This is a selection of papers that will be presented during the conference. The full conference programme including all papers to be presented coming soon.

Papers

A Compact Reverse Rankine Cycle Combines Surface Enhancement and Jet Impingement to Remove High Heat Fluxes

Presenting Author: Carneiro, Marcus Vinicius, Federal University of Santa Catarina, Brazil

Abstract: We present an experimental assessment of a compact reverse Rankine cooling system driven by a small-scale oil-free linear compressor. The expansion device (an array of micro orifices) is integrated with the evaporator to produce two-phase jets that impinge on the surface of the element supplying the thermal load. The benefit of the proposed technology for high heat flux applications is twofold: the large heat transfer coefficient associated with spray/jet impingement and the ability to maintain evaporating temperatures equal to or below that of the ambient. Here, we improve the system performance even further by using resilient micro structures (micro pillars fabricated by laser ablation) to increase the surface energy and promote higher values of heat transfer coefficient and critical heat flux. In addition to specific quantitative results on the capillary driving force of the enhanced surfaces, we present data on the thermodynamic performance of the vapor compressor unit. High-speed video sequences are used to illustrate the phase change heat transfer phenomena involved.

A Dynamic Simulation of a Cryogenic Power Generation System on an LNG Fueled Vessel Based on ORC Technology technology

Presenting Author: Li, Yi, University of Birmingham, United Kingdom

Abstract: With the growth of the LNG market, using LNG as fuel becomes more appealing to ship owners and operators. More ships on orderbooks choose LNG fueled propulsion systems to replace conventional HFO and marine diesel-fueled system. This study proposes a waste energy power generation system to recover the exhaust heat of marine engines and use the cryogenic energy from LNG fuel evaporation systems. The system is built on the main cycle, i.e. an Organic Rankine cycle (ORC), with a bottom cycle with LNG direct expansion process. The selected working fluid is operated in the temperature range of -104 to 200°C. The operating data from a real LNG fueled case ship is applied as the input data in the dynamic simulation using the software – Siemens LMS Imagine. Lab AMESim. Multiple working conditions are studied in the simulation in terms of the different fuel consumption levels of the case ship. The result shows a significant improvement in efficiency and power production.

A R744 Transcritical Refrigeration Test Rig Equipped With A Transparent Two-phase Ejector For Flow Visualisation: Experimental Study

Presenting Author: Haida, Michal, Silesian University of Technology, Poland

Abstract: The R744 transcritical system has high thermodynamic losses during expansion process and there is potential to improve its operation by understanding the complexity of phenomena
occurring inside the R744 two-phase ejector. Thus, a two-phase ejector has to be designed based on
the accurate numerical model to observe flow behaviour during expansion, mixing processes in
mixing section and kinetic energy conversion into pressure energy in diffuser. The main aim of this
paper is to perform an experimental study of the R744 transcritical system equipped with the
transparent ejector based on the steady-state and long-term system operation. The ejector with a
transparent pre-mixer, mixer and diffuser using smooth Plexiglas material was designed using the
ejectorPL numerical CFD tool. Determination of the velocity field and analysis of flow structure inside
the ejector will be used for additional device shape optimisation. Furthermore, an unsteady effect of
the ejector work during change of system operating conditions is investigated. The ejector efficiency
up to 30% was recorded for motive nozzle pressure of 90 bar.

**An LNG-based System for the Combined Production of Power and Cooling**

**Presenting Author:** Atienza-Márquez, Antonio, Universitat Rovira i Virgili, Spain

**Abstract:** Liquefied Natural Gas (LNG) is forecasted to be crucial in the energetic transition towards a
decarbonized economy. Apart from its environmental advantages, LNG is thermodynamically
attractive for many industrial applications because of its very low temperature (111 K). However,
that cold energy is rarely recovered in conventional LNG-regasification processes.

This paper investigates a system for LNG cold recovery and the combined production of power and
cooling for air-conditioning applications at buildings. Electricity is produced in a direct expansion unit
and in a cryogenic Organic Rankine Cycle. On the other hand, cooling is produced directly in heat
exchangers that recover LNG’s cold energy.

The system produces 6.05 MW of electricity and has a cooling capacity of 5.86 MW which could be
increased using a cold energy storage. Exergy destruction rates are still high and a low-temperature
refrigeration unit could be integrated in the system to enhance the performance of the plant.

**Analysis Of Load Variation Of Absorption Chiller With Rankine Cycle**

**Presenting Author:** Singh, Kirtivardhan, Inderprastha Engineering College (affiliated to Dr. A.P.J.
Abdul Kalam Technical University), India

**Abstract:** Thermal power plants working on Rankine cycle present numerous applications in addition
to providing more than 38% of the world energy needs. One such an application is the combination
of Rankine cycle and vapour absorption system, which needs a low grade energy easily available at
thermal power stations. This paper presents the techno-economic consolidation of Rankine cycle
with vapour absorption system using a tapoff steam from the boiler. The load compatibility of air
conditioned zone is mapped to load/capacity variation of power plant. In order to safely control and
monitor the variables, Supervisory Control and Data Acquisition System (SCADA) along with PLC
tocontrols are used, which provides advanced real-time data to monitor the flow control with
utilisation of all safety systems. This control utilizes best of both the systems and its effect on several
variables is plotted with the help of graphs with respect to load variation. This will help in reducing
power wastage at different locations in the plant thus acting as an energy conservation model.

