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D3.7 Durability assessment of condensing surface

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Abstract	In this task, heat exchanger standards were reviewed in order to identify the specification for coating application. No direct result was found. The review then focused in examination of current standards and the job required for the applicability of the GeoHex coatings based on standards.	

REVISION HISTORY

Version	Date	Main Authors/Contributors	Description of changes
V1	24.10.2023	David Martelo	The First version was created
V2	26.10.2023	Paul Jones	Review the hole document
V3	27.10.2023	David Martelo	Revised and edited the whole document to final version

[1] Dissemination level security:

PU – Public (e.g. on website, for publication etc.) / **PP** – Restricted to other programme participants (incl. Commission services) /

RE – Restricted to a group specified by the consortium (incl. Commission services) / **CO** – confidential, only for members of the consortium (incl. Commission services)

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CONTENTS

Summary and Scope

A summary of revised standards for heat exchangers is presented in this report. No specifications were found in relation to coatings for internal parts of heat exchangers were found. Geometry, corrosion and fouling were factors to take into account for the design of coating for heat exchangers. Cleaning is another topic that should has been taken into account. Considerations specific to the standardisation of coatings for heat exchangers are presented.

Objectives Met

The deliverable contributed towards the work package WP8 objective:

To identify barriers regarding the current HX codes and standards and recommendation to overcome those.

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1. INTRODUCTION

The initial objective of this deliverable was to determine if the coatings developed in Geohex complied with recommendations in heat exchangers standard and codes. The examination of the documentation revealed that coatings are not incorporated in heat exchangers standards, at least in relationship to the materials that are related to the heat transfer, where GeoHex innovation take place. Taken this account, this deliverable will be focused in the following two objectives[†]:

-Determination of the requirements that should be taken into account for a coating design, if this is going to be applied on a heat exchanger application (This is somehow opposite to the requirements of the deliverable).

-To establish the features that should be taken into in case that a heat exchanger standard decided to include coatings.

2. REVIEW OF INFORMATION

In order to complete this deliverable, three different sources of information were reviewed: (i) Heat exchangers standards, (ii) standards in geothermal and (iii) heat exchangers manufacturers.

For source 1 (heat exchangers standards), the following documentation was reviewed:

- The standard of the tubular exchanger manufacturers association (TEMA) [1] was reviewed in detail.
- The ASME Section VIII, Div. 1 code [2], which used for pressure vessels (this include heat exchangers). Other documents associated to this standard were also reviewed
- API standards for heat exchangers, i.e. STANDARD 662 part I [3]and part II [4] or STANDRAD 661 [5]were reviewed in detail.

From source I, the knowledge collected from this examination regarding, the recommendations and requirement involved in the steps of production heat exchangers[‡] will be presented in section 2.1, including from the list of requirements and recommendations , the aspects that could be of relevance for coatings (as indicated, opposite to the initial objective of the deliverable). Again, it should be noted that the standards do not invalid the use of heat exchangers outside the range of specifications in the standard itself, as they open the door for innovative solution, as long as stated that they are outside the range of requirements of the standard used for fabrication.

For standards in geothermal (source II), it was requested to the information services team of TWI to made a full compilation of standards in geothermal and in heat exchangers, in order to determine if there was a specific standard for heat exchangers for geothermal, Appendix A shows the results of this investigation.

For source III, the manufacturers told us that there are two type of coatings used in heat exchangers, external for atmospheric corrosion, and some internals for improving corrosion resistance. More detail regarding some specifications in these two topics can be found in section 2.3

[†] With respect to the specific topic of the deliverable, some of the standards reviewed indicate that innovations are allowed, as long as indicated that this is not covered in the standard used for the manufacturing of such as heat exchanger

[‡] Although this information might seem irrelevant with respect to the original deliverable, it should provide an idea of what are the requirements in the current standards.

2.1 Heat exchanger standards

A consideration of the examined heat exchanger standards, it is that some of the requirements can be imposed by client (i.e. Geothermal industry[§]), while other are imposed by the heat exchanger manufacturer. Therefore, despite there is no specific standard for heat exchanger for geothermal industry, the current standards allow to some extent tailoring for geothermal. See below in table 1 a compilation of information that could either go in the checklist or specification sheet of a heat exchanger (as indicated before, this is just to provide an idea of the information typically covered in the codes and standards):

Table 1. Summary of heat exchanger specification sheet/checklist information

	Shell / hot side	Tube / cold side
Fluid type		
Flow		
Temperature	design	Design
Pressure	design	Design
Fluid properties (liquid and or vapour)	Viscosity, molecular weight, specific heat, thermal conductivity	Viscosity, molecular weight, specific heat, thermal conductivity
Temperature	Inlet/outlet	Inlet/outlet
Corrosion allowance		
Fouling margin		
Type of heat exchanger	Pitch, tube arrangement, joining method	
Size	#of plates, dimensions	
Gasket fixing	Material, glued?,	
Connection design	Connections, Nozzle, flanges	
Painting specifications*		
loading	Loads/moments, explosion blast pressure, earthquake loading	
Testing and inspection	Testing according to pressure vessel regulations, welding isnpections (when required),	

*This refers to avoid environmental corrosion in the outer cover.

