Paper ID:1105 - Predicting and Assessing Energy Performance of Refrigeration Systems

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.

Paper ID:1106 - The Natural Cycle Of Development Applied to Refrigeration – Winners And Casualties

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 virgin site can be considered. If we take a cleared piece of land, fairly soon some a pioneer specy will establish itself. Initially it will have no competition and it will spread throughout the space. Other species will follow and there will be a variety of species in the space. This variety of species will rise to a maximum. Competition will continue: variety will decrease – non-maximally adjusted species will be weeded out. Possibly the pioneer becomes extinct. The most successful will predominate and the space may become a monoculture. This is called the climax level. It applies for that time/space.

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.

Paper ID:1107 - Energy Analysis of a Heating and Cooling Plant Equipped with a Thermally Driven Heat Pump and PVT Collectors

Lazzarin, Renato; 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.

Paper ID:1108 - Investigation of Novel Configuration for Dual Organic Rankine Cycle Configurations for Maximization of Waste Heat Utilization

Novotny, Vaclav; Spale, Jan*; Szucs, David Juraj; Vodicka, Vaclav; Mascuch, Jakub; Kolovratnik, Michal,

***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.

Paper ID:1112 - Determining the Optimum Condenser Fan Speed for Refrigeration Systems

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.

Paper ID:1114 - Applied Optimisation of a Twin Screw Expander for Electrical Power Generation in a Waste Heat Recovery System Using an Organic Working Fluid

Spencer, Sean*; Churchus, Rebecca; Oliver, David; Miller, Jeremy; Lawson, Donald; Smith, Richard,

***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.

Paper ID:1116 - Performance of a Linear Refrigeration Compressor with Small Clearance Volume

Zhu, Zhennan*; Jiang, Hanying; Liang, Kun; Li, Zhaohua,

***University of Sussex, United Kingdom (This paper may be withdrawn)**

Abstract: Linear compressor could be the pre-dominant efficient design for refrigeration in the future. The cooling capacity of the refrigeration system using linear compressor can be increased by decreasing axial clearance volume, which results in the deterioration of motor efficiency at the time. This paper experimentally compares the refrigeration performance of a linear compressor among using various clearance volumes and using an offset of 0 mm. Measurements with different clearances and an offset of 0 mm were carried out for compressor strokes of 11-13 mm and pressure ratios of 2.5-4.0 using R1234yf. The cooling capacity for a pressure ratio of 2.5 and a stroke of 13 mm increases by 12% as the clearance decreases from 1.07 mm to 0.4 mm. It was concluded that the operation with small axial clearance is more beneficial for the overall coefficient of performance (CoP) when operated at high pressure ratios.

Paper ID:1117 - Semi-empirical Evaluation of HCFO-1224yd(Z) as a Replacement for HFC-245fa in High Temperature Heat Pumps

Mateu-Royo, Carlos*; Navarro-Esbrí, Joaquín; Mota-Babiloni, Adrián; Molés, Francisco; Amat-Albuixech, Marta,

***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 ºC, whereas the heat sink temperature was varied from 110 to 140 ºC 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 ºC, 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.

Paper ID:1118 - Review of Ultra-Low GWP Molecules – Thermodynamic Properties and Their Characteristics for Use in HVAC&R

Kujak, Stephen Anthony*; Schultz, Kenneth John; Sorenson, Elyse Marie,

***Trane, United States of America**

Abstract: This paper provides a review of current, proposed and potential future molecules with ultra-low GWP suitable for use as refrigerants in vapor compression (e.g., HVAC&R) or expansion (e.g., ORC) applications. A summary of thermodynamic properties and cycle performance, along with flammability, stability, and toxicological properties is provided for a variety of single molecules (in pure form), including descriptions of potential application areas.

This paper summarizes information on the olefin-based refrigerants currently in use, such as R1130(E), R1336mzz(Z), R1233zd(E), R1234ze(E), and R1234yf. It also includes several “new” molecules recently brought forward to serve as potential low GWP refrigerants by themselves or as components to create new low GWP refrigerant blends. These include R1224yd(Z), R1336mzz(E), R1123, R13I1 (CF_3I) and R1132a. In addition, potential future molecules suggested by McLinden (2017) are reviewed, such as R1132(E) and trifluoropropyne.

