IMPROVEMENT ON PIERCING PLUG LIFETIME THROUGH ENHANCED COOLING AT VALLOUREC JECEABA'S PIERCING MILL *

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Abstract

The seamless tube rolling process consists of 3 main steps: heating, piercing, and elongation. Billet piercing is a process developed by the Mannesmann company more than 100 years ago. This manufacturing process produces tubes that are pierced from steel billets and rolled into a hollow form. In a piercing mill, heated billets are pierced using a piercing plug. The diameter reduction of the rolled billets creates a tension at their center that generates an inner hole and transforms the billets into tubes. A piercing plug shaped like a bullet is placed precisely to control the dimensions of the forming tube and to avoid cracks and other inner surface defects. The high forces and temperatures at this stage of the process require that the piercing plug maintain its physical properties and remain wear resistant. After piercing, the plugs are cooled and remain in the circuit to pierce a new billet after 2-3 minutes. Plug lifetime at Vallourec Jeceaba suffered a severe reduction after a mill modification. An improvement to the plug's cooling system was made and tested. This paper aims to study the effects of cooling on plug lifetime, present the improvements made to the cooling process and review the results of this modification.

Keywords: Mannesmann process, plug lifetime, cooling.

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1 INTRODUCTION

Until the end of the 19th century, despite poor welding quality, steel tubes were mainly manufactured by welding steel sheets folded into a tubular shape. After the discovery of the Mannesmann process in 1885, the production of steel tubes shifted to a process called seamless tube manufacturing. By the end of the 2nd World War, almost all steel tubes were manufactured according to this process. It was only until welding technology advanced that welding recovered its position in the tube manufacturing process. (1)

The seamless tube rolling process consists of 3 main steps: heating, piercing, and elongation. In the heating step, a round billet is loaded into a furnace and heated until the desired temperature is reached. The amount of heat transferred in this phase depends on several criteria such as steel grade, furnace features, and cross-section temperature deviation. To avoid the generation of inner surface defects, the cross-section temperature difference is controlled and usually set below 15 degrees Celsius.

In the piercing step, the billet is pierced by a piercing press or a cross-rolling mill and conformed into a tubular shape. The last step of the process is elongation. It varies across production lines and can be divided into two smaller steps. The first is a significant wall thickness reduction that requires a special internal tool. The second consists of reaching the desired outer diameter and wall thickness. This last step does not require internal tools. (2)(3)

