Institution: Brunel University London		
Unit of Assessment: UoA 12 Engineering		
Title of case study: Heat Pipe-based Mate Tea Drying System		
Period when the underpinning research was undertaken: 2015-2018		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Hussam Jouhara	Professor	08/2014-present
Period when the claimed impact occurred: 2017-Dec 2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact (indicative maximum 100 words)

The traditional way of drying leaves during the manufacturing of mate tea increases the level of polycyclic aromatic hydrocarbons (PAHs) in the tea, which are carcinogenic. The Brunel University London research team worked with staff at the Brazilian mate tea producer Ervateira São Mateus to create a new manufacturing line using novel heat pipe technology. The new line uses less energy and produces less waste than the old process as well as producing tea with reduced PAHs. This allowed Ervateira to retain and expand their existing markets and enter new markets, expanding production by 25% and safeguarding 30 jobs, whilst delivering health benefits for an estimated 1,400,000 consumers of their mate tea.

The UK company Econotherm developed this innovation with a new product line, subsequently selling a dozen mate manufacturing units worth GBP12,000,000 across 4 South American countries. Their parent company Spirax Sarco also benefitted from GBP1,850,000 of new business. Overall in the UK, the research has led to 18 new jobs and secured 10 jobs across these 2 companies, as well as boosting exports.

The Brazilian company SENAI Innovation Institute for Biomass has developed additional technical capabilities to support innovation that has helped strengthen the innovation infrastructure in Brazil.

2. Underpinning research (indicative maximum 500 words)

A heat pipe is a structure with a very high thermal conductivity, recognised as one of the most efficient heat transfer technologies available at present. It can transport a large amount of heat, passively and over a relatively long distance, while maintaining a uniform temperature profile in the ends receiving and releasing heat. Professor Jouhara of Brunel University London is an internationally known researcher on the study of waste heat recovery through heat pipe-based solutions [Refs 1,2,3,4,5,6].

Funded by the Innovate UK Newton Fund (Sept 2016-Aug 2018), Professor Jouhara of Brunel University London worked with the project partners to provide a heat-pipe solution for Ervateira São Mateus in Brazil, who produce 7,000t of mate tea per year for its markets and who were faced with new regulations regarding the levels of polycyclic aromatic hydrocarbons (PAHs) in their product. The project developed an integrated system, which disposed of waste safely and generated a solid clean fuel for heating [Ref 5].

Professor Jouhara designed and developed a new heat-pipe based manufacturing line (Figure 1) in collaboration with Ervateira in Brazil. The other partners in this project were Econotherm UK Ltd, a heat pipe heat exchanger manufacturer based in South Wales, and the SENAI Innovation Institute for Biomass, in Três Lagoas, Brazil. SENAI undertook the chemical analysis of the residual waste from the manufacturing process and also of the local eucalyptus bark to

produce biofuels. SENAI also did some economic analysis to investigate new potential markets for the cleaner mate tea product resulting from this project.

