ISAE 2023

The 6th International Symposium on Agricultural Engineering, 19th – 21st Oct 2023, Belgrade–Zemun, Serbia

DIMENSIONING AND ASSEMBLYING OF BRAZED ALUMINIUM HEAT EXCHANGER FOR NEEDS OF AGRICULTURAL PROCESS PLANTS

Marko S. Jarić,
Innovation Center of the Faculty of Mechanical engineering in Belgrade
Sanja Z. Petronić,
Institute of General and Physical Chemistry in Belgrade
Nikola J. Budimir,
Innovation Center of the Faculty of Mechanical engineering in Belgrade
Suzana R. Polić
National museum of Serbia
Nedzad Rudonja
Faculty of Mechanical engineering University of Belgrade

Abstract (bold). *Heat exchangers used in agricultural processes are mainly manufactured by three technologies: brazed copper-brass, mechanically assembled aluminum and brazed aluminum. The appropriate choice depends on various criteria: price, weight, corrosion resistance, performance in a limited volume, required pressure drops, temperature resistance, reliability, etc. Brazed aluminum is increasingly popular due to several advantages, such as resistance to high pressure and temperatures. Aluminum heat exchangers can be exposed to external and internal corrosion in various environmental conditions. Corrosion has a negative impact on the mechanical integrity and thermal performance of heat exchangers. Therefore, specific operating design parameters, as well as mechanical design characteristics, are of great importance for consideration in construction. Proper selection and design can ensure the successful and safe operation of the heat exchanger and the plant itself. The HVAC industry is directed towards the search for the best solutions in order to increase the performance, energy efficiency and durability of the equipment while reducing the costs of their production. Aluminum pipes and other aluminum components are increasingly replacing copper pipes. In this paper, application, design, assembling process and operation considerations for brazed aluminum heat exchangers used for needs in agricultural processes have presented.*

Key words (bold): *HVAC, heat exchanger, aluminum, dimensioning, agriculture*

1 Introduction

Heat exchangers used in agricultural processes are mainly produced by three technologies: brazed copper-brass, mechanically assembled aluminum and brazed aluminum. The appropriate choice depends on various criteria: cost, weight, corrosion resistance, performance in limited volume, required pressure drops, temperature resistance, reliability, etc [1]. For years, aluminum (Al) and aluminum alloys have been used as heat exchanger tube materials due to their low density, good thermal conductivity, and satisfactory mechanical properties suitable for heat exchangers [2, 3]. As the pipe becomes thinner, corrosion resistance has a greater effect [4]. Brazed aluminum is increasingly popular due to several advantages, such as resistance to high pressure and temperatures, one of the reasons being fattening in order to reduce fuel consumption [1].

Brazed aluminum heat exchangers are designed and manufactured according to pressure equipment standards and need to meet safety requirements related to mechanical design, material, manufacturing, testing and inspection requirements of various standards [5,6]. Brazed aluminum heat exchangers are highly efficient, used for a variety of cryogenic and non-cryogenic heat transfer applications, including industrial gas production, petrochemical applications and agricultural processes. Considering that they have a high surface compactness and excellent heat transfer characteristics, they have an advantage over other traditional heat transfer technologies in the application of non-corrosive liquids and gases [7]. Research has shown that the rate of heat transfer in residential air conditioners is 50% higher than the rate of conventional heat exchangers [8].

Taking into consideration the fact that heat exchangers fabricated from aluminum much less represented in agricultural industry such as and problems related to their dimensioning have not been sufficiently explored, hence and the main goals of this paper is mechanical calculations of metal elements of one very specific construction of heat exchanger of which has been fabricated from SB-209-5083-0 material. Beside with the previously mentioned in this paper is also given and methodology of merging of elements of this apparatus with relevant brazing (welding) parameters.