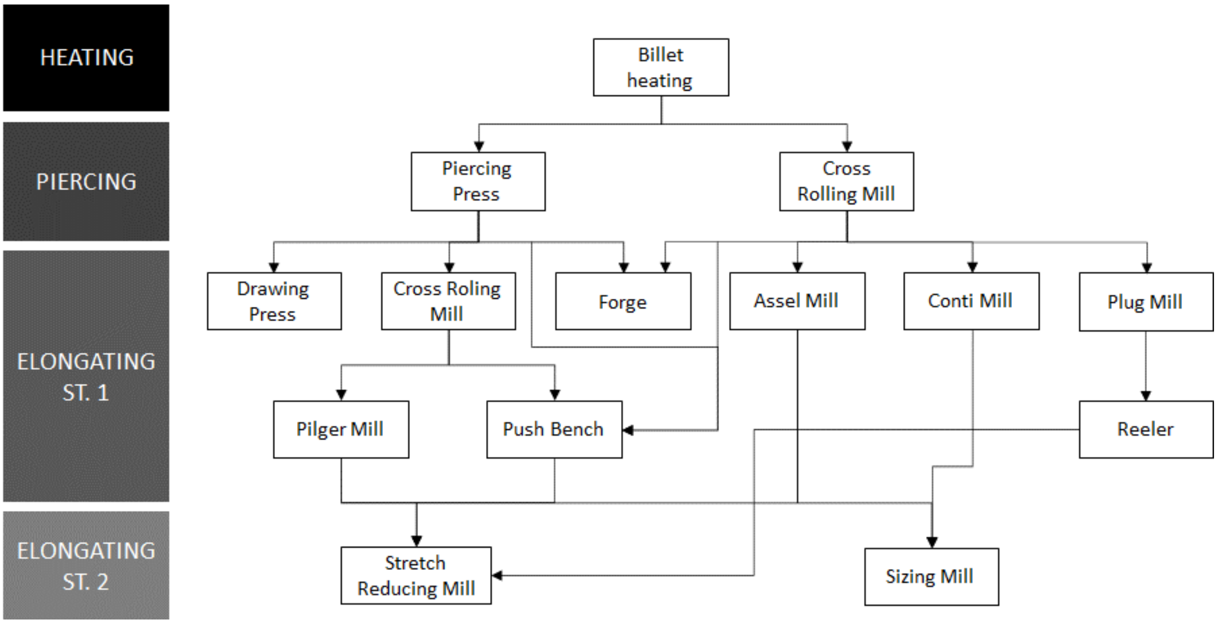

Fig.1: Seamless tube rolling flowchart

The Vallourec Jeceaba Tube Mill consists of a Billet Heating Furnace (rotary hearth), a Piercing Mill (cone type with discs), a PQF (SMS 3 roll elongating mill), and a Sizing Mill. It can produce tubes ranging from 6” to 16” outside diameter (OD) and be considered a new mill, with state-of-the-art technology. In 2021, a tooling lifetime inspection signaled a reduction in piercing plug lifetime that would require a deeper analysis.

Vallourec Jeceaba’s piercing mill has a cone-type piercer with Diescher discs as guiding elements. Piercing mills use either barrel or cone-type rolls. Barrels have simple mechanics and easy construction, while cones enable higher expansions and torsion always in the same direction. Guiding elements also vary across piercing mills. Guide shoes are more suitable to produce hollows with smaller wall thicknesses and work well for shorter hollows, while discs are more suitable for longer hollows and present lower wear. In summary, the choice of piercing equipment varies according to production line features. (4)