**Applied Optimisation of a Twin Screw Expander for Electrical Power Generation in a Waste Heat
Recovery System Using an Organic Working Fluid**
Presenting Author: Spencer, Sean, Spirax Sarco, United Kingdom

Abstract: This research investigates the applied optimisation of a twin screw expander which forms part of a prototype Controlled Phase Cycle (CPC) application, addressing the energy trilemma of emissions reduction, security of supply and cost savings in industrial environments. The optimisation of the expander’s performance affords an opportunity to improve on the low conversion efficiencies displayed by current ORC waste heat recovery systems, with projected CPC efficiencies upward of 6%.

The system uses R1233zd (E) as the organic working fluid and is designed to generate 120kW of electrical power by harnessing a 1MW thermal low pressure steam supply. A comparison of theoretically and empirically derived elements, including the effects of Built in Volume Ratio (BIVR), fluid gas faction, mass flow rate, pressure and temperature on the expander’s operation enable the validation and quantification of optimised expander operation.

Carbon Dioxide In Industrial Refrigeration

Presenting Author: Webb, Stuart R, Star Refrigeration Ltd, United Kingdom

Abstract: Carbon dioxide (CO₂, R744) has a number of properties that make it an attractive working fluid for refrigeration systems, as demonstrated by the marked resurgence of CO₂ as a refrigerant in recent years. It is suitable for a range of applications and can be utilised within a variety of system architectures, but also requires specific design considerations in order to ensure robust, efficient operation. From an industrial refrigeration perspective, CO₂ can offer a natural, low-GWP alternative to traditional synthetic refrigerants as well as a low-toxicity, non-flammable alternative to ammonia. It can also be used effectively in combination with ammonia, for example as a secondary refrigerant or in the low stage of a cascade system.

This paper examines the use of carbon dioxide in industrial refrigeration systems, using examples of real world installations. Two subcritical configurations are assessed, in order to compare the performance of alternative system architectures.

Comparison of CO₂-Glycol-Ammonia Cascade to Trans-Critical CO₂ and Ammonia-CO₂ Cascade Systems

Presenting Author: Oliver, Gavin, Star Refrigeration, United Kingdom

Abstract: With the need to use low GWP / ODP refrigerants as a result of environmental factors, including new legislation, carbon dioxide has returned to the fore as an industrial refrigerant – particularly for freezer and cold storage applications. Typical system types include trans-critical CO₂ and ammonia cascade systems. A variation that uses cooled glycol from ammonia package chillers to condense the carbon dioxide within a subcritical system has been developed and installed in industrial cold storage applications. The system takes advantage of equipment already being installed for chilled storage on site in order to avoid trans-critical operation of the CO₂ system.

This paper describes the CO₂-glycol-ammonia cascade system and presents examples of installed systems. The paper then compares trans-critical CO₂, ammonia-CO₂ cascade and CO₂-glycol-ammonia cascade systems, and concludes with recommendations in terms of efficiency and capital cost.
Design Options for Increasing the Efficiency of an R717 Heat Pump

Presenting Author: Jack, Martin James, Star Refrigeration, United Kingdom

Abstract: The price of electricity in the UK is relatively high and the price of gas relatively low. Designers of heat pumps, therefore, face an uphill struggle to design a heat pump which is economically viable compared to conventional gas fired central heating, which also has a relatively low capital cost. A high bar is thus set efficiency wise in order to attain a reasonable payback period. This paper will discuss the control of large, river source, ammonia heat pumps for maximum efficiency, with particular reference to the current such project being undertaken in Clydebank. In this case, a desire for boiler back up of the full heating load and a low heat demand in the early phases in the development of the district, led to the hot water circuit configuration of heat pumps and boilers in parallel.

Determining the Optimum Condenser Fan Speed for Refrigeration Systems

Presenting Author: Dowling, Ciaran, Star Refrigeration Ltd, United Kingdom

Abstract: The use of variable speed drives to improve the efficiency of rotating machines, particularly at part-load conditions, is now common practice but the operation of one machine in a refrigeration plant impacts on other machines and their energy consumption. This paper proposes methodologies for the refrigeration plant’s control system to calculate the optimum speed of machines to take best advantage of variable speed control to maximise overall refrigeration plant efficiency.

The machines considered in this work are particularly compressors and fans. The characteristics of fan speed against energy consumed and airflow are considered. The impact of airflow across heat exchangers on refrigerant pressures and their corresponding impact on compressor efficiency are then calculated to determine optimum speeds for all operating conditions. A methodology for the control system of a refrigeration plant to calculate the optimum machine speeds, whilst taking account of fan, heat exchanger and compressor characteristics is proposed.