In brief, we think that the standards for heat exchangers do not cover coatings simply because coatings are not load bearing components in a pressure vessel[**]).

Aspects of heat exchanger and coating design that could, if implemented, put the component outside of compliance with design recommendations, are noted in yellow highlight in table 1. Twomajor factors were found in this category, geometry and corrosion (including fouling).

[§] It should be noted that no specific standard was found for heat exchangers in geothermal

[**] In terms of the codes, heat exchangers are considered pressure vessels.

Another factor that should be taken into account and that it is not included typically in the specification sheets is the cleaning (although this is mentioned in the standards). Figure 1 shows an example of the tube pattern geometry arrangements allowed in in the TEMA standard. With respect to the geometry, what it is important from this, in relationship to coatings, it is that the application of a thick coating needs to be considered in terms of keeping an adequate pitch distance, as seen in Figure 1, depending of the thickness of a coating, application of coatings in neighbouring plats or tubes might not be possible.

In GeoHex, the thickest coating applied was the TSA (≈300um), while the minimum lane distance, for heat exchangers specified for mechanical cleaning is of 6.4mm. While many other of the coatings developed are in the range below the 10µm. This suggest that geometry will not play a significant constraint in the application of GeoHex material/coatings. Note: In deliverable 5.1 and 5.2, the topic referring if the coatings methodologies developed in GeoHex can be extended to the full range (size) of available heat exchangers was elucidated. The standards also indicate some other requirements in relationship to cleaning of a heat exchanger[††], for example, chemical cleaning is included. If a coating is developed for a heat exchanger, this needs to be compatible with the cleaning products and operations.

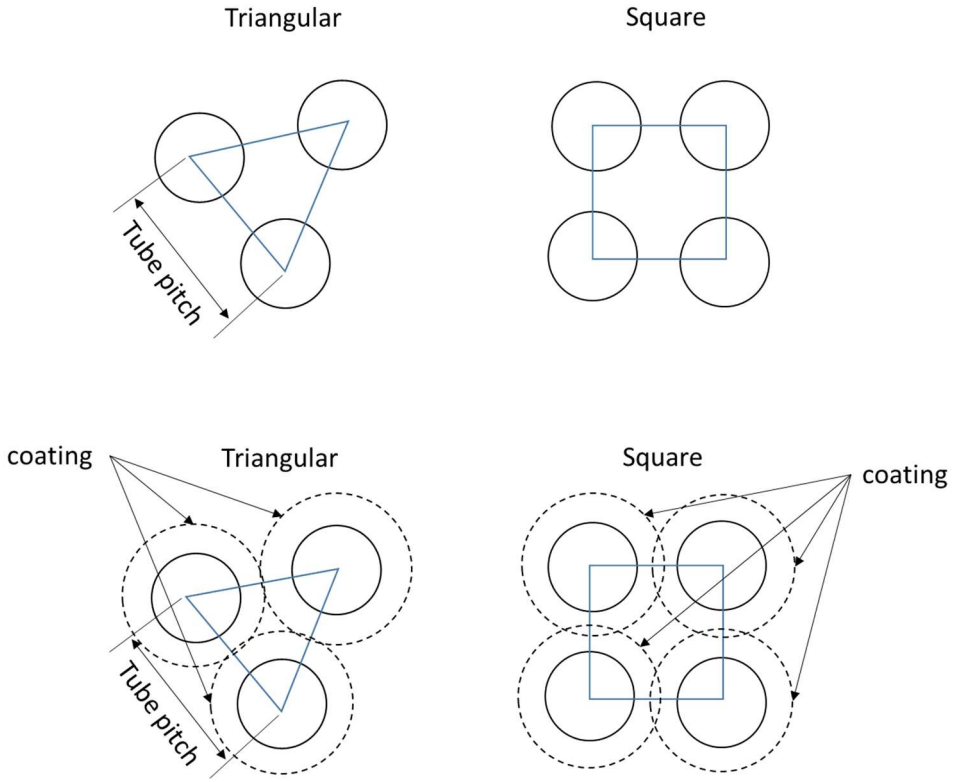

Figure 1. Standard tube pattern for heat exchangers manufactured according to TEMA standard. Variations of these two exist in its rotated forms.

