Utilizing waste construction and industrial materials in an underground HGHE system

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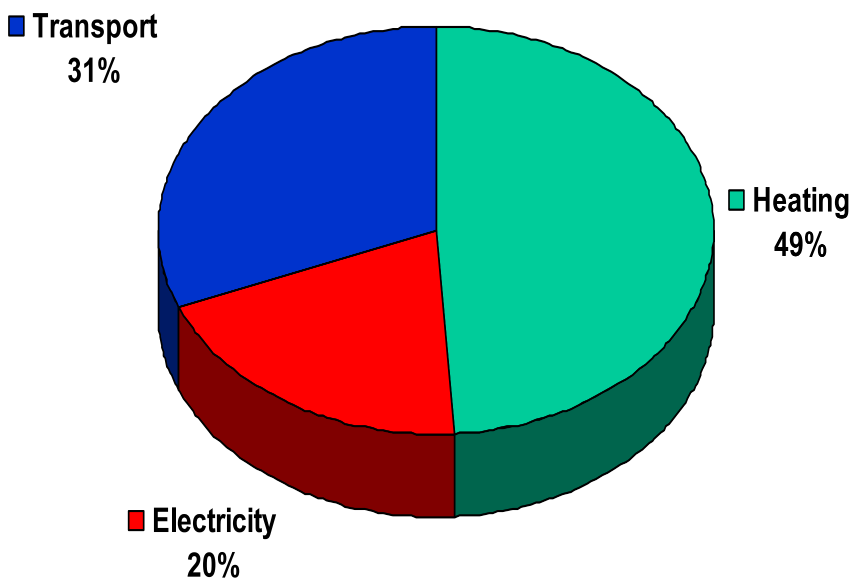
Motivation

‘MEETING THE FUTURE NEEDS OF ENERGY CONSUMPTION’



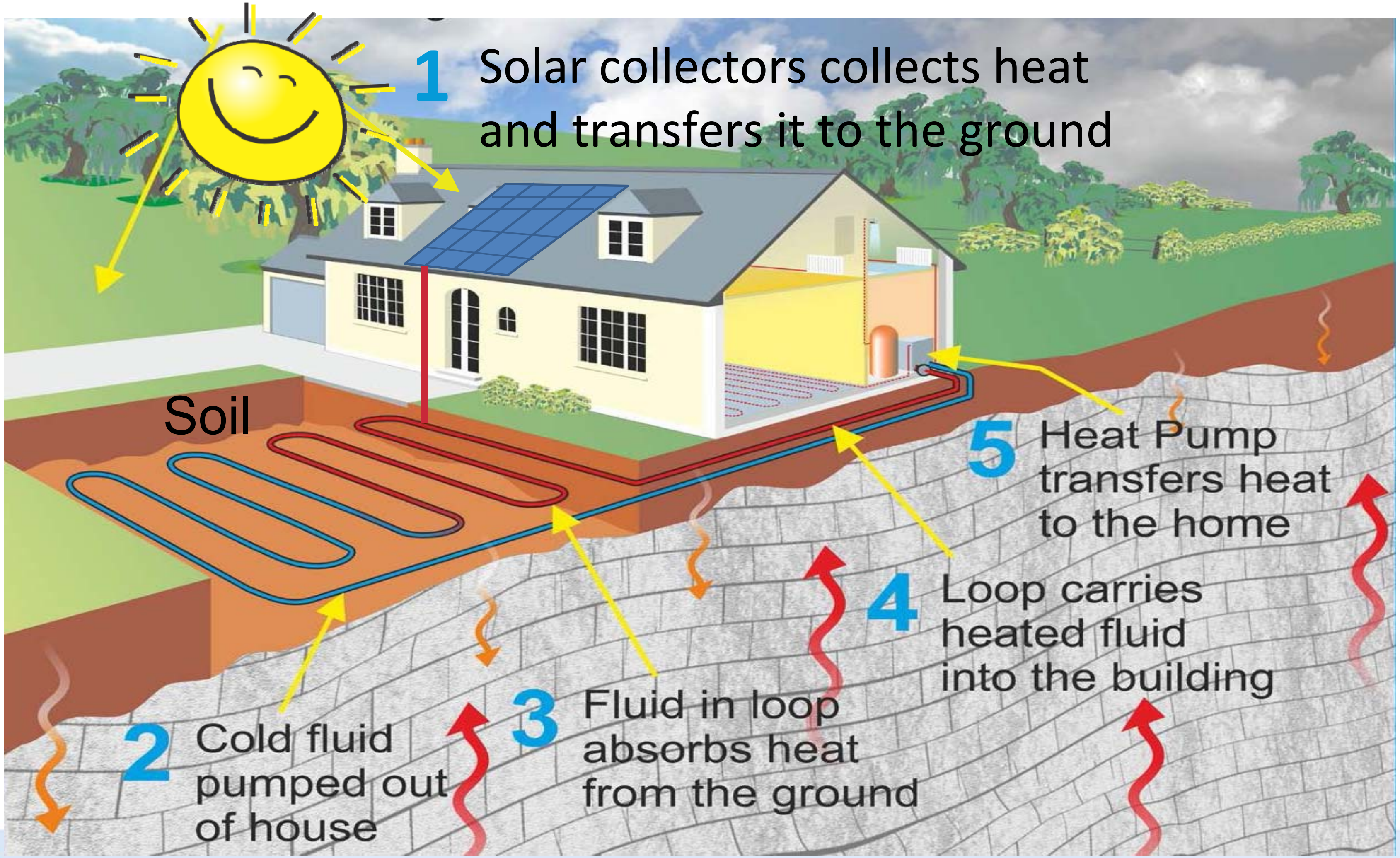
EU energy consumption

Sustainable energy sources:

- Solar
- Wind
- Geothermal
- Biomass
- Waste Heat
- Others…

Underground Heat Storage

Horizontal ground heat exchanger (HGHE)



Developed experimental HGHEs (loop)

- A small scale experimental solar assisted HGHEs was designed and tested to meet a test room heating load of 1kW
- The inlet mass flowrate of the HTF was the most significant parameter affecting heat exchange rates
- Heat exchange rates were calculated to be between 14W/m and 83W/m depending on the flowrate
- A comparison of seven soils backfills were studied
- The sand filled system operated with a better efficiency

Published work

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Thermal performance of a solar assisted horizontal ground heat exchanger

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ABSTRACT

This paper presents an experimental study of a solar assisted horizontal ground heat exchanger system (HGHEs) operating as a daily heat storage unit. Initially, several soils were assessed as sensible heat storage mediums, with sand and gravel selected as the most appropriate. Then, a HGHEs was designed and connected to a 15 m^2 test room with a heating load of 1 kW at Nottingham Trent University. Heating cables, simulating solar input, were used to heat the soil in the HGHEs to 70 °C, then a heat transfer fluid (HTF), was circulated through a closed loop heat exchanger to extract the stored heat. The parameters of soil backfill and HTF mass flow rate were investigated in the HGHEs. Several output flowrates ranging between 0.1 and 0.6 L/min were tested, producing discharge times varying between a few hours to a few days. The HTF mass flowrate was found to be the most significant parameter, affecting the HGHEs thermal capacity and heat exchange rates. The sand filled HGHE produced approximately 50% more hot water ($T > 35$ °C) during a longer duration achieving an efficiency of 78% compared to the gravel filled HGHE with a lower system efficiency of 58%. Insulating the HGHE system was found to reduce heat losses and avoid temperature fluctuations in the HGHEs. Overall, the results show the hot water quantity, temperature range and duration produced from the system were in line with low temperature district heating guidelines and can be applied to some household heating applications incorporating low flows and low temperatures.

1. Introduction

1.1. Background

Over recent years, there has been a shift from conventional resources towards energy efficient renewable sources of energy for building heating purposes [1]. The use of solar energy is of considerable interest because it leads to diminution of fossil fuels consumption and is a non-polluting source of energy [2]. Several types of solar energy systems are integrated with heat collection storage systems and have been developed for heating/cooling purposes in residential and commercial buildings. The main heat storage media are water, latent heat materials and ground materials. The ground is a stable heat exchange medium and is essentially unlimited and always available [1,3]. Ground heat exchanger systems (GHEs) have gained recognition for improved and easy exploitation of thermal energy from the ground [4]. Claims made by Garg [5] are that GHEs can 1) collect heat more efficiently, 2) store more heat at a lower cost, 3) be cheaper to build, and 4) deliver a higher solar fraction with the same collector area compared to a water tank HGHE system maintaining a higher level of performance even in colder climates [3,5].

GHEs installed for heating and cooling purposes in buildings have been extensively studied by various authors [6,7]. Closed ground-loop GHEs can either be installed in vertical (VGHEs) or horizontal (HGHEs) arrangement, and a comparison of HGHEs and VGHEs performance was studied by Lee et al. [8]. In this study, the focus was a solar assisted HGHEs with operating temperatures ranging between 35 and 70 °C [9]. HGHEs consists of heat exchange pipes, the pipes can come in a variety of configurations including straight, coil, slinky or loops that are buried in shallow ground trenches of up to 1–2 m depths. A HTF (water or anti-freeze solution) is circulated through the system to extract the stored heat upon requirement and return the cooled HTF to the ground storage where it gathers further energy, in a continuous cycle. HGHEs are surrounded by soil, and hence the performance of the system is highly dependent on ground heat-transfer characteristics [10]. Ground thermophysical properties including soil texture, grain size distribution, bulk density, water content and thermal conductivity are correlated and highly influences the heat transfer between the circulating HTF in the GHEs and the surrounding soil, affecting the performance of the system [7,11–13]. HGHEs are preferred over VGHEs for residential installations because of their lower initial installation costs [14]. Although HGHEs offer a cost-effective and environmentally friendly alternative compared to other methods, large shallow land areas are required for pipe installations and the system is affected by temperature fluctuations caused by the system's proximity to the ground surface. Most GHEs are equipped with a ground source heat pump (GSHP) to assist the store charge and discharge process and to avoid the extreme high or low temperature conditions that compromise the energy performance of the systems [15]. Sarbu & Sebarchievici [16]; provided a detailed literature regarding of GSHP systems, and their recent advances. Lund et al. [17] reported that GSHPs have the largest energy use and installed capacity, according to 2005 data, accounting for 54.4% and 32.0% of the worldwide capacity and use.

