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DESIGN AND MANUFACTURE OF A NUCLEATED BOILING CHAMBER FOR HIGH PRESSURES

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Abstract: Many engineering situations involve boiling processes. In the case of nucleated boiling, a more in-depth study is needed to improve its technical use of intensification and be able to minimize the risks involved in confinement when it is imposed by theproject, as this can lead to problems linked to the premature triggering of the critical flow, which represents the limit at which the system is operated in nucleated boiling. This course conclusion work aims at the design and construction of a nucleated boiling chamber having its working pressure limited to 60 bar. For the construction of the nucleated boiling chamber, the materials used are a mechanical tube used for the body of the equipment, and the other parts all made of SAE 1020 steel, being manufactured by the machining process, the union of the parts where necessary is made by screws with or without nuts and locknuts or by welding process. The chamber has two tempered glass hatches so that it can be seen inside during the tests carried out, thus being able to see what happens in the refrigerant used for testing

Keywords: Nucleate boiling. Nucleate boiling chamber. pressure vessel. Pressure. boiling curve.

INTRODUCTION

In the late 1960s, studies on the phenomenon of boiling were intensified, many authors define boiling as a process in which a change occurs from its liquid condition to a gaseous one (steam), occurring when the liquid used comes into contact with an area heated to a temperature higher than the saturation temperature of this liquid. The first note on the study of boiling was a publication in the mid-17th century by the physician Joan Gottlob Leidenfrost (1756), where he carried out an experiment in which he witnessed the vaporization of a drop of water on a heating surface (DA ROCHA, 2007). The event considered as the landmark for the understanding of the boiling emerged with the work of Nukiyama (1934) phenomenon entitled as *"The Maximum and Minimum Values of the Heat Q Transmitted from Metal to Boiling Water under Atmospheric Pressure"* , this work provided a new view on the phenomenon of boiling, where the so-called "Boiling Curve" was introduced for the first time (STELUTE, 2004).

Currently, one of the most prominent and very common areas of boiling in academic works and research is nucleated boiling, which is the phase in which bubbles appear in the fluid during the boiling phenomenon, the most used answer for this interest is the possibility of the most several areas of application of the study of nucleated boiling, giving great emphasis to the industry, which can be cited as an example of the evaporators of refrigerators where nucleated boiling is present, in flooded evaporators for liquid cooling, also being observed in pressure vessels (CABRAL , 2012), (DA SILVA, 2005).

For the studies of nucleated boiling, the equipment most used in academic and research circles is the experimental bench for nucleated boiling, where one of the most important items of equipment is the nucleated boiling chamber. Unlike the design of other equipment, a nucleated boiling chamber is not an item manufactured in series, being equipment made to measure for specific operating circumstances, as can be seen in academic equipment manufactured by Da Rocha (2007) and Passarella (2016).

Due to the scarcity of articles, norms and academic works directly directed to the design and production of nucleated boiling chambers, generally the material used for the manufacture of these equipments, are the bases for the design and construction of pressure vessels and their norms, since that functionality of both equipment is similar (storing fluids in high pressure inside) (TELLES 1996).

In order to enable the Centro Universitário da Serra Gaúcha (FSG) to produce research and studies on various refrigerant fluids in the nucleated boiling regime, in addition to providing practical classes in subjects such as fluid mechanics to students of the educational institution, this monograph has The purpose was the design and construction of a nucleated boiling chamber to be integrated with a boiling study bench, using the ASME Section VIII Division I pressure vessel standard.

RESEARCH QUESTION

With the increasing use of equipment whose operation is based on the phenomenon of nucleated boiling, research in this particular area of boiling has gained prominence in recent years in academic circles. Despite the high demand in the market for equipment with the purpose of analyzing fluids in the nucleated boiling regime, there are no companies specialized in the construction of this type of equipment, and the amount of reliable literary material for their construction is very scarce, in view of this, equipment with designs based on existing alternative systems are always welcome.