Diffusion Absorption Refrigeration Cycle Analysis with Low GWP Refrigerants

Presenting Author: Lee, Gawon, Korea University, Republic of South Korea

Abstract: Many refrigerant/absorbent pairs such as ammonia/water and various HCFCs or HFCs with organic absorbents have been applied for diffusion absorption refrigeration (DAR) system. However, due to the toxicity and corrosiveness of ammonia and high GWPs of other refrigerants, this study focuses on applying low-GWP refrigerants as alternatives and executing a numerical simulation of the DAR system. R600a/n-Octane is used for the working fluids and helium is chosen as an auxiliary gas. The performance and minimum evaporation temperature characteristics are investigated with different generator temperatures in the range of 85°C-160°C. The effects of the total system pressure and the evaporation temperature are also considered as the key parameters. It was found that minimum evaporation temperature monotonically dropped as the generator temperature increased. However, the coefficient of performance (COP) reached its peak at a certain point and decreased when the generator temperature increased beyond a critical point. The highest COP was estimated 0.48 at the total system pressure of 3.5 bar and the generator temperature of 85°C.
Dynamic Analysis of Energy Recovery Utilizing Thermal Storage from Batch-wise Metal Casting

Presenting Author: Andresen, Trond, SINTEF Energy Research, Norway

Abstract: The thermal exergy contained in the liquid metal in ferroalloy production makes it an interesting source for energy recovery. The heat released during casting is rarely utilized today. This work investigates the feasibility of continuous power production from batch wise ferroalloy casting using an energy recovery system concept that includes a thermal energy storage to buffer captured heat between casting cycles and enable a more stable heat supply to a Rankine cycle. A dynamic model of the heat recovery and storage system was developed, and a demonstration case applied to evaluate basic system behaviour. Every two hours, liquid metal at 1450 °C was poured into moulds and placed in a cooling tunnel. With the investigated concept, only 54.6 % of the available heat was captured into the system, indicating a potential for further improvements. Overall, the system was able to output 667 kWhel from the 4 005 kWh of thermal exergy available in the metal in each casting cycle, equivalent to an exergy efficiency of 16.7 %.

Dynamic Simulation Of A PV Driven Hydraulic Based Vapour-Compression Heat Pump

Presenting Author: Dahmani, Merzaka, Batna 1 University, France

Abstract: An innovative thermal-hydraulic process for cooling has been developed. The work of compression is performed by an alternating movement of a liquid piston. The inert liquid, while compressing the refrigerant, flows through a hydraulic pump. The liquid motion oscillates between two cylinders operating at different operating pressures: one is connected to the evaporator, while the other is connected to the condenser.

The paper presents the results of dynamic thermodynamic modeling and simulations of an air conditioning system where the conventional compressor is replaced by the new hydraulic system. The calculations are performed on the OpenModelica environment. The case study examines the feasibility of connecting the water pump in the refrigeration system to a PV array in a rural house located in Algeria. Indeed, a high efficient compression system helps the PV system to take advantage of the match between cold demand and the solar resource availability with an optimal size.

Enabling Power Production from Challenging Industrial Off-gas – Model-based Investigation of a Novel Heat Recovery Concept

Presenting Author: Skjervold, Vidar Torarin, SINTEF Energy Research, Norway

Abstract: Off-gas from the metal industry is a significant surplus heat source that is often not utilized due to lack of internal and external heat demands. Power production from the surplus heat in the off-gas could be a promising option for utilization. This work considers an off-gas at 150 °C from a metallurgical process, suitable for a Rankine Cycle (RC). Metallurgical off-gas typically contains particles that can deposit on heat exchanger surfaces, therefore requiring specialized heat recovery solutions for robustness and consistent performance. To maximize competitiveness of an RC implementation, it is crucial to recover the surplus heat at the highest possible temperature. We explore a novel plate-type heat exchanger concept for improved heat recovery from scaling-prone
Energy Analysis of a Heating and Cooling Plant Equipped with a Thermally Driven Heat Pump and PVT Collectors

Presenting Author: Noro, Marco, University of Padova, Italy

Abstract: Solar assisted heat pumps till now have used the solar collectors as a cold source. Solar collectors provided when possible direct heating, otherwise they offered temperature levels higher than outside air for the heat pump evaporator. At the same time, solar thermal cooling exploits solar collectors and the absorption chiller only in hot months. The paper considers the possibility of employing ETCs to drive an absorption heat pump that is in summertime the absorption chiller. The cold source is the ground which is recharged by the solar collectors in mid seasons and by the cooling of absorber-condenser in summer. The study analyses the system behaviour in yearly operation evaluating also the role of suitable storage capabilities in a temperate climate, considering the contribute to the energy balance of a PVT section.

Energy Recovery From Furnace Off-Gas: Analysis Of An Integrated Energy Recovery System By Means Of Dynamic Simulation

Presenting Author: Andresen, Trond, SINTEF Energy Research, Norway

Abstract: Surplus heat recovery and electricity generation from furnace off-gas has been implemented at several silicon and ferro-alloy plants in Norway. There is likely significant potential for improvement of both technology elements, system concept, and operation methodology. The main reported issues in current systems include challenging heat recovery due to heat exchanger wear, operation instabilities due to intermittent changes in furnace off-gas conditions, as well as required downtime due to system maintenance.

