PROJECT SUMMARY

THERMOACOUSTIC COOLING

Preliminary study on the Solar-powered Low-cost Thermoacoustic (SaLT) Refrigerator

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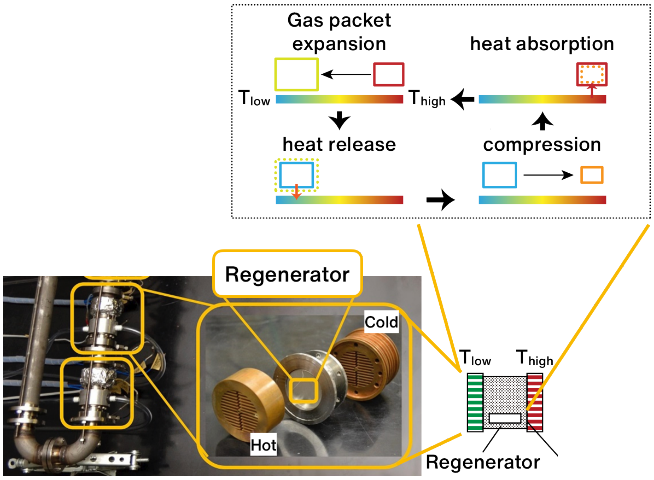
Background

Challenges on energy

The world demand in cooling is undergoing a constant and rapid rise. This has caused growing concern for its environmental impacts. Nearly 7% of the world's energy, around 2100 TWh, is used in space cooling in 2016. This causes a worrying 1135 Mt of CO_2 emissions in 2016, as well as the CFC refrigerants used by refrigeration devices, are damaging the global environment.

Lack of access to refrigeration

Over 85% of the global air-conditioning devices are installed in the more developed countries, and the less developed countries only share the remaining 15%. The main obstruct prevent people from

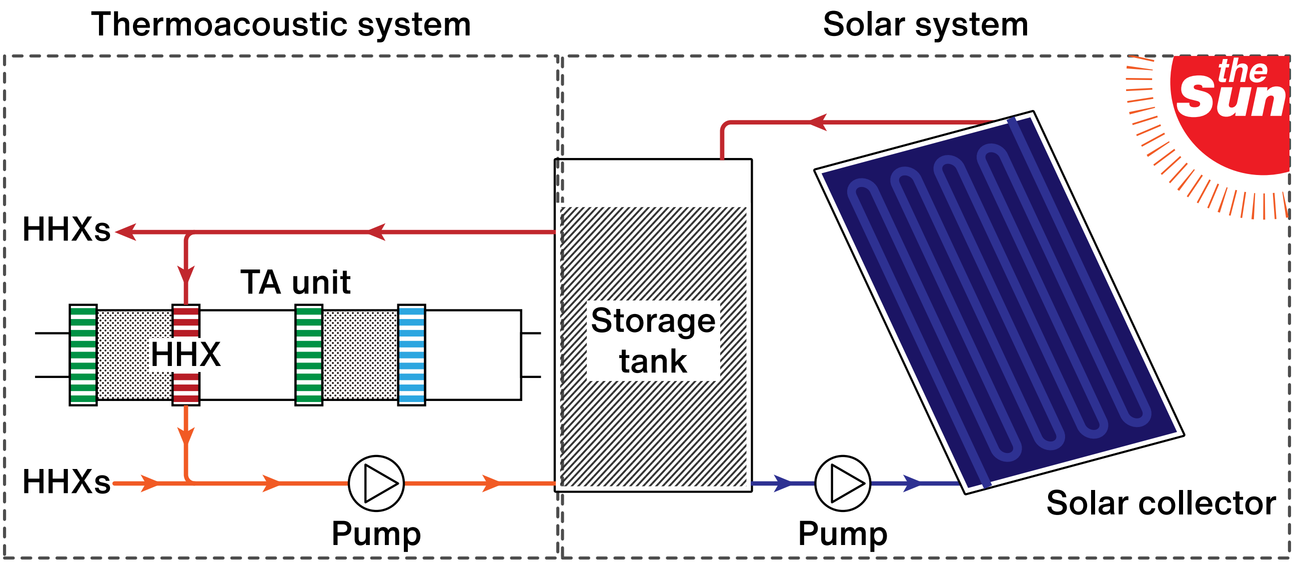


Onset physics of the thermoacoustic devices

installing refrigerators are majorly high installation and maintenance costs. Developing a device that's able to achieve high cooling power with relatively low associated costs will benefit millions.