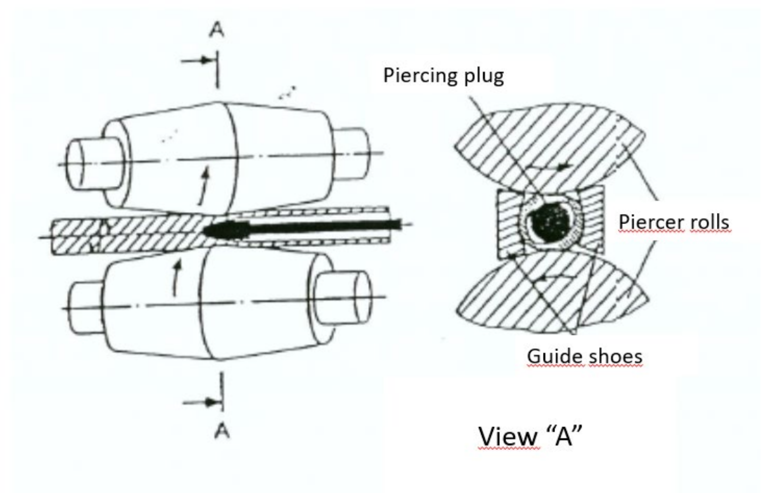

Fig.2: Piercing mill with barrel rolls and guide shoes

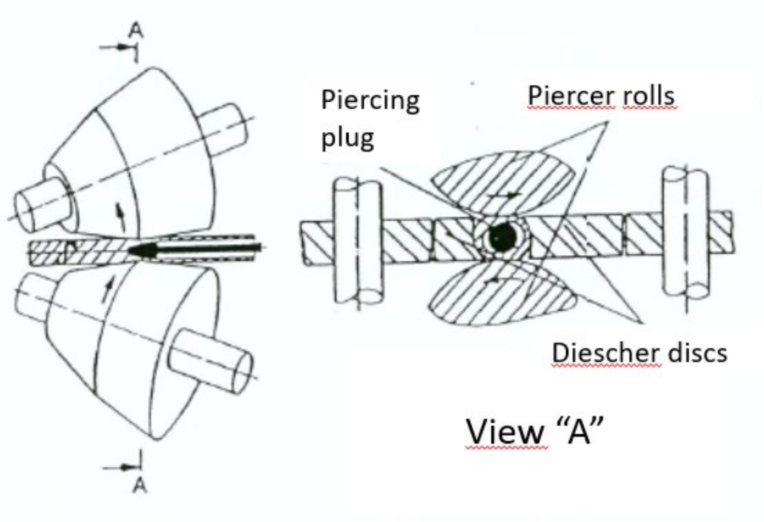

Fig.3: Piercing mill with cone rolls and Diescher discs

The element subjected to the harshest working conditions during the piercing process is the piercing plug. Piercer rolls and Diescher discs are also subjected to similar thermal and mechanical stresses, but they are cooled during the piercing cycle and have a larger surface area in which wear and heat are distributed. Plugs are utilized during the entire piercing process without any external cooling and must maintain their physical properties to withstand high tensile strains and temperatures.

An oxide layer that forms on the plug's surface works as a thermal barrier and reduces part of the wear on this element. (5)

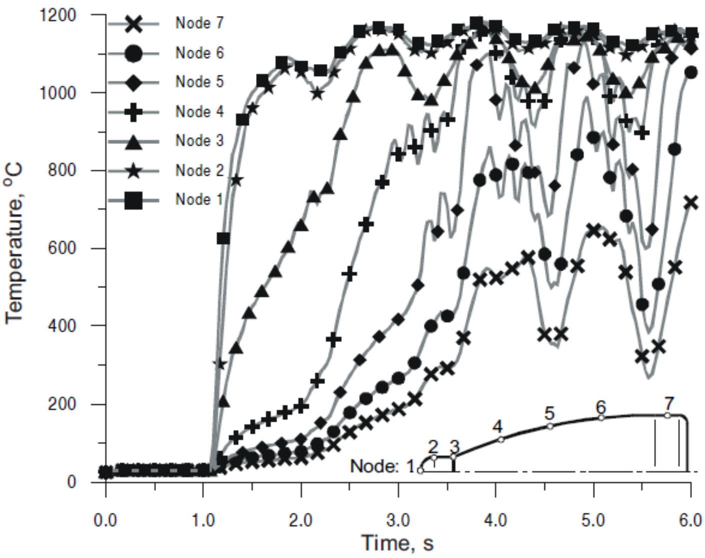

Fig.4: Plug temperature profile during piercing (5)

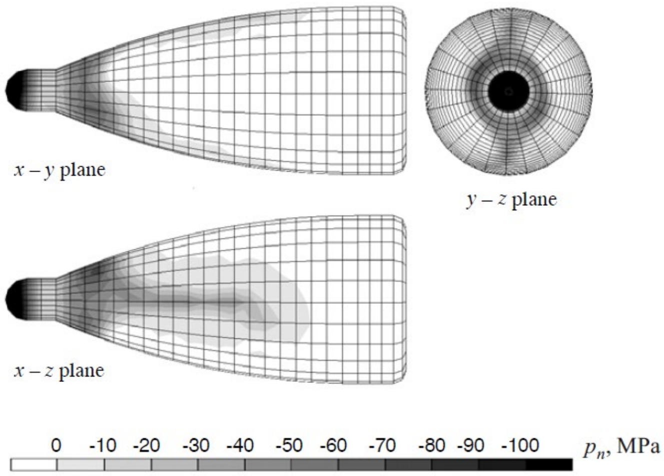

Fig.5: Contact pressure on a plug during piercing (5)

Measurements of plug lifetime displayed in Figure 6 below show a significant drop in plug lifetime after 2020. This reduction could be partially explained by different production mixes or more cautious inspections. However, they were not enough to justify a 60% drop in plug lifetime. In 2020 modifications to the changing car were made and the cooling system was supposedly improved as a higher volume of water was made available. However, the timeline indicated a strong and negative correlation between the changes made to the piercing plug changing car and the plug lifetime drop. A deeper study was proposed based on this hypothesis.