Paper ID:1119 - Characteristics of Blends Using Low GWP Molecules for Application in Centrifugal and Screw Compressor-based Chillers

Schultz, Kenneth John*; Kujak, Stephen Anthony; Sorenson, Elyse Marie,

***Trane, United States of America**

Abstract: This paper summarizes information on blends utilizing ultra-low GWP (<10) olefin-based refrigerants targeted to application in centrifugal and screw compressor-based water chillers. These types of chillers tend to use shell-and-tube heat exchangers that permit fractionation to occur when running with zeotropic blends. Fortunately, many of these blends form azeotropic mixtures, such as R513A, R514A, R515A/B, and R516A.

This paper provides a review of the thermodynamic interactions when blending various ultra-low GWP refrigerants suitable for use in vapor compression (e.g., HVAC&R) or expansion (e.g., ORC) applications. This includes molecules already in commercial use and those that have recently come to light. A summary of thermodynamic properties, thermodynamic cycle performance, heat transfer characteristics, flammability, stability, and toxicological properties are provided.

Paper ID:1120 - Characteristics of Blends Using Ultra-Low GWP Molecules for Application in Positive Displacement Compressor-based Systems Operating at Higher Pressures

Schultz, Kenneth John*; Kujak, Stephen Anthony; Sorenson, Elyse Marie,

***Trane, United States of America**

Abstract: This paper summarizes information on higher (R404A/R22- to R410A/R32-like) pressure blends utilizing ultra-low GWP (<10) olefin-based refrigerants targeted to application in HVAC&R systems. This includes molecules already in commercial use (e.g. R1234yf) and those that have

recently been brought forward (e.g. R13I1, R1123, and R1132a). In addition, potential future molecules suggested by McLinden et al. (2017) are reviewed (e.g. R1132(E)). A summary of thermodynamic properties and cycle performance, heat transfer characteristics, flammability, stability, and toxicological properties are provided.

McLinden, M. O. et al. Limited options for low-global-warming-potential refrigerants. Nat. Commun. 8, 14476 doi: 10.1038/ncomms14476 (2017).

Paper ID:1121 - Performance Predictions of Adiabatic Flow of Isobutane Inside a Helically Coiled Capillary Tube: Artificial Neural Network

Dubba, Santhosh Kumar*; Menda, Venkata Ramana; Dhurandher, Bhisham Kumar; Kumar, Ravi,

***Aditya Institute of Technology and Management, Tekkali, India**

Abstract: This paper presents an artificial neural network correlation for predicting the mass flow rate of R-600a inside a helically coiled capillary tube. 480 sets of experimental measured mass flow rate data of R-600a inside straight and helically coiled capillary tube covering wide range of inlet sub-cooling degree of 3-15°C, inlet pressure 600-750 kPa, capillary geometry (capillary tube diameter: 1.12-1.52 mm and length: 2.8-4.6 m) and coil diameter of 40, 60 & 80, collected from the literature to train the neural network model. The neural network model of an adiabatic straight capillary tube shows the variation in the mass flow rate data measured through experiments within ±20 percentage error band. Also the neural network model of an adiabatic coiled capillary tube predicts the mass flow rate data within ±20 percentage of experimental data.

Paper ID:1122 - Experimental Investigation of Low GWP Alternative R1233zd(E) for Use in Organic Rankine Cycle Condensers

Jacob, Tabeel A.*; Fronk, Brian M.,

***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.

Paper ID:1124 - Opportunities to Decarbonise Process Heating Using Heat Pumps in New Zealand

Cleland, Don*; Love, Richard; Neale, James; Atkins, Martin,

***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 CO_2 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.

Paper ID:1125 - Potentials of Zeotropic Mixtures with Large Temperature Glides as Working Fluids for Organic Rankine Cycles (ORC) and Heat Pumps

Meyer, Benedikt Gregor*; Thomas, Christiane; Hesse, Ullrich,

***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.

Paper ID:1128 - Fast Calculation Method For Performance Upper-limit Of (Quasi) Two-stage Vapour Compression System

Yang, Xufei*; Wang, Baolong; Cheng, Zuo,

***Tsinghua University, China, People's Republic of**

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.

Paper ID:1129 - Experimental Comparison of HCFO R1233zd(E) and R1224yd(Z) in a High Temperature Heat Pump up to 150 °C

Arpagaus, Cordin*; Bertsch, Stefan S.,

***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.

Paper ID:1131 - What Will Professor Rankine Inspire In You?

Spanswick, Ian David*,

***O2RC Solutions, United States of America**

Abstract: Professor Rankine and his perspectives have been central to my career. Following in my father’s footsteps and from beginnings in the UK, via France to eventually emigrating to the USA, this paper provides an overview of just some of the ideas that I was part of, the places, equipment and experiences this provided. My hope is that by exploring these less traditional industrial refrigeration and ORC ideas this might inspire solutions to the new challenges currently facing humanity.