2 Strength calculation of three header aluminum heat exchanger

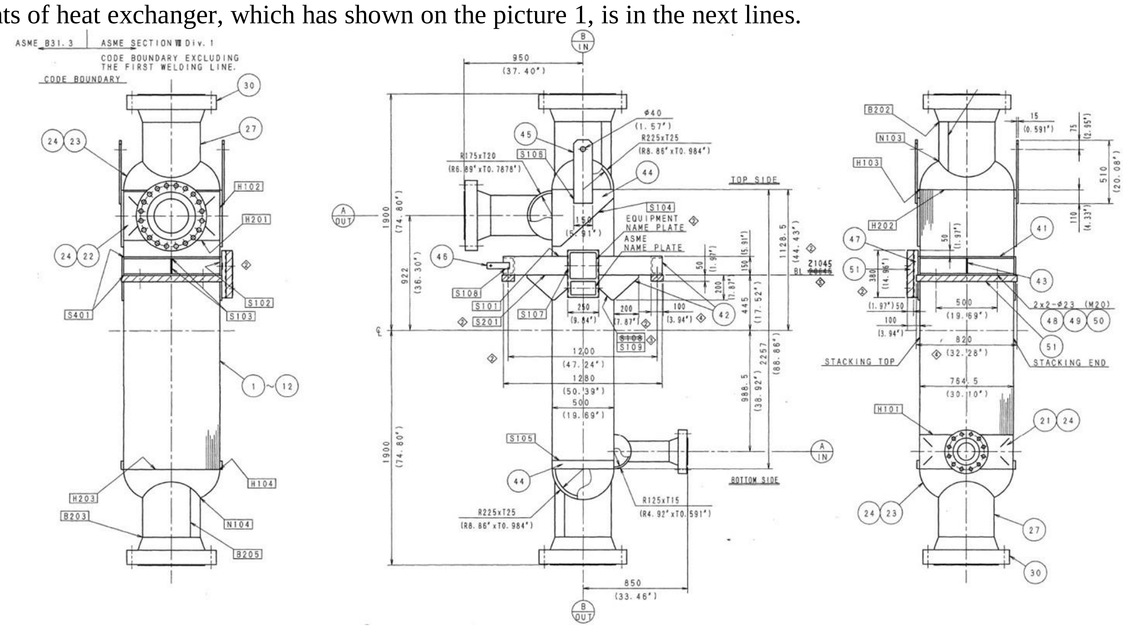
Full calculation of the heat exchangers before starting its fabrication in the workshops usually consists three following necessary types of calculations: calculation of required thermal power (heat transfer), calculation of pressure drop (for needs of further adopting of pumps) and mechanical or strength calculation of metal elements.

After finishing calculation of required heat transfer and pressure drop and determining required design conditions it is starting phase of strength calculation of all metal elements [9-11]. In this paper, it will presented of dimensioning of aluminum heat exchanger, which is using in agricultural engineering. The required design conditions have shown in the table below:

Table 1 Design conditions of brazed aluminum heat exchanger

Stream	-	(A1165)	(B1433)
Fluid	-	Liquified HC	Deethanizer reflux
Design pressure	Kgf/cm^{2}G	51	36.7
	psig	725	522
	barg	50	36
Design temperature	°C	-100÷65	-100÷65
	°F	-148÷149	-148÷149
Hydro test pressure	Kgf/cm^{2}G	66.3	47.8
	psig	942.5	678.6
	barg	65	46.8
Pneumatic test pressure	Kgf/cm^{2}G	-	-
	psig	-	-
	barg	-	-
Air leakage test pressure	Kgf/cm^{2}G	51	36.7
	psig	725	522
	barg	50	36

For needs of performing strength, calculations and analysis of place installation it was adopted latest edition of ASME Section VIII Division 1 such as relevant standard for this calculation. Review of strength calculations of assembly elements of heat exchanger, which has shown on the picture 1, is in the next lines.



Picture 1 Construction and dimension of aluminum heat exchanger

Header 1 thickness:

Minimum required thickness-t_m(according to the ASME Section VIII Division 1-UG-27(c))

$$t_m = \frac{p \cdot R}{S \cdot E - 0.6 \cdot p} + Co = \frac{51.0 \cdot 125}{801 \cdot 0.65 - 0.6 \cdot 51.0} + 0 = 13.01 \text{ mm} < Ta = 14.31 \text{ mm}$$

where

p=51 Kg/cm^{2}G, design pressure;

R=125 mm, inside radius of header;

S=801 kg/cm^2, maximum allowable stress for material SB-209 5083-0;

E=0.65, joint efficiency;

Co=0, corrosion allowance;

Header 2 thickness:

Minimum required thickness-t_m(according to the ASME Section VIII Division 1-UG-27(c))

$$t_m = \frac{p \cdot R}{S \cdot E - 0.6 \cdot p} + Co = \frac{51.0 \cdot 175}{801 \cdot 0.65 - 0.6 \cdot 51.0} + 0 = 18.22 \text{ mm}$$

where

p=51 Kg/cm^{2}G, design pressure;

R=175 mm, inside radius of header;

S=801 kg/cm^2, maximum allowable stress for material SB-209 5083-0;

E=0.65, joint efficiency;

Co=0, corrosion allowance;

Header 3 thickness:

Minimum required thickness-t_m(according to the ASME Section VIII Division 1-UG-27(c))

$$t_m = \frac{p \cdot R}{S \cdot E - 0.6 \cdot p} + Co = \frac{36.7 \cdot 225}{801 \cdot 0.65 - 0.6 \cdot 36.7} + 0 = 16.57 \text{ mm}$$

where

p=36.7 Kg/cm^{2}G, design pressure;

R=225 mm, inside radius of header;

S=801 kg/cm^2, maximum allowable stress for material SB-209 5083-0;

E=0.65, joint efficiency;

Co=0, corrosion allowance;

Minimum required nozzle thickness (A-in)

(6) Minimum required thickness-tm(according to the ASME Section VIII Division 1-UG-27(c))

$$t_1 = \frac{p \cdot Ro}{S \cdot E + 0.4 \cdot p} + Co = \frac{51.0 \cdot 84.15}{752 \cdot 1.0 + 0.4 \cdot 51.0} + 0 = 5.56 \text{ mm}$$

where

p=51.0 Kg/cm^{2}G, design pressure;

R=84.15 mm, outside radius of pipe;

S=752 kg/cm^2, maximum allowable stress for material SB-209 5083-0;

E=1.0, joint efficiency;

Co=0, corrosion allowance;

(2) The smallest of the following:

(a) the thickness of the cylindrical shell (assuming E=1.0)

$$t_2 = \frac{p \cdot R}{S \cdot E - 0.6 \cdot p} + Co = \frac{51.0 \cdot 125}{801 \cdot 1.0 - 0.6 \cdot 51.0} + 0 = 8.28 \text{ mm}$$

where
p=51 Kg/cm^{2}G, design pressure;
R=125 mm, inside radius of header;
S=801 kg/cm^2, maximum allowable stress for material SB-209 5083-0;
(b) the minimum thickness of standard wall pipe (STD)

$$t_3 = STD \cdot 0.875 + Co = 7.112 \cdot 0.875 + 0 = 6.23 \text{ mm}$$

The smallest thickness is 6.23 mm
(3) Minimum required thickness-t_m
t_m should be greater value of thicknesses calculated by (1) or (2)
t_m=6.23 mm<t_n·0.875=12.48 mm
where is t_n=14.27 mm-nominal thickness for this pipe;

Minimum required nozzle thickness (A-out)

(6) Minimum required thickness-tm(according to the ASME Section VIII Division 1-UG-27(c))

$$t_1 = \frac{p \cdot Ro}{S \cdot E + 0.4 \cdot p} + Co = \frac{51.0 \cdot 161.9}{752 \cdot 1.0 + 0.4 \cdot 51.0} + 0 = 10.69 \text{ mm}$$

where
p=51.0 Kg/cm^{2}G, design pressure;
R=161.9 mm, outside radius of pipe;
S=752 kg/cm^2, maximum allowable stress for material SB-209 5083-0;
E=1.0, joint efficiency;
Co=0, corrosion allowance;
(2) The smallest of the following:
(a) the thickness of the cylindrical shell (assuming E=1.0)

$$t_2 = \frac{p \cdot R}{S \cdot E - 0.6 \cdot p} + Co = \frac{51.0 \cdot 175}{801 \cdot 1.0 - 0.6 \cdot 51.0} + 0 = 11.59 \text{ mm}$$

where
p=51 Kg/cm^{2}G, design pressure;
R=175 mm, inside radius of header;
S=801 kg/cm^2, maximum allowable stress for material SB-209 5083-0;
(b) the minimum thickness of standard wall pipe (STD)

$$t_3 = STD \cdot 0.875 + Co = 9.525 \cdot 0.875 + 0 = 8.34 \text{ mm}$$

The smallest thickness is 8.34 mm
(3) Minimum required thickness-t_m
t_m should be greater value of thicknesses calculated by (1) or (2)
t_m=10.69 mm<t_n·0.875=22.22 mm
where is t_n=25.40 mm-nominal thickness for this pipe;