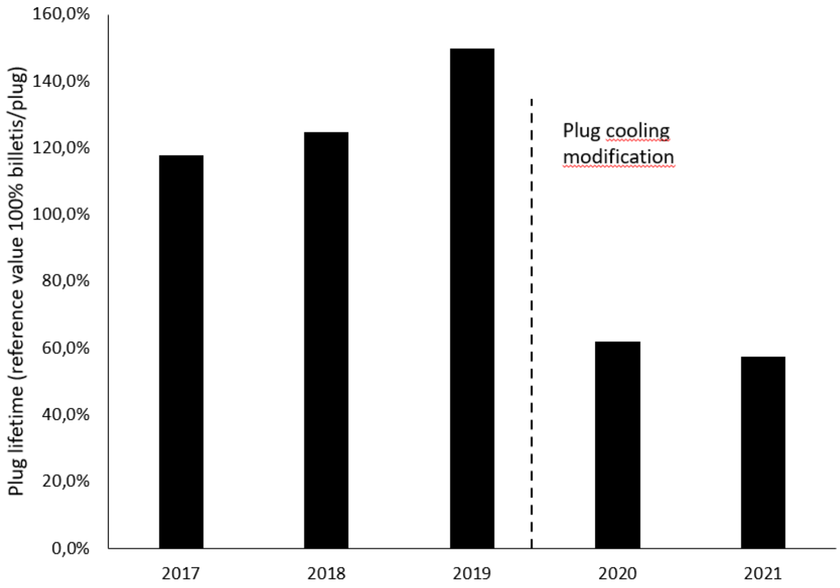

Fig.6: Plug lifetime

The damages on the plug surface that reduce plug lifetime can be seen in Figure 7.

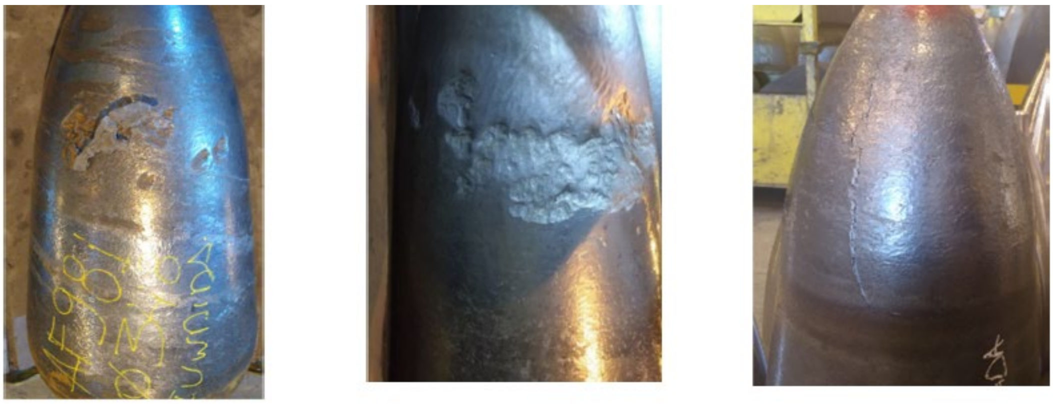

Fig.7: Plug defects, from left to right: a) defect known as "mapa", b) melted plug c) cracks

2 DEVELOPMENT

The project was divided into 3 main phases:

1. Status of the cooling system
2. Cooling system modification proposal
3. New cooling system efficiency follow up

2.1 Status of the cooling system

One of the hypotheses for the significant reduction in plug lifetime was the plug cooling system that had recently been modified. To validate this hypothesis a thermo-camera was used to monitor the temperature profile during the rolling process of a high-cadence product considered a worst-case scenario. The results are shown in Figure 8 below.

