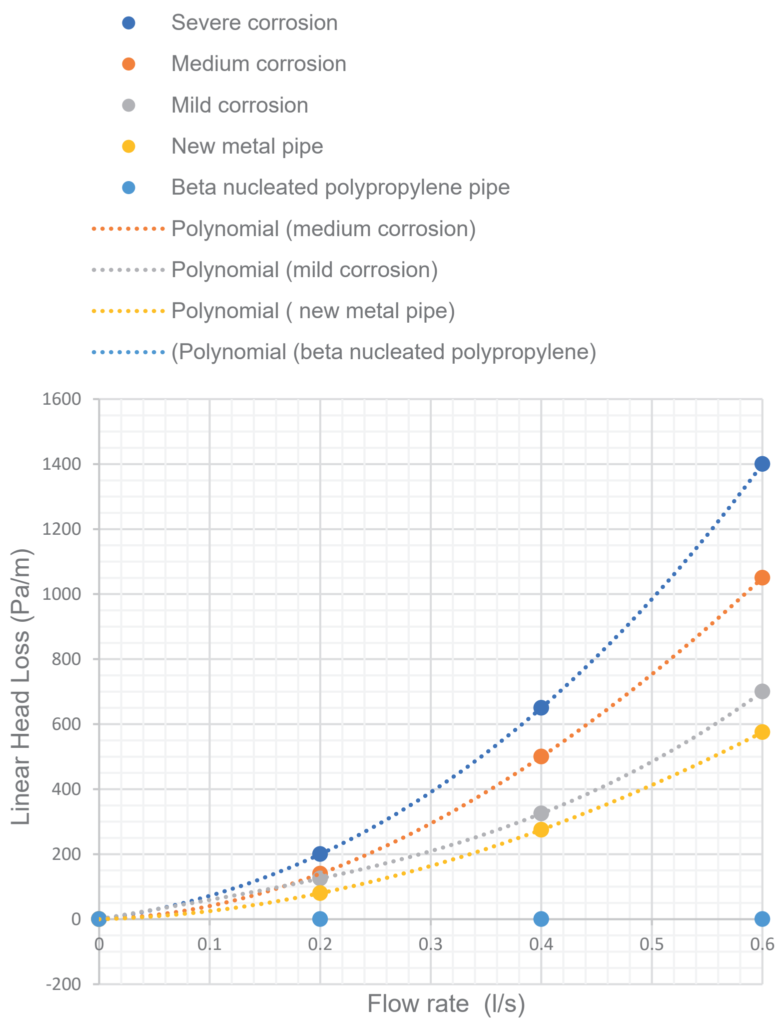


***Figure. 2***. Head losses in steel pipes vs. corrosion state.
Source: Serrano (2017).

steel. On this basis, it is evidenced that the use of beta nucleated polypropylene piping systems would represent an optimization regarding corrosion resistance of the material.

There is also empirical knowledge concerning the structural load of the beta nucleated polypropylene pipe system, as this material is much lighter than a stainless steel pipe system, which allows for a lighter weight structure and easier installation (see Table 1).

Attention should be drawn to the economic advantages of using a beta nucleated polypropylene pipe system, since this material is much more economical compared to the high prices of a stainless steel pipe system.

## DISCUSSION

### Physical Characteristics Directly Related to Thermal Energy Efficiency

**a. Low heat transfer capacity, limited heat dissipation and condensation**

The low heat conductivity of polypropylene pipes (λ = 0.24 W/mK) can lead to a significant reduction in material temperature, diameter and insulation thickness.

Thickness can be calculated using the loss calculation software on the international market. The calculation is based on the thermal conductivity coefficient according to UNE-EN ISO

**Table 1**. *Premium Polypropylene vs. Stainless Steel Piping System Overview.*

| Parameter | AISI 304 Stainless Steel | AISI 316 Stainless Steel | PP-R Polypropylene Piping System | Premium Polypropylene Piping System |
|---|---|---|---|---|
| **Corrosion resistance** | Limited to certain compounds | Above 304, limited to chlorides and others | Total | |
| **Biosafety** | Potential for MIC, also promoting both adhesion and biofilm growth | | High | **Superior** |
| **Absence of fouling** | No | | High fouling resistance | Superior fouling resistance |
| **Suitability in seismic risk areas** | No | | Yes | |
| **Resistance to stray currents** | Can participate in its planning/difussion | | Total | |
| **Compatible with glycol water** | Yes | | Yes | |
| **Thermal conductivity (λ)** | 16.3 W/(mK) | | 0.24 W/(mK) | 0.24 W/(mK) |
| **Coefficient of linear thermal expansion** | 0.017 mm/(mK) | | 0.04 mm/(mK) | |
| **Necessary insulation thickness (according to RITE[4])** | According to the RITE simplified procedure | | Reduction according to alternative procedure | |
| **Density** | 7.98 g/cm$^3$ | | 0.90 g/cm$^3$ | 0.91 g/cm$^3$ |
| **Maximum fluid velocity (according to CTE[5])** | 2.5 m/s | | 3.5 m/s | |
| **Sound absorption** | Limited (vibration conductor) | | Significant | |
| **Estimated normalized service life** | Uncertain data | | 50 years | 30 years at 4.3 ppm, 60 °C and 5.5 bar |
| **Optimal joint type** | Torch welding | | Thermofusion welding | |
| **Support** | Clamps/Profile bars | | Clamps | |
| **Mounting** | High specialization requirements | | Simple, intuitive and safe | |

Source: Prepared by the authors based on data from Goodfellow (n.d.a; n.d.b), AISI 304 and ASI 316 stainless steel.

