PARTIAL ELECTRIFICATION OF A CERAMIC TILE DRYER BY INTEGRATING HEAT PUMPS

S. Ferrer[1], E. Monfort[1], J.P. Martí[2], R. Collado[2], M. González[2],J. Navarro[3].

[1] Instituto de Tecnología Cerámica (ITC). Asociación de Investigación de las Industrias Cerámicas (AICE)
Universitat Jaume I. Castellón. Spain.
[2] Expander Tech, s.l. La Vall d'Uixó. Castellón. Spain.
[3] Grupo ISTENER. Universitat Jaume I. Castellón. Spain.

1 INTRODUCTION

The ceramic tile manufacturing process has evolved over the years, and different technologies have been implemented to increase process energy efficiency. An interesting technology that could be implemented in the ceramic industry is heat pump technology, as it can enable recovery of low-temperature industrial heat and revalorise it for reuse in the process.

This technology is able to produce useful heat at a higher temperature than that of the starting heat source. The heat pumps produce approximately three units of energy in the form of useful heat per unit contributed electricity, using available waste heat as system input. Therefore, its application also significantly increases process energy efficiency.

In the ceramic tile manufacturing process, an interesting option for possible use of this technology is in ceramic tile dryers. Implementing such a system would allow reduction of natural gas consumption at the burners and hence reduce CO_2 emissions. It would therefore involve shifting from natural gas consumption towards electric power consumption, thus fostering electrification of the sector and facilitating decarbonisation of low-temperature heat.

This presentation sets out the results obtained in a study analysing the possible application of this technology in a ceramic tile dryer.

2 HEAT PUMP TECHNOLOGY

Assuming industrial processes that operate at low temperature (<200 ºC) to be the main market for industrial heat pumps, there are two differentiated segments, depending on the level of temperature:

- Applications up to 100 °C, which can be satisfactorily addressed by already mature heat pump technologies.
- Applications in the range of 100 °C to 200 °C, where technological developments are still required to meet market needs.

A heat pump is a thermal machine that uses a cooling gas in a closed thermodynamic cycle, which enables heat transfer from a cold source to another, hot source with great efficiency. This can be done by having the additional work performed by a compressor, generally in the form of electric energy.

The work fluid or coolant is one of the main components of heat pumps as, by means of its thermodynamic properties, it transfers thermal energy from a cold source to a hot source.

The temperature difference between a cold source and a hot source that a heat pump can provide ranges from about 30 °C to 70 °C.

The operating principle of high-temperature heat pumps is based on waste heat recovery from an industrial process, which lies in a range of temperatures between 60 °C and 120 °C.

Figure 1 depicts an operating scheme of the technology. First, the coolant is evaporated in the evaporator, which operates at low pressure. Once that heat has been captured, the coolant in vapour state is compressed in the compressor, which is generally driven by an electric motor, increasing coolant pressure. The coolant then enters the condensing unit where it releases its useful heat to the incoming stream to be revalorised, the aim being to reach temperatures up to 140 °C to 150 °C. Once that heat is released, the coolant condenses and returns to its liquid state. The condensed liquid reaches the expansion valve, where it reduces its pressure on passing through the expansion valve, to restart the cycle.