Minimum required nozzles thickness (Bin and Bout)

(6) Minimum required thickness-tm(according to the ASME Section VIII Division 1-UG-27(c))

$$t_1 = \frac{p \cdot Ro}{S \cdot E + 0.4 \cdot p} + Co = \frac{36.7 \cdot 228.5}{801 \cdot 1.0 + 0.4 \cdot 36.7} + 0 = 10.29 \text{ mm}$$

where
p=36.7 Kg/cm^{2}G, design pressure;
R=228.5 mm, outside radius of pipe;
S=801 kg/cm^2, maximum allowable stress for material SB-209 5083-0;
E=1.0, joint efficiency;

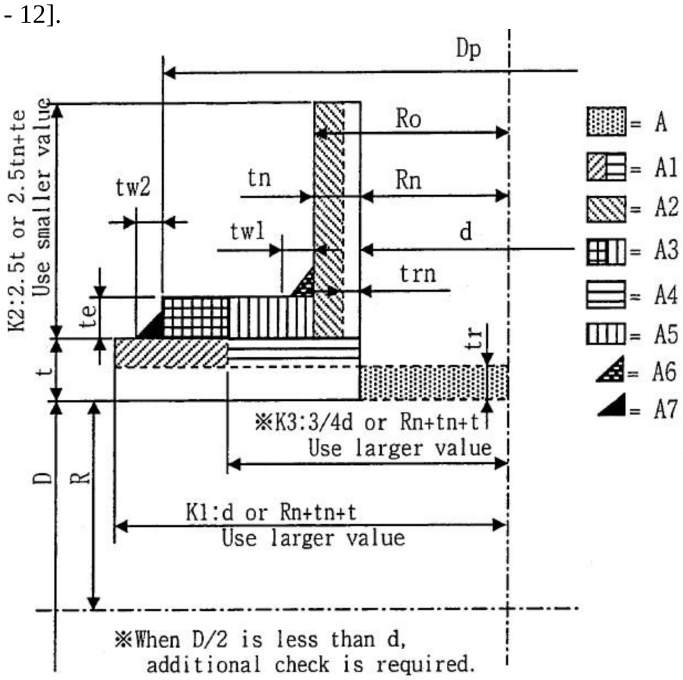
Co=0, corrosion allowance;
(2) The smallest of the following:
(a) the thickness of the cylindrical shell (assuming E=1.0)

$$t_2 = \frac{p \cdot R}{S \cdot E - 0.6 \cdot p} + Co = \frac{36.7 \cdot 225}{801 \cdot 1.0 - 0.6 \cdot 36.7} + 0 = 10.61 \text{ mm}$$

Where
p=36.7 Kg/cm^{2}G, design pressure;
R=225 mm, inside radius of header;
S=801 kg/cm^2, maximum allowable stress for material SB-209 5083-0;
(b) the minimum thickness of standard wall pipe (STD)

$$t_3 = STD \cdot 0.875 + Co = 9.525 \cdot 0.875 + 0 = 8.34 \text{ mm}$$

The smallest thickness is 8.34 mm
(3) Minimum required thickness-t_m
t_m should be greater value of thicknesses calculated by (1) or (2)
t_m=10.69 mm<t_n·0.875=17.50 mm
Where is t_n=20.00 mm-nominal thickness for this pipe;
Together with calculations for headers and nozzles, also calculations of nozzles reinforcement also should be performed especially in case heat exchanger, which are working in high-pressure environment. Taking into consideration that nowadays exist specialized software for this activities in this paper only will be presented nozzle Ain together with its appropriate markings [6, 10 - 12].



Picture 2 Markings of nozzle reinforcement dimensions

One of the most used software, which is using for calculation of pressure equipment elements, is ’’Bend-Tech-Header’’ which enables performing nozzle reinforcement calculations according to the relevant international standard related to pressure equipment. ’’Header software’’ also enables creating 3D-simulations of tube behaviour and bending simulations, which help the fabricator, visualize the bending process before running the part through the part through the machine. This helps to confirm the manufacturability of the part and the bend order [8].

