Utilizing waste construction and industrial materials in an underground HGHE system

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Motivation

‘MEETING THE FUTURE NEEDS OF ENERGY CONSUMPTION’

Sustainable energy sources:
- Solar
- Wind
- Geothermal
- Biomass
- Waste Heat
- Others…

EU energy consumption
Underground Heat Storage
Horizontal ground heat exchanger (HGHE)

1. Solar collectors collect heat and transfer it to the ground.
2. Cold fluid pumped out of house.
3. Fluid in loop absorbs heat from the ground.
4. Loop carries heated fluid into the building.
5. Heat pump transfers heat to the home.
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

Gravel, $\eta = 58\%$  Vs.  LB Sand, $\eta = 78\%$
Published work

Title: Thermal performance of a solar assisted horizontal ground heat exchanger

ENERGY Journal

Authors: Yasameen Al-Ameen, Anton Ianakiev, Robert Evans
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

Wastes from construction materials and products industry, kt (excluding quarry wastes)

- Wood products: 1%
- Finishes, coatings, adhesives etc: 12%
- Plastic products: 32%
- Basic metals and fabricated metal products: 9%
- Cabling, wiring and lighting: 2%
- Glass – based products: 8%
- Ceramic products: 2%
- Bricks and other clay based products: 4%
- Cement, concrete, plaster etc: 2%
- Stone and other non-metallic mineral products: 25%
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

- Containment Wall
- Insulation Wall
- Back-fill Material
- Copper loop pipe
- Thermocouples

Dimensions in mm

1000
1150
650
500
125
Backfill material selection

Criteria: waste, density, temperature, environmentally friendly

1. LB
2. TBR
3. TBW
4. IP
5. IFN
6. IFO
7. AO
8. CS
9. MS
10. BAF
11. BAC
12. CON
Material thermal testing

Thermal testing in Environmental Chamber (EC)

Testing cycle regime:
• Fill container with material (≈ 20kg)
• Embed thermocouples in containers
• Attach thermocouples to data logger
• Put container in EC and heat to 70°C
• Take container out of EC and cool to 20°C
• Assess materials behaviour
Results - Thermal testing (Materials)

Temperature (°C) vs. Time (hours)

- TEC
- AMB
- SAND

Temperature threshold: 35°C

Time period: 6.5 hours
Results - Thermal testing (Materials)

Up to 70% improvement

Temperature (°C) vs Time (hours)

- IP
- MS
- CS
- TEC
- CON
- AO
- IFN
- AMB
- BAF
- IFO
- SAND
- BAC
- TBW
- TBR
Results - Thermal testing (Additions)

100%CS → 77% improvement
80%CS → 54% improvement
60%CS → 39% improvement
40%CS → 23% improvement
20%CS → 12% improvement
Results - Thermal testing (Gradations)

![Graph showing temperature over time for different samples: TEC, AMB, LB, AOM, AOC, AOA.]

- AOM → 92% improvement
- AOC → 77% improvement
- AOA → 62% improvement

Note: The time it takes for each sample to reach a specific temperature is indicated, with 6.5 hours being the time for AOM to reach the temperature.
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

<table>
<thead>
<tr>
<th></th>
<th>0m (center)</th>
<th>0.02m</th>
<th>0.04m</th>
<th>0.06m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating at 4hr</td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
</tr>
<tr>
<td>AO,CS,MS</td>
<td>340K</td>
<td>338K</td>
<td>336K</td>
<td>334K</td>
</tr>
</tbody>
</table>
Comparison and Validation of results (Heating HGHEs; Inlet 343K; Backfill 298K)

<table>
<thead>
<tr>
<th>Material</th>
<th>Thermodynamic results range ( Q = mC_p \Delta T ) (kJ/kgK)</th>
<th>Av. Surface temperature at HGHE centre (K)</th>
<th>Av. Surface temperature at 0.04m (K)</th>
<th>Av. Surface temperature at 0.06m (K)</th>
<th>Temperature difference between centre and top (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LB SAND (ALSO CON, IP) EXPERIMENTAL</td>
<td>10000 – 16000</td>
<td>329</td>
<td>312</td>
<td>306</td>
<td>23</td>
</tr>
<tr>
<td>LB SAND (ALSO CON, IP) NUMERICAL</td>
<td>“</td>
<td>327</td>
<td>309</td>
<td>302</td>
<td>25</td>
</tr>
</tbody>
</table>
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 (1.18-2.36 mm) 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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