Objective

Construct a nucleated boiling chamber using ASME Section VIII Division I pressure vessel standard.

THEORETICAL REFERENCE

THE PHENOMENON OF NUCLEATED BOILING

Boiling can be cited as the process of changing the liquid-vapor phase in a similar way to evaporation, with only a few differences. Evaporation occurs in the vapor-liquid phase, when the vapor pressure is lower compared to the saturation pressure of the fluid being heated. This phenomenon ends up taking place at the solid-liquid interface, when the fluid is placed in contact with a surface heated to a temperature significantly higher than the saturation temperature of the liquid (Çengel, 2012).

The heat flux present at boiling is described by Newton's law of cooling according to Eq. (1).

$$q''_{ebu}=h(Ts-T_{sat}) \tag{1}$$

Where q''_{ebu} is defined as the heat flux present at boiling, h the convection heat transfer coefficient, TS surface temperature and T_{sat} the saturation temperature.

Bubbles are formed in this process by the balance of forces conceived between the pressure of the liquid and the vapor, and by the surface tension σ during the liquid-vapor phase, which is the result of the attractive force of the molecules at the interface towards the liquid phase. . The tension found on the surface can be reduced with increasing temperature, making it null at its critical temperature, so bubbles are not formed during boiling at supercritical pressures and temperatures (Çengel, 2012).

The boiling curve

Studies dedicated to the recognition of nucleated boiling regimes with Nukiyama (1934), using a rudimentary apparatus composed of a platinum wire in a horizontal position immersed in a bath of distilled water. Where the temperatures of the bath were measured, through saturation pressure, and of the wire by its electrical resistance using the Wheatestone bridge.

With prior knowledge of the electric current and voltage applied to the wire, it was possible to obtain the dissipated power by constructing a curve of q” vs ΔT , later being designated as a boiling curve (Figure 1) (NUKIYAMA, 1934).

Boiling regimes

According to the author Kandilikar (1999) boiling can be divided into the following six regimes (Figure 2):

- Free convection: The liquid adjacent to the surface, being in thermal equilibrium with it, appears with a higher temperature compared to the temperature at saturation, however, it is in a metastable state. There is only one heat exchange mechanism affiliated with this regime, that of natural convection, which generates low rates of heat transfer.
- Partial nucleate boiling : When the heat is high enough to activate bubble nucleation areas, which causes an unexpected increase in their withdrawal of surface heat flux when the heating mode used is manipulated temperature or a decrease in surface temperature. The areas activated in this phase are few and far between.
- Transition: the heat flux increases the neighboring tendency is for the interaction between bubbles or those that are on the surface to detach, this sub-regime is characterized by the presence of bubbles in larger sizes and coalesced in shape. reminiscent of mushrooms.
- Nucleated boiling: The greater the number of activated areas, there is an increase in heat removal to the point that, due to the high frequency of bubble appearance and spacing between the active areas, columns of bubbles start to form from the union between them. When there is a considerable movement between these columns with the effectiveness of preventing surface rewetting, thus creating hydrodynamic instabilities and a thin vapor film between the face and the liquid, the critical heat flux (FCC) is reached.