In this study, an integrated system for energy recovery from furnace off-gas has been analyzed by means of dynamic simulations with Dymola/Modelica. Electricity generation using a steam Rankine cycle and heat export to district heating were included. Efficient operation of the system is challenged by frequently occurring temperature spikes in the off-gas and fluctuating district heating demand. Focus of this study was the comparison of different operation modes to efficiently handle the transient effects and their impact on overall energy system performance.

Evaluation Of Different ORC Power Plant Concepts For Geothermal Heat And Power Generation

Presenting Author: Eller, Tim, Center of Energy Technology, University of Bayreuth, Germany

Abstract: In this work, different geothermal heat and power generation concepts are evaluated under techno-economic aspects. The investigated solutions cover different geothermal conditions and ORC power plant technical features available in Germany. The evaluation is based on annual simulations by using Aspen Plus V8.8. For the heat demand, a peak load of 5 MW is assumed. In case of a geothermal well-head temperature of 135 °C, the double-stage ORC shows a second law efficiency of 38.5 %, while the one-stage concept leads to 33.1 %. In general, the analysis shows that
the technically more challenging ORC concept leads to a higher amount of produced electrical energy and to a lower levelized cost of electricity (LCOE). For instance, the double-stage ORC provides a higher turbine power output than the one-stage. In addition, an economic analysis shows that the double-stage concept leads to a slightly lower LCOE of 13.79 €ct/kWh compared to the one-stage ORC. The results enable operators and planners to identify the most suitable power plant configuration in dependence of reservoir conditions and specific heating demand.

Experimental Comparison of HCFO R1233zd(E) and R1224yd(Z) in a High Temperature Heat Pump up to 150 °C

Presenting Author: Arpagoaus, Cordin, NTB University of Applied Sciences of Technology Buchs, Switzerland

Abstract: Hydrofluoroolefins (HCFO) are part of the 4th generation of refrigerants with very low global warming potential (GWP), almost zero ozone depletion potential (ODP), non-flammability and high critical temperature for use in high temperature heat pumps (HTHP). This study investigates R1233zd(E) and R1224yd(Z) experimentally as drop-in replacements for today's R245fa in a laboratory HTHP with 10 kW heating capacity. COPs in the range of 4.5 to 2.1 were achieved at 30 to 80 °C heat source and 30 to 150 °C heat sink temperature (30 to 70 K temperature lift). The COPs with R1224yd(Z) were comparable with R1233zd(E) in the entire operation map. An internal heat exchanger increased the efficiency by up to 16%. The heating capacity of R1224yd(Z) was on average 8% higher than that of R1233zd(E) due to the lower boiling temperature. R1233zd(E) potentially achieves higher condensing temperatures due to the higher critical temperature. After about 100 operating hours in the HTHP, there was negligible oil or refrigerant degradation.

Experimental Drop-in Replacement Of HFC-245fa By HCFO-1224yd(Z), A Low-GWP Working Fluid Candidate For Low-Temperature Organic Rankine Cycles

Presenting Author: Mateu-Royo, Carlos, University Jaume I, Spain

Abstract: The Organic Rankine Cycle (ORC) has gained prominence due to the urgent need to preserve the environment. This technology contributes to reduce the carbon footprint through the generation of electric power from renewable energy sources and low-grade waste heat. HFC-245fa is commonly used as working fluid in low-temperature ORCs, despite its zero Ozone Depletion Potential, its Global Warming Potential (GWP) is 858. With increasing restrictions on greenhouse gases, the price of those fluids with high GWP has risen. In this context, HCFO-1224yd(Z) has been recently presented as potential candidate for HFC-245fa replacement. Therefore, this work aims to experimentally test the suitability of using this low-GWP candidate in an existing low-temperature and small-scale HFC-254fa designed ORC. The drop-in replacement tests show similar behaviour between HFC-245fa and HCFO-1224yd(Z) and although HFC-245fa provides higher expander power output, net cycle efficiencies are similar, and several adjustments can be introduced to compensate the lower electrical output.

Experimental Investigation of Low GWP Alternative R1233zd(E) for Use in Organic Rankine Cycle Condensers

Presenting Author: Jacob, Tabeel A., Oregon State University, United States of America
**Abstract:** Simulated and experimental system level investigations of Organic Rankine Cycle (ORC) systems have shown that R1233zd(E) can be considered as a low global warming potential (GWP) alternative to R245fa, with higher thermal efficiencies, but lower power output per unit mass. In addition to thermodynamic considerations, the heat transfer performance and resulting component size of this alternative must be considered. Thus, in this study, we experimentally investigate in-tube condensation heat transfer coefficients and pressure drop of R1233zd(E) at representative ORC conditions, and compare the results with R245fa data and correlations from the literature. Experiments are conducted in a smooth round tube with inner diameter of 4.7 mm, mass fluxes from 100 to 400 kg m⁻² s⁻¹, and saturation temperatures of 30 °C to 60 °C. The results are then used to design and compare the size of a water- and air-cooled condenser using the two different refrigerants.