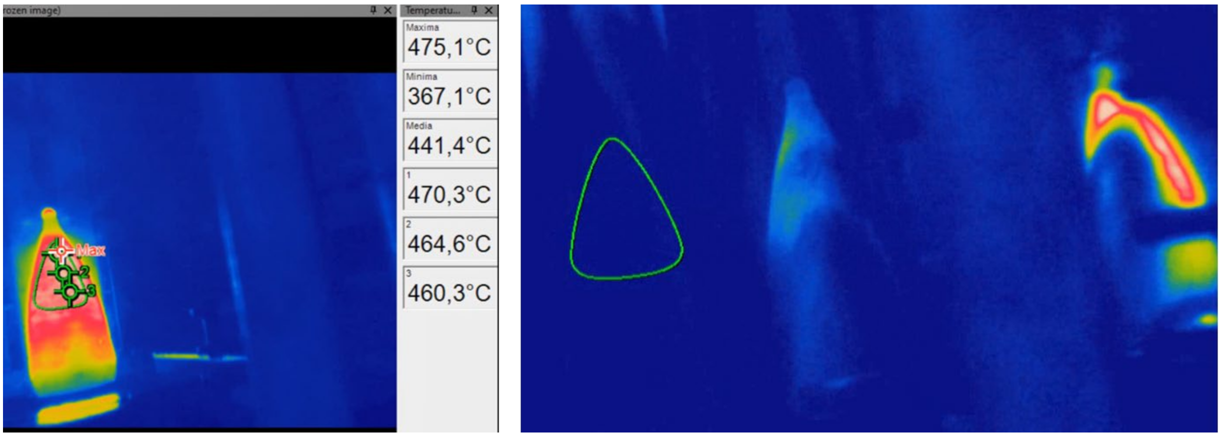

Fig.8: Plug temperature captured by Thermo-camera, left: higher temperature, middle: plug cooling by shower, right: plug cooling by frontal jet

The former cooling system shown in Figure 9 consisted of sprays coming from three different directions: one upper shower spray and two diagonal sprays. The upper sprays cooled the plug's cylindrical body along its length and width, while the diagonal sprays cooled only part of the plug's conical tip.

Two of the most important and observed factors during the cooling process are temperature reduction and temperature distribution. Figures 4, 5, and 8 show how the configuration of the former cooling system affected the efficiency of the cooling process. While the conical tip of the plug presented extremely high temperatures, the cylindrical part of the plug was subjected to highly uneven temperature distributions.

Fig.9: Plug cooling: left side: upper shower, right side: diagonal jet

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The heat transfer form most responsible for the plug's cooling is heat transfer by convection. Although heat transfer by conduction and radiation are also present, their contribution to the overall heat transfer of the cooling process is much smaller compared to convection's heat transfer between plug and spray. According to Newton's law of cooling, the rate of heat transferred by convection per unit of time is proportional to the convective heat transfer coefficient, to the surface contact area, and the temperature difference between the body and its surrounding. The equation for heat transfer by convection is:(6)

$$\dot{Q} = hA(T_b - T_s) \quad (1)$$

Where $\dot{\boldsymbol{Q}}$ is the rate of heat transferred per unit of time, $\boldsymbol{h}$ is the convecctive heat transfer coefficient, $\boldsymbol{A}$ is the contact area, $\boldsymbol{T_b}$ is the temperature of the body and $\boldsymbol{T_s}$ is the temperature of the body's surrounding.
As can be deducted by the formula (1), the cooling process can be improved by increasing the contact surface area between the two bodies or by increasing the convection coefficient. The convective heat transfer coefficient is an experimentally determined parameter that depends upon the surface geometry, the nature of the fluid in motion, the properties of the fluid, and its velocity. Determining the optimal nozzle for a cooling application can often be accelerated by relating performance to spray characteristics, especially drop size and spray distribution. The main factors that affect drop size are nozzle type, nozzle capacity, spray angle, pressure, and liquid properties such as viscosity. (6)
One droplet of radius r has a surface area of $A=4\pi r^2$ and a volume of $V= (4/3)\ \pi r^3$. According to the formulas, by reducing the radius of a droplet by half, the same volume of liquid will be comprised of 8 smaller droplets and the surface area will be 2 times greater. This pattern can be followed, breaking droplets into smaller sizes and increasing the surface area until heat transfer is optimized.

2.2 Cooling system modification proposal

Vallourec contacted Spraying Systems do Brasil to analyse and suggest a modification to the cooling system. Based on the thermo-camera results, process requirements, and desired spray positions, a new cooling system was proposed. The recommended modification was separated and performed in two steps: upper nozzles and frontal nozzles. This allowed for a fast installation without causing any production stoppages.

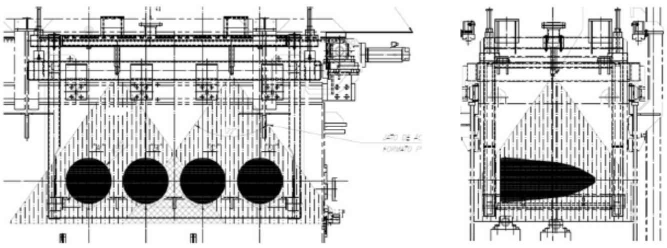


Fig.10: Step 01: Upper nozzles

Fig.11: Step 02: Frontal nozzles

A draft of the former cooling system and the suggested modifications can be seen in Figure 12 below.