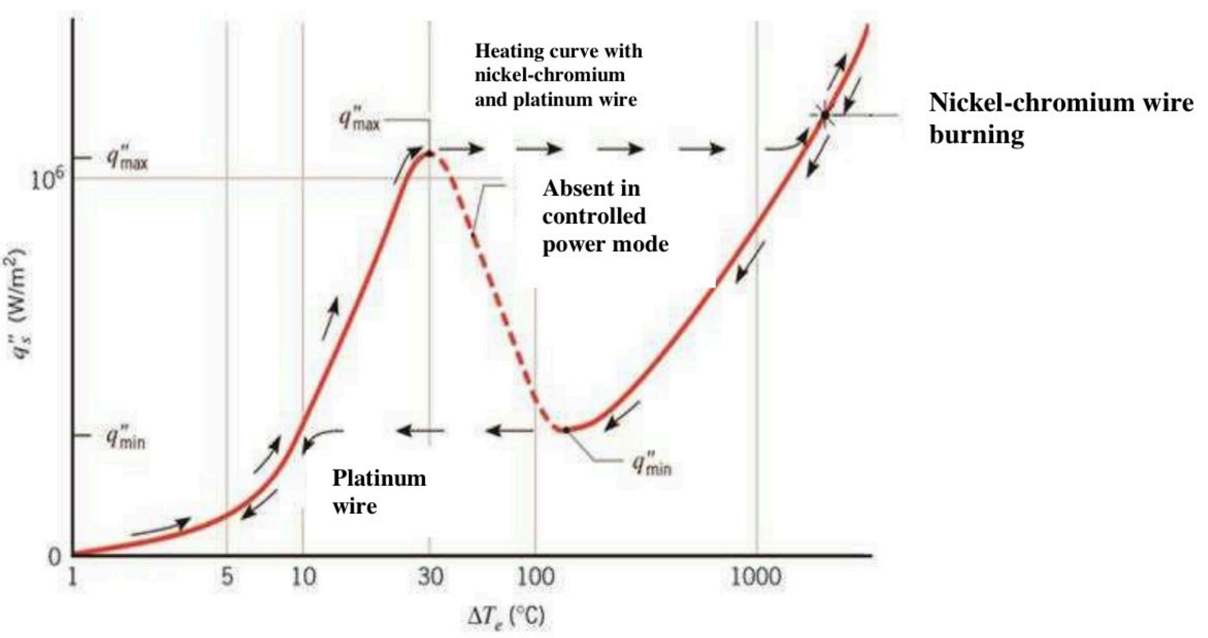

Figure 1 - Nukiyama boiling curve.

Source: Adapted from Incropera et. al, 2014.

- Boiling transition: Characterized by the intermittence between nucleate boiling and film boiling. In accordance with the heat flux, it approaches the critical heat flux, creating a strengthening in the constitution of the bubbles to the point that it makes hydrodynamically difficult the flow of the liquid to the region that is occupied by the bubbles and, consequently, the drying of the wall site occurs.
- film boiling After the variability ceases, a continuous vapor film forms between the surface and the liquid. The influence of radiation can become considerable, at the same time as the heat transport by convection and conduction increases in the degree of superheat, thus generating an increase in heat transfer rates considered new, in an amount smaller than that of nucleate boiling.

THE NUCLEATED BOILING CHAMBER

The nucleated boiling chamber (Figure 3), is a waterproof equipment produced with low carbon steel classified according to the Society of Automotive Engineers (SAE) updated in 2020, as SAE 1020.

The chamber has an internal diameter of 204.50 mm, with an internal layer of 0.1 mm of chromium to make the interior of the equipment resistant to oxidation, having an internal height of 346 mm, which corresponds to a volumetric capacity of approximately 11.4 liters.