**Fast Calculation Method For Performance Upper-limit Of (Quasi) Two-stage Vapour Compression System**

**Presenting Author:** Yang, Xufei, Tsinghua University, People’s Republic of China

**Abstract:** (Quasi) two-stage system is an important method to improve the energy efficiency of vapour compression refrigeration cycle, especially under high compression ratio. Since vapour injection was proposed for room air conditioners, many researches were conducted to study the performance of the vapour injection system and the factors that affected the performance of system. Many experiments and simulations were conducted to investigate the performance of two-stage compression or gas injected systems. However, the performance improvements reported by different researches vary in a large range due to different systems, refrigerants, operating conditions or methods. These results are barely comparable, which is not good for distinguishing the wrongs or drawbacks in design or control of the system. Therefore, it is important to propose a method which can quickly obtain the performance upper-limit of different refrigeration under different operating conditions in order to evaluate the research conclusions. In this research, general analytical expressions of (quasi) two-stage vapour compression cycle are proposed and verified to quickly calculate the upper-limit performance of (quasi) two-stage systems.

**Fluid Selection for Small-Scale Rankine Cycle Plants: Can You Draw Some Lines in The Sand?**

**Presenting Author:** White, Martin, City University of London, United Kingdom

**Abstract:** The aim of this paper is to define general guidelines for fluid and cycle selection for small-scale Rankine cycle power systems based on heat-source temperature, heat-source temperature drop and heat sink availability. This is developed through optimisation studies for subcritical and supercritical cycles, which includes a model to estimate the achievable efficiency for a single-stage radial-inflow turbine, and the introduction of a fluid ranking procedure. The method is applied to 20 potential working fluids including hydrocarbons, hydrofluoroolefins, and siloxanes, alongside water, CO₂, Novec 649 and Novec 774. The results indicate that the top five working fluids are isobutane, isopentane, n-propane, R1233zd and n-pentane. Moreover, fluid selection is not significantly affected by heat-sink availability, whilst subcritical cycles are preferred for lower heat-source temperatures and heat-source temperature drops, whilst supercritical cycles are better for higher heat-source temperatures and are most suitable when trying to maximise power output.
Focus on Ammonia Expander in a Hybrid Cycle for Power Production and Cooling

Presenting Author: Tauveron, Nicolas, CEA, France

Abstract: This work aims at studying and developing a thermodynamic heat recovery cycle for the combined production of cold energy and low power electricity (5 kW of cold, 1 kW of electricity) using water/ammonia as working fluid. The target temperature range is low enough (80 to 160 °C) to suit on-road transportation, residential and various industrial heat recovery applications. Thermodynamic modeling of the cycle was carried out and a parallel architecture was proposed, in which the refrigerant vapor at the output of the generator can be used to feed the expander (production of electricity) and/or the condensation-expansion-evaporation part (production of cold).

Two technologies of expander are investigated: volumetric and turbine components are considered. Different criteria are used to select the most suitable technology: experimental performance (1kW ammonia turbine is currently tested at the laboratory), model (a detailed model of the complete hybrid cycle is developed) and possibility of reverse mode (which opens a large range of applications).

Gradient Based Design Optimization of a Radial Inflow Turbine

Presenting Author: Hagen, Brede Andre Larsen, NTNU - Norwegian University of Science and Technology, Norway

Abstract: The expander is one of the key components of an ORC as the cycle efficiency strongly depends on the expander efficiency. This paper presents a method for design optimization of a radial inflow turbine (RIT) using a mean-line model. The novelty of this work lies in the equation-based formulation of the mathematical problem which enables the use of an efficient gradient based method for optimization. This means that there is no distinction between real decision variables such as specific speed and specific diameter, and parameters that are unknown a priori such as rotor outlet entropy and velocity. Constraints are imposed to ensure conservation of mass- and energy, and to ensure a feasible design, and the objective is to maximize the isentropic efficiency. The optimizations carried in this work converged to a feasible solution within a few seconds and we therefore recommend the proposed method for preliminary RIT-design or to be integrated into an ORC system design model.

Heat Exchanger for ORC, Adaptability and Optimization Potentials

Presenting Author: Haugg, Albert Thomas, AKG Thermotechnik International GmbH & Co. KG, Germany

Abstract: The recovery of waste heat requires heat exchangers to extract it from a liquid or gaseous medium into another working medium, a refrigerant.

In Organic Rankine Cycles (ORC) on Combustion Engines there are two major heat sources, the exhaust gas and the water/glycol fluid from the engine’s cooling circuit. A heat exchanger design must be adapted to the different requirements and conditions resulting from the heat sources, fluids, system configurations, geometric restrictions, and etcetera.
The Stacked Shell Cooler (SSC) is a new and very specific design of a plate heat exchanger, created by AKG, which allows with a maximum degree of freedom the optimization of heat exchange rate and the reduction of related pressure drop.

This optimization in heat exchanger design for ORC systems is even more important because it reduces the energy consumption of the system and therefore maximizes the increase in overall efficiency of the engine.