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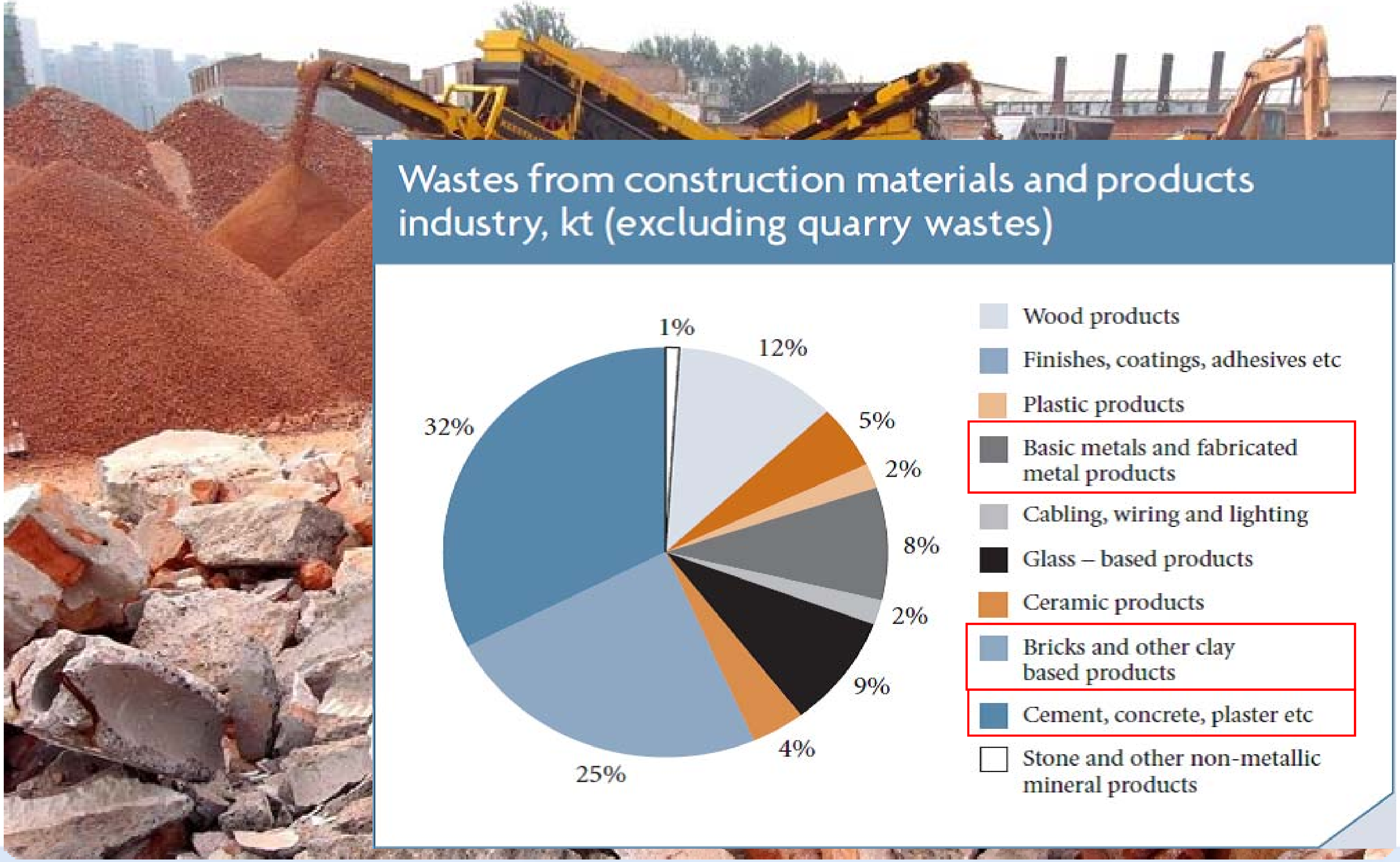
Proposed improvements to HGHE system

Improve the efficiency and thermal performance of the system

- This can be improved by:
  - Improving the soil's thermal properties
  - Increasing the volume of soil
  - Ground source heat pump (GSHP)
  - Improving the heat transfer pipe
    - Thermal conductivity
    - Thickness
    - Configuration
    - Pipe spacing
  - Use waste materials with better thermal properties