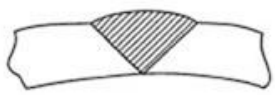
3 Merging process of aluminium heat exchanger

In engineering practice, the working life of a certain apparatus includes the following stages: development, dimensioning and production of technical documentation, apparatus production, and functionality check of apparatus after production, installation of apparatus in a suitable complex system, functionality check after installation, maintenance, etc. After phase of dimensioning respectively creating heat transfer calculations, pressure drop and mechanical calculations, creating welding procedures specifications (WPS) are performing [14].

WPS-For Aluminium three header-heat exchanger
Material: SB-209 5083-O+SB-209 5083-O-GTAW

JOINTS
Joint Design: Groove
Backing/Retainer ■ YES ■ NO
Backing Material: 1st : No; Others : Weld Metal
Insert □ YES ■ NO

DETAILS
Root Spacing : See Dwg's
Welding Joint No. (s): B204,B205



PROCESS (ES)
■ GTAW (Manual, Auto., Semi-Auto.Machine.)
□ SMAW
□ SAW (Machine.)
□ GMAW (Auto., Semi-Auto.Machine.)
□ Other

BASE METALS	Material	SB-209 5083-O + SB-209 5083-O	
	P. No. (Gr)	25 + 25	
	Thickness Range	B.M.	■ Groove □ Fillet □ Overlay 4.8~48
		W.M.	■ Groove □ Fillet □ Overlay ≦48
	Pipe Dia. Range	□ N/A 25.4≦	
PREHEAT & PWHT	Preheat Temp. (Min.℃)	Min. 5	
	Interpass Temp. (Max.℃)	Max. 250	
	Preheat Maintenance	■ N/A □ Prior to welding of each pass □ Throughout welding until	
	Postheating	□ YES ■ NO	
	PWHT	□ YES ■ NO	
	Welding Position(s)	■ Flat □ Vertical (□ Up □ Down) □ Horizontal □ Overhead □	
	Welder's Group	■ ASME □ TI-6R51-64 TI-622-64	
GAS	Shielding Gas(es)	■ YES □ NO Ar ≧ 99.99 Min. 10 l/min.	
	Gas Backing	■ YES □ NO Ar ≧ 99.99 Min. 25 l/min.	
	Trailing Shielding Gas	□ YES ■ NO /min.	

TECHNIQUE	Bead Technique	■ String ■ Weave
	Initial and Interpass Cleaning	■ Grinding ■ Brushing
	Method of Back Gouging	□ Arc-Air □ Grinding □ Machining ■ N/A
	Peening	□ YES ■ NO
	Orifice or Gas Cup Size for GTAW/GMAW	□ N/A 12 ~ 19
	Contact Tube Distance for GMAW/SAW	■ N/A
	Pass/Layer per Side	■ Multi □ Single
	Number of Electrodes for Auto. W.	■ N/A □ Multi( ) □ Single
	Electrode Spacing for Auto.W.	■ N/A
	Closed Chamber for P-No. 5X Metals	■ N/A
	Oscillation for Auto. W. – Width	■ N/A
	Oscillation for Auto. W. – Frequency (Time/min.)	■ N/A
	Oscillation for Auto. W. – Dwell Time (sec.)	■ N/A
ELEC. CHARACTERISTICS	Tungsten Electrode for GTAW – Size	□ N/A 3.2 or 4.0
	Tungsten Electrode for GTAW	□ N/A □ Pure Tungsten ■ 2% Thoriated
	Pulse バルス	□ YES ■ NO
	Mode of Metal Transfer for GMAW	■ N/A □ Spray □ Globular □ Short Circuiting
	Wire Feed Speed for Auto. GTAW & PAW	■ N/A
	Current and Polarity	■ GTAW AC; □ SMAW; □ SAW; □ GMAW; □

