Journal of Namibian Studies, 33 S3(2023): 3532-3554 ISSN: 2197-5523 (online)

Determination Of Cost Decrease In A Spherical Tank Construction Project By Using Phased Array Ultrasound

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Abstract:

This article aims to evaluate the economic, environmental and operational benefits and costs of using the Phased Array (PAUT) ultrasound technique in the inspection of welds in storage tanks of the oil industry. To this end, a comparison was made between the use of this technique and conventional ultrasound in terms of inspection time, probability of detection of discontinuities, water consumption and economic costs. The results obtained in the demonstration to the client and in the complete project showed that the use of the PAUT technique is more economical throughout the project due to the reduction of inspection times. In addition, it was found that the probability of detection of discontinuities with this technique is much higher than with conventional ultrasound. In terms of water consumption, significant savings were identified as it was found that more than 24,000 liters of water were saved during the project instead of conventional ultrasound. In economic terms, it was determined that the daily cost of availability for the PAUT technique is higher than that of conventional ultrasound. However, the savings in inspection time and the increase in the probability of detection of discontinuities, make the use of this technique more cost-effective in the long term. In conclusion, the use of the technique in the inspection of welds in storage tanks of the oil industry offers economic, environmental and operational benefits that exceed the initial costs of availability and training. This study suggests the importance of evaluating the adoption of more efficient technologies in the industry to achieve greater sustainability and long-term profitability.

Keywords: ultrasound, non-destructive testing, clean energy, Pashed Array, scanning.

1. Introduction

The optimization and reduction of energy costs and expenses in industrial processes is a topic of great importance today. Companies are constantly seeking to implement good practices and technologies that allow them to achieve the best results in terms of scope, time, cost and quality in their projects. In the construction of spherical tanks, welding is the most widely used material joining process and the evaluation of welded joints is commonly performed by non-destructive ultrasonic techniques.

Initially, it should be noted that non-destructive testing (NDT) are methods that are used to analyze equipment and components without the need to destroy them or affect their proper functioning. Within these tests for, are validated: acoustic emission, electromagnetism, radar tests, guided waves, laser tests, leakage methods, penetrating liquids, magnetic leakage field, magnetic particles, industrial radiography, infrared tests, industrial ultrasound, vibration analysis, visual inspection. [1]

Non-destructive testing (NDT) methods can be classified into volumetric and surface methods, and radiography, ultrasonic testing and acoustic emissions are included in the volumetric category. Radiography uses harmful gamma rays, while ultrasonic testing and acoustic emission are clean technologies. Industries such as construction, food, petrochemical and marine rely on NDT codes and standards such as AWS, ASME and API to ensure the integrity of their equipment through welding NDT. [2]

Non-destructive testing (NDT) of phased array ultrasound is used in the inspection of welded joints by volumetric analysis. This method uses probes with different frequencies composed of piezoelectric elements, which are capable of converting electrical energy into mechanical and vice versa. These elements can be manipulated electronically to generate angles, focus, and appropriate energy density for specific applications. According to piezoelectric elements are manufactured from different combinations of chemical elements, such as barium titanate, lithium sulfate, lead methaniobate and polarized ceramics. [3][4]

The recommended practice SNT-TC-1A is the most widely used scheme in Colombia for the qualification and certification of personnel in non-destructive testing, and is issued by the American Society of Non-Destructive Testing (ASNT).[5]

To give a clear idea, the differences between conventional ultrasound and the Phased Array are presented, the first is characterized by a volumetric method that is used in industries to analyze the cross section of the inspected element, with frequencies over 20,000 Hertz, its results are reliable and do not emit harmful radiation, since it is a clean technology, provides results in real time, does not require clearance zones, has a high probability of detection and only requires access on a single face of the element to be inspected to perform the analysis, for this there are 4 types of wave (Longitudinal wave, Transverse wave, Surface wave and Lamb wave); The second is characterized by being a technique that uses multiple piezoelectrics to emit ultrasonic waves, in this way, the individual manipulation of each piezoelectric allows to change inspection variables such as refracted angle and focusing. When the direction and positioning of the beams emitted by each piezoelectric is electronically controlled, the wavefront resulting from the encounter of the multiple ultrasonic beams directed at different angles is formed. [6]