Recycling Waste Materials ♻



Aim and objectives

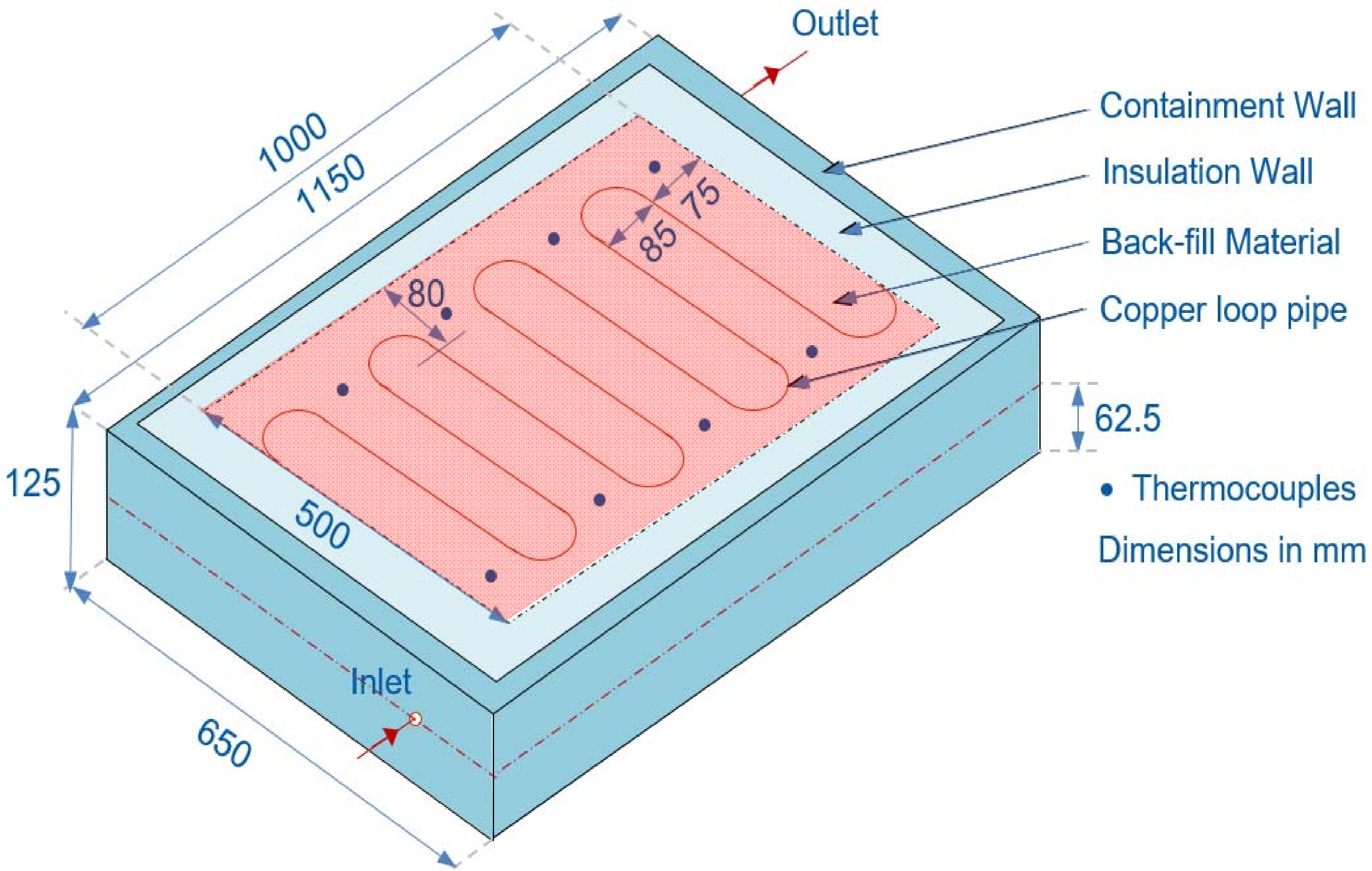
‘TO INVESTIGATE THE ENHANCEMENT OF HGHEs USING RECYCLED WASTE MATERIALS’

- Identify waste materials to be used
- Establish material properties by experimental procedures
- Develop a numerical model simulating HGHEs

to determine temperature distributions within materials

- Improve thermal performance of HGHEs
- Demonstrate novel storage system

Experimental Set-up



Backfill material selection

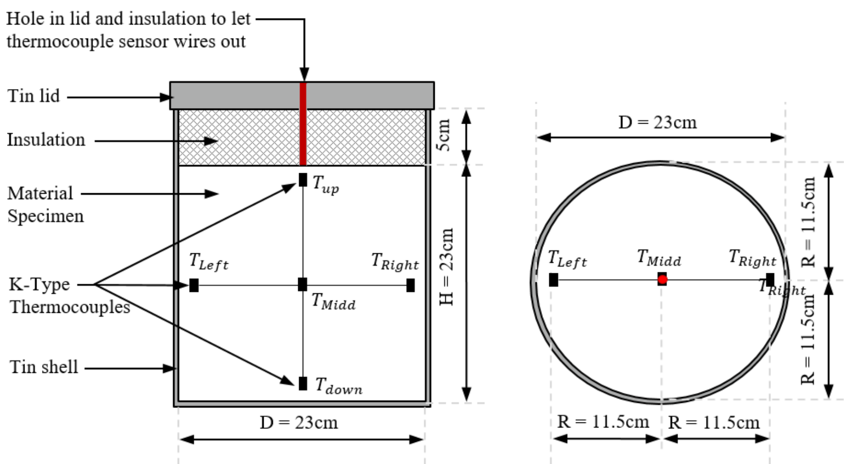
Criteria: waste, density, temperature, environmentally friendly

Material thermal testing

Thermal testing in Environmental Chamber (EC)

