Project acronym:	**GeoHex**		
Project title:	Advanced material for cost-efficient and enhanced heat exchange performance for geothermal application		
Activity:	LC-CS3-RES-1-2019-2020 Developing the next generation of renewable energy technologies		
Call:	H2020-LC-CS3-2019-RES-TwoStages		
Funding Scheme:	RIA	**Grant Agreement No:**	851917
WP8	**Impact assessment and compliance recommendation**		

D8.1 Impact and opportunities of GeoHex on flash plant

Due date:	M48	
Actual Submission Date:	24/10/23	
Lead Beneficiary:	TVS	
Main authors/contributors:	Mahfuza Ahmed and M A H Chowdhury	
Dissemination Level[1]**:**	PU	
Nature:	Report	
Status of this version:		**Draft under Development**
		For Review by the Coordinator
	X	**Submitted**
Version:	V2	
Abstract	The deliverable reports the impact of GeoHex materials in the Flash-type geothermal power plant.	

REVISION HISTORY

Version	Date	Main Authors/Contributors	Description of changes
V1	20/09/2023	Mahfuza Ahmed	The first version was created
V2	15/10/2023	M A H Chowdhury	Reviewed the whole document
V3	20/10/2023	Mahfuza Ahmed	Revised and edited the whole document to a 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)

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under grant agreement No. 851917

This project has received funding from the European Union's Horizon 2020 program Grant Agreement No 851917. This publication reflects the views only of the author(s), and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Document: D8.1 **Impact and opportunities of GeoHex on flash plant**

Version: 2

Date: 25 October 2023

Table of Contents

Executive Summary

The impact of GeoHex material on heat exchangers adapted for flash-type geothermal power plant is described in this report. In the flash-type geothermal power plant, there is only one heat exchanger, a condenser positioned after the turbine. A novel GeoHex material wasbeen applied to this condenser to analyse the impact of GeoHex materials. The impact of the GeoHex-enabled condenser adopted for flash-type geothermal power plant was analysed using the cost and environmental impact results reported in deliverables D7.7 and D7.8. A use case scenario, of a 100 MW, geothermal power plant at Reykjanes in Iceland taken from the current scientific literature, was used as a reference point for this analysis. The cost and carbon footprint savings per MW in the 100 MW Reykjanes geothermal power plant using the GeoHex-enabled tubular condenser instead of using a standard tubular condenser are about – 11, 812 € / MW and – 341 kg CO_2 eq / MW, respectively.

The primary factors contributing to these adverse impacts were the limited improvement in the heat transfer coefficient of the GeoHex-enabled condenser and the high cost and resource consumption associated with coating deposition on a laboratory scale.

Objectives Met

The deliverable contributed towards the work package WP8 objective:

- To assess the impact of the GeoHex-enabled heat exchanger in terms of CO2 saving, cost saving, and efficiency enhancement for the application in different geothermal power technologies for different temperatures, enthalpy, scaling and corrosion potential of geofluid.

1. INTRODUCTION

Heat exchangers (HXs) are critical components in a steam-based flash type and Organic Rankine Cycle (ORC) geothermal power plants. , Geothermal energy has the potential to help address the address the economic and environmental challenges posed by the transition to sustainable energy generation . To enhance the efficiency and overall performance of geothermal power plants, it is critical to improve the heat transfer capabilities of HXs through the application of g innovative coating materials on heat exchanger surfaces. In the GeoHex project, coating materials were selected according to their heat transfer coefficient, mechanical and tribological properties for improving the performance of HXs. Using innovative GeoHex materials in HXs can bring advancements to geothermal energy production. This study explores how these coatings can benefit the environment and the geothermal energy sector economically.