Among the differences that stand out most between conventional ultrasound and Phased Array ultrasound, they analyze the comparative advantage of these in the inspection of composite materials, evidencing the advantages over inspection times and probability. Similarly, it provides a comprehensive review of test physics, advantages, optimization, inspection and best practices when performing ultrasonic testing presenting special care in the comparison of specific factors between conventional ultrasound and Phased Array ultrasound. [7][8]

Next, he highlights the advantages of using Phased Array technology in the industrial field of welding inspection. However, no material or study has been found that analyzes a real-world project by comparing not only the physics, scope, advantages and disadvantages of ultrasonic techniques, but also performs quantitative analysis with real data related to time reduction, cost and energy savings.[9]

In this way, the application of the technology is sought in different sources, showing a clear idea of its use, being the one who presents guidelines for the inspection of welded joints using the technique with the use of austenitic welding. Likewise, it performs the ultrasonic inspection protocol from the Phased Array technique in order to determine the integrity of mechanical systems with welded joints, performing different tests to evaluate discontinuities.[10][11]

Consequently, he characterized corrosion in fillet-overlap welds in which he performed an analysis of the fluid and gases using the Phased Array technique to determine the loss value, calculating the corrosion rate and remaining life. design a procedure for the application of the Phased Array technique under the E2700 standard, allowing to determine the availability from different inspection processes and improve the execution of activities. [12][13]

One of the applications provided is presented by those who evaluate the detection and dimensioning capacity through ultrasonic inspection with the aforementioned technique, thus showing the characterization and location of the defects that were in friction welded plates. [14]

In this context, this article focuses on demonstrating the advantage of the use of the Phased Array ultrasound technique over the conventional ultrasound technique in the inspection and quality control of welding in the construction of a spherical tank in Cartagena de Indias, Colombia. It seeks not only to improve the quality of the welding process, but also to reduce the costs and electricity and water consumption associated with the inspection.

The work is based on data obtained directly from the personnel involved in the construction of the tank, from the managerial and administrative part to the operational and construction part. A theoretical part on the physics of the test and the equipment used is presented, as well as a quantitative analysis of the data obtained through tables and graphs that allow to demonstrate the viability of the Phased Array ultrasound technique in the inspection of the welded joints of a tank with approximately 900 linear meters of welding.

With this research, it is expected not only to demonstrate the effectiveness of the Phased Array ultrasound technique in the inspection of welded joints, but also to contribute to the development of good practices and technologies that allow companies to reduce costs and energy expenses without sacrificing the quality of the processes.

Based on the above, in 2021, the company manufacturing the spherical tank cone a capacity of 8000m3 of Ecopetrol, decides to contract the manufacture of the spherical tank cone a capacity of approximately 8000m3. Manufactured with low carbon steel bonded by SMAW (Shield Metal Arc Welding) welding process. The submitted inspection proposals were made by conventional ultrasound and by Phased Array ultrasound, however, no written evidence is presented during the comparison on cost reduction of the process involved (welding), electrical and hydraulic savings when using one or the other ultrasonic technique.

This article discusses the relationship between phased die inspection and cost savings in the welding process of a specific tank. In a world focused on clean energy and reducing economic and energy costs, it is important to understand the potential benefits of using phased array inspection. The study aims to find the determinants in cost reduction, in a spherical tank construction project by using phased array ultrasound to identify the reduction of energy savings associated with welding, which could help in decision making when hiring inspection services.

2. Materials and Methods

For the realization of this article, mixed type research was used, which defines qualitative and quantitative data and a correlational methodology between conventional ultrasonic inspection times and Pashed Array, evidencing the impact of these regarding the reduction of costs and energy savings in the welding process.

Activities are carried out to optimize the responses regarding scanning times and probability of detection in welded joints through the use of phased array ultrasound; Types of discontinuities were chosen: lack of fusion and lack of penetration due to their frequency in the current welding work of the project. [15]

- Activities include:
- generate specimens with induced discontinuities,

- generate scan plans using software,
- determine the scanning speed that records the best probability of detection,
- select relevant profiles,
- generate an inspection plan,
- Verify mechanical equipment and direct costs of personnel and energy consumption.