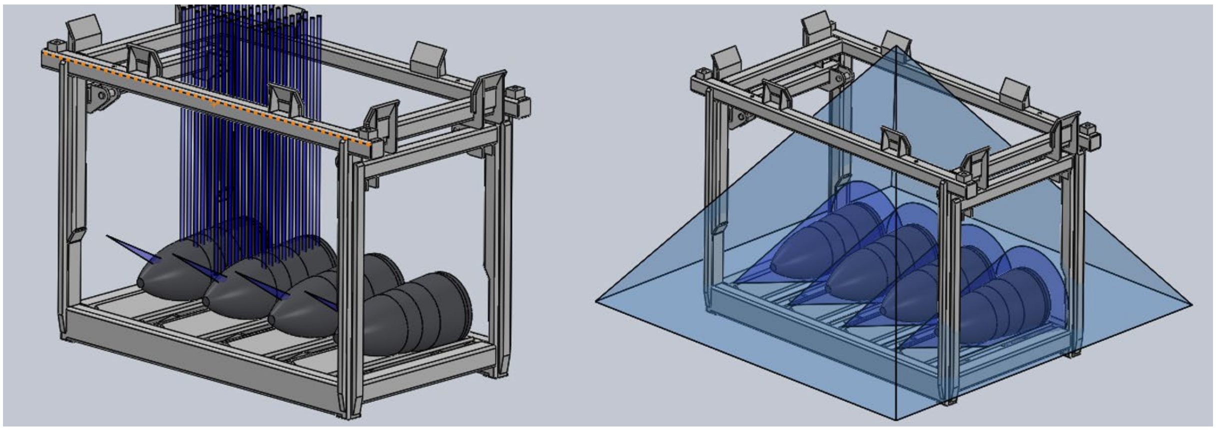


Fig.12: Draft of the former cooling system and system with proposed improvements

The new nozzles installed delivered constant sprays with homogenous drop size distribution. Proper drop size increased contact surface and subsequently heat exchange between plug and water droplets. Figure 13 shows the difference between the two systems in operation.

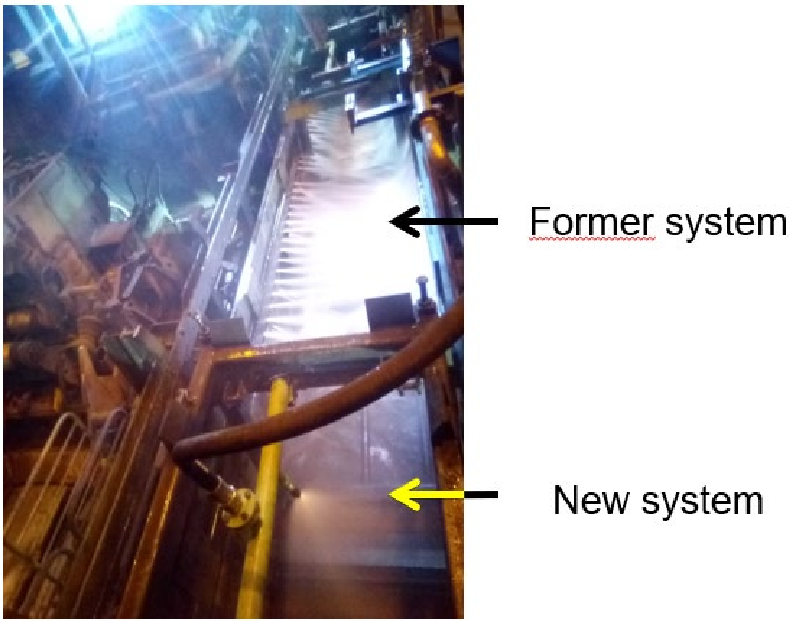
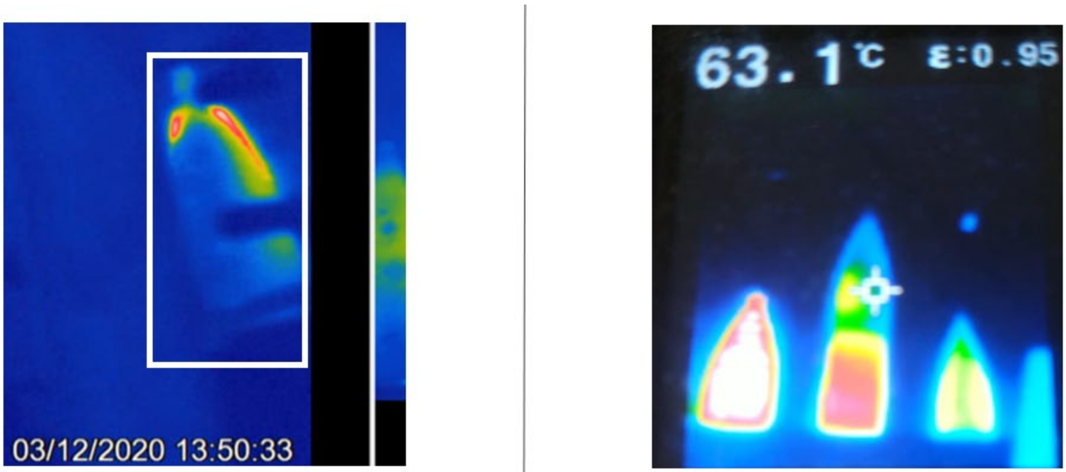