What will Professor Rankine inspire in you?

Paper ID:1133 - Improvement of Capacity and COP Through Use of Two-stage Compressor in Transcritical R744 Systems

Elbel, Stefan*; Hrnjak, Pega,

***University of Illinois at Urbana-Champaign, United States of America**

Abstract: Transcritical R744 systems have become increasingly popular in recent years. For applications that span a wide temperature range between the heat source and heat sink, the use of two-stage compressor results in numerous advantages in terms of efficiency and compressor discharge temperature. This paper presents experimental data for a transcritical R744 compressor system operating at high heat rejection temperatures. A comprehensive system model was developed and validated with the experimental results. Based on this, the simulation tool was used to further optimize the system design specifically to accommodate the two-stage compression process. The optimum heat transfer area distribution has been determined to simultaneously ensure efficient intercooling at intermediate pressure and gas cooling at the high-pressure level. Simultaneously, the system was also optimized with respect to optimal intermediate pressure. The results show that for this particular system, the optimum intercooler pressure deviated substantially from the standard design approach that uses the geometric mean between suction and discharge pressures.

Paper ID:1134 - Ejector Selection Made Easy: A New Way of Mapping Performance of Two-phase Ejectors

Haider, Muhammad*; Elbel, Stefan,

***University of Illinois at Urbana-Champaign, United States of America**

Abstract: Ejector as a work recovery device offers potential for developing energy efficient heating and cooling systems based on vapor compression technology. For many applications, the operating conditions vary significantly, leading to considerable performance degradation when system is operated in off-design conditions. Therefore, system designing warrants development of accurate ejector performance models for wide range of operating conditions. In this paper, a novel methodology for ejector performance maps is proposed using ejector efficiency as performance parameter and volumetric entrainment ratio as characterizing parameter. The proposed performance map is developed after conducting experiments to find appropriate performance representation where ejector driven flow can be characterized using ejector motive flow. The developed performance map can predict ejector pressure lift within an accuracy of 20% using an iterative solver. In later part of the paper, a system design study is conducted to select optimum ejector for a given compressor using proposed ejector performance maps.

Paper ID:1135 - Evaluation Of Different ORC Power Plant Concepts For Geothermal Heat And Power Generation

Toselli, Davide; Eller, Tim*; Weith, Theresa; Heberle, Florian; Brüggemann, Dieter,

***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.

Paper ID:1137 - Working Fluid Screening for Ocean Thermal Energy Conversion (OTEC) Applications

Bell, Ian*,

***NIST, United States of America**

Abstract: Ocean Thermal Energy Conversion (OTEC) is one of the few renewable energy production systems that can provide base load capacity. While there are significant technical challenges with OTEC systems, a comprehensive study of working fluids for OTEC applications has not been carried out thus far. In this work we will apply techniques that we have previously used to screen refrigerants for air conditioning applications in order to screen candidate working fluids for OTEC.

Our hope is that we will identify a novel working fluid that is superior to ammonia, which is the most popular working fluid proposed for OTEC to date. We will consider a few different optimization figure-of-merits.

Paper ID:1140 - Comparison of CO_2-Glycol-Ammonia Cascade to Trans-Critical CO_2 and Ammonia-CO_2 Cascade Systems

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 CO_2 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 CO_2 system.

This paper describes the CO_2-glycol-ammonia cascade system and presents examples of installed systems. The paper then compares trans-critical CO_2, ammonia- CO_2 cascade and CO_2-glycol-ammonia cascade systems, and concludes with recommendations in terms of efficiency and capital cost.

Paper ID:1141 - Diffusion Absorption Refrigeration Cycle Analysis with Low GWP Refrigerants

Lee, Gawon*; Kim, Gahyeong; Kang, Yong Tae,

***Korea University, Korea, 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℃-160℃. 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℃.

Paper ID:1143 - Gradient Based Design Optimization of a Radial Inflow Turbine

Hagen, Brede Andre Larsen*; Cavo, Matteo; Andresen, Trond; Nekså, Petter,

***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.

Paper ID:1144 - Dynamic Analysis of Energy Recovery Utilizing Thermal Storage from Batch-wise Metal Casting

Andresen, Trond*; Lingaas, Simon J. N.; Hagen, Brede A. L.; Nekså, Petter,

***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 %.

Paper ID:1145 - Enabling Power Production from Challenging Industrial Off-gas – Model-based Investigation of a Novel Heat Recovery Concept

Skjervold, Vidar Torarin*; Skaugen, Geir; Andresen, Trond; Nekså, Petter,

***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 off-gas. Simulations show that the investigated concept can be competitive both in terms of weight and compactness compared to both a clean gas reference exchanger and alternative dirty gas concept.