For the development of activities It is classified as a linear discontinuity (It has three or more times its width in length) and can be due to multiple factors, such as:

- Inadequate cleaning of the base material to be welded
- Low soldering amperage
- Wet consumables
- Lack of skill on the part of the welder
- Very fast feed speed
- Improper welding angle
- Inadequate joint geometry

This discontinuity was obtained as described below:

Board 1 Amperages used in the manufacture of the specimen with lack of induced fusion.

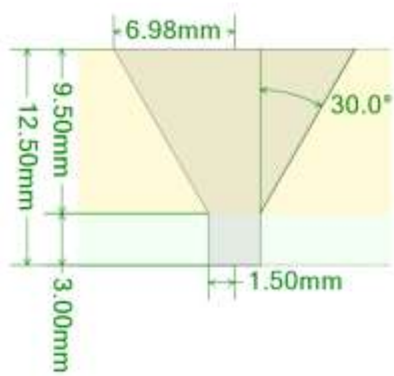
Pass	Process Used	Material	Contribution	Observation
1 (Root)	SMAW	ASTM A 36	E-6010	Amperage: 90- 110
2 (Filling)	SMAW	ASTM A 36	E-7018	Amperage: 100- 115
3 (Filling)	SMAW	ASTM A 36	E-7018	Amperage: 100- 115
4 (Filling)	SMAW	ASTM A 36	E-7018	Amperage: 100- 115

5 (Presentation)	SMAW	ASTM A 36	E-7018	Decreases amperage 80-90 amps) and increases welding speed

Source: author

The geometry of the welded discontinuity is presented below:

Figure 1 Geometry of the welded joint used in the specimen with no fusion



Source: author

As can be seen in the following image, the specimen has a lack of surface fusion, lying on one side of the bevel with straight morphology.

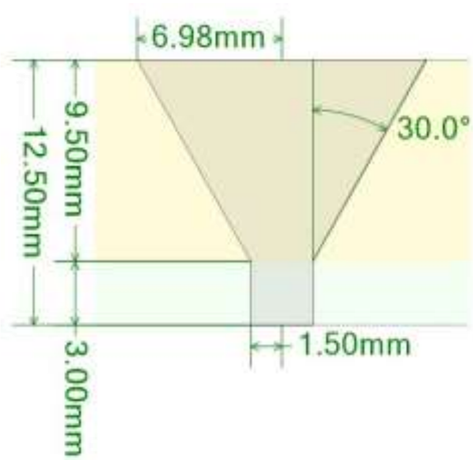
Figure 2 Lack of induced fusion in test tube.

Source: author

Preparation of specimen with lack of penetration

Linear discontinuity is presented in the root of the welded joint, the possible causes of this type of discontinuity can be: excessive root face, inadequate root opening, Electrodes of very large diameter, Insufficient amperage, Lack of skill on the part of the welder, Dirty base material, Wet filler material. Figure 3 shows the test piece case study welded with SMAW process and contribution E-6010 for the root and E-7018 for subsequent passes. The test piece case study in this project is presented, which has been welded in ASTM A 36 material, with SMAW process and E-6010 contribution for the root and subsequent passes E-7018.}

Figure 3 Geometry of the welded joint used in the specimen with no fusion.



Source: author

Among the electrical variables of application are presented:

Board 2 Amperages used in the manufacture of the specimen with lack of induced penetration

Pass	Process Used	Material	Contribution	Observation

1 (Root)	SMAW	ASTM A 36	E-6010	Amperage: 90-110, when reaching the area where the discontinuity was to be induced, the amperage is suddenly reduced to a value of 70 amps.
2 (Filling)	SMAW	ASTM A 36	E-7018	Amperage: 90- 100
3 (Filling)	SMAW	ASTM A 36	E-7018	Amperage: 100- 115
4 (Filling)	SMAW	ASTM A 36	E-7018	Amperage: 100- 115
5 (Presentation)	SMAW	ASTM A 36	E-7018	100- 110