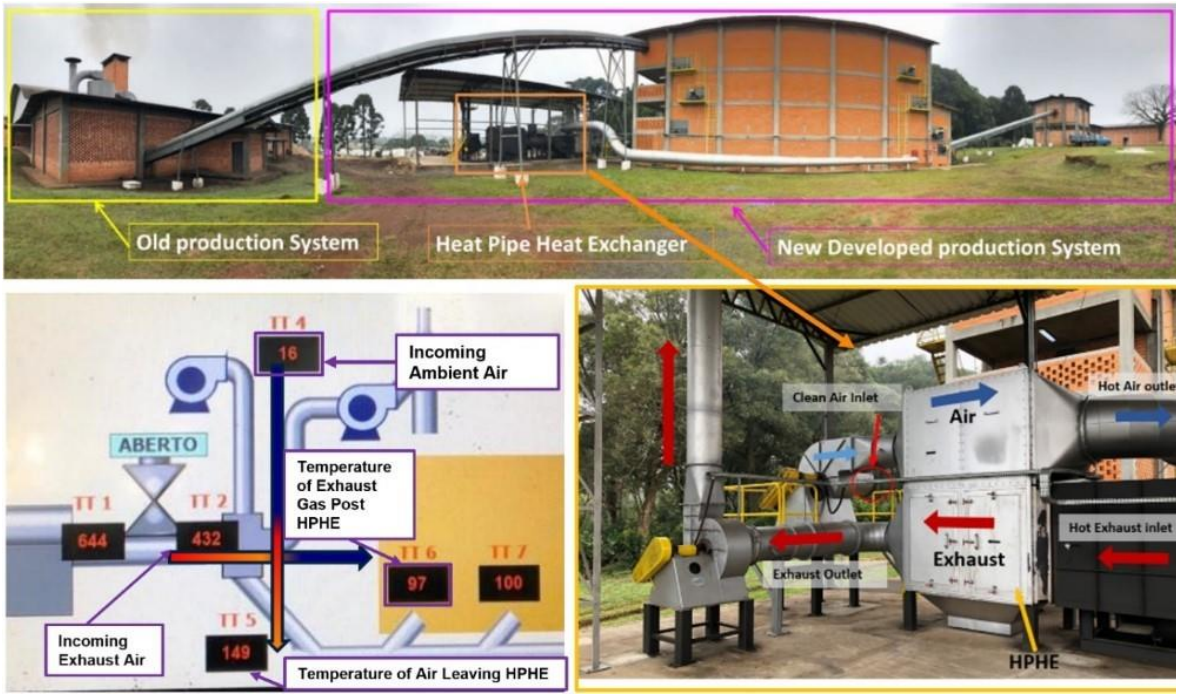

Figure 1: The installed Heat Pipe Based Production Line at Ervateira

Mate tea is a popular drink in Brazil and South America. Made from the dried, chopped and ground leaves of the rainforest holly tree mate, like many natural foods and drinks it naturally contains polycyclic aromatic hydrocarbons (PAHs), which are a group of organic compounds consisting of fused aromatic rings bound in various geometric configurations. They are by-products of reactions occurring in the incomplete combustion of organic matter (pyrolysis), and are formed when high temperatures are involved. A key challenge for the product is that the traditional wood smoke process used to dry mate tea leaves further contaminates the leaves with high levels of PAH.

The Brunel researchers reviewed the drying process in place at Ervateira and used their research expertise to develop a new heat-pipe manufacturing line that ensured that none of the mate tea product was in contact with any fumes from the waste exhaust energy. This ensured that the mate tea was not contaminated with additional PAH and so reduced the amount of PAH in the final product. The new heat-pipe unit provided the company with a reactive system that offered differing control options, suitable for sensitive apparatus. In addition, it did not require pre-heating, therefore saving energy.

The intermediate pipe working temperature allowed for higher exhaust temperature limits on some applications.

There are many energy saving outcomes of the new unit. The new design improved the isothermal operation of the unit by eliminating hot and cold spots and the resulting condensation, which also improved energy recovery. Furthermore, the passive devices mean that there was no need to pump energy to drive the heat transfer process through the heat pipe, again saving energy [Ref 5].

The longevity of the unit is supported by the use of robust materials so that the pipes can expand and contract without generating stress on the structure. The thick walls ensure that erosion and corrosion are minimised. The smoothness of the pipes allows for better fouling management of the heat exchangers and, overall, the unit is easier to clean and maintain in-situ. In addition, the multiple independent heat pipes enabled the system to continue operating even if

a number of heat pipes failed, so that the whole system does not have to be shut down in such an event, allowing production to continue until the next maintenance cycle.

Finally, the new unit is future proof in that it was highly scalable, customisable and configurable. The modular design enabled on-site assembly and was designed for future expansion, and to meet specific applications or operational needs.