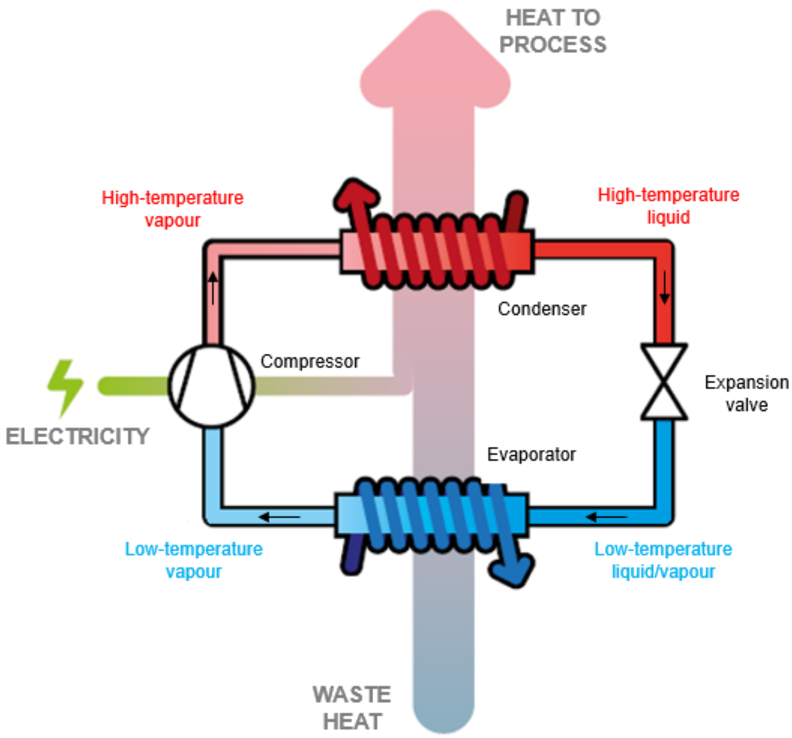

Figure 1. *Scheme of heat pump operation.*

As heat pumps deliver as heat a multiple of the amount of electricity consumed, their application significantly increases process energy efficiency, shifting thermal consumption to electricity consumption.

This generated heat can then be used elsewhere in the process, enabling reduction of fossil fuel consumption by heat generation systems and, hence, lowering greenhouse gas emissions.

The relation between the heat supplied and the electricity input is known as the **coefficient of performance (COP)** and it is an important parameter that characterises heat pump efficiency. This value usually ranges from 2 to 5, depending on the waste heat and heat temperatures of the process.

$$COP = \frac{Q_D}{W}$$

By way of example, a heat pump that is able to deliver 3 kW of thermal power to the process with just 1 kW of input electric power to the pump compressor has a COP=3. The COP is indicated without a unit.

3 APPLICATION OF HEAT PUMPS IN THE CERAMIC SECTOR

After analysis of the technology, a possibility that could be considered in the ceramic industry is process waste heat recovery and generation of useful heat, at working temperatures similar to those at which dryers run.

With this aim, various options could be considered for recovering waste heat from a low-temperature process and raising its temperature by a heat pump:

- **Option 1:** Valorising **waste heat from the dryer stack**, which generally lies at a temperature around 100ºC, by leading it to a heat pump, raising its energy value and using it to preheat the air feed to the dryer burners, thus reducing natural gas consumption at the burners or, if possible, using a heat exchanger, heating part of the air in the recirculation systems.
- **Option 2:** Analysing the possibilities of replacing or eliminating the existing burners in the dryer recirculation systems, and generating the thermal leap needed to heat the recirculated gases by a heat pump. This would require studying some **process waste heat source** in ceramic tile manufacturing, such as waste heat from the kiln, for use as input source to the heat pump.
- **Option 3:** This option resembles option 2, which seeks to eliminate or replace the burners in the dryer recirculation systems. In this case, however, the source of the **waste heat** fed into the heat pump could come from a **solar energy concentration facility**. It would therefore be necessary to estimate the amount of heat needed from the heat pump for the dryer to heat the gases in the recirculation systems to temperatures between 140 ºC and 160 ºC.

In every option, installation in the dryer recirculation systems of thermal fluid/recirculated gas heat exchangers is considered, for transferring the heat of the thermal fluid from the heat pump to the gases in the dryer.

By way of example, Figure 2 shows how a high-temperature heat pump could be integrated, in above options 2 and 3, in a ceramic tile vertical dryer.