Source: author

The result obtained is:

Figure 4 Specimen with induced lack of penetration

Source: author

BeamTool software scanning plans for conventional ultrasound

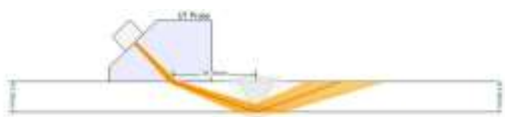
For the development of the scan, a conventional ultrasound test will be performed on a specimen with lack of induced fusion, using a simulated scan plan in the BeamTool software. The inspection will begin with the half-step, that is, the inspection towards the root of the welded joint.

According to the simulation in the Beamtool software presented in Figure 5, the ultrasound beam output must be located 34.34 mm from the center of the weld to inspect the half-pass.

$$\text{Semipaso} = 12{,}5\ \text{mm} * \tan 70° = 34{,}34\ \text{mm}$$

Then it is shown how the calculation of the half-step by the equation gives the same result as that obtained by the simulation in the software.

Figure 5 Half-pass inspection using conventional UT



Source: author

For the inspection of the simulation presentation in BeamTool software, Figure 6 presents the welded joint should be positioned approximately 48.68 mm from the center of the weld with respect to the ultrasonic beam output in the probe.

The step calculated by the mathematical equation:

$$\text{Paso} = 2 * 12{,}5 * \tan 70° = 68{,}68\ \text{mm}$$

Figure 6 Inspection of the passage by conventional UT

Source: author

Based on the above, simulation software and mathematical calculation have yielded the same result of 34.34 mm for the half-pass of the welded joint. Therefore, the sweep zone is plotted between approximately 34 mm and 48 mm, and it is in that area that the ultrasonic scan presented in figure 7 will be carried out.

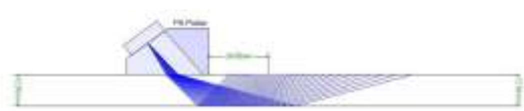
Figure 7 Sweeping area. In the sweeping area, the probe shall be moved in such a way as to inspect the cross-section of the welded joint.

Source: author

Scan plans using BeamTool software for phased array

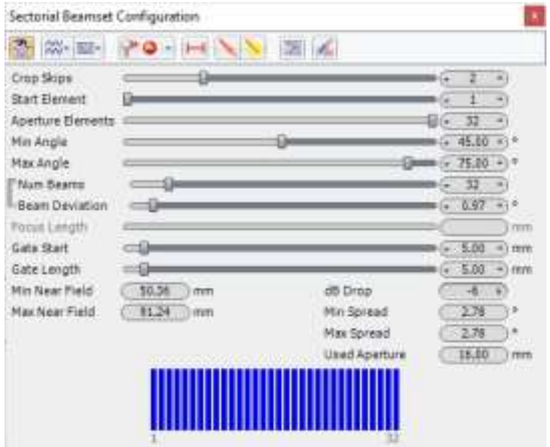
Discontinuities that are parallel to the ultrasonic beams cannot be detected so the inspection must be performed on both sides of the welded inspection. Figure 8 shows the generated scan plan:

Figure 8 Phased array scan plan. Simulation performed in BeamTool 6.0



Source: author

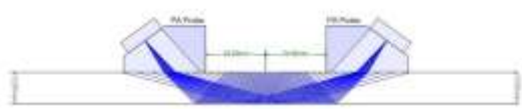
Figure 9 Variables used in the phased array scan plan.



Source: Simulation performed in BeamTool 6.0

The use of a scanner will allow two probes to be mounted simultaneously and the inspection to be carried out in a single pass presented in Figure 10. This will not only save time in the scanning process, but also allow inspection from both sides of the welded joint simultaneously.

Figure 10 Scanning plan with double phased array probe.



Likewise, the scanner used for the inspection of the specimens is presented, the optimization of the inspection time by the double probe is also achieved, Through the scanning plan the probes are located at the simulated distance from the center of the weld

Figure 11 Dual probe scanner

Equipment to use

The ultrasound equipment to be used in the project is a defectology equipment of the Doppler brand, specifically the Anyscan-30 model, which has been verified both horizontally and vertically. After performing the necessary validations, a real angle of 70° was obtained.