**Heat Transfer Assessment of the Low GWP Substitutes for R245fa in ORC**

**Presenting Author: Zilio, Claudio, Universita di Padova, Italy**

**Abstract:** This paper presents the heat-transfer assessment of different low GWP substitutes for traditional R245fa as a working fluid for ORC. The assessment was obtained by applying both an experimental analysis based on the direct measurement of thermal (heat transfer coefficients) and hydraulic (pressure drops) performances and a theoretical analysis based on a specific Performance Evaluation Criteria (PEC), the Total Temperature Penalisation (TTP), in the specific case of boiling and condensation inside smooth and microfin tubes. The results of the assessment confirm that the refrigerants R1233zd(E), R1234ze(Z) and R1224yd(Z) have comparable heat transfer characteristics to R245fa.

The use of theoretical assessments tuned on experimental measurements provides a sound procedure for the heat-transfer assessment of the low GWP alternatives for traditional HFC working fluids in ORC.

**Investigation of Novel Configuration for Dual Organic Rankine Cycle Configurations for Maximization of Waste Heat Utilization**

**Presenting Author: Spale, Jan, Czech Technical University in Prague – University Centre for Energy Efficient Buildings, Czech Republic**

**Abstract:** Thermal cycles based Organic Rankine Cycle (ORC) are nowadays the most convenient method for conversion of the low-temperature heat to electricity. Alternative concepts combining (cascading) multiple are being investigated yet the theoretical efficiency gain hardly satisfies the added complexity and uncertainty.

A common approach is a dual ORC (DORC) which splits the heat input into two serial cycles. ORCs match the temperature profile rather well and cascading configurations exhibit large exergy loss from the superheated vapours during heat rejection.

This work presents a thorough theoretical analysis of a novel configuration of DORC for better utilization of the waste heat source. The high-temperature (HT) cycle is designed to exploit maximum energy from the heat source and to condense near ambient. The heat input into the low-temperature (LT) cycle is driven only by the vapour desuperheating after the expansion in the HT cycle. This configuration is compared to other ORC and DORC configurations.

**Latent Heat And Thermochemical Storage As Enablers For Waste Heat-to-Power And Heat-Upgrade: A General Approach**

**Presenting Author: Manente, Giovanni, University of Birmingham (UK), United Kingdom**
**Abstract:** Most excess heat/cold in industrial processes is unrecovered due to intermittency and variability in grades and amounts, which complicates the heat-to-power conversion and heat upgrade using traditional technologies. The decoupling of heat sources/sinks and thermal power utilisation via generation/heat upgrade enabled by the integration of a suitable storage system has the potential to address the challenges. The aim of this study is to develop a framework based on heat storage (latent and thermochemical), heat-to-power (organic/steam Rankine cycle, etc.) and/or heat upgrade (heat pumps, etc.) options for the utilization of the industrial waste heat. A wide temperature range is considered which spans applications from the food to the steel sectors. Based on an extensive literature survey, mutual links are established on the basis of temperature and illustrated in maps. This facilitates the primary screening of the latent heat and thermochemical storage systems for heat to power and heat upgrade applications. With such generalized maps, the application of the Rankine cycle (both direct and reverse) using refrigerants in relationship to the thermal energy storage technologies is discussed.

**New ISO 17584 Standard Formulations for cis-1,1,1,4,4,4-Hexafluorobutene [R1336mzz(Z)] and trans-1-Chloro-3,3,3-trifluoropropene [R1233zd(E)]**

**Presenting Author:** Akasaka, Ryo, Kyushu Sangyo University, Japan

**Abstract:** New fundamental equations of state have recently been developed for cis-1,1,1,4,4,4-hexafluorobutene [R1336mzz(Z)] and trans-1-chloro-3,3,3-trifluoropropene [R1233zd(E)]. The former is a very promising candidate for working fluids in organic Rankine cycles, and the latter is a potential refrigerant alternative for 1,1,1,3,3-pentafluoropropane (R245fa) for centrifugal chillers. There are regions in previous equations of state for these fluids where calculated values exceed the uncertainties required for use of the fluids; for example, liquid-phase sound speeds show relative deviations of over 1% from accurate measurements. The new equations calculate all thermodynamic properties within the experimental uncertainties of the measurements. Typical relative deviations are 0.05% for densities in the temperature range from 220 K to 460 K, 0.1% in densities outside this range, 0.03% for vapor pressures, and 0.04% for sound speeds in the liquid and vapor phases below 480 K. These equations have been recommended as international standards by the working group presently revising ISO 17584 (Refrigerant Properties). The equation for R1336mzz(Z) is already available in NIST REFPROP 10.0

**Opportunities to Decarbonise Process Heating Using Heat Pumps in New Zealand**

**Presenting Author:** Cleland, Don, Massey University, New Zealand

**Abstract:** Process heating accounts for 27% of New Zealand’s energy-related GHG emissions, and about 25% is for food processing mostly at temperatures <200oC. Heat pumps (HPs) are an opportunity to decarbonise process heating because NZ’s electricity is >85% renewable, and electricity to fuel price ratio is about 3 and likely to lower as carbon charges increase. However, for most food processing sites once heat recovery is optimised, waste heat sources are seldom available above 60oC. HP opportunities are examined technically and economically via case studies. Below 120oC, existing technologies such as water MVR, ammonia high temperature and trans-critical CO2 HPs are suitable and available, and will become more economic as carbon prices rise. Cost of enhanced electricity supply and paucity of experience of such HPs in NZ are significant barriers. Above 120oC, multi-stage cascaded HPs or hybrid compression/absorption systems look promising. However, the lower COPs due to larger temperature lifts and the technology immaturity remain
significant barriers. To be successful, HPs will need to be closely integrated with other heat recovery and thermal storage systems.