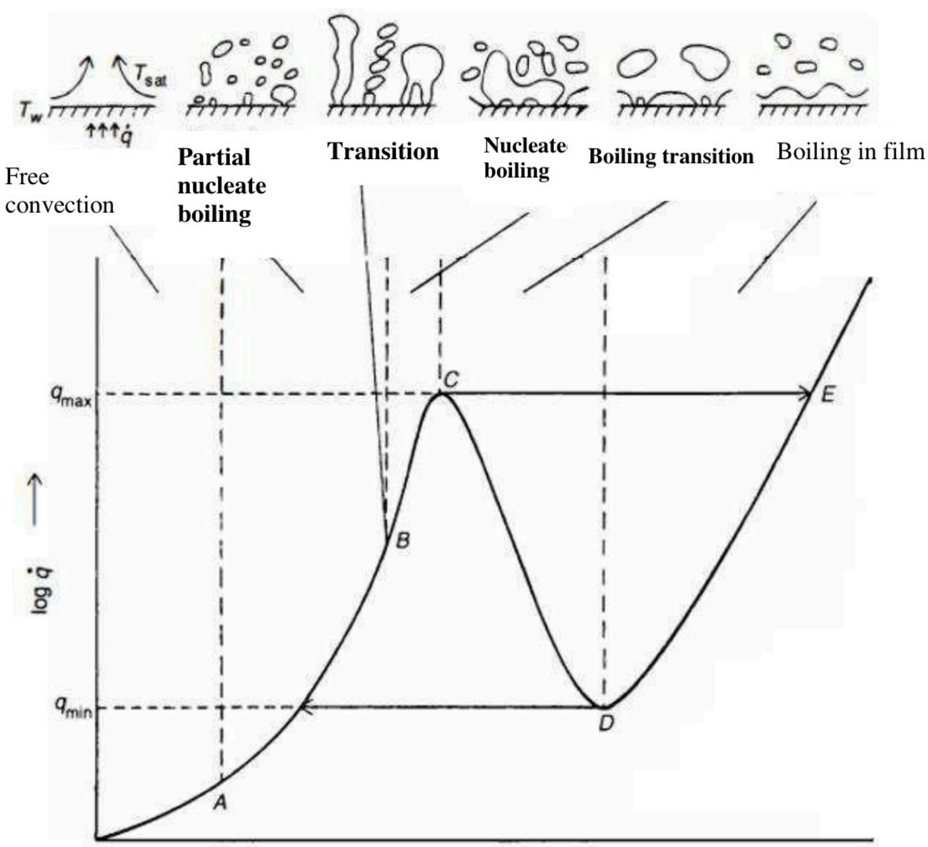

Figure 2 - Boiling schemes.

Source: Adapted from Kandlikar, 1999.

The chamber walls have a minimum thickness of 24.25 mm, having a maximum working pressure of 60 bar and a maximum allowable pressure of 80 bar, when compared to the equipment designed by Passarella (2016), which used a thickness of 15 mm for the wall of the equipment, which has a maximum working pressure of 40 bar. At the average height of the chamber, there are two hatches with a diameter of 83 mm for viewing inside. Despite the maximum working pressure of the equipment being 60 bar, all the equipment was dimensioned for a pressure of 80 bar, thus having a safety margin considered high, so the equipment designed and made in this monograph does not need the reinforcements made in the chamber produced by Passarella (2016), and the equipment before its first operation must undergo a hydrostatic test to be validated and have its safety attested, since this equipment, despite having safety systems, presents a great degree of danger for working with pressures considered high.

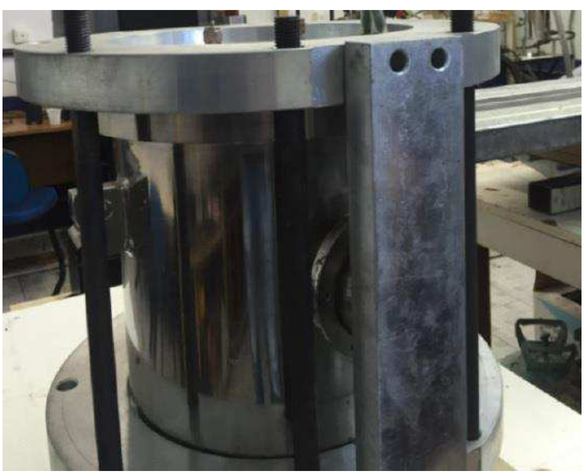

Figure 3 - Example of a nucleated boiling chamber.

Source: Adapted from Catwalk, 2016.

Pressure vessel

According to Carter and Ball (2002), the first literary references to a pressure vessel date back to the 15th century, where Leonardo Da Vinci described similar equipment to modern pressure vessels in his work " *Codex Madrid I* ".