Figure 12 Equipment used in this project. Doppler Anyscan 30.

Source: author

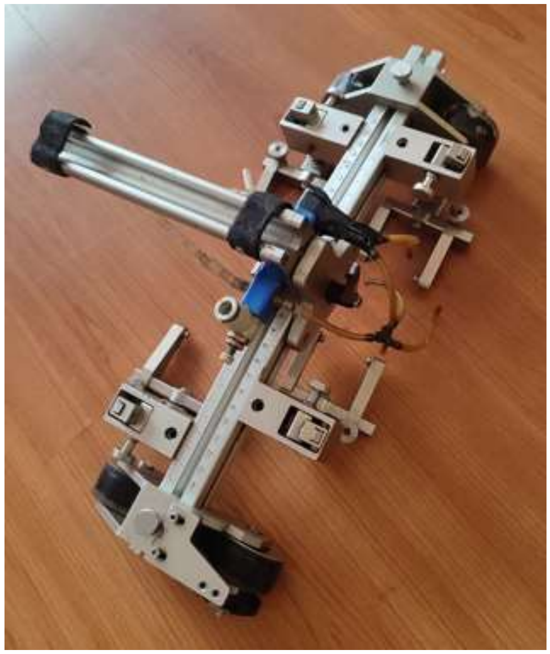
The equipment used in this procedure is a DOPLER FLEXSCAN 16:64PR, which has multiple channels, focal law generation software, external storage devices and the ability to view multiple types of scans simultaneously. It also provides A-Scan, S-Scan, B Scan, and C Scan views during inspection as needed.

Figure 13 PAUT equipment to be used: DOPPLER FLEXSCAN 16:64PR.

Source: author

An FC-01 Doppler scanner made of aluminum, irrigation system and magnetic tires will also be used.

Figure 14 Scanner to use: FC-01 from the manufacturer Doppler.



Source: author

Probes

The probes involved have a frequency of 5 MHz and 32 elements. An array of two 5L32 0.5x10 probes mounted on the FC-01 scanner will be used.

The shoes that will be used are SD2 N55S-IHC (With irrigation channel to ensure an adequate passage of water, which will act as a coupler).

Taking scan times

The activity consists of taking measurements of scanning time and probability of detection of discontinuities in a welded joint. The inspector records the scanning time for each test and the probability of detection, based on variables such as amplitude, color and dimension of the indication. Using a scale, the inspector assigns a value to the POD (probability of detection).

Table 3 shows how easily an ultrasound inspector can detect a discontinuity in a welded joint. Tests were performed on the elaborated specimens and two inspectors of the company generated results according to the findings obtained related to inspection time and probability of detection, the inspection time for PAUT was approximately three times faster than conventional ultrasonic tests

Board 3 Probability of detection related to visualization of ultrasound equipment

LOW POD			POD MEDIA				HIGH POD			
0-10%	11%-20%	21%-30%	31%-40%	41%-50%	51%-60%	61%-70%	71%-80%	81%-90%	91%- 100%	**Amplitude of Scan A**
										Color Scan C
1 (Very low)	2	3	4	5	6	7	8	9	10 (Very high)	**Ease of appreciatio**
1 (Very difficult)	2	3	4	5	6	7	8	9	10 (Very easy)	Easy sizing of the indication

Source: author

Scan plan in BeamTool of tank to be inspected

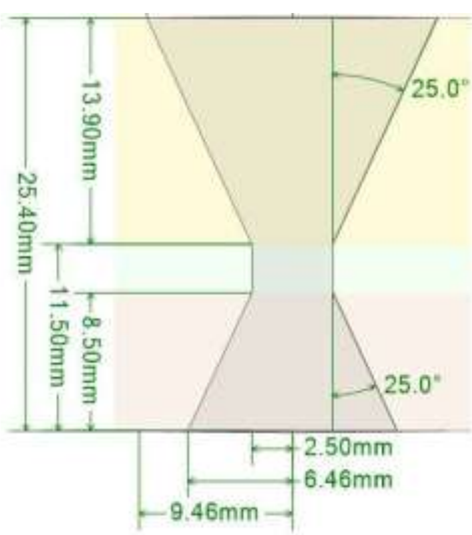
According to the results obtained and cost projection that will be presented later, the client decided to hire the phased array ultrasound service. The tank to which the work of inspection of the welded joints is carried out

