School of Computing, Engineering, and the Built Environment
Edinburgh Napier University

PHD STUDENT PROJECT

Funding and application details

Funding status: Self funded students only

Application instructions:
Detailed instructions are available at https://blogs.napier.ac.uk/scebe-research/available-phd-student-projects/

Prospective candidates are encouraged to contact the Director of Studies (see details below) to discuss the project and their suitability for it.

Project details

Supervisory Team:
- DIRECTOR OF STUDY: Dylan Ryan (Email: D.Ryan@napier.ac.uk)
- 2ND SUPERVISOR: Zuansi Cai

Subject Group: Engineering & mathematics

Research Areas: Energy Technologies, Environmental Engineering, Mechanical Engineering, Thermodynamics, Pollution, Environmental Biology

Project Title: Biocoal research for use in heritage steam railways

Project description:

The UK has over 200 heritage railway lines in operation. These are mostly operated by volunteers and devoted to the preservation of historic railway engines and rolling stock, most notably at least 1000+ steam engines. Traditionally these have run on coal, preferably Welsh steam coal, a form of bituminous coal known for its good calorific values, low sulphur content and semi smokeless properties. However, many of these mines in Wales are now either closed, or scheduled to close shortly. There is also competition for coal from other users (such as steel production). Similar coals sourced from Scottish mines were used up until 2020, when the last mines in Scotland closed.

Importing coal is one alternative, however this tends to be quite expensive and can yield varying results and is subject to geopolitical factors, e.g. a lot of coal was coming from Russia prior to the invasion of Ukraine. Now that's been cut off, plus the supplies of Polish coal have become scarce. Colombian coal has another possible alternative, although it much more volatile with higher levels of pollutants, quite apart from the extra cost and higher carbon footprint of bringing the fuel all the way from South America.

One alternative that has been investigated is biocoal. These take various forms, but typically consisting of subjecting solid biomass (such as forest product residuals, wood chippings, bagesse, wood pulp, etc.) to pyrolysis to produce biochar. This is typically produced in the form of small pellets. However this produces a number of technical issues for steam engines.

Firstly, they have a much lower and more inconsistent calorific value compared to regular coal. Indeed there seems to be an absence of data on exactly how significant this is. Hence more fuel is needed to provide the same level of traction. Meaning the engines need to be refueled more regularly, increasing costs and reducing the range of engines between stops.

Secondly, incomplete combustion of the fuel. Coal, being of odd shapes and sizes, means air is able to easily circulate within the firebox, allowing the necessary air to circulate between the coal lumps. However, biocoal tends to sit together in a large pile, with only the fuel on the outside undergoing complete combustion. This also results in excessive amounts of ash.

It is worth noting that steam engines are largely naturally aspirated, relying on natural convection to drive air through the firebox and into the boiler. The boiler tubes are at a slight upward angle, ensuring the hot gases will pass through them at a suitable velocity to maximise heat transfer to the water in the boiler. The smoke box (under the smoke stack) is designed to create a vacuum via a venturi effect in the smoke stack, to further draw air through the engine. Air is typically circulated from underneath the engine via the fire grate (primary air) but also via the coal chute doors (secondary air). In many cases operators have been forced to rely heavily on secondary air, which increases the draft level through the engine. While this increases the rate of fuel burn of the biocoal, much of the heat energy is subsequently lost up the smoke stack.

A third issue is the need to keep biocoal dry, as it is usual to store coal out in the open (given the large volumes a fleet of steam engines will consume). Biofuels tend to be hydroscopic and will readily absorb moisture. This not only reduces their calorific value (meaning yet more fuel is needed) but also will increases the release of particulate matter (as wet fuel produces more particulate matter when burned), which produces much greater levels of pollution. Thus a means to keep the fuel dry must be found, e.g. supplying it in waterproof bags, or designing it to be less hydroscopic.

Incidentally, the idea of mixing biocoal and regular coal to counteract these issues has been proposed and tested. This experiments have had mixed results. In some cases for example it has resulted in heavy clinker

Proposed order of work:

- A more complete analysis of the problem, including investigation of the air flowrates through an engine, its energy consumption and fuel consumption.
- Investigation of the quality of biofuel and its calorific values, combustion temperatures and emissions via lab experiments. This will probably require the purchase of equipment, as we have very limited lab resources to support this kind of research.

- Development of new forms of biocoal, e.g. in different shapes to create air gaps, or with air vents cast inside of them, to improve combustion.
- Development of new storage and handling techniques to avoid moisture absorption.
- Consideration of design changes to the steam engines themselves, e.g. using forced convection of air (blowers/superchargers?) into the combustion process or use of a heat exchanger to pre-heat the input air.

Candidate characteristics

Education:

A first-class honours degree, or a distinction at master level, or equivalent achievements in mechanical engineering and/or energy related topics.

Subject knowledge:

- Thermodynamics including combustion, convection, steam cycles & heat transfer
- Mechanical engineering, including properties of materials & mechanical design
- Sustainability, biomass & life cycle analysis

Essential attributes:

- Student will ideally have a degree in a related field (mechanical engineering, energy and environmental engineering, renewabler energy, etc.) and prior research experience in a related field, e.g. a student project related to thermodynamics, sustainability or combustion.

Desirable attributes:

- A working knowledge of steam engines would be advantageous