GeoHex-enabled high-performance heat exchanger materials were developed to improve the heat transfer performance of the HXs for geothermal applications and beyond. The small-scale GeoHex-enabled HXs were manufactured using the best-ranked coating materials for testing their performances in the mini-ORC plant at CEA facilities. In this report, the impact of GeoHex coating materials for a use case of flash type of geothermal power plant have been evaluated based on the heat transfer performance of GeoHex-enabled HXs obtained from the mini-ORC plant. The only heat exchanger considered in a use-case scenario of a type of power plant is the tubular type of condenser.

As implied in this report's title, in addition to assessing the impact, opportunities for using GeoHex material in the flash-type geothermal power plant are also considered. Deliverable D1.7 thoroughly explored the possibilities and opportunities of implementing innovative GeoHex materials within the HXs for the flash-type geothermal power plant. Therefore, this report investigates how these materials can impact flash-type geothermal power plants' overall cost and environmental performances without compromising the possibilities and opportunities for adopting these innovative GeoHex materials.

As outlined in the Grant Agreement, analysis of the impact of the GeoHex materials is made with reference to a a Turkish flash-type geothermal power plant has been considered initially. Unfortunately, as the Turkish plant owner is not a GeoHex partner data was not made available,. Nonetheless, the impact analysis was completed using the use case scenario of the Reykjanes flash-type geothermal power plant in Iceland, from which heat exchanger data was available [1].

Figure 1 shows the Reykjanes flash-type geothermal power plant's process flow diagram used in this report as a use case scenario [2]. This single-flash condensing geothermal power plant was commissioned in 2006 with a total capacity of 100 MW and approximately 96 MW net electrical output to the grid. The only heat exchanger used after the turbine in the flash-type power plant is a condenser; a shell and tube surface condenser are connected to the exit of each of the turbines. Therefore, we have used the heat transfer performance result of tubular-type condensers to evaluate the impact of the GeoHex material on the condenser of the use case scenario, Reykjanes geothermal Flash-type power plant.

The GeoHex-enabled HXs were manufactured using the best-ranked coating materials in two technology options. The best coatings were selected based on the lab-scale heat transfer and mechanical & tribological performances described in details in the deliverable D5.5. Table 1 provides the best-ranked selected condensers (plate and tubular type) materials.

Table 1 - Best performance coating materials selected through ranking for plate and tubular types condensers.

Items	**Condenser**	
	Plate	**Tubular**
Coating material - ORC side	Superhydrophobic, superoleophobic surface with CuO nanostructures - silica-based coating -Hydrophobic	Superhydrophobic, superoleophobic surface with CuO nanostructures - silica-based coating -Hydrophobic
Coating material - Brine side	None	None
Substrate material	Stainless steel SS-316	Carbon steel CS-S275JR

This report analyses the impact GeoHex material with reference to the performance of the GeoHex-enabled condenser in the GeoHex mini-ORC power plant. The cost and environmental impact of adopting the GeoHex materials in the Reykjanes flash type plant's condenser were assessed. A model has been developed to evaluate the economic and environmental impact of GeoHex materials on the Reykjanes flash-type geothermal power plant.

2. METHODS

The heat transfer coefficients (HTCs) of tubular-type GeoHex-enabled and standard condensers have been determined using 10 kW_e electricity-generating mini ORC plant at CEA facilities. The heat transfer performance results are reported in deliverables D7.5 and D7.6 for both the standard and GeoHex-enabled condensers. With consideration of these HTCs results and the estimated costs and environmental performance of these HXs, the cost and environmental footprint savings per m^2 heat exchanged surface area of GeoHex enabled condenser instead of using respective standard HXs have been evaluated.

The cost and environmental footprint savings for the GeoHex-enabled condenser, compared with the standard condenser, are reported in deliverables D7.7 and D7.8. Based on these cost and environmental footprint savings per m^2 area, a model has been developed to evaluate the cost and environmental impacts of adopting tubular type GeoHex enabled condenser instead of tubular type standard condenser.