[††] The cleaning topic raises an important aspects of the coatings properties that it was studied only partially in the GeoHex project. The wear resistance of the coatings. The coating down-selected in this project for trials (deliverables 2.6, 2.7, 3.6, 3.7 and 4.7 and 4.8) had a good adhesion strength, however, specifically wear tests were not considered for all coatings. If water jetting is used for cleaning, then erosion is another property of consideration.

The other topic of consideration is the corrosion[‡‡]/fouling. For the API standard 662, the corrosion allowance in the plate of the heat exchanger is 0mm/year. Similarly, the corrosion allowance for air cooled condensers is of 0mm, according to API 661. As stated in deliverable 5.1, some types of heat exchangers are not fabricated anymore from carbon steel. Despite GeoHex materials can protect the substrate carbon steel from corrosion to some extent, it cannot be guaranteed such as demanding requirement[§§]. No galvanic coupling interaction was mentioned between the coating developed in GeoHex and other substrate materials tested, therefore, the criteria of corrosion allowance required by standards should be able to be fulfilled in the remaining coating/substrate combination.

In terms of fouling, this is specified in a heat exchanger by the client according to equation 1. The client specify the fouling margin (F), where U is the overall heat transfer coefficient. In addition to the common forms of fouling, scaling is a typical and very important form of fouling in Geothermal. Actually, according to Brown et al. scaling is potentially the main limiting factor in the harvesting of energy from geothermal wells [6]. The results of the silica scaling tests produced in the GeoHex project are reported in deliverable 2.6 and 2.7. However, we think that imposing a specific recommendation from this investigation could not be beneficial for the geothermal sector given that the impact of silica scaling is specific for each site, for example, for the same scale thickness, the reduction in overall heat transfer coefficient could be different from two different sites due to the specific chemistry of the scale [7]. The coatings developed in GeoHex has an impact in the silica scale.

$$F = \frac{U_{clean}}{U_{service}} - 1$$

Finally, even if the existence of this clause was not verified for all the standards, it is a requirement, from API standard 662, that the gasketed, semi-welded and plate and frame heat exchangers allows for installation of additional plates, or individual replacement. The removal of such as constraint, open the possibility to the installation of GeoHex materials for already existent heat exchangers. Similar to the case of the heat exchangers selected in WP7 for trials in the modular pilot Organic Rankine Cycle (ORC) cycle. Note: Brazed compact plate-fin type heat exchanger (or other types of compact welded heat exchangers) are not suitable for individual replacement, this type of heat exchanger were examined from a point of view from scalability and manufacturability in deliverables 5.1 and 5.2. And considerations from this deliverable will be incorporated in section 3 (in the fabrication topic), where the recommendations for standardization of coating for heat exchangers are mentioned.

2.2 Geothermal and heat exchangers standards

Making a full revision of each of all these document would have required of a truly extensive amount of time, and it is clear that many of them are not related to heat exchangers. The few studies that incorporate

[‡‡] The values of corrosion allowance provided in this report are specific to the components where heat exchange takes place, and where are based the GeoHex innovations. Corrosion allowance for other components of a heat exchanger (including parts exposed to the process fluid) might be different.

[§§] In Collaboration with University of Leicester, a paper in the topic of corrosion and scaling in heat exchangers was published in peer review journal. This document includes a section that shows the results of investigations carried out in the topic of corrosion intervention from utilization of coatings for heat exchangers applications [9].

geothermal and heat exchangers as a topic are related to U-tube borehole heat exchangers, which is out of the scope of this project. As seen earlier current heat exchanger standards take into can account client's requirements.Therefore, we think that the lack of specific standards for heat exchangers for geothermal are partially covered. However, we think that more studies in topic of coatings for heat exchangers in geothermal applications would be required, in order for the geothermal sector be able to demand better heat exchangers for this sector.

2.3 Heat exchangers manufacturers comments

No unique code/standard was found to be used for heat exchangers manufacturers to apply paints/coatings to protect the outer surface of a heat exchanger. For example, astandard that may be applicable in this specific topic includes EN ISO 12944. This This standard focuses on corrosion protection, and the specification of the coating depends on the aggressiveness of the environment, table 2 shows a summary of the categories. In any case, it was indicated that this type of coating is usually defined by the client independently of the environment, and heat exchanger manufacturer just have to follow the standard according to the category.