For Bizzo (2003), the modern history of pressure vessels ended up proceeding with the initial steam industries around the 17th century. Thomas Savery patented a water pumping system that used steam as a motive force, this in 1698, after thirteen years of Savery's invention, Newcomen ended up creating equipment with the same purpose, in the case of a spherical reservoir, which had heating. straight to the bottom. James Watt in the year 1769 ended up adapting this project for use in steam locomotives thus creating the wagon boiler.

Pressure vessel, also known as hyperbaric chambers (Figure 4), is any watertight container, capable of containing pressurized fluids or gases, which may or may not be superior to the environment, among these equipments, the simplet ones can fit, such as a pressure cooker. to sophisticated equipment such as a nuclear reactor. As they are equipment that are always subject to pressure, they are considered high risk because they store a large amount of energy accumulated inside (TELLES, 1996).

Figure 4 - Example of a pressure vessel

Source: Adapted from www.totalmat.com.br, accessed on 04/19/20.

STANDARD, CALCULATIONS AND TABLES USED

In the following subchapters, a summary of the formulas and criteria of the ASME code, Section VIII, Division I is presented, thus being able to perform the mechanical calculations for the usual components of a pressure vessel (TELLES, 1996). Remembering that this code only ends up considering the effect of internal or external pressure, leaving the other loads at the designer's discretion, not just restricted to the way of calculating these, but also regarding the primordiality or not of being calculated. The formulas that are present in this code are based on membrane theory, containing some empirical correction coefficients. The decursive bending efforts of the thickness or geometric discontinuities are not considered (TELLES, 1996).

Calculation of Cylindrical Hulls for Internal Pressure

The code divide in between you hooves cylindrical in little and great thickness (according paragraph UG-27), naming in "great thickness" you hooves for you which if $e_{int} > \frac{1}{2} R_{int}$ or for $P_{int} > 0.385\sigma_{adm}E$. Where if It's defined e_{int} as the thickness minimum for pressure internal, R_{int} as lightning internal of cylinder, P_{int} as pressure internal of project, E coefficient in solder (Telles, 1996).

For thin cylindrical calculations, Eq. (2) located in paragraph UG-27 of the standard (Telles, 1996):

$$e_{int} = \frac{P_{int} R_{int}}{\sigma_{adm} E - 0.6 P_{int}} + C \qquad (2)$$

Being C the margin for corrosion. The basic minimum allowable stress of the material being found by the code table UCS-23() (Telles, 1996).

Being coefficient in solder The only unknown unknown up until time value of this can be obtained by the standard according to paragraph UW-12 and table UW-12 (Table 2) of the code, but according to Telles (1996) the value of E is taken as the standard for seamless cylinders = 1.

Calculation in tops for Pressure internal

According to paragraph UG-32 of the code, the thickness of elliptical tops must be calculated according to Eq. (3):

$$e_{te} = \frac{P_{int} R_{int}}{\sigma_{adm} E - 0.1 P_{int}} + C \qquad (3)$$

According to paragraph with UG-32, the thickness in tops torispherical must be calculated according to Eq. (4):

$$e_{tt} = \frac{0.885 P_{int} L}{\sigma_{adm} E - 0.1 P_{int}} + C \qquad (4)$$

Being L, the side greater than the torispherical profile.

According to paragraph UG-32, the thickness in tops conical he must to be calculated according to Eq. (5):

$$e_{tc} = \frac{P_{int} R_{int}}{\cos 30° (\sigma_{adm} E - 0.6 P_{int})} + C \qquad (5)$$

According to paragraph UG-34, the thickness in tops plans he must to be calculated according to Eq. (6):

$$e_{tp} = d_{tp} \sqrt{\frac{N P_{int}}{\sigma_{adm}}} + C \qquad (6)$$

Where N, an admensional factor that depends on the top and fastening system in the hull, being used the value of 0.30 in the building project (Telles, 1996).

form of presentation	ASTM specification	tensions admissible (MPa) Temperature (° Ç)					
		-30 The 93	150 to 260	300	325	350	400
Plates	A-285-C	108,0	108,0	106,0	104,0	101,0	88,9
~~Cond. tubes~~	~~A-53-A~~	~~108,0~~	~~108,0~~	~~106,0~~	~~104,0~~	~~101,0~~	~~88,9~~
Cond. tubes	A-53-B	80,6	80,6	80,6	80,6	78,8	62,3
Tubes t.e.	A-179	101,0	101,0	101,0	101,0	98,4	75,9
forged	A-181-60	92,3	92,3	91,8	90,4	87,5	73,3

Table 1 - UCS-23 table summary for carbon steels.