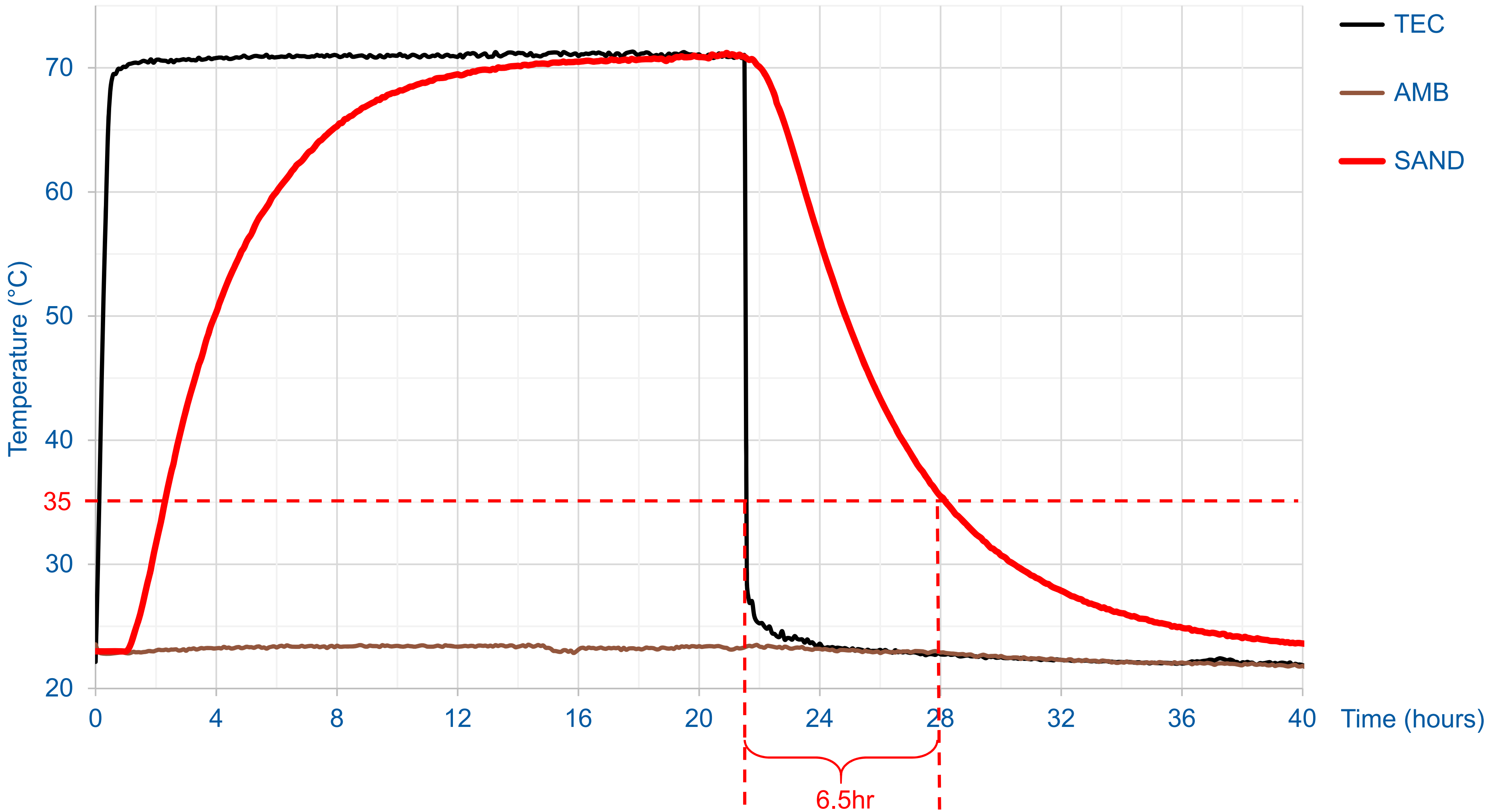
<u>Testing cycle regime:</u>

- Fill container with material (≈ 20kg)
- Embed thermocouples in containers
- Attach thermocouples to data logger
- Put container in EC and heat to 70℃
- Take container out of EC and cool to 20℃
- Assess materials behaviour