**Organic Rankine Cycles Combined with Thermochemical Heat Transformers to Enhance the Power Output from Waste Heat**

**Presenting Author:** Manente, Giovanni, University of Birmingham, United Kingdom

**Abstract:** The conversion of waste heat into electricity in organic Rankine cycles (ORCs) is often limited by the incomplete utilization of the heat source due to the lack of adequate heat sinks below the pinch point. In this context, low temperature thermochemical sinks could provide new opportunities of heat integration, which have been largely overlooked until now. This study investigates the coupling of organic Rankine cycles with chemical heat pumps (i.e. thermochemical heat transformers). By taking advantage of the pressure dependence of the chemical equilibrium, a low grade heat source drives an endothermic reaction, leading the production of higher temperature heat source (heat upgrade) through an exothermic reaction. The upgraded heat can then be converted to power. Different chemical compounds and integration schemes have been investigated to optimise the ORC performance. The proposed integrated system improves by 7.5% the power output of an optimized ORC.

**Performance Prediction and Optimisation of Twin-Screw Expander**

**Presenting Author:** Vimalakanthan, Kisorthman, City, University of London, United Kingdom

**Abstract:** Positive displacement machines have been identified as appropriate expanders for small scale power generation systems such as ORCs. Screw expanders can operate with good efficiency for working fluids under both dry and two-phase conditions. Detailed understanding of the fluid expansion process is required to optimise the machine design and operation for specific applications, and accurate design tools are therefore essential. Using experimental data for air and R245fa expansion, both CFD and chamber models have been applied to investigate the influence of the inlet port geometry and leakage on the filling process. Both models are shown to predict pressure variation and power output with good accuracy. The validated chamber model is used to identify optimum volume ratio and rotational speed for the specified experimental conditions. Finally, the model is used to investigate the performance of the machine for the expansion of R245fa across a range of single and two-phase conditions.

**Potentials of Zeotropic Mixtures with Large Temperature Glides as Working Fluids for Organic Rankine Cycles (ORC) and Heat Pumps**

**Presenting Author:** Meyer, Benedikt Gregor, University of Technology Dresden, Germany

**Abstract:** Nowadays, zeotropic mixtures with a temperature glide up to 15 K are the state of art in air-conditioning. Less intention is spent to mixtures with larger temperature glides (LTG). The small number of research activities can be explained by the lack of promising applications as refrigerants in cooling applications. However, these glides can be beneficial for heat pump applications and Organic Rankine Cycles (ORC), since these systems mainly operate with sensible heat sources and heat sinks. The paper points out the potentials of LTG working fluids in heat pumps and ORCs and discusses fluid combinations for different temperature levels. The limits of these applications are
identified, an overview about challenges reported in the literature are presented and the advantages are demonstrated. Furthermore a new kind of ORC is presented, which operates as a heat transformer integrated in an industrial heat recovery system.

Predicting and Assessing Energy Performance of Refrigeration Systems

Presenting Author: Pearson, Andy, Star Refrigeration Ltd, United Kingdom

Abstract: Rising energy costs continue to motivate users of refrigeration to play close attention to the operating efficiency of their systems. In cold storage and distribution it is difficult to assess the effectiveness of improvement initiatives due to the large daily variations in system load and weather conditions. Specific Energy Consumption (SEC) is becoming more widely used, but it takes a long time to build an accurate assessment.

This paper presents a novel method of predicting annual SEC for cold stores, chill stores and distribution centres based on daily energy readings. Using measured data from various sizes and types of site the method was checked and a means of assessing the margin of error in the prediction was developed. A simple tool for evaluating the effect of maintenance and repair is presented.

Opportunities for extending the methodology to other types of refrigeration and air conditioning systems are considered.

Semi-empirical Evaluation of HCFO-1224yd(Z) as a Replacement for HFC-245fa in High Temperature Heat Pumps

Presenting Author: Mateu-Royo, Carlos, Universitat Jaume I, Spain

Abstract: This paper investigates a promising low-GWP refrigerant HCFO-1224yd(Z) as an alternative replacement for HFC-245fa in high temperature heat pumps. A comprehensive thermophysical properties analysis was realised along with thermodynamic modelling of a single stage cycle with Internal Heat Exchanger (IHX) and semi-empirical drop-in test replacement. The heat source temperature was fixed in 80 °C, whereas the heat sink temperature was varied from 110 to 140 °C to cover a wide range of industrial applications. The theoretical and semi-empirical results illustrate that the heating capacity of HCFO-1224yd(Z) becomes around 8.9% lower than HFC-245fa. However, the higher suction density of HCFO-1224yd(Z) compared to the reference fluid can compensate this phenomenon, reducing the compressor power consumption. Hence, HCFO-1224yd(Z) presents a COP increase up to 4.5% compared to the reference fluid. At heat sink temperature of 140 °C, HCFO-1224yd(Z) shows a COP of 2.33, whereas HFC-245fa has a value of 2.23. Therefore, HCFO-1224yd(Z) can be used as an alternative to HFC-245fa in high temperature heat pumps due to its proper thermophysical and environmental properties.