Source: Adapted in Telles, 1996.

Type in soldering	limitations	total radiography	Grade in inspection Partial radiography (by sampling)	not radiographed
solder in top carried out on both sides, or equivalent procedure, to achieve penetration and fusion totals (exclude permanent gasket welds)	None	1.0	0.85	0.70
solder in top, in just one side, with permanent gasket	None	0.90	0.80	0.63
solder top, in only one side, without gasket	Only allowed for welds circumferential, for thicknesses less than 15 mm, and diameter vase less than 610 mm	-	-	0.60
Lap weld, with fillet double in height total	Only allowed for welds longitudinal in thicknesses of less than 10 mm and for circumferential welds in thicknesses of less than 15 mm	-	-	0.55

Table 2 - UCS-23 table summary for carbon steels.

Source: Adapted in Telles, 1996.

Calculation in glasses of hatches

For calculation of the thickness of glass it was chosen per one search in manufacturers specialized in the manufacture of glass for boilers, as they are risky items, the manufacturer Vidrak Visores de Industrial Glass by if take care of one company specialized in the branch and what has been operating for quite some time.

Being required for first step, the calculation of diameter medium (d_{md}) Eq. (7):

$$d_{md} = \frac{d_{tot} + d_{vis}}{\text{two}} \quad (7)$$

Where d_{tot} it is defined as the diameter total of glass and d_{vis} the diameter visible of glass.

With the value of d_m calculated it is possible to obtain the value of the thickness of the glass according to Eq. (8):

$$e_{vdr} = 0.55 \times d_{md} \sqrt{\frac{P_{int} \times C.S.}{\gamma}} \quad (8)$$

Being *C. S.* the safety factor that for this type of equipment is adopted as standard 8 for untempered glass, P_{int} the internal pressure and *y* a constant where it takes on the value of 500 for ordinary glass and 2000 for tempered glass and d_{md} the average diameter.

Calculation in screws for Vases in Pressure

According to Cruz (2008), to start calculating the diameter of the screws, it is first necessary to calculate the area of the acting force through Eq. (9):

$$A_{fat} = \frac{\pi d_{fat}^{\text{two}}}{4} \quad (9)$$

Where d_{fat} It is the diameter of the force active.

getting up the value of the A_{fat} second step the calculation of the force total applied F_{ta} using Eq. (14):

$$F_{ta} = P_{int} \times A_{fat} \quad (10)$$

Where P_{int} It is the pressure internal and A_{fat} It is the area of the force active.

With the value calculated in F_{ta} one must calculate the value force due to the pressure internal F_{int} being this strength what will be applied in each screw with the aid of the Eq. (15):

$$F_{int} = \frac{F_{ta}}{Z_{par}} \quad (11)$$

Where F_{ta} force total applied and Z_{par} It is The the amount in screws.

As last step for to determine the type in screw It is used The Eq. (12):

$$Nom_{par} = 0.1tpf \sqrt{\frac{4Z_{par} \times F_{int}}{\pi P_{int}}} \quad (12)$$

Being *tpf* o stored content at the vase of pressure taking over value in 1 to fluids and 0.8 for steam.

Remembering the distance recommended in between screws must nor surpass 120 mm a on the side of the other.

WELDS IN VASES IN PRESSURE

One great majority of the vases in pressure, are manufactured with plates in steel connected in between itself by the welding process. Welding is also used for fixing all other parts of the vessel pressure wall, as well as for many of the non-pressurized parts of the vessel both internally and externally (Telles, 1996).