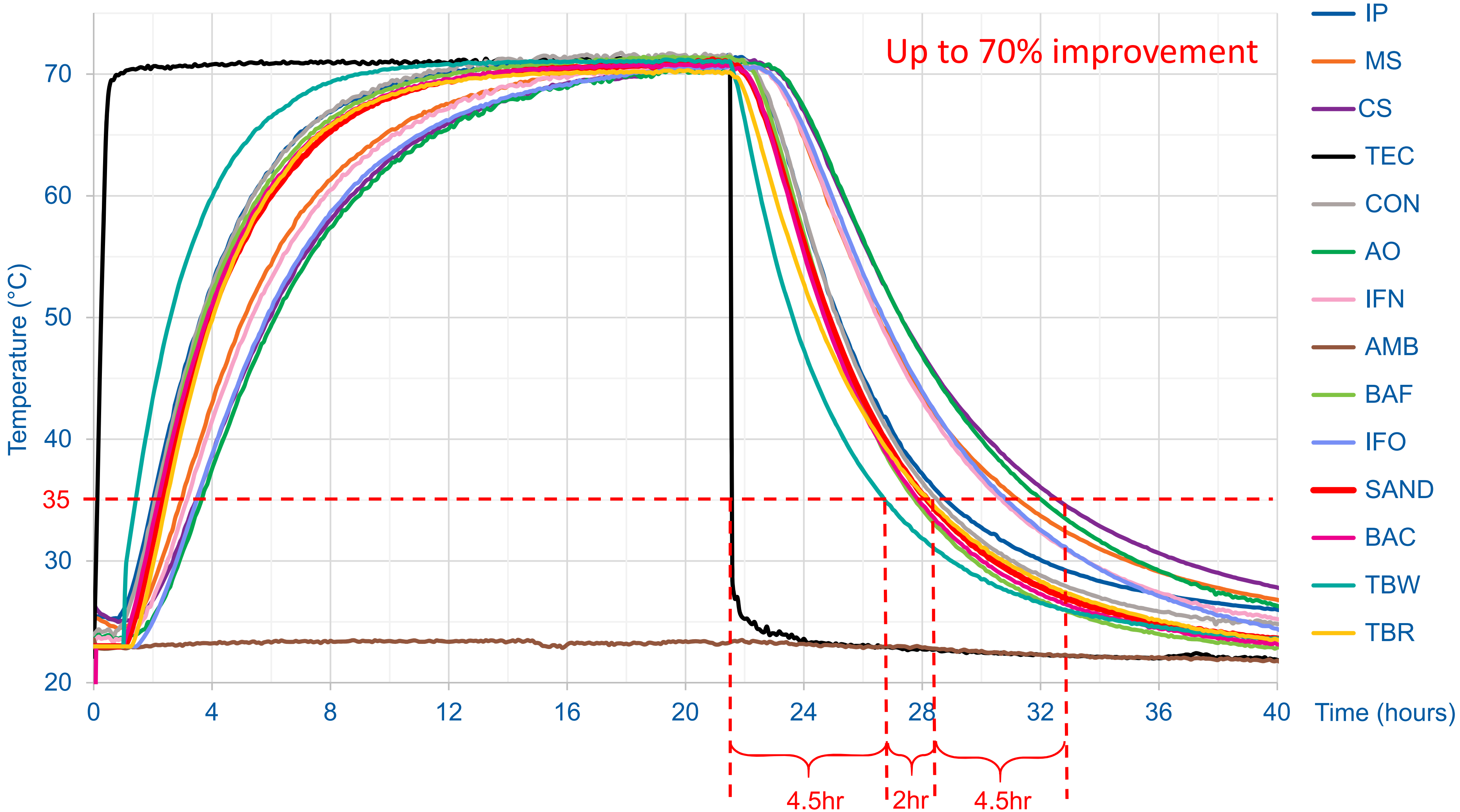


FDM C-SERIES (EC) CLIMATIC CHAMBER

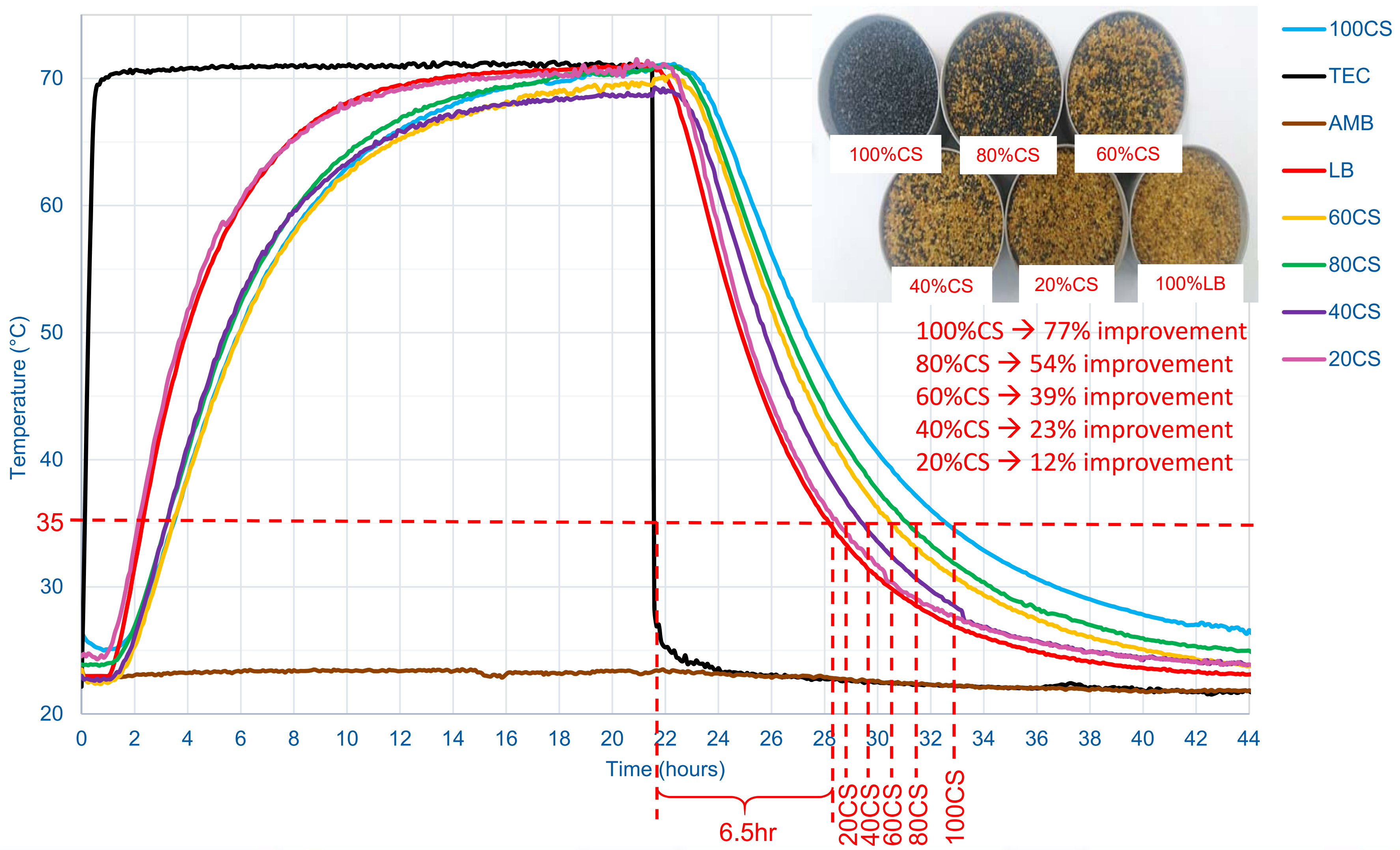
Results - Thermal testing (Materials)