Figure 15 Spherical carbon steel tank located at the esenttia plant, Cartagena – Colombia

Source: author

The scan plan is generated in BeamTool software with the applicable characteristics. The geometry of the welded joint used in the project, Scan plan will be used with the following characteristics in both probes and shoes:

Figure 16 Geometry used in the welding of the spherical tank project Characteristics of probes and shoes to be used.

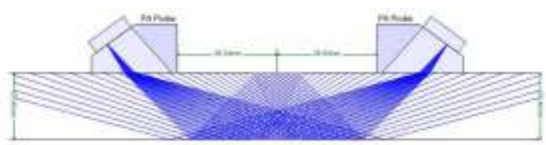


Source: author

Source: Simulation performed in BeamTool 6.0

The inspection will be carried out on both sides of the welded joint, as previously evidenced to obtain greater POD, savings in inspection times and linked energy savings in different ways (man hours, consumables, equipment spare parts, etc.).

Figure 17 Sector configuration on both sides of the weld.



Source: author

The calculation of consumption is made for 26 days since, as mentioned above, Sundays are not working days and a consumption of energy expenditure is not relevant in the work equipment.

Board 4 Equipment involved in the process, quantity and electricity consumption of each

APARATO	CANTIDAD	CAPACIDAD WATTS	HORAS AL DÍA DE TRABAJO	KW/HORA	CONSUMO DÍA (KW/HORA)	CONSUMO UNITARIO MES (KW/HORA) (26 DÍAS)	CONSUMO TOTAL MES (KW/HORA) (26 DÍAS)
Máquinas de soldar	10	6000	4	6	24	624	6240
Pulidoras	10	2400	2.5	2.4	6	156	1560
Iluminación	15	100	8	0.1	0.8	20.8	312
Hornos	10	955	8	0.96	7.6	197.6	1976
Otros	4	500	5	0.5	0.9	23.4	93.6

Source: author

3. Results

The demonstration of the techniques (conventional UT and PAUT) to the customer was carried out in a real welding section on the tank. In the same way, the cost plan and inspection times for each of the techniques was generated.

The perimeter joints of the tank were inspected in sections of 3 meters each, with a total of 900 linear meters inspected using conventional ultrasonic and phased array tests. The client agreed to pay a daily availability fee for inspection services, taking into account that most of the time is spent on tasks other than testing, such as assembling scaffolding, cleaning joints and verifying equipment standardization. The daily availability rate for conventional ultrasonic tests was COP 850,000, while for ultrasonic tests Phased Array was COP 1,200,000, both in line with market rates in Colombia. The tank, belonging to the Essentia plant in Cartagena, a subsidiary of Ecopetrol, is a low-carbon steel sphere with an approximate capacity of 8,000 m3. The results of the demonstration are presented to the client and the final data of the project.

Board 5 Inspection values in time recorded in welding sections in demonstration to the customer. Both in conventional ultrasound and in PAUT.

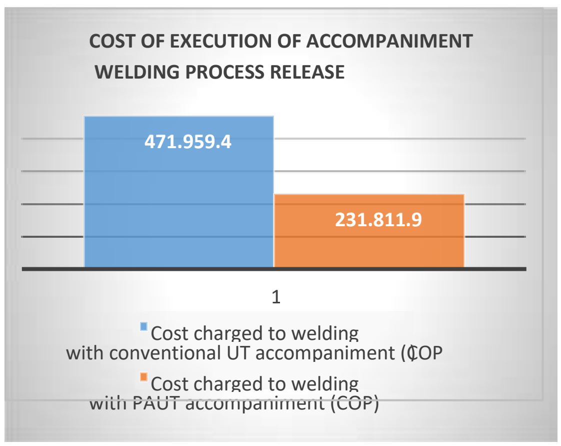
Inspected section (9 meters)	Conventional UT inspection time (minutes)	PAUT inspection time (minutes)	DATA PAUT analysis time (minutes)	Total inspection + PAUT analysis (minutes)
First section (3 meters)	31,23	8,13	6,4	14,53
Second section (3 meters)	32,49	10,11	6,2	16,31