Table 2. Categories listed in DIN EN ISO 12944 for specifications of paints

Categories	Environment
C1	Heated building
C2	Atmosphere with little pollution
C3	City with industrial atmosphere
C4	Industry and coastal areas
C5	Coast and sea areas, and industry and coastal areas with high humidity and aggressive environment

From our interactions, we found that outer surface coatings for heat exchangers are not only focused on corrosion but also in the role of the coating as a thermal barrier (although this is a topic that we did not find to be incorporated in the heat exchanger standards).

For the internal (wetted) parts, typically, the manufacturers do not use coatings. Corrosion was seen as one of the main criteria for investigation of coatings for internal parts of heat exchangers. However, currently, this is an aspect managed through adequate material selection, from carbon steel, to stainless steels, to nickel alloys. Rodriguez [8] published an article on the specific topic of materials selection for heat exchangers.

From the same interaction with heat exchanger manufacturers, they mentioned that there were some enamel type coatings that were used in heat exchangers. In fact, there is a standard for specifications of this type of coatings BS EN ISO 28763:2019.This standard is for air- gas and gas-gas heat exchangers, but also, it was found that this type of coatings was used in other type of industries where metal contamination could be an issue. Enamel type coatings do not improve the thermal efficiency of a heat exchanger.

3. RECOMMENDATIONS FOR STANDARDS IN THE TOPIC

As in any other standard, it is suggested that information about regulation of coatings for heat exchangers includes aspects in the design, safety requirements, fabrication (including surface preparation), inspecting,

testing and shipment and storage. Given that coating developed in Geohex are for three different types of heat exchangers, it seems more appropriate to include the guidance for each type of coating in each appropriated document, rather than a general guidance. Just to give an example, the materials requirement for boiler heat transfer are completely opposite to the requirements for condensers heat exchangers, at least in terms of surface roughness.

Safety

The first topic of consideration should be the safety. This should consider aspects related to the coating itself, for example, the surface treatment for the coatings developed in deliverable 3.2 includes an anodising treatment in orthophosphoric acid, where safety precautions should be taking for handling acids. However, aspects in relationship to geothermal/ORC plants should also be considered, for example, for the application of a coating, adequate ventilation should be taken into account (this is a typical aspect for coating applications), also, it should be considered the full removal of the refrigerant fluid, in case of the ORC power plants.

Attention should also be given to operation of the equipment used for the implementation of each coating, for example, electrical connections is spray systems.

Fabrication (design and surface preparation)

From design, as mentioned in section 2.1, some factors that could be foreseen to cause issues in the implementation of coatings for heat exchangers are the ones related to the size constraint and cleaning. Given the inexistence of a document that could agglomerate information about heat exchanger and coatings, it was proposed to release a paper in this topic as a part of the GeoHex activities [10]. We hope this assists in the visualization of this topic. For example, the paper mentions coating thickness for different type of coatings that could have potential for application in heat exchangers in geothermal.

Almost invariably for all coatings application, the surface must be prepared to some extent, these are common steps found for all the coatings in heat exchanger applications:

-Any surface that does not require coating must be disconnected or protected

-Any type of sludge must be removed from the surface

-Oil and grease should also be removed from surfaces

-Any sign of corrosion or scale should be stripped off the surface

-If the coating is going to be applied from the initial manufacturing of the heat exchanger and high temperature process will be involved, i.e. welding, special considerations are required. For example, cases where parts are to be welded after coating: an area of 5-10 mm should be left uncoated around where a weld is to be placed, see more details in deliverable 5.1.

-Any sharp or defective surface should be ground before coating application.

As mentioned before, the details regarding surface finish are specific to each application; processes as grit blasting, grinding, application of primers, pickling, etc... need to be included. The times between surface preparation and application of the coating should also be defined. And clauses should be included indicating that if surface deterioration is observed, re-preparation should be carried out.

Specifications regarding the conditions at which the coatings should be applied should also be mentioned. For example, temperature and humidity in the place where coatings are applied.

Special directions of application should be given to the areas where envisioned critical in terms of coating deterioration. This could either re-assuring of surface preparation, or increasing the coating thickness, etc…

Finally, the coating developers should provide indication regarding the acceptable cleaning procedures, for example, if mechanical (including if water jet) or chemical are acceptable

Regarding coating selection, to the best of our knowledge, given the novelty in the topic, there is no guidance.

Inspection and Testing

As in other applications where large volumes/areas require to be inspected, and detailed inspection of the entire surface its impractical or not possible. The first step for ensuring high quality is rigorous monitoring of the manufacturing variables. Despite of this, visual inspection is considered in coatings a relevant criteria of examination, this would imply in a first step to the relevant bodies to produce guidelines of the defect types relevant for each coating system. Note: As in other coating systems, coating thickness is considered important variable. However, it should be noted that a criteria in this topic would be difficult to assess for GeoHex materials due to the low coating thickness of some of this.