3. RESULTS AND DISCUSSION

In the deliverable report D7.7, a cost model was developed to estimate the total capital costs (CAPEX) associated with standard and GeoHex-enabled heat exchangers per m^2. The model considered the inverse relationship between the heat exchanger's surface area and its heat transfer coefficient, indicating that an improvement in the heat transfer performance of GeoHex-enabled heat exchangers would result in a reduced surface area requirement and, subsequently, lower costs for the geothermal flash power plant.

Table 2 compares the estimated total costs of tubular and plate & gasket types of standard and GeoHex-enabled condensers and the corresponding percentage cost change due to changes in the heat transfer coefficients. The cost and heat transfer performance data of these HXs in Table 2 are sourced from D7.7, D7.5, and D7.6, respectively. The costs of these HXs are expressed in units of €/m^2.

Table 2 - Cost Performance results of Plate and Tubular types GeoHex enabled and standard condensers.

Items		**Units**	**Amount**	
Technology options		-	Plate	Tubular
Standard condenser costs		€ / m^2	516	844
GeoHex-enabled condenser costs	Coating deposition	€ / m^2	193	193
	Total	€ / m^2	709	1037
HTC enhancement or degradation in GeoHex-enabled condensers as compared with respective standard condensers		%	+3.5	+2.0
Cost reduction/increase of GeoHex-enabled condenser due to HTC performances		€ / m^2	685	1017
Cost impacts for adopting GeoHex-enabled condensers instead of using respective standard condensers		€ / m^2	-169.0	-173.1
		%	-24.7	-17.0

Table 3 lists the carbon and environmental footprints results of tubular and plate-gasket types of standard and GeoHex-enabled condensers and the respective carbon and environmental footprints savings results for 1 m^2 heat exchanger surface area. The environmental impacts of these HXs were evaluated using the inventoried data of these HXs for cradle-to-grave system boundaries and LCA tool SimaPro 9.5.0.0 and the background processes dataset from ecoinvent database 3.9.1.

The carbon and environmental footprints savings in % for adopting GeoHex enabled tubular type condenser instead of standard tubular type condenser is calculated and presented in Table 3. The environmental and heat transfer performance data of these HXs in Table 3 are sourced from D7.8, D7.5, and D7.6. .

Table 3 - Carbon and environmental footprints results of Plate and Tubular types GeoHex enabled and standard condensers.

Items	**Units**	**Amount**	
Technology options	-	Plate	Tubular
HTC enhancement or degradation in GeoHex-enabled condensers as compared with respective standard condensers	%	+3.5	+2.0
The carbon footprint of GeoHex-enabled condensers	kg CO2 eq / m^2	77.0	304.0
Carbon footprint of standard condensers	kg CO2 eq / m^2	71.5	299.0
Carbon footprint savings for adopting GeoHex-enabled condensers instead of standard condensers	kg CO2 eq / m^2	-5.5	-5.0
	%	-7.7	-1.7
Environmental footprint of GeoHex-enabled condensers	mPt / m^2	46.38	134.90

Environmental footprint of standard condensers	mPt / m^2	46.58	133.12
Environmental footprint savings for adopting GeoHex-enabled condensers instead of standard condensers	mPt / m^2	0.20	-1.78
	%	+0.4	-1.3

3.1 Impacts of the GeoHex materials in the Reykjanes 100 MW flash-type geothermal power plant

The impacts of GeoHex-enabled tubular type condenser have been evaluated for the use case scenario - Reykjanes 100 MW flash type geothermal power plant. Table 4 shows the cost calculations and netsavings per MW for adopting a tubular-type GeoHex-enabled condenser in the reference plant instead of using a standard condenser.

