Position paper on the upcoming PFAS regulation for Organic Rankine Cycle power systems

Organic Rankine Cycle (ORC) power systems are an emission-free technology suitable for the conversion of thermal energy into electricity. ORC systems can be used to harvest waste heat, generated from industrial processes and engines for example, which would otherwise be wasted to the environment. In Europe, this has the potential to generate as much as 150 TWh/year[1] of emission-free electricity using industrial waste heat alone. As of 2019, this could abate 46 Mt of CO_2-emissions per year, taking national emission factors into account[2]. Low temperature waste heat (<200 °C) has a share of up to 40 TWh/year of green electricity, but for these temperature levels it is much more challenging to harvest.

Many of the commercially available ORC systems are currently using PFAS fluids in a closed loop, which is sealed from the environment (comparable to a refrigeration system). All HFCs and HFOs are indexed as PFAS fluids, and these fluids are used as working fluids in ORC systems. PFAS are only emitted due to leakages or improper handling of the working fluid. When properly disposed, potential PFAS compounds are decomposed and do not pose any further threat to the environment. Therefore, the impact of PFAS can be minimized effectively by safety measures during operation and maintenance, which are already in place through compliance with existing regulations, such as the F-Gas Regulation. Beyond this, many different sealing materials, used for O-ring and flat gaskets for example, are affected by the proposed PFAS ban.

Replacing PFAS fluids with a natural refrigerant is possible and desirable but requires significant amounts of development and adjustment time for the industry and certifying bodies. All natural refrigerants (except CO_2) are flammable, and explosive or toxic in some cases. In sectors such as the maritime industry, the current regulations do not allow installations with flammable fluids of any kind. The realization of systems with flammable fluids might be a viable option in other sectors, and for large scale ORC systems in the MW-scale, as the costs for additional devices have a lower impact on the installation costs, while this is not the case for the smaller scale. Using CO_2 as a working fluid requires a transcritical power cycle that suffers the drawback of high operational pressure levels. This might be feasible in small dimensions for small scales (size of few kW) and very large scales, but it is not a viable option for medium scales in the range of a few kW up to 1 MW. This drives up the cost for the installation and may prevent some installations from realization due to longer pay-back periods. Consequently, reducing the potential for CO_2 mitigation means a lost opportunity for power generation and for saving CO_2 emissions.

The proposed ban of fluorinated greenhouse gas refrigerants has an impact on other laws, rules, and regulations. While a regulation is highly desired and necessary, its implementation requires time and so does the development of alternatives.

It may also impact existing plants which can no longer be serviced and subsequently may need to be shut down. The investment horizons in terms of energy efficiency measures are rather long term, typically between 15-20 years.

[1] https://www.kcorc.org/en/committees/thermal-energy-harvesting-advocacy-group/
[2] https://www.eea.europa.eu/ims/greenhouse-gas-emission-intensity-of-1

The most beneficial path for the environment must be taken in this transition process, where different aspects of climate change and environmental pollution concerned. The reason to ban PFAS is that they are reported to be toxic, persistent and bioaccumulative. However, the toxicity and the environmental impact of ORC working fluids has been properly assessed[3] and this should be considered in any future regulations. For example, most of the fluids applied in ORC systems are not classified as persistent. Independent of this, the fluids are already adequately regulated through the F-Gas regulation.

Therefore, we suggest a permanent derogation for using fluorinated greenhouse gases as working fluids in waste heat recovery applications using ORC technology, in the same way exemptions have been proposed for the HVACR sector. This should also include the maintenance and service of such systems.

As mentioned, ORC systems can generate annually up to 150 TWh of electricity from industrial waste heat in Europe. With energy consumption data from Eurostat based on the year 2019, this could lead to a reduction of approximately 46 Mt of CO_2-emissions per year.

A total of 9 kt of CO_2 can be abated by a single 200 kW_e ORC unit over an operational lifetime of 20+ years (this estimate is sector-specific and takes the country specific CO_2 emissions into account). To quantify the advancements implied by the F-Gas regulation, the figures below compare R245fa (GWP=1030) with R1233zd(E) (GWP=5), a low-GWP working fluid. Both fluids perform similarly, enabling similar efficiencies, and they are both indexed in PFAS appendices.

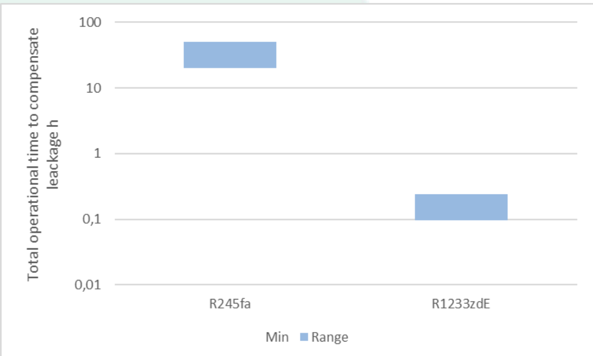

FIGURE 1: TOTAL OPERATIONAL TIME TO COMPENSATE GWP FROM LEAKAGE FOR R245FA AND R1233ZD(E)

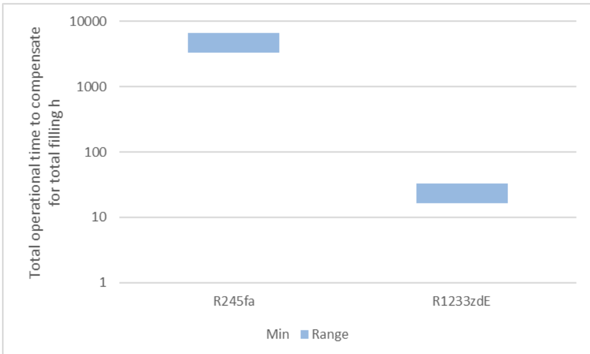

FIGURE 2: TOTAL OPERATIONAL TIME TO COMPENSATE GWP FROM LOSS OF TOTAL FILLING FOR R245FA AND R1233ZD(E)

Note: Assumptions for the above calculations are as follows: the amount of fluid needed to fill the closed process cycle is ~1-2 kg/kW_e, based on feedback from ORC manufacturers of medium sized ORC systems. The operational lifetime is set to 20 years, with 8000 (full-load) equivalent operating hours per year, and a maximum leakage rate of 3 g/year for each flange joint (min 20 to max 30 flange joints). This is a threshold value for hermetically sealed components.

It can be seen that the global warming potential of fluid loss due to leakage over the lifetime (20 years) of a system working with R245fa is compensated within 20 to 30 hours of operation. With R1233zd(E), the time reduces to 6 to 10 minutes. With respect to entire fluid charge, the global warming potential for R245fa and R1233zd(E) would be compensated within 3300 – 6600 hours and 16 – 32 hours, respectively. At the end of

[3] Scientific assessment of ozone depletion. 2022: Executive Summary (2022). Geneva, Switzerland: World Meteorological Organization (Global Atmosphere Watch report series, no. 278). and https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_TS.pdf

life of the ORC system the fluid can be recycled and re-used, or it can be disposed properly. In the latter case, the fluid is thermally destroyed and no PFAS compounds are emitted following combustion.

In the absence of a comparative base for PFAS with the global warming challenge of today, it needs to be kept in mind that reducing the potential for CO_2 mitigation is a lost opportunity for power generation and for saving CO_2 emissions.

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