Paper ID:1146 - Performance Prediction and Optimisation of Twin-Screw Expander

Vimalakanthan, Kisorthman*; Read, Matthew; Kovacevic, Ahmed,

***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.

Paper ID:1147 - Simulation of Organic Rankine Cycle Heat Exchanger with DPF and DOC for Heavy-Duty Vehicle

***Ye, Zhenhong; Yang, Jingye; Chen, Jiangping,**

***Shanghai Jiao Tong University, China, People's Republic of**

Abstract: Effective heavy-duty vehicle waste heat recovery using Organic Rankine cycle technology is a key solution toward meeting the increasing fuel economy while high cost along with a long payback period hinders its development. The re-architecture of gas heat exchange by coupling ORC and diesel engines is an effective technical route. This paper is targeted to propose a new heat exchange equipped with Diesel Particulate Filters and Diesel Oxidation Catalysts. The simulation model of the ORC and engine system including four-cylinder high-pressure common rail direct injection and exhaust post-treatment was established. Performance of ORC and species concentration of exhaust post-treatment were studied based on chemical dynamics. The results show that chemical reaction heat can effectively improve the thermal efficiency and output work of ORC. The efficiency increased from 11.26% to 15.8% and the output work increased from 5.63KW to 6.63KW due to the extra heat input.

Paper ID:1148 - Focus on Ammonia Expander in a Hybrid Cycle for Power Production and Cooling

Tauveron, Nicolas*; Voeltzel, Nicolas; Phan, Hai Trieu; Gonzalez, Brigitte,

***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).

Paper ID:1149 - Comparing Three Methods for Design Analyses of Rankine Cycle for Waste Heat Recovery from Natural Gas Compression

Deng, Han*; Hagen, Brede; Nikolaisen, Monika; Andresen, Trond,

***SINTEF Energy Research, Norway**

Abstract: This study applies three methods for design of Rankine cycles utilizing waste heat in the oil and gas industry. The methods differ in the level of detail of heat exchanger model applied and in the flexibility with respect to heat exchanger design. All the methods involve formulating a constrained optimization problem with the objective of maximizing net power output, but vary in the constraints related to limit the size of the heat exchangers. The cycles with using two working fluids, n-butane and a n-butane/n-pentane mixture (30%/70%), are compared for each method. The methods yield different results; both the maximized net power output and the best-performing working fluid differ with respect to the method used, emphasizing the importance of method selection.

Paper ID:1151 - Evaluation of Heat Recovery Heat Exchanger Design Parameters for Heat-to-Power Conversion from Metallurgical Off-gas

Nikolaisen, Monika*; Skjervold, Vidar; Andresen, Trond,

***SINTEF Energy Research AS, Norway**

Abstract: Our study investigates and identifies key heat exchanger design parameters for minimizing the surface area of heat recovery heat exchangers. We explore the effect of basic heat exchanger design parameters on performance through a combined Rankine cycle and heat exchanger optimization. We consider both "ideal" and "real" heat exchangers. The ideal heat exchangers are characterized by few practical design constraints and provide a reference for the lowest achievable heat transfer surface area. The "real" heat exchangers are not based on detailed heat exchanger designs, but represent different practical design constraints inspired by well-known heat exchanger concepts. This enables evaluation of different heat exchanger types on a system level without detailed modelling of the heat exchangers. Results show that the different heat exchanger types result in significantly different surface areas under the investigated conditions. Concepts that allow large differences between hot and cold side cross-sectional flow areas and hydraulic diameters can be better optimized to off-gas heat-to-power conversion. Heat exchangers with these flexibilities, such as plate-and-fin type concepts, appear to be promising for off-gas heat-to-power conversion.