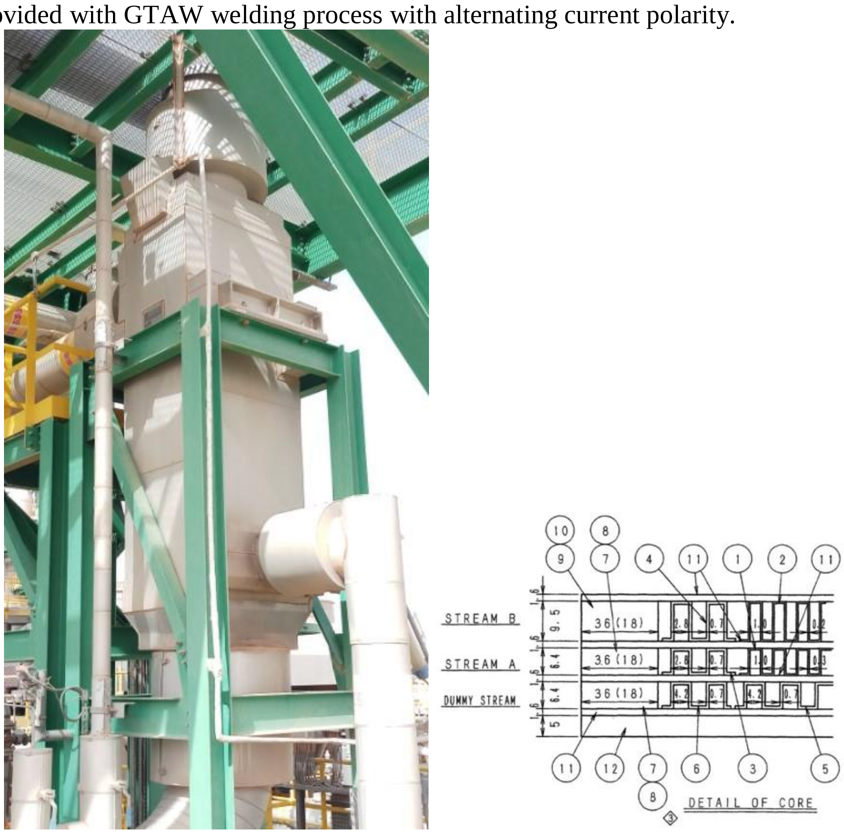
WELDING CONDITION

Layers/Passes	Weld Process	Welding Material – Trade Desig.	Welding Material – Spec.No. / AWS.No.	Welding Material – F-No	Welding Material – A-No	Size (ϕmm)	Amperage (A)	Voltage (V)	Speed(cm/min.)
Tack Weld	GTAW	R 5183	SFA5.10/R5183	22	-	3.2	150 ~ 380	14~35	-
ALL	GTAW	R 5183	SFA5.10/R5183	22	-	3.2 or 4.0	150 ~ 420 150 ~ 450	14~38 14~40	-

Supplementary Filler Metal / Powdered Filler Metal □ YES ■ NO | Flux from Recrushed Slag □ YES ■ NO | Magnetic Control □ YES ■ NO

Picture 3 Welding procedure specification for aluminium heat exchanger

Creating of WPSs is of exceptional meaning for integrity of apparatus and safety of workers, which are doing maintenance of apparatus during its required working life. This phase is usually carried out in one of two possible ways, either a suitable WPSs are created which are checked and approved, or it is provided appropriate approved WPSs (or standardized WPS-SWPS) from renowned Welding houses. When is in question welding of specific materials (such as aluminium, titanium, magnesium, etc.) often is cheaper and more reliable buying of appropriate WPSs than preparing and approving of their own especially when fabrication companies does not have experienced Welding engineers especially trained for preparation specific WPSs and also when are requiring to performing of destructive examinations of welding samples for needs of qualifying these WPSs. For needs of fabrication, this apparatus appropriate approved WPSs have been provided with GTAW welding process with alternating current polarity.



Picture 4 Aluminium heat exchanger after installation in plant and shape of internal core

Here should be mentioned that alternating current has chosen because alternating current provides a cathodic cleaning (sputtering) that removes refractory oxides from the surface of weld joint, which is necessary during welding of aluminium, and magnesium. The cleaning action occurs during the portion of ac wave, when the electrode is positive with the respect to the work piece [15].