Third section (3 meters)	36	9,27	6,2	15,47

Source: author

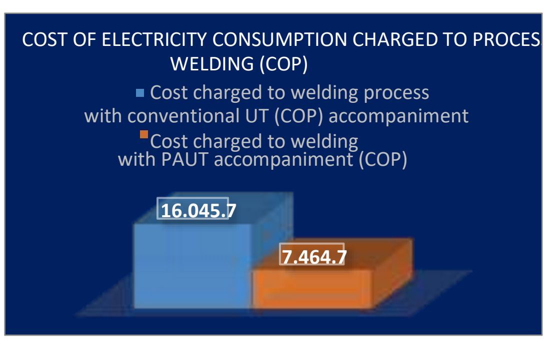
Figure 1 compares the costs of performing welding inspection with conventional ultrasound and phased array ultrasound. Although the daily cost of the phased array technique is higher, it is shown that throughout the project it is more economical due to the reduction of inspection times.

Graphic 1Cost charged to conventional UT welding process vs PAUT.



Graph 2 shows a reduction of almost 50% in electricity savings if the inspection accompaniment is carried out by PAUT.

Graphic 2 Cost of electrical consumption charged to welding process. Conventional UT vs PAUT.



Source: author

Water consumption per person was measured quantitatively with 5 people and an average value was taken to project the total consumption during the welding inspection project. Depending on the number of working days and the technique used (conventional ultrasound or PAUT), the total projected water consumption and its cost in POPs were calculated.

Table 6 and Figure 3 show a water saving of 24,305 litres if the welding inspection is performed by PAUT. This significant amount was analyzed only for the welding process and raises the question of how much total water and electricity could be saved by adopting more efficient technologies throughout the tank manufacturing process.

Board 6 Water consumption of personnel involved in the welding process

Consumo aprox persona	40 litros/día (turno)	Consumo total en el trabajo se realiza mediante ultrasonido convencional		Consumo total en el trabajo se realiza mediante ultrasonido PAUT	
Cantidad de personas	19	Consumo durante 2,3 meses	45440 litros	Consumo durante 1,07 meses	[illegible]
Consumo aproximado total	760 litros/día				
Consumo por mes (26 días)	19760 litros				

Source: author

Graphic 3 Cost of water consumption charged to welding process. Conventional UT vs PAUT.

Source: author

4. Conclusions

In conclusion, it can be said that energy savings are directly related to economic savings in industrial projects, and there are different variables that influence the cost of the process. In the specific case of the welding process, the use of efficient ultrasound technologies can contribute significantly to energy savings and cost reduction. In addition, it is important to take into account other processes involved in the construction of industrial works, such as design, assembly, painting, pre-commissioning and commissioning, and evaluate how they can be affected in terms of energy expenditure if more efficient technologies are used.

Therefore, it is essential to raise awareness about energy saving, promoting the efficient and responsible use of resources, which will result in the reduction of the electricity bill and the impact of greenhouse gases. To achieve this, more efficient accompaniment/inspection teams can be used and lifestyles that promote the sustainability of the planet can be adapted.

Likewise, the importance of defining the equipment and processes to be analyzed, and generating quality plans in all stages of construction, from purchases to the delivery of the final product, with the aim of reducing energy costs and improving efficiency, is highlighted. In this sense, companies should implement quality management systems focused on reducing energy costs, in addition to meeting the requirements of delivery to the end customer.

Finally, it is mentioned that there are several non-destructive testing techniques that can be used to deepen the issue of energy saving, such as infrared thermography, which allows identifying damage mechanisms that generate greater energy consumption. It is important not only to energetically analyze the welding process, but also other processes and optimize cost control. The transition to technologies that generate higher performance with lower energy expenditure is a trend in constant evolution, and is an excellent option for labor and sustainable development projects.

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