Simulation of Absorption Power Cycle and Organic Rankine Cycle Using Evacuated Tube Solar Collectors

Presenting Author: Novotny, Vaclav, Czech Technical University in Prague, Czech Republic

Abstract: Absorption power cycles (APC) working with LiBr-H2O working fluid, serve as an alternative to ORC for micro-scale applications. The APC, similarly to zeotropic ORC, has an advantage of higher exergy efficiency of heat exchangers by smoother temperature match of hot and cold fluids provided
by temperature glide of the working fluid. This work explores application with evacuated tube solar collectors a prospective low temperature heat source. Such configuration may be interesting for buildings application, offering to use excess of the thermal energy for electricity production. A model is developed coupling performance of the heat engine (APC and ORC) with the collectors. Behaviour and overall performance of such system is estimated based on weather data for one year. The results are compared to performance of photovoltaic modules. The models show lower potential for heat engines power production, but the APC system especially can be beneficial for its possibilities of thermal integration.

**Successful Application Examples of Industrial Heat Pumps in Switzerland**

**Presenting Author:** Arpagaus, Cordin, NTB University of Applied Sciences of Technology Buchs, Switzerland

**Abstract:** Domestic heat pumps are well established in Switzerland with 22,000 units per year and a market share of around 80% in new buildings. In the Swiss industry, fossil-fuel driven heat generation systems are still preferred, mainly due to the low gas-to-electricity price ratio. Sales of industrial heat pumps (>100 kW) are around 145 units per year, with growing importance in the food, chemical, pharmaceutical and paper industries. 30% to 40% reduction of CO2 emissions and savings of large quantities of fossil fuels are achieved. This study provides an up-to-date overview of 20 case studies of successful application examples of industrial heat pumps in Switzerland. The case studies include heating and cooling examples of the Swiss food industry with the production of chocolate, cheese, vinegar and meat as well as the heat treatment of metal parts and the generation of district heating. Potential applications are the generation of hot water, hot air and steam. The refrigerants used are R134a, R245fa, R1234ze(E), ammonia, and CO2.

**The Effect of Internal Efficiency of Expander on The Working Fluid Selection**

**Presenting Author:** Kustán, Réka, Budapest University of Technology and Economics, Hungary

**Abstract:** The final state of the expansion process has a crucial effect on the ORC design. If it ends in the dry vapour region, it requires isobar cooling for reaching the saturated vapour state, leading to smaller efficiency and higher investment and operating costs due to the extra recuperative heat exchanger. If however, the expansion terminates in the two-phase, wet region, the droplets may cause erosion problems and they may decrease the net efficiency due to moisture loss. Hence it is essential to design an expansion, where the process’s initial and final states are both saturated vapour states while all intermediate states are in the dry or slightly wet region.

Thus a method is proposed to determine the optimal working fluid for a real expander (characterized by isentropic efficiency) for a given heat source and heat sink with the simplest ORC layout.

**The Natural Cycle Of Development Applied to Refrigeration – Winners And Casualties**

**Presenting Author:** Lawrence, John Michael W, JTL Systems Ltd, United Kingdom

**Abstract:** Innovation occurs because of a change in the relationship between the environment, materials, technology and/or imagination. To illustrate natural variation, the plant development on a
The paper will examine the changes that have occurred in refrigeration technology using the biological model as the comparator. The varieties on the market of refrigerants, compressors, system structures, system controls etc. will be discussed in this light.

**Theoretical Analysis of Transcritical HTHP Cycles with low GWP HFO Refrigerants and Hydrocarbons for Process Heat up to 200 °C**

**Presenting Author: Arpagaus, Cordin, NTB University of Applied Sciences of Technology Buchs, Switzerland**

**Abstract:** Transcritical heat pump cycles are suitable for processes that require large temperature glides on the heat sink, such as air or hot water heating. Refrigeration systems or hot water heat pumps often apply transcritical CO₂ cycles. For industrial waste heat recovery with high temperature heat sources, transcritical CO₂ heat pumps are not suitable. This study investigates the feasibility of low GWP HFO refrigerants and hydrocarbons for the delivery of process heat up to 200 °C using transcritical HTHP cycles. Steady-state models with IHX and parallel compression have been developed to analyse the cycle performance for heating air from 30 to 200 °C and water from 100 to 200 °C. The design aspects of the main cycle components are discussed, especially compressor and refrigerant-oil selection. The analysis shows that the gas cooler pressure is the most important optimization parameter to achieve highest efficiency up to 3.5. The transcritical cycle with IHX is easy to control and is technically feasible with one or two compression stages. R1233zd(E), R1224yd(Z) and R600 are considered the best refrigerant candidates.