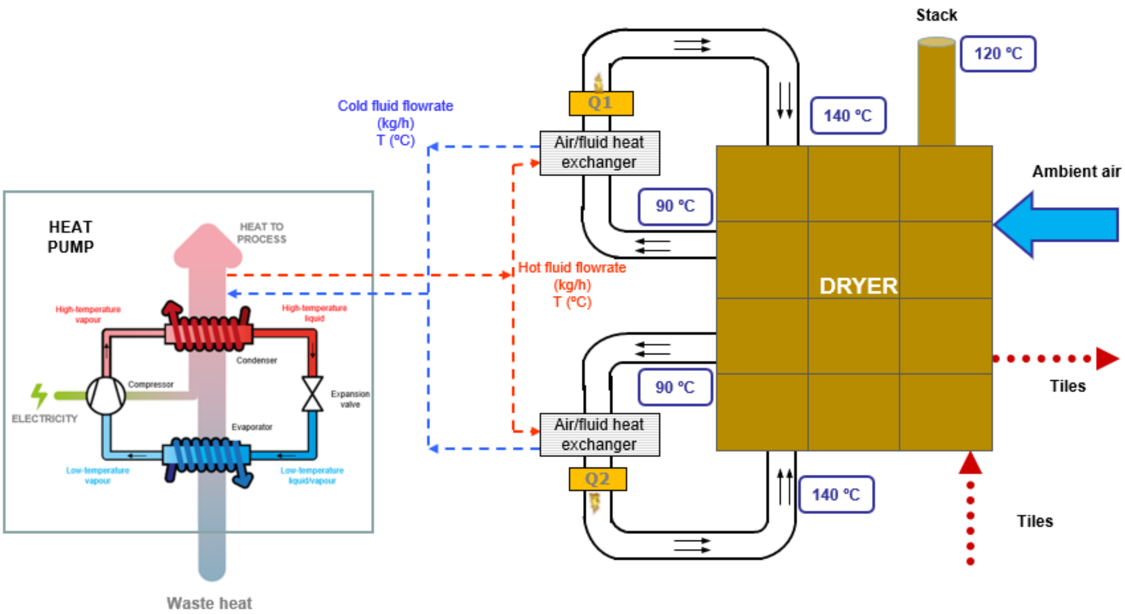

Figure 2. *Integration of a heat pump in an industrial tile dryer means of recirculator gases/thermal fluid heat exchange.*

In vertical dryers, each recirculation volume flow rate is estimated to lie between 15,000 and 20,000 Nm^3/h hot gases, although this depends on dryer size and could be greater. These gases exit the dryer at 90–100 ºC and, by means of natural gas burners, their temperature is increased to 140–160 ºC.

For these reasons, a heat exchanger that uses a heat-transfer fluid, heated by a heat pump, would enable obtainment of this heat jump that is currently produced by burners, in order thus to partially reduce or even eliminate its energy input.

Such would be particularly the case in dryers that run at temperatures close to 140 ºC. However, according to the literature surveyed, there are as yet few manufacturers who can offer a solution for working at higher temperatures. Projects are currently being conducted to achieve temperatures between 160 ºC and 200 ºC, though market implementation could still take some years.

4 CONCLUSIONS

The following conclusions may be drawn from this study:

- On a European level, one of the options being considered for low-temperature heat decarbonisation (< 200 ºC) is heat pumps.
- The high-temperature heat pumps that could be integrated into the processes can generate temperatures up to 100 °C. Applications in the range of 100 °C to 200 °C are still in the development stage.
- In the case of their application in the ceramic sector, it is possible to consider waste heat recovery from the process and useful heat generation by heat pumps at working temperatures resembling those at which dryers run.
- Although fully developed equipment is not yet available, commercial equipment that will allow operation at temperatures of 140 ºC is expected to become available shortly, and it will therefore allow this heat jump with heat pumps instead of burners. However, in cases of higher temperatures, longer-term developments are required.

5 ACKNOWLEDGEMENTS

This is part of the activities conducted in the project "Strategic lines for the energy transition of the ceramic tile manufacturing process (ENERGÈTIC)", co-funded by the Valencian Institute for Business Competitiveness (IVACE) and the European Union through the ERDF Operational Programme for the Valencia Region (IMDEEA/2020/100 and IMDEEA/2021/35).

6 REFERENCES

[1] Marina, S. Spoelstra, H. Zondag y A. Wemmers. 2021. An estimation of the European industrial heat pump market potential. Renewable and Sustainable Energy Reviews. Volume 139.

[2] Annex 35/13 Application of Industrial Heat Pumps. 2014. Industrial Energy-related Technologies and Systems.

[3] Annex 48 Industrial Heat Pumps, Second Phase. Final Report. 2020. IEA. HTP.

[4] Arpagaus, Cordin & Bless, Frédéric & Uhlmann, Michael & Schiffmann, Jürg & Bertsch, Stefan. 2018. High temperature heat pumps: Market overview, state of the art, research status, refrigerants, and application potentials. Energy. 152. 10.1016/j.energy.2018.03.166.

[5] Mateu; C. Arpagaus, A. Mota; J. Navarro-Esbrí, S. Bertsch. 2021. Advanced high temperature heat pump configurations using low GWP refrigerants for industrial waste heat recovery: A comprehensive study. Energy conversion and management. Vol. 229. pp. 1-18. 2021.

[6] Mateu; J. Navarro-Esbrí; A. Mota; F. Molés; M. Amat. 2019. Experimental exergy and energy analysis of a novel high-temperature heat pump with scroll compressor for waste heat recovery. Applied energy. Vol. 253. pp. 1-14.

[7] https://waermepumpe-izw.de/

[8] Plataforma tecnológica Española de Eficiencia Energética (PTE-EE). Estudio de prospectiva 2030-2050 de tecnologías de eficiencia energética. December 2020.

[9] R. De Boer, A. Marina, B. Zühlsdorf, C. Arpagaus, M. Bantle, V. Wilk, B. Elmegaard, J. Corberán y J. Benson. 2020. Strengthening Industrial Heat Pump Innovation - Decarbonizing Industrial Heat. Report.