P**aper ID:1154 - Dynamic Simuation Of A PV Driven Hydraulic Based Vapour-Compression Heat Pump**

Dahmani, Merzaka*; Khaldi, Fouad; Stitou, Driss; Semmari, Hamza,

***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.

Paper ID:1155 - Analysis Of Load Variation Of Absorption Chiller With Rankine Cycle

Singh, Kirtivardhan*; Pandey, Kartikey,

***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 controls 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.

Paper ID:1156 - 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)]

Akasaka, Ryo*; Lemmon, Eric W.,

***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

Paper ID:1158 - Carbon Dioxide In Industrial Refrigeration

Webb, Stuart R*,

***Star Refrigeration Ltd, United Kingdom**

Abstract: Carbon dioxide (CO_2, R744) has a number of properties that make it an attractive working fluid for refrigeration systems, as demonstrated by the marked resurgence of CO_2 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, CO_2 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.

Paper ID:1160 - Multi-Component Numerical Investigation of a Micro Organic Rankine Cycle

Fadiga, Ettore*; Casari, Nicola; Suman, Alessio; Pinelli, Michele; Ziviani, Davide,

***University of Ferrara, Italy**

Abstract: Organic Rankine Cycles are frequently adopted for waste heat recovery applications from industrial processes. Micro-ORCs are characterized by low-grade heat sources (temperatures below 150 °C) with non-stationary operating conditions and small output power. ORC designers need to understand the system dynamics to perform the most efficient choice of components and working fluid. Furthermore, the analysis of off-design conditions can contribute tuning control strategies capable to deal with this variability. The authors propose a three-dimensional approach based on Computational Fluid Dynamics (CFD) for the study of the dynamics of ORCs. The simulation of a scroll expander coupled with plate heat exchangers has allowed the investigation of the dynamic behaviour of the two components. This demonstration shows the potentiality of this approach, investigating component mutual interaction, off-design conditions and the system's transient behaviour. The analysis is performed with an open-source CFD tool showing the importance of fully integrated 3D analyses.

Paper ID:1161 - Fluid Selection for Small-Scale Rankine Cycle Plants: Can You Draw Some Lines in The Sand?

White, Martin*; Sayma, Abdulnaser,

***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, CO_2, 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.

Paper ID:1162 - Investigation On The Performance Characteristics Of A Novel Heat Pump Directly Driven By Wind Turbine

Sun, Xiangyu*; Zhong, Xiaohui; Zhang, Mingming; Xu, Jianzhong,

***China, People's Republic of, China, People's Republic of**

Abstract: The typical wind energy utilization is transferring wind energy to electricity power, and then driving specific equipment according to specific requirements. For the demand of heating, heat pump is driven and the energy flows are from wind energy to electric energy, and then to thermal energy. To improve the energy conversion efficiency, avoid wind curtailment, and supply energy locally by distributed energy systems, a novel heat pump directly driven by wind turbine is proposed by deleting the conventional intermediate power generation link, which is consisted by three subsystems. One is the wind turbine to capture wind energy. The second one is the gearbox to transmit the energy, and drive the compressor belonging to the heat pump as the third subsystem. Due to the instability of wind energy, different wind conditions are tested to find the rule of coupling the wind turbine and the heat pump. The experimental results prove the feasibility and the high energy efficiency of the novel system.

Paper ID:1163 - Experimental Drop-in Replacement Of HFC-245fa By HCFO-1224yd(Z), A Low-GWP Working Fluid Candidate For Low-Temperature Organic Rankine Cycles

Amat Albuixech, Marta; Navarro-Esbrí, Joaquín; Molés, Francisco; Mota-Babiloni, Adrián; 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.

Paper ID:1166 - Thermodynamic Analysis of Low GWP HFO and HCFO Refrigerants in HTHP with Large Temperature Glides on the Heat Sink

Diewald, Kevin*; Arpagaus, Cordin; Hebenstreit, Babette,

***NTB University of Applied Sciences of Technology Buchs, Switzerland**

Abstract: High temperature heat pumps (HTHP) supplying process heat have a large application potential in the food, paper, and chemical industries. In this study, the low-GWP hydrofluoroolefins (HFO) and hydrofluorochloroolefins (HCFO) R1234ze(Z), R1336mzz(Z), R514A, R1233zd(E) and R1224yd(Z) are analysed as refrigerants in a single-stage IHX cycle, a two-stage extraction cycle (2SE) and a two parallel cycle (2CP). Achieving high temperature glides on the heat sink with supply 100 °C

to 160 °C and 70 °C inlet temperature is a focus of the study. At 130 °C supply temperature, the COP of the 2SE and 2CP cycles improves around 2.5 % and 7.8 % respectively compared to the IHX cycle. R1336mzz(Z) provided the highest COP in all three cycles, however the lowest volumetric heating capacity (VHC). In both, the 2CP and the 2SE cycle,the exergy losses in the condenser are reduced compared to the IHX cycle.