After fabrication of heat exchanger, it were performed necessary non-destructive examinations of the weld joints. On that occasion for checking of surface indications penetrant tests were performed in range of 100% while for checking of volume indications radiography tests were performed in range of 20% for circumferential weld joints and in range of 100% for longitudinal weld joints [16]. Hydro tests of the working spaces have been performed whereby care it was taken regarding the space which is not pressure test in order to increasing pressure in not tested side in sense of avoiding its damaging during external pressure. After finishing all activities, heat exchanger was installed in the agricultural plant, name plate has been attached and insulation on the apparatus has been installed from exterior side (Picture 4). Also, proposed type of maintenance during estimated working life has been adopted according to the relevant international standards for pressure equipment.

4 Conclusion

The paper has shown phases of creating process equipment from defining designing conditions up to its installation. Mechanical calculations of specific type of aluminium heat exchanger, which has installed in agricultural process plant has presented which have conducted according to relevant ASME standards. Taking into consideration that selected material for heat exchanger is SB-209 5083-0 appropriate approved welding procedure specification has provided is given in chapter 3 and GTAW-welding process with alternating current has been used for welding activities. After fabrication process dye penetrant tests of weld joints in range of 100% performed for needs of examination of surface defects while for volume defects radiography has been used in range of 100% for longitudinal weld joints and in range 20% for circumferential weld joints. Hydro tests of both working spaces were performed on calculated test pressures and heat exchanger successfully put in service in agricultural plant.

5 Acknowledgement

Acknowledgement: This research was funded by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia through contracts Nos. 451-03-47/2023-01/200051, 451-03-47/2023-01/ 200213, 451-03-47/2023-01/200026 and 451-03-47/2023-01/200105.

6 References

1. Paquet, A. (1993) *Comparison of Brazing Processes for Aluminum Heat Exchanger Manufacturing*, SAE Technical Paper 931093. https://doi.org/10.4271/931093.
2. Cavallini, A., Del Col, D., Doretti, L., Matkovic, M., Rossetto, L., Zilio, C. (2005) *Condensation heat transfer and pressure gradient inside multiport mini channels*, Heat Transfer Eng. 26 pp. 45-55.
3. Lacaze, J. , Tierce, S., Lafont, M.C., Thebault, Y., Pébère, N., Mankowski, G., Blanc, C., Robidou, H., Vaumousse, D., Daloz, D. (2005) *Study of the microstructure resulting from brazed aluminum materials used in heat exchanger*, Mater. Sci. Eng. A. 15, pp. 413-414
4. Yong-Sang Kim, In-Jun Park, Byeong-Seon An, Jong Gil Park, Cheol-Woong Yang, Young Hee Lee, Jung-Gu Kim (2020) *Improvement of corrosion penetration resistance for aluminum heat exchanger by alloying zirconium*, Materials Chemistry and Physics, 241, pp. 122275
5. ***EN 13445 Unfired pressure vessels.
6. ***ASME-Boiler and pressure vessels-Section VIII-Division 1-Rules for construction of pressure vessels, July, 2023.
7. Miller, D., Belling, J. (2008*) Application, Design and Operation Considerations for Brazed Aluminum Heat Exchangers in Liquefied Natural Gas Service*, Proceedings of PVP 2008, 2008 ASME Pressure Vessels and Piping Division Conference July 27-31, Chicago, Illinois, USA, PVP2008-61627
8. Webb, R.L., Jung, S.H. (1992) Air-side performance of enhanced brazed aluminum heat exchangers, Ashrae, Atlanta, GA (USA), pp. 91-401.
9. The standards of the brazed aluminum plate-fin heat exchangers manufacturer associations-ALPEMA, 3rd edition, May 2012;
10. Hussain, I., Safety design brazed aluminium heat exchangers to avoid thermal shock, Gas Processing&LNG, 30-November-2012;
11. ***Strength calculation sheet serial number 49C3369 (Revision 2)-Kobe steel, ltd, Japan
12. Jarić, M., Budimir, N., Dobrnjac, M., Bajc, T.,(2015) Cost analysis of heat exchangers with concentric helical tube coils, Proceedings of 6-th International Symposium on Industrial Engineering, SIE 2015, pp. 195-199, ISBN 978-86-7083-864-2,.
13. ***Bend-tech.com/bend-tech-se-software
14. ***Welding procedure specification serial number 262202B-1-Kobe steel, ltd, Japan
15. ***API 577-Welding processes inspection and metallurgy, American Petroleum Institute, October, 2020;
16. ***ASME-Boiler and pressure vessels-Section V-Division 1-Non-destructive examination, July, 2023