Thermoacoustic - novel cooling method

Thermoacoustic cooling is an emerging novel cooling technology. The thermoacoustic phenomena have been discovered for decades without being fully understood. The operation principles of a thermoacoustic engine involve the generation of acoustic waves by the periodic expansion and con-



Integrated system design

traction of the working gas resulting from the heat transfer into the oscillating gas across a temperature gradient. Consequently, the thermoacoustic refrigerator involves converting the acoustic energy back to temperature difference to achieve heat pumping.

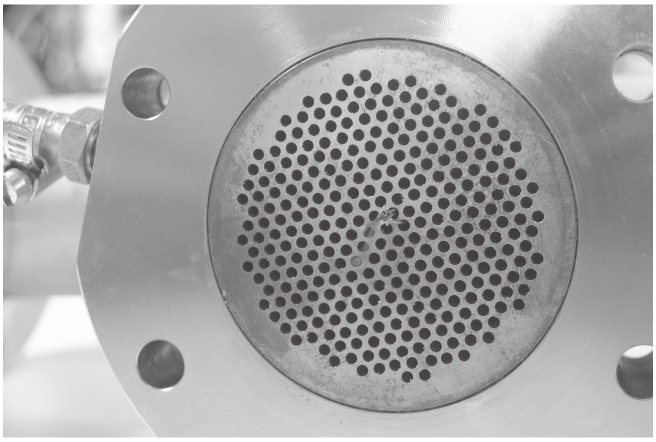
The previous researches[1] have developed and simulated an apparatus of a looped three-stage thermoacoustic refrigerator with gas-liquid resonator in principle able to tackle the main challenges in thermoacoustic refrigerators – high onset temperature and low power density.

Project aim

Solar-powered thermoacoustic cooler

The project's ultimate aim it to design and produce a solar-powered thermoacoustic refrigerator that can be applied with low-cost. This year's research forms a fundamental keystone to the entire process.

The system is coupled with the solar system using pressurised water, with an intermediate storage tank to store the collected solar energy. Flat-plate solar collector is used to convert solar energy into thermal energy. The energy is then transmitted to drive the thermoacoustic system via pressurised high-temperature water.



Proposed heat tube-shell heat exchangers

Methodology

Deliverables in the project this year

The apparatus used by the previous researches can only work under strict designated conditions with expensive components, and the efficiency is also not desirable. Moreover, the most common thermoacoustic simulation software DeltaEC is proven to be inaccurate and produces around 20% to 50% error. It also doesn't have enough functionalities for the project.

The following tasks are committed during this one-year project:

- Verifying the thermoacoustic assumptions can be used in this specific application.
- Creating computational tools to assist in designing the ultimate device. Including a simulation model in software 'DeltaEC'; and Matlab simulator for obtaining the device's onset condition.
- Lookup table contains geometries and performance parameters for iterative design.
- Provide validation results of the computation models.

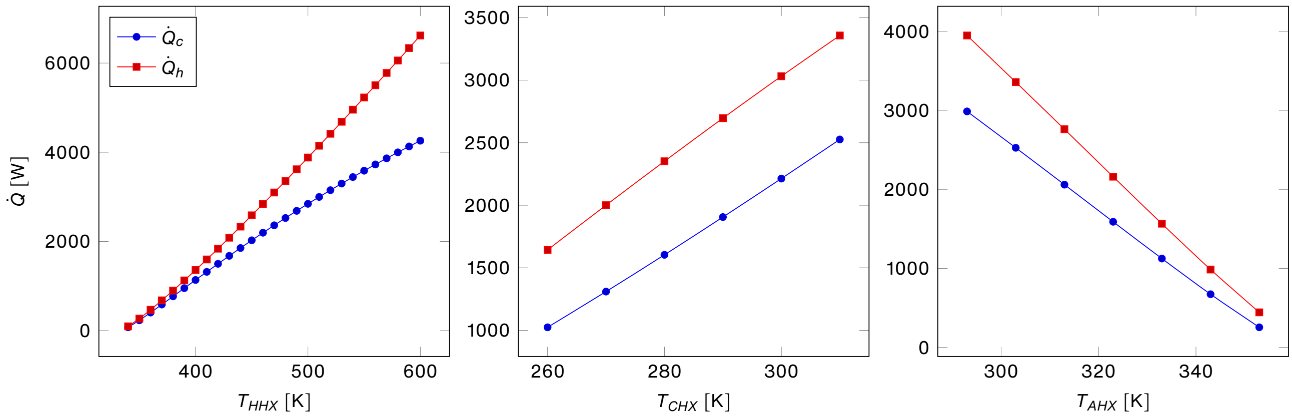
The following assumptions are used and validated:

- 1D linearised thermoacoustic theory: properties $\xi = \overline{\xi} + \xi_1(x)e^{i\omega t}$ for pressure, velocity, temperature, density, etc.
- No thermal conduction in working gas.
- Penetration depth of gas much less than wavelength.
- Uniform heat exchanger temperature.
- Ambient heat exchangers (AHX) at same temperature.
- Cold heat exchanger (CHX) at cooling delivery temperature.
- The model with gas-liquid resonator is valid.