For splicing welds on plates on the hull and on the tops of pressure vessels, it is mandatory that these be in top, with penetration total and in type easily radiographable, these requirements Pressure wall welds are a general requirement of all standards, for example paragraph UW-35 of ASME Code Section VIII Division I (Telles, 1996).

When there is a possibility, these welds must be made on both sides, remembering that in small vessels with a diameter of 500 mm or less where there is no possibility of welding fur side internal, exists The possibility of this to be done only at the side external, being what the code ASME Section VIII Division II as It is cited at the paragraph AD-415, if It is required welding on both sides of all butt welds in high strength steels (Telles, 1996).

METHODOLOGY

ELABORATION OF THE PROJECT

For the design of the chamber parts, the calculations presented in the theoretical framework are used, for the calculation of the thickness of the chamber body and the thickness of the hatches, the value obtained in the thickness of the body was taken as a standard so that the project is standardized, all values obtained in the calculations can be seen below:

Thickness of the body and of hatches:

$$e_{int} = \frac{P_{int} R_{int}}{\sigma_{adm} E - 0.6 P_{int}} + C = 24.25\ mm \qquad (2)$$

Thickness of the glass:

$$e_{vdr} = 0.55 \times d_{md} \sqrt{\frac{P_{int} \times C.S.}{\gamma}} = 16.00\ mm \qquad (8)$$

Thickness from flat tops:

$$e_{tp} = d_{tp} \sqrt{\frac{N P_{int}}{\sigma_{adm}}} + C = 43.00\ mm \qquad (6)$$

screws of the hatches:

$$Nom_{par} = 0.1tpf \sqrt{\frac{4Z_{par} \times F_{int}}{\pi P_{int}}} = M8 \qquad (12)$$

Screw From tops:

$$Nom_{par} = 0.1tpf \sqrt{\frac{4Z_{par} \times F_{int}}{\pi P_{int}}} = M20 \qquad (12)$$

With the previous results obtained, the chamber can be made as it can be seen in Figure 5 .

ANALYSIS AND DISCUSSION RESULTS

RESULT FOR VOLTAGE IN VON MISSES

The comparison between the pressures, he can to be View in Figure 6 - a, Figure 6 - b and Figure 6 - c the chamber it presents around in your cover one color blue marine and at the center The hue blue clear, already in your body in the sides close at hatches It is introduced the tone that is blue clear and at the remaining of body the predominant shade is navy blue, in the hatches the navy blue shade predominates on the exterior of the item, the great distinction of shades can be witnessed inside the chamber near the bright corner a light blue and yellow tone is noticed showing a tendency for red coloring.

The colors presented in the 3 pressure studies in Figure 6, undergo subtle variations that do not are significant at the study, what if he can conclude with you results of the voltage in will Mises, is that the chamber is safe up to pressures of 100 bar and the sharp corner inside the hatches it has one coloring Yellow tending for red and its score Where go if to concentrate at higher voltages on the equipment.

Based on studies carried out previously in the area of finite element analysis of equipment watertight performed per Of the Silva (2015), iecker (2014), Mendonça (2011) and In Freitas (2017) it is possible to deduce that the nucleated boiling chamber supports the simulated pressures without having its integrity compromised, since the equipment