In terms of testing, it is considered that the assessment methodologies included in GeoHex are adequate, the topics of assessment are mentioned deliverable 1.6 (key performance indicators): Porosity, cracking, adhesion, roughness, heat transfer coefficient enhancement, corrosion rate (including coating peeling) and scaling rate. In addition to these, it is envisioned that further testing are required to guarantee wear resistance and compatibility with cleaning agents.

Shipment and Storage

API standard 662 and 661 includes specification for shipment of heat exchangers. This should be adequate itself. However, it should be noted that due to the low thickness of the GeoHex coatings, any situation causing wear of the coating could cause exposing of the bare metal. Therefore, attention should be given if the equipment is sent disassembled. A special crater should be formulated in this cases, the crater should avoid contact of any surface against coated surfaces, this should include plastics. Also, the crater should provide temporary support to avoid high deflection, whether be for tubes or plates.

The storage condition for the raw materials for the fabrication of the coatings should also be specified, along storage conditions during intermediate steps.

4. CONCLUSIONS

It was not possible to meet the original objective of the task because there is no specification no comply. Some of the standards reviewed indicate that innovation is possible, giving rise to the possible application of GeoHex innovations without having to reformulate the current standards. Surface preparation and rigorous monitoring of the parameters during coating application are seen as the main factors to take into for standardization.

REFERENCES

1. TEMA, “the standards of the tubular exchanger manufacturers association”.
2. ASME, “ASME Section VIII, Div. 1 code”.
3. ANSI/API Standard 662, “Plate Heat Exchangers for General refinery services Part 1 - Plate and Frame heat exchangers”.
4. ANSI/API 662, “Plate Heat Exchangers for General Refinery services Part - Brazed aluminium late-fin heat exchangers”.
5. API Standard 661, “Petroleum, Petrochemical, and Natural Gas industries - Air cooled Heat exchangers”.
6. K. Brown, “Thermodynamics and kinetics of silica scaling. In International Workshop on Mineral Scaling (p. 8). Manila, Philippines.” 2011.
7. S. Zarrouk, “Silica scaling in geothermal heat exchangers and its impact on pressure drop and performance: Wairakei binary plant, New Zealand. Geothermics, 51, 445-459.,” 2014.
8. P. Rodriguez, “Selection of materials for heat exchangers.” 1997.
9. Penot, D. Martelo and S. Paul, “Corrosion and Scaling in Geothermal Heat Exchangers,” Applied Sciences, 2023.
10. Bhuvanendran Nair Jayakumari, A.; Malik, N.G.; Mittal, G.; Martelo, D.; Kale, N.; Paul, S. Coatings for Geothermal Heat Exchangers. Preprints 2023, 2023101728. https://doi.org/10.20944/preprints202310.1728.v1

APPENDIX A

	Standard number	Standard title	Publication date	Status	Geothermal specific?	Re Heat exchangers	Publisher
1	(PED) 2014/68/EU	Pressure Equipment Directive (PED)	41640	Current	N		
2	20/30414401 DC/BS EN 17522	Design and construction of borehole heat exchangers.	27/05/2020	Current	Y	Y	British Standards Institute
3	ANSI/API RP 100-2 1ST ED (R 2020)	Managing Environmental Aspects Associated with Exploration and Production Operations Including Hydraulic Fracturing; First Edition	01/08/2020	Current	N		
4	ANSI/IAPMO USHGC 1	Uniform Solar, Hydronics & Geothermal Code	19/05/2020	Current	Y		American National Standards Institute (ANSI)
5	API 5L	Line pipe	2019	Current	N		
6	API RP 54 4TH ED (A1)	Occupational Safety and Health for Oil and Gas Well Drilling and Servicing Operations; Fourth Edition; Addendum 1	01/06/2021	Current	N		
7	API SPEC 16RCD 2ND ED (2015)	Specification for Rotating Control Devices; Second Edition	10/03/2016	Current	N		
8	API SPEC 5CT 10TH ED (E1) (E2) (E3) (A1)	Specification for Casing and Tubing; Tenth Edition	01/07/2019	Current	N		
9	ASME B31.1	Power piping	2021	Current	N		
10	ASME B31.3	Process piping	2021	Current	N		