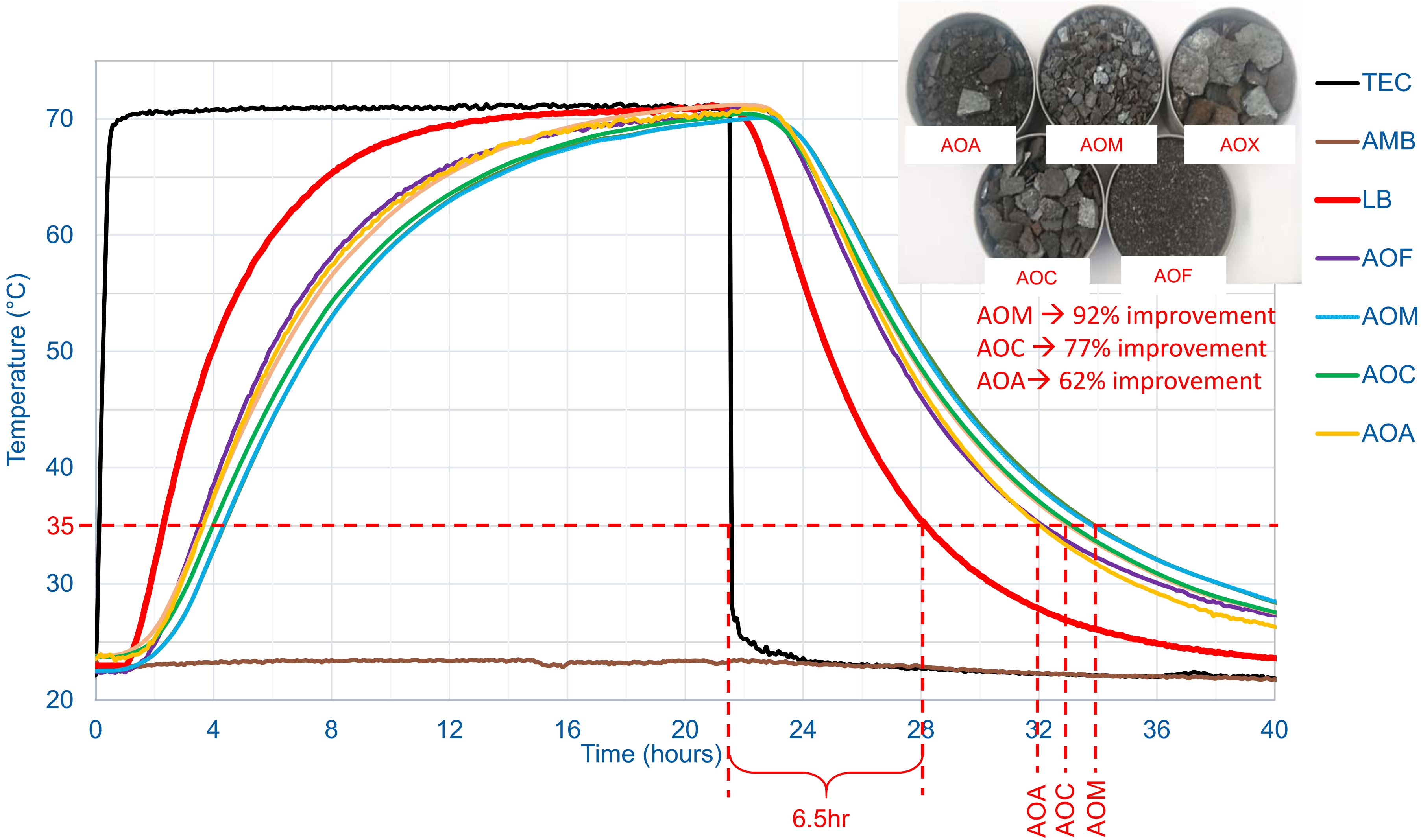
Results - Thermal testing (Materials)



Results - Thermal testing (Additions)



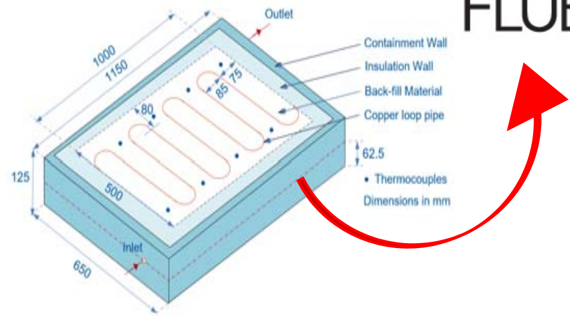
Results - Thermal testing (Gradations)