Paper ID:1167 - Air Cycle Feasibility Using a Novel, Single Rotor Compander for Refrigeration and Heating

Fenton, Jonathan*; Subert, Joseph; Hinchliffe, Kirsty; Bianchi, Giuseppe; Tassou, Savvas,

***FeTu, United Kingdom**

Abstract: Air-cycle is an alternative thermodynamic approach to vapour compression/adsorption cycles, satisfying cooling & heating needs for industrial and residential processes with zero GWP and zero ODP. This paper presents a one-dimensional analysis of a novel open air-cycle system, incorporating the FeTu™ positive displacement compander, a single spherical two-stage rotor acting both as compressor and expander. The cooling capacity and Coefficient Of Performance (COP) of a small 84mm rotor are simulated over temperature differentials between 0-80C and operating speeds 500-3000r/min. The indicated cooling power is 210W at 3000r/min and temperature differential (ΔT) of 80°C. The study indicates that this single device approach overcomes COP limitations normally associated with conventional air-cycle cooling solutions. Based on 20°C ambient air inlet temperature, the COP is determined to be 2.5 at ΔT 0°C, 5 at ΔT 20°C and 9 at ΔT 40°C. These simulations characterise the device and demonstrate pre-test performance and feasibility as a cooling/heating solution. A proof of concept test is eventually presented and benchmarked against the model results to outline paths for improvement for the 'roticulating' compander.

Paper ID:1168 - Theoretical Analysis of Transcritical HTHP Cycles with Low GWP HFO Refrigerants and Hydrocarbons for Process Heat up to 200 °C

Arpagaus, Cordin*; Bless, Frédéric; Bertsch, Stefan S.,

***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 CO_2 cycles. For industrial waste heat recovery with high temperature heat sources, transcritical CO_2 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.

Paper ID:1170 - The Effect of Internal Efficiency of Expander on The Working Fluid Selection

Kustán, Réka*; Groniewsky, Axel; Imre, Attila,

***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.

Therefore 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.

Paper ID:1171 - Accurate Modeling Of Heat Pump Cycles With Steam Injection In Off-Design Regimes Utilizing An Integrated Approach

Moroz, Leonid; Pastrikakis, Vasileios*; Yevlakhov, Viktor; Altukhova, Olga; Hoisan, Stanislaw,

***SoftInWay Inc., United States of America**

Abstract: The calculation of heat pump cycles is usually made with a number of assumptions. Common mistakes in this early stage are to improperly account for the hydraulic resistance of the heat exchange equipment, the use of constant compressor efficiency (independent from operating mode), and etc. All of these assumptions critically affect the change in parameters, important to the consumer.

The authors of this article consider an integrated method for the heat pump cycle designing in various operating modes. The proposed approach includes the preliminary design of the compressor unit and takes into account the influence of the heat exchangers' hydraulic resistance. The integration process of the calculated systems enables accurate evaluation of the parameters after the 1st stage of the compressor, taking into account the steam injection. The authors then compare the proposed approach against a cycle analysis which doesn't consider the additional influence of real equipment parameters.

Paper ID:1174 - Energy Recovery From Furnace Off-Gas: Analysis Of An Integrated Energy Recovery System By Means Of Dynamic Simulation

Rohde, Daniel*; Andresen, Trond; Zotică, Cristina; Wilpert, Paul,

***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.

Paper ID:1175 - Organic Rankine Cycles Combined with Thermochemical Heat Transformers to Enhance the Power Output from Waste Heat

Manente, Giovanni*; Ding, Yulong; Sciacovelli, Adriano,

***University of Birmingham (UK), 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.

Paper ID:1176 - Latent Heat And Thermochemical Storage As Enablers For Waste Heat-to-Power And Heat-Upgrade: A General Approach

Manente, Giovanni*; Ding, Yulong; Sciacovelli, Adriano,

***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.

Paper ID:1179 - Design Options for Increasing the Efficiency of an R717 Heat Pump

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.

Paper ID:1181 - Investigation of ORC Architectures for High-Temperature WHR from Naval Ship Service Diesel Generators (SSDGs)

Ren, Junyan*; Damle, Nishad G.; Caskey, Stephen; Shaffer, Bryce R.; Ziviani, Davide; Groll, Eckhard A.,

***Purdue University, United States of America**

Abstract: Naval vessels typically require several diesel engines for propulsion and electricity generation with an average thermal efficiency around 40-