11	ASME Boiler & Pressure Vessel Code, section VIII	Boiler and Pressure Code	2021	Current	N		
12	ASTM A106-M-19a	Standard Specification for Seamless Carbon Steel Pipe for High-Temperature Service	2019	Current	N		
13	ASTM A53-M-20	Standard Specification for Pipe, Steel, Black and Hot-Dipped, Zinc-Coated, Welded and Seamless	2020	Current	N		
14	ASTM D6286/D6286M – 20	Standard Guide for Selection of Drilling and Direct Push Methods for Geotechnical and Environmental Subsurface Site Characterization	01/05/2020	Current	N		
15	ASTM E 1675	Standard Practice for Sampling Two-Phase Geothermal Fluid for Purposes of Chemical Analysis	2020-00-00	Current	Y		American Society for Testing and Materials (ASTM)*American Society for Testing and Materials
16	ASTM E 947	Standard Specification for Sampling Single-Phase Geothermal Liquid or Steam for Purposes of Chemical Analysis	1983-00-00	Current	Y		American Society for Testing and Materials (ASTM)*American Society for Testing and Materials
17	ASTM E947 - 83(2015)	Standard Specification for Sampling Single-Phase Geothermal Liquid or Steam for Purposes of Chemical Analysis	03/01/2015	Current	Y		
18	ASTM E 957	Standard Terminology Relating to Geothermal Energy	27/12/2016	Current	Y		American Society for Testing and Materials (ASTM)*American

							Society for Testing and Materials
19	ASTM E957 - 03(2019)	Standard Terminology Relating to Geothermal Energy.	01/04/2019	Current	Y		
20	ASTM E 974	Standard Guide for Specifying Thermal Performance of Geothermal Power Systems	04/01/2021	Current	Y		American Society for Testing and Materials (ASTM)*American Society for Testing and Materials
21	ASTM E974 - 21	Standard Guide for Specifying Thermal Performance of Geothermal Power Systems.	01/04/2021	Current	Y		
22	ASTM E1675 - 20	Standard Practice for Sampling Two-Phase Geothermal Fluid for Purposes of Chemical Analysis.	01/09/2020	Current	Y		
23	ATEX Directive (2014/34/EU)	Equipment for potentially explosive atmospheres (ATEX)	2016	Current	N		
24	BS 22475-2:2011	Geotechnical investigation and testing. Sampling methods and groundwater measurements. Qualification criteria for enterprises and personnel	31/01/2011	Current	N		
25	BS 22475-3:2011	Geotechnical investigation and testing. Sampling methods and groundwater measurements. Conformity assessment of enterprises and personnel by third party	31/10/2011	Current	N		
26	BS EN 13445	Unfired pressure vessels [10 sections in this standard]	20/05/2021	Current	N		
27	BS EN 15112:2006	External cathodic protection of well casing.	31/10/2006	Current	N		
28	BS EN 16228	Drilling and foundation equipment. Safety. [7 sections in this standard]	31/08/2014	Current	N		

29	BS EN 1997-2:2007	Eurocode 7. Geotechnical design. Ground investigation and testing	30/04/2007	Current	N		
30	BS EN ISO 10405:2006	Petroleum and natural gas industries. Care and use of casing and tubing	15/05/2001	Current	N		
31	BS EN ISO 11960:2021	Petroleum and natural gas industries. Steel pipes for use as casing or tubing for wells	30/04/2021	Current	N		
32	BS EN ISO 14689:2018	Geotechnical investigation and testing. Identification, description and classification of rock. Part 1: Identification and description	16/03/2018	Current	N		
33	BS EN ISO 14693:2003	Petroleum and natural gas industries. Drilling and well-servicing equipment	10/02/2004	Current	N		
34	BS EN ISO 17628:2015	Geotechnical investigation and testing. Geothermal testing. Determination of thermal conductivity of soil and rock using a borehole heat exchanger.	31/08/2015	Current	Y	Y	
35	BS EN ISO 22475-1:2006	Geotechnical investigation and testing. Sampling methods and groundwater measurements. Technical principles for execution	31/10/2006	Current	N		
36	CJJ 138-2010 (CJJ138-2010)	Technical specification for geothermal space heating engineering	17/04/2010	Current	Y		
37	EN 16228-2	Drilling and foundation equipment - Safety - Part 2: Mobile drill rigs for civil and geotechnical engineering, quarrying and mining	21/05/2014	Current	Y		CEN European Committee for Standardization
38	GB/T 11615	Geologic exploration standard of geothermal resources	10/11/2010	Current	Y		Standardization Administration of the People's Republic of China (SAC)
39	GB/T 19962	Technical rule for connecting geothermal power plant to power system	29/08/2016	Current	Y		Standardization Administration of the People's