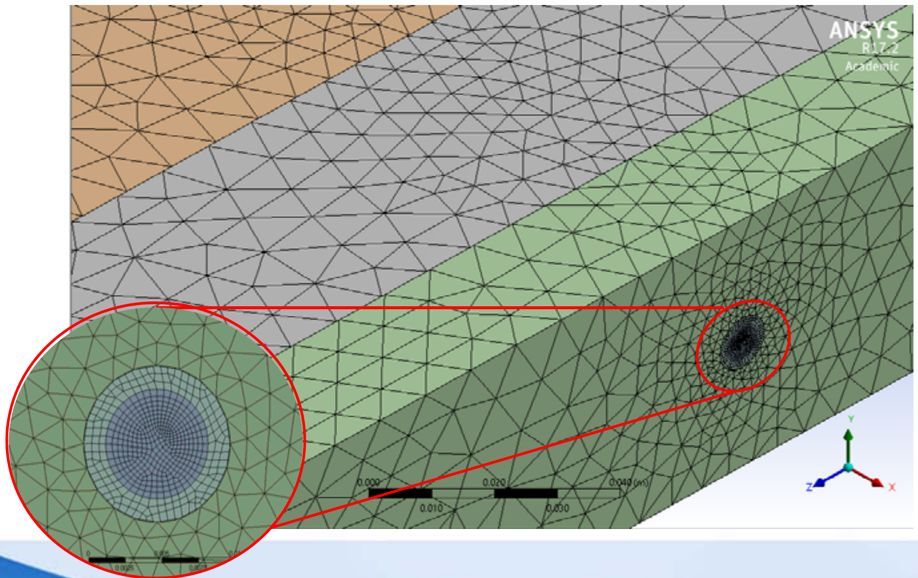
Numerical Model Development

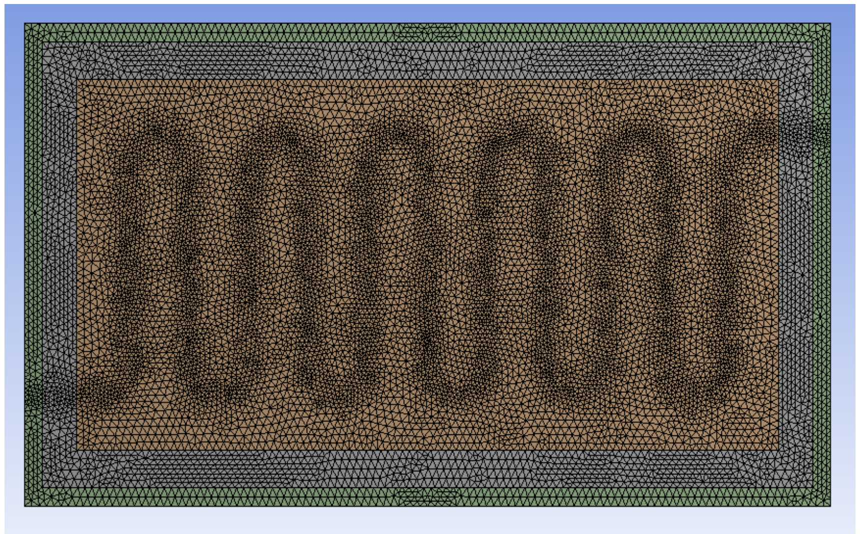
- 3D CFD simulations produced to model HGHE
- Modelled in ANSYS Fluent 17.2 workbench
- Transient conductive heat transfer

$$\frac{\partial}{\partial x}\left(\lambda \frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(\lambda \frac{\partial T}{\partial y}\right) = \rho c \frac{\partial T}{\partial t}$$

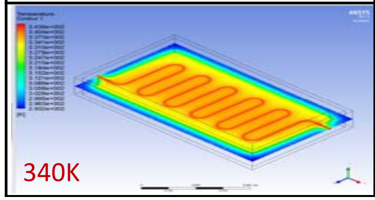
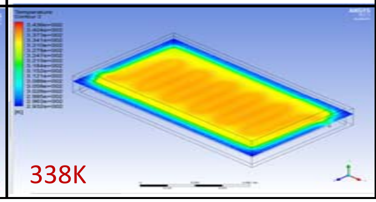
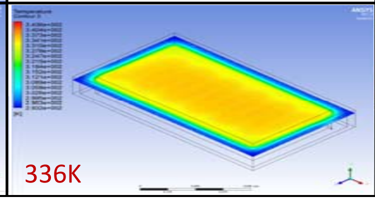
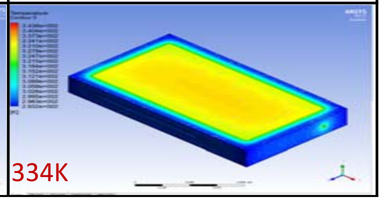


- Two models created for: (A) Charging and (B) Discharging modes





Numerical model results

	0m (center)	0.02m	0.04m	0.06m
Heating at 4hr AO,CS,MS	 340K	 338K	 336K	 334K

Comparison and Validation of results (Heating HGHEs; Inlet 343K; Backfill 298K)

Material	Thermodynamic results range $Q = mC_p \Delta T$ (kJ/kgK)	Av. Surface temperature at HGHE centre (K)	Av. Surface temperature at 0.04m (K)	Av. Surface temperature at 0.06m (K)	Temperature difference between centre and top (K)
LB SAND (ALSO CON, IP) **EXPERIMENTAL**	10000 – 16000	329	312	306	23
LB SAND (ALSO CON, IP) **NUMERICAL**	"	327	309	302	25

Conclusions



- Results showed that metallic materials including CS, AO, MS, IFO, IFN had better heat storage performance, and up to 70% improvement
- The thermal capacity of the HGHE system can be doubled by using CS,AO,MS,IFO,IFN materials instead of sand alone
- IP, CON, TBR, BAC, BAF had similar performance to sand
- TBW and GR underperformed
- Gradation is a significant parameter in backfill selection, where medium sized particle sizes (1.18-2.36mm) performed better by 92% compared to course and fine gradations
- The higher the percentage addition (100%) of the material blended with the sand, the better the heat storage by 77%
- The selected materials are cheap and have a high thermal capacity
- Numerical and experimental results confirmed and validated

THANK YOU
Any questions?

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