Table 4 - Economic impact of tubular GeoHex enabled condenser on the Reykjanes 100 MW flash geothermal power plant

Items	Unit	Amount
Total heat exchanged surface area of tubular type condenser in 100 MW Reykjanes plant	m^2	6828
Estimated cost of standard tubular type condenser	€/m^2	844
Cost reduction/increase of GeoHex enabled tubular type condenser due to HTC performances	€/m^2	1017
Total costs of standard tubular type condenser installed in 100 MW plant	€	5,762,832
Total costs of GeoHex enabled tubular type condenser installed in 100 MW plant	€	6,944,076
Cost savings (positive or negative) for adopting GeoHex enabled tubular type condenser instead of using respective standard condenser	€	-1,181,244
	(%)	-17
	(€/MW)	-11,812

The negative cost savings due to the adoption of tubular type GeoHex enabled condenser in the 100 MW Reykjanes flash type geothermal power plant, the plant owner/operator needed to be invested further about €11,812 per MW; the total negative cost savings will be about -€1,181,244. These negative cost impacts occurred mainly due to lab-scale high coating deposition cost and a lower increase of heat transfer coefficient in GeoHex enabled condenser.

Table 5 shows the carbon and environmental footprint calculations in units of kg CO_2 eq and mPt, respectively, and net carbon and environmental footprints savings per MW for adopting a tubular type GeoHex enabled condenser in the reference plant instead of a tubular type standard condenser.

Table 5 – Environmental impacts of tubular GeoHex enabled condenser on the Reykjanes 100 MW flash geothermal power plant.

Items	Units	Amount
Total heat exchanged surface area of tubular condenser used in 100 MW Reykjanes plant	(m^2)	6828
Total carbon footprint for adopting standard tubular condenser in 100 MW Reykjanes plant	kg CO_2 eq	2,041,572

Total carbon footprint for adopting GeoHex-enabled tubular condenser in 100 MW Reykjanes plant	kg CO_2 eq	2,075,712
Total environmental footprint for adopting standard tubular condenser in 100 MW Reykjanes plant	mPt	908,943
Total environmental footprint for adopting GeoHex-enabled tubular condenser in 100 MW Reykjanes plant	mPt	921,097
Net savings of carbon footprints for adopting tubular GeoHex-enabled condenser in place of standard condenser	kg CO_2 eq	-34,140
	kg CO_2 eq /MW	-341
Net savings of environmental footprints for adopting tubular GeoHex-enabled condenser in place of standard condenser	mPt	-12,154
	mPt / MW	-122

It is evident from Table 5 that the net savings of carbon and environmental footprints for adopting tubular GeoHex enabled are about – 34,140 kg CO_2 eq and -12,154 mPt, respectively. It has been demonstrated that net savings of carbon and environmental footprints per MW installed capacity of the plant are about -341 kg CO_2 eq / MW and -122 mPt / MW, respectively. These negative environmental impacts occurred mainly due to material and energy consumption during lab-scale coating deposition and a lower heat transfer coefficient increase in GeoHex-enabled condenser.

Literature searches confirmed that no plant data were available for the flash-type plant that uses plate-type HXs. Therefore, this study did not analyse the impact of GeoHex materials on the plants that use plate & gasket type heat exchangers.

4. CONCLUSIONS

The adoption of a GeoHex-enabled tubular condenser instead of the standard tubular condenser in 100 MW Reykjanes plant showed negative impacts on environmental and cost performances. These negative impacts occurred mainly due to a low heat transfer coefficient increase in GeoHex-enabled condenser and lab-scale high coating deposition cost and resource consumption during coating deposition. The main important results for adopting a GeoHex-enabled tubular condenser in place of the standard tubular condenser in the 100 MW Reykjanes plant are:

- Cost savings per MW installed capacity of the plant is about -11,812 € / MW
- Carbon footprint savings per MW installed capacity of the plant is about - 341 kg CO_2 eq / MW
- The plant's environmental footprint savings per MW installed capacity is about - 122 mPt / MW.

REFERENCES

1. <https://balcke-duerr.com/wp-content/uploads/2021/08/Reference-List-Condenser.pdf> accessed 10 August 2023

2. <https://orkustofnun.is/gogn/unu-gtp-report/UNU-GTP-2015-31.pdf> - accessed 10 August 2023