							Republic of China (SAC)
40	GB/T 28812	Steam turbine specification for geothermal power station	01/05/2013	Current	Y		Standardization Administration of the People's Republic of China (SAC)
41	GB/T 38678	General technical requirements for shallow geothermal energy utilization	31/03/2020	Current	Y		Standardization Administration of the People's Republic of China (SAC)
42	GOST R 55004	Renewable power engineering. Geothermal power plants. Base safety requirements	21/01/2014	Current	Y		Federal Agency on Technical Regulating and Metrology (GOST R)
43	GOST R 55005	Renewable power engineering. Geothermal power plants. Safety requirements under operation	2012-00-00	Current	Y		Federal Agency on Technical Regulating and Metrology (GOST R)
44	GOST R 56909	Untraditional tehnologies. Geothermal energy. Terms and definitions	2016-00-00	Current	Y		Federal Agency on Technical Regulating and Metrology (GOST R)
45	IED(2010/75/EU)	Industrial Emissions Directive	2010	Current	N		
46	ISO 17628	Geotechnical investigation and testing - Geothermal testing - Determination of thermal conductivity of soil and rock using a borehole heat exchanger	2015-07-00	Current	Y	Y	ISO International Organization for Standardization

47	ISO 22475-1:2021	Geotechnical investigation and testing. Sampling methods and groundwater measurements. Technical principles for the sampling of soil, rock and groundwater	05/10/2021	Current	N		
48	ISO/ASTM 51026	Practice for using the Fricke dosimetry system	2015-07-00	Current	Y		ISO International Organization for Standardization
49	JB/T 6506-1992 (JB/T6506-1992)	Turbine specification for geothermal power generation	21/12/1992	Current	y		
50	JIS B 0127	Glossary of terms for thermal power plant - Steam turbines and auxiliary equipment of thermal and geothermal power plant	21/05/2012	Current	Y		Japanese Standards Association (JSA)
51	KS B 0055	Glossary of Terms for Thermal Power Plant(Steam Turbines, Geothermal Power Plant and Auxiliary Equipment)	13/11/1987	Current	Y		Korean Agency for Technology and Standards (KATS)
52	NACE MR0175/ISO 15156 -1	Petroleum and natural gas industries. Materials for use in H2S-containing environments in oil and gas production. Cracking-resistant carbon and low-alloy steels, and the use of cast irons, Part 1 - general principles	2020	Current	N		
53	NACE MR0175/ISO 15156 -2	Petroleum and natural gas industries. Materials for use in H2S-containing environments in oil and gas production. Cracking-resistant carbon and low-alloy steels, and the use of cast irons, Part 2 - Carbon/low alloy steels	2020	Current	N		
54	NACE MR0175/ISO 15156 -3	Petroleum and natural gas industries. Materials for use in H2S-containing environments in oil and gas production. Cracking-resistant carbon and low-alloy steels, and the use of cast irons, Part 3 - CRAs	2020	Current	N		

55	NB/T 10099-2018 (NBT 10099-2018)	Geothermal recharge technical requirements	29/10/2018	Current	Y		
56	NB/T 10264-2019 (NBT 10264-2019)	Technical specification for geothermal geophysical exploration	04/11/2019	Current	Y		
57	NB/T 10265-2019 (NBT 10265-2019)	Code for investigation and evaluation of shallow geothermal energy development engineering	04/11/2019	Current	Y		AFNOR
58	NB/T 10266-2019 (NBT 10266-2019)	Geothermal well drilling engineering design specifications	04/11/2019	Current	Y		
59	NB/T 10267-2019 (NBT 10267-2019)	Geological design specifications for geothermal well drilling	04/11/2019	Current	Y		AFNOR
60	NB/T 10268-2019 (NBT 10268-2019)	Geothermal well logging technical specifications	04/11/2019	Current	Y		AFNOR
61	NB/T 10269-2019 (NBT 10269-2019)	Geothermal logging technical specifications	04/11/2019	Current	Y		AFNOR
62	NB/T 10270-2019 (NBT 10270-2019)	Specification for performance acceptance test of geothermal generating set	04/11/2019	Current	Y		AFNOR
63	NB/T 10271-2019 (NBT 10271-2019)	Guidelines for calculating thermal performance of geothermal power generation system	04/11/2019	Current	Y		AFNOR
64	NB/T 10272-2019 (NBT 10272-2019)	Technical requirements of geothermal wellhead device	04/11/2019	Current	N		