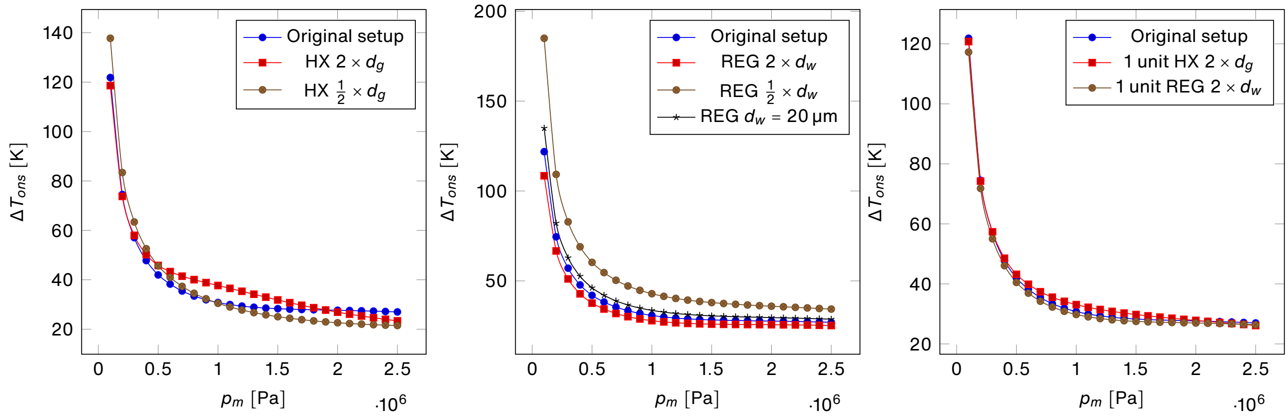
Results

The assumptions on the linear thermoacoustic theory, simulation software DeltaEC, and the uniform

[1] Jingyuan Xu, Ercang Luo, and Simone Hochgreb, Study on a heat-driven thermoacoustic refrigerator for low-grade heat recovery, Applied Energy, Vol. 271, 2020, https://doi.org/10.1016/j.apenergy.2020.115167.



Power flux variation with heat exchanger temperatures



Onset temperature difference found by the code for the current design

heat exchanger (HX) temperatures are quantitatively analysed by order of magnitude analysis. Addition tools to assist the design iteration are developed in this project. A calculator for rapidly estimating the onset conditions is programmed in Matlab and proved to work reliably comparing it to the results from other researches. Moreover, a lookup table and an interpolater which documents and interpolates the design parameters are designed and programmed in Python, this allows the rapid interpolation in the simulated data without repeatedly executing the numerical simulator. Furthermore, some preliminary designs have been done on the replacement of DeltaEC, a new solver for pressure and flow rate is now able to reproduce the result similar to DeltaEC within 5% relative difference.

The lookup table is used by the solar system simulator developed in the other part of this project and produces results that prove the current device is able to work in Chad disregarding the cost. Unlike in the previous work, the hot HX is heated by pressurised water. The safe minimum liquid flow rate is found to be 0.5 m^3/s for all assumptions in the project to be valid. The effect of geometries on the TA onset performance is found. When the mean pressure decreases from 1 to 0.1 MPa, the onset temperature difference increases from about 30 K to over 100 K and the resonant frequency decreased from around 14 Hz to about 4 Hz. However, the effect by ambient temperature on the onset temperature difference and frequency is much smaller. Moreover, the geometry of the key components is found to have impacts on the onset temperature differences. However, the results from the onset calculator suggest that the trend is not linear and will require interpretation in the further design process.

The original plan involves less computation work but more testing rig construction in the third academic term (Easter term). However, due to the COVID-19 pandemic and UK nation-wide lockdown measures, the demonstration models associated with this project and the constructions for the outreach materials are unfortunately unachievable.

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