Fig.13: Comparison between former and new cooling systems' water volume

2.3 New cooling system efficiency follow up

A Thermo-camera was used to validate the new cooling system efficiency. Figure 14 shows the results.



Former cooling system:
ΔT ≈ 500°C

New cooling system:
ΔT < 100°C (measurement device limit)
T after cooling: 63,1°C

Fig.14: Efficiency comparison between the former and new cooling system

The new cooling system allowed the plug to be cooled more intensely and evenly. According to measurements made, plug lifetime increased by 60% compared to lifetime values measured in two previous years. A strong indicator of heat transfer and cooling efficiency was the considerable increase in the amount of water vapor generated. The smaller drops of water increased the contact surface and amount of heat transferred from the plug.

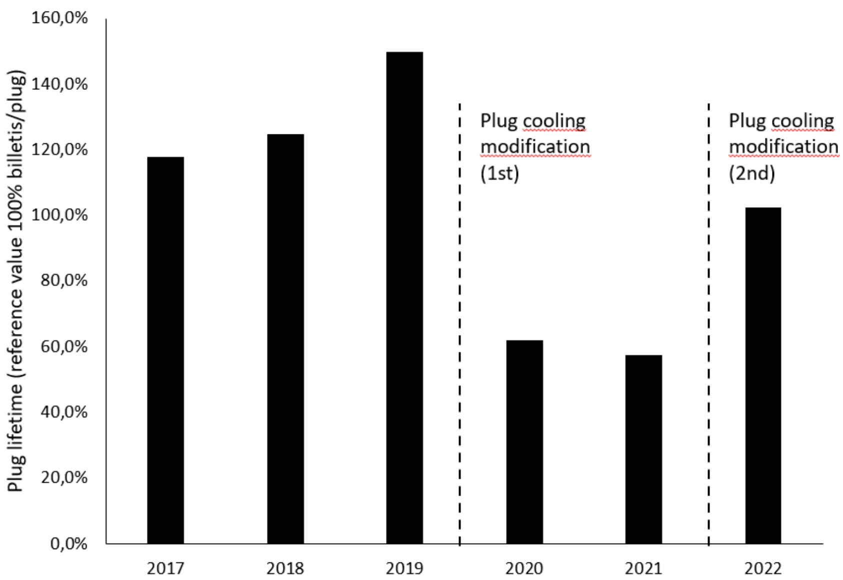


Fig.15: Plug lifetime after cooling modification

Figure 15 shows clearly the improvements in plug lifetime after the second cooling modification. It is important to notice that several other measurements took place to enable this plug lifetime increase, but the cooling modification certainly played an important role in this achievement.

3 CONCLUSION

Cooling has a significant impact on the lifetime of piercing plugs. The new plug cooling system increased the plug lifetime significantly and reduced the consumption of water.

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