3. References to the research (indicative maximum of six references)

[Ref 1] B. Fadhl, L.C. Wrobel, H. Jouhara (2015) CFD modelling of a two-phase closed thermosyphon charged with R134a and R404a, *Applied Thermal Engineering* **78**: 482-490. https://doi.org/10.1016/j.applthermaleng.2014.12.062

[Ref 2] H. Jouhara, B. Fadhl, L.C. Wrobel (2016) Three-dimensional CFD simulation of geyser boiling in a two-phase closed thermosyphon, *International Journal of Hydrogen Energy* **41**: 16463-16476. https://doi.org/10.1016/j.ijhydene.2016.02.038

[Ref 3] H. Jouhara, T.K. Nannou, L. Anguilano, H. Ghazal, N. Spencer (2017) Heat pipe based municipal waste treatment unit for home energy recovery, *Energy* **139**: 1210-1230. https://doi.org/10.1016/j.energy.2017.02.044

[Ref 4] H. Jouhara, A. Chauhan, T. Nannou, S. Almahmoud, B. Delpech, L.C. Wrobel (2017) Heat pipe based systems - Advances and applications, *Energy* **128**: 729–754. https://doi.org/10.1016/j.energy.2017.04.028

[Ref 5] H. Jouhara, T. Nannou, B. Delpech, S. Almahmoud, A. Chauhan, M. Boocock, L.C. Wrobel, I. Carrau, F. Carrau (2017) Heat pipe based heat exchanger for clean yerba mate drying process, *Tenth International Conference on Sustainable Energy and Environmental Protection*, Wroclaw, Poland. Pages 9-20 Doi 10.18690/978-961-286-063-9.2

[Ref 6] H. Jouhara, S. Almahmoud, A. Chauhan, B. Delpech, G. Bianchi, S. Tassou, R. Llera, F. Lago, J.J. Arribas (2017) Experimental and theoretical investigation of a flat heat pipe heat exchanger for waste heat recovery in the steel industry, *Energy* **141**: 1928–1939.

Relevant Grant

Innovate UK Newton Fund Project 102716, ‘Erva Mate Drying’ (Sept 2016-Aug 2018), GBP258,110.

4. Details of the impact (indicative maximum 750 words)

Professor Jouhara’s heat pipe technology installation at Ervateira in Brazil has produced a number of multifaceted benefits to a number of organisations: Ervateira **[S1]**, Econotherm **[S2]** and SENAI **[S3]**. Ervateira has created a safer manufacturing environment and protected staff working at the plant as well as its mate tea consumers. The company has been able to grow the company by enabling it to meet changing legislative requirements and thus increasing its market as well as distribution. Furthermore, the changes in the manufacturing process have resulted in the reduction of both energy usage and waste, making the product more profitable. In addition, the research has led to a new international market for Econotherm, enabling them to secure jobs. Finally, the research has enabled SENAI to develop new capabilities to support research and development in heat-pipe technology.

Safer Manufacturing for consumers and employees.

Ervateira, in Brazil, produces 7,000t of mate tea per year for its markets **[S4]**. We calculate that this equates to an average consumption per year of about 1,400,000 mate consumers. The traditional production of the team utilised wood smoke in direct contact with the tea during the drying process. This resulted in high levels of polycyclic aromatic hydrocarbons (PAHs), a known carcinogen, which had the potential for contamination of the tea and also exposed the workers to the damaging smoke. Workers who breathed in the smoke or come into contact with PAHs have

been shown to be at a risk of cancer. Furthermore, the beverage has also been linked to mouth, throat, kidney and bladder cancers, which reduces its export potential to countries with stricter food and drink regulations.

Professor Jouhara's research into innovative heat pipe technologies was central to the design and manufacture of a new production line at Ervateira. This led to a 20-tonne heat pipe heat exchanger containing over 1,100 heat pipes being manufactured and installed by Econotherm, a UK based company. The new design separated the exhaust from the drying fluid, ensuring that it was not recycled back into the tea leaves during the drying process. This transformed the traditional process into a much safer one and ensured that the PAH levels in the tea were now within acceptable international limits [Ref 5]. The changes in the production process also meant that the company has now been able to increase its production of mate tea by approximately 25% since 2018, which is equivalent to an increased income of BRL1,000,000 (GBP128,090, 03-2021) per year.