65	NB/T 10273-2019 (NBT 10273-2019)	Design specification for geothermal heating station	04/11/2019	Current	N		
66	NB/T 10274-2019 (NBT 10274-2019)	Code for monitoring and evaluation of geological environmental impact of shallow geothermal energy development	04/11/2019	Current	Y		TSE-Turkish Standards Institution
67	NB/T 10277-2019 (NBT 10277-2019)	Code for Geophysical Exploration of Hydropower Projects	04/11/2019	Current	Y		TSE-Turkish Standards Institution
68	NB/T 10278-2019 (NBT 10278-2019)	Technical specification of shallow geothermal energy monitoring system	04/11/2019	Current	Y		TSE-Turkish Standards Institution
69	NF X10-960-1	Water and geothermal drilling - Vertical geothermal probe - Part 1 : general	27/03/2013	Current	Y		
70	NF X10-960-2	Water and geothermal drilling - Vertical geothermal probe - Part 2 : polyethylene 100 (PE 100) probe loop	27/03/2013	Current	Y		
71	NF X10-960-3	Water and geothermal drilling - Vertical geothermal probe - Part 3 : crosslinked polyethylene (PE-X) probe loop	27/03/2013	Current	Y		
72	NF X10-960-4	Water and geothermal drilling - Vertical geothermal probe - Part 4 : raised temperature resistance (PE-RT) polyethylene probe loop	27/03/2013	Current	Y		
73	NF X10-970	Well and geothermal drilling – Vertical geothermal probe (U-shaped vertical geothermal exchanger with closed curcuit coolant) – Execution, implemenatation, maintenance, abandonment	01/01/2011	Current	Y	Y	
74	NF X10-999	Water welll and geothermal drilling – Construction, monitoring, and dismantling of catchworks and wells to tap into underground water	30/08/2014	Current	Y		

75	NZS 2403:2015	Code of practice for deep geothermal wells	30/04/2015	Current	Y		
76	PD ISO/PAS 12835:2013	Qualification of casing connections for thermal wells	28/02/2014	Current	Y		
77	TS 11927	Geothermal energy – Specifying Thermal Performance of Geothermal Power Systems	23/03/2006	Current	Y		
78	TS 11928	Geothermal energy -Sampling Single Phase Geothermal Liquid Or Steam For Purposes of Chemical Analysis-Equipment	09/01/1996	Current	Y		
79	TS 11929	Geothermal Energy-Testing Nonmetallic Seal Materials By Immersion In A Simulated Geothermal Test Fluid	09/01/1996	Current	Y		
80	UNE 100715-1:2014	Guide for the design, implementation and monitoring of a geothermal system. Part 1: Vertical closed circuit systems	21/05/2014	Current	Y		Asociación Española de Normalización
81	UNI 11466:2012	Heat pump geothermal systems - Design and sizing requirements	27/11/2012	Current	Y		UNI - Ente Nazionale Italiano di Unificazione
82	UNI 11467:2012	Heat pump geothermal systems - Installation requirements	27/11/2012	Current	Y		UNI - Ente Nazionale Italiano di Unificazione
83	UNI 11468:2012	Heat pump geothermal systems - Environmental requirements	27/11/2012	Current	Y		UNI - Ente Nazionale Italiano di Unificazione
84	UNI 11517:2013	Heat pump geothermal systems - Requirements for qualification of installing firms providing geothermal exchanger	05/12/2013	Current	Y	Y	UNI - Ente Nazionale Italiano di Unificazione
85	UNI/TS 11487:2013	Heat pump geothermal systems - Installation requirements for direct expansion systems	18/04/2013	Current	Y		UNI - Ente Nazionale Italiano di Unificazione
86	XP X10-950	Geothermal energy drilling - Grouting for closed vertical geothermal exchanger (geothermal probe)	14/02/2018	Current	Y	Y	AFNOR

87		The African Union Code of Practice for Geothermal Drilling	2016	Current	Y		
88	HEI-26-23	Standards for Shell and Tube Heat Exchangers, 5th edition		Current	N	Y	The Heat Exchanger Institute
89	HEI 2854	Performance standards for liquid ring vacuum pumps and compressors, 5th edition		Current	N	Y	The Heat Exchanger Institute
90	HEI-2866	Standards for steam jet vacuum systems, 7th edition		Current	N	Y	The Heat Exchanger Institute
91	HEI-2954	Standards and typical specifications for tray type deaerators, 10th edition		Current	N	Y	The Heat Exchanger Institute
92	HEI-3087	Standards for air cooled condensers, 2nd edition		Current	N	Y	The Heat Exchanger Institute
93	HEI-3092	Standards for gasketed plate heat exchangers, 1st edition		Current	N	Y	The Heat Exchanger Institute
94	HEI-2622	Standards for closed feedwater heaters, 9th edition		Current	N	Y	The Heat Exchanger Institute
95		TEMA book of standards (Tubular Exchanger Manufacturers Association	2019	Current	N	Y	The Tubular Exchanger Manufacturers Association, Inc.