4 Spanish standard for thermal installation in buildings.

5 Spanish technical building code.

12241:2010 (Organización Internacional de Normalización [ISO], 2010). This procedure determines the heat loss and pore condensation that occurs in the pipe (Table 2).

There are two reasons why insulation should be placed in the pipe network of thermal installations:

- To prevent the generation of surface condensation on the pipe surface.
- The total heat loss of all pipes should not exceed 4% of the maximum transport power, as established in the Regulation of Thermal Instructions for Buildings (RITE) (Royal Decree 1027/2007, 2007).

**b. Reduction of condensation risk**

Based on the physical principle that indicates that a mass of air with relative temperature and humidity X will produce condensation on the surface of the material as long as the surface temperature of the insulation ($T_x$) is lower than the dew temperature of the outside air under the temperature and humidity conditions considered, it follows that:

- condensation occurs when Tdp > Tx
- condensation does not occur when Tdp < Tx.

For this case, the least favorable conditions are cold fluid transfer, high ambient temperature and high relative humidity.

PP-R is not a good conductor of heat, and its thermal conductivity value is very low, so the risk of surface condensation on the pipe decreases and can reach very low levels.

In addition, in the event of surface condensation, there is no possibility of degradation by corrosion of the material, since the material is the same as that found inside the pipes in contact with water. Steel pipes have a very high thermal conductivity coefficient; therefore, the risk of surface condensation is much higher than that of PP-R pipes.

**c. Reduction of thermal losses**

The main issue for an efficient system is to avoid wasting energy during its production and subsequent distribution. The low thermal conductivity of PP-R helps maintaining the temperatures of the transported fluid, resulting in improvements due to the raw material, since it sometimes allows reducing the insulation thickness with regard to that considered in the simplified method of the RITE. In these cases, the space required for pipes is considerably reduced, and this represents a reason for choosing the polypropylene pipe system in renovation works.

In the pseudo-stationary arrangement, the lower thermal conductivity of polypropylene, λ=0.024 W/(mK), reduces the disturbances, which is favorable compared to systems with metallic materials. The thermal dispersion produced along the system is more contained; therefore, producing so much heat to supply DHW, heating and air conditioning up to the terminal points is unnecessary (Italsan, n. d.).

Such an event can be interpreted as a decrease in boiler consumption of up to 10% in systems where there is recirculation of fluid with temperature 24 hours a day and 365 days a year.

In conclusion, the use of PP-R pipes and a thermal loss calculation tool guarantee maximum thermal losses of 4% with the insulation thickness appropriate to the material of the system.

**d. Minimum noise level in the system**

Owing to its acoustic impregnation and isolation properties, our polypropylene piping system significantly dampens the sound effects in the installation, providing acoustic comfort in all rooms.

**Table 2**. *Advantages of Using Heat Loss Calculation Software.*

| Advantages | HEAT LOSS CALCULATION SOFTWARE |
|---|---|
| UNE-EN 12241 | Adequacy of insulation thickness |
| | Space reduction |
| | Reduction of the overall installation cost |
| | Reduction of energy demand thanks to energy efficiency (4% guarantee) |

Source: Serrano (2017).

## CONCLUSIONS

### Reduced Handling Times

The polypropylene pipe connection system is based on a molecular coupling. These types of joints are unprecedented in the polymeric materials industry and offer the following advantages:

- Shorter welding times (DVS Standard 2207-1) compared to stainless steel pipes
- Immediate start-up of the system after welding, without having to wait for cooling as in the case of metallic pipes.

Note that joining processes involving flames can be avoided, i.e., the processes for connecting polypropylene pipes are much safer than stainless steel welding, which requires the use of torches and specific protections (Aristegui, 2017).

### Reduced Weight for Handling

Owing to its density, which is virtually the same as that of water, pipes made of PP-R have a considerably lower weight than those made of stainless steel with the same diameter and length. This fact, in addition to reducing the total weight of the system, means a considerable reduction in stresses and, therefore, in the difficulty of handling. As PP-R pipes are much lighter, a wider range of users can comfortably use them.

### Joining Simplicity

Provided that quality standards are maintained during the process, thermofusion is much simpler than metal welding. Specifically, poor flame application during welding can create corrosion-prone areas.

### Biosafety

Both the formation of rust and fouling (such as scale) on the stainless steel surface increases its roughness, which favors the accumulation of microorganisms (which in turn may be metabolically active to the metal oxides) that can create biofilms, which are aggregates of biological material that protect the microorganisms that lodge therein and also serve as a medium for their evolution. Risk of legionellosis increases considerably in this respect. Consequently, users have to increase the concentration of disinfectants in the water which, although it may destroy a maximum of approximately 70% of the biofilm, it initiates or aggravates corrosion processes. Once the disinfection actions are finished, the new microorganisms (always present in the water) have new settlements in the most critical parts of the installation to be deposited again, thus creating a cycle that will lead to a drastic reduction of the service life of the system and to sanitary risks.

Owing to its composition, the polypropylene piping system is more resistant to fouling and is completely immune to corrosion.

Specifically, the beta nucleated polypropylene pipe offers a higher resistance to thermo-oxidative degradation, so that the adherence of biofilm, which must be avoided to prevent the proliferation of Legionella, is reduced thanks to the good condition of the surface in contact with the fluid.

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