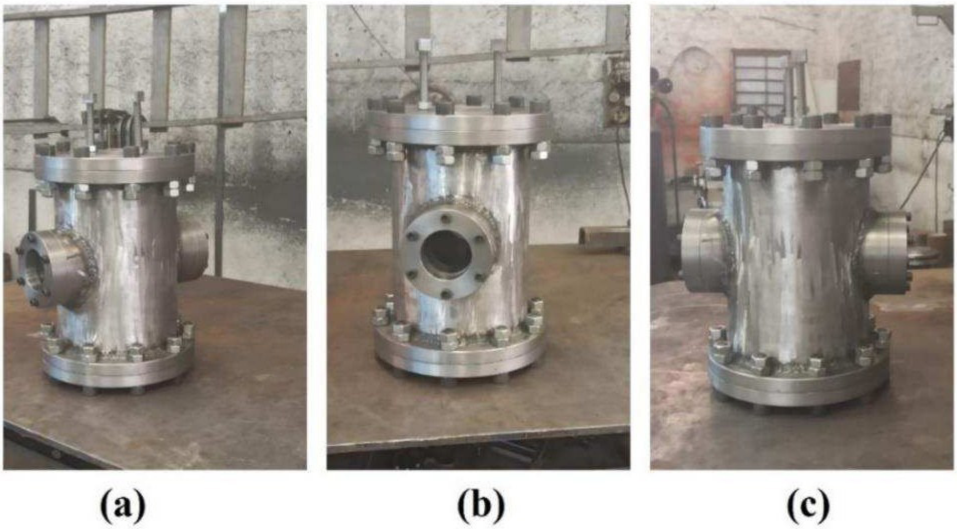

Figure 5 - (The) View diagonal of the mounted camera; (B) View front of the chamber mounted; (ç) View side of the camera mounted.

Source: the author, 2020.

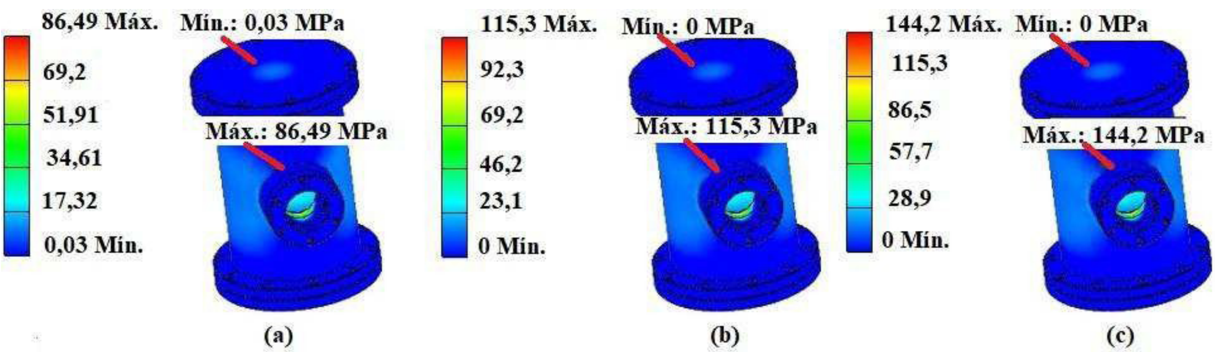

Figure 6 - Voltage in will Mises (MPa) in pressures many different: (The) Pressure in 60 Pub; (B) Pressure in 80 Pub; (ç) Pressure of 100 bar.

Source: the author, 2020.

designed by the authors mentioned above in your analysis in elements finite, have coloring similar to this study and also similar stress concentration points when tested at pressures in some cases up to 100 bar.

FINAL CONSIDERATIONS

In the present work, the design and manufacture of a nucleated boiling chamber based on the ASME Section VIII Division I pressure vessel standard was developed, the study was supported in pressure vessels by the lack of reliable material for the design and construction of a nucleated boiling chamber.

During the design and manufacture of the equipment, there were no major difficulties because the knowledge theoretical past during you years old in the subjects of course in engineering mechanics can be put into practice, there were no difficulties in the manufacturing part, since the experience acquired over the years in the machining processes was enough for this step to be completed.

The simulation from elements finite he was carried out in pressures in 60.80 and 100 Pub generating as results the Von Misses stresses and the displacement, before the simulation the biggest jump, was referent to correct sizing From tops of the chamber, then imagined what in this region would be score in larger accumulation in tensions. By having been performs the simulation in finite elements and obtained you results, these demonstrated what the chamber possibly it has your structural integrity unshaken until pressures in 100 bar, and that the possible points of accumulation of pressure are the insides of the hatches and not the tops.

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