Growing Business – Exporting to Europe having met the legislative requirements
When exporting herbs to Europe, companies like Ervateira are required to comply with various legal requirements. The General Food Law is the legislative framework regulation for food safety in the European Union and compliance with this legislation ensures that the product is safe to consume. As Ervateira's strategy was 100% focused on exports, compliance with food safety legislation meant that they were in a position to safeguard their international products and sales. Furthermore, in addition to protecting their core products and sales, Ervateira have been able to grow significantly in new markets, thanks to their new safe drying process. They have expanded their markets to the European Union, United States, Russia, China, South Korea and Turkey. These new markets have enabled their profits to increase by 15%.

Safe and secure working conditions
Having completed the transformation of its entire manufacturing line, Ervateira's operation had created safer working conditions for their 30 employees, who were now protected from the occupational exposure to PAHs through woodsmoke, thus reducing their risk of contracting cancer. The company has secured these jobs for the future by ensuring that its product meets export conditions which would have impacted their company had they not done so.

Reducing Waste and Energy
Heat pipe heat exchangers effectively recover waste heat, saving energy and reducing greenhouse gas emissions. This is an efficient way for industry to recover valuable energy sources and reduce the overall energy consumption. Ervateira has been able to reduce its environmental footprint by 20% since the installation of the heat pipe heat exchanger.

Ervateira had always grown their own raw materials for their tea. The redesigned pipes enabled them to utilise the waste product, which had previously been discarded, as a biomass fuel which has consequently reduced the waste production by 15%. Overall this has resulted in further reduced fuel costs as they have been able to save on purchasing other fuel types.

In their supporting letter **[S1]**, Ervateira recognised the partnership was 'a total success in drying innovation in the mate product' and that 'Our production increased by approximately 25%'. They also stated that 'the main benefit of this project was to promote to the consumer market a product with low content of contaminants, PAHs, Anthraquinone, Folpet, and Phthalimide', and that 'the technological innovation has opened new markets such as the European Union, United States, Russia, China, South Korea, Turkey, etc. etc.'

Creating new international markets and strategies for a UK based business
Econotherm, a UK heat-pipe business joined the Innovate UK project as the manufacturing partner. The project enabled the company to supply and demonstrate its product to a brand-new

market. Econotherm was able to use this opportunity to develop a new product line in South America. The CEO stated **[S2]**:

> *To date we have sold 12 units with an average price of GBP1,000,000 per unit across 4 South American countries. This new business has changed our overseas sales strategy and these new opportunities have created 16 new jobs, secured 10 jobs as well as supported the financial sustainability of our business. As a result of our involvement in the Brunel research project, Econotherm has a much stronger portfolio of technological capabilities and a more detailed understanding of their potential application. This places the company in a very strong position to expand over the next few years, and to secure a strong position in the very competitive energy sector.*

Spirax Sarco **[S5]**, which holds a 48% share in Econotherm, highlighted additional benefits to both companies. The project enabled the parent company to develop their strategy in heat pipe product sales into new product lines in steam specialities. Spirax Sarco reported that since the completion of the project it had secured GBP1,850,000 in new sales across 8 contracts and expected this new technology to be an important source of income. Furthermore, as well as securing the employment of existing staff, the company has recruited 2 additional senior engineers with appropriate expertise in these new areas of applied research in steam and heat pipes. Overall in the UK, the research has led to 18 new posts and secured 10 posts across these 2 companies.

Developing research and innovation capacity in Brazil

The project also involved a research and technology organisation in Brazil – SENAI Innovation Institute for Biomass. The project enabled the organisation to strengthen the innovation infrastructure in Brazil by giving them the additional technical capabilities to support innovation across a broader technical range and to enhance the knowledge and skills of their research staff to enable them to utilise this technology. The Director of the SENAI Innovation Institute for Biomass confirmed that they had a fruitful partnership with Brunel University. The Brunel research team led the designing and implementation of heat exchangers and thermal systems to bring about a new way of drying mate tea leaves. This has increased the export potential of Brazilian mate tea and minimised negative health effects.

5. Sources to corroborate the impact (indicative maximum of 10 references)

[S1] Letter from Ervateira São Mateus
[S2] Letter from Econotherm
[S3] Letter from SENAI Innovation Institute for Biomass
[S4] Screenshot of Ervateira's homepage
[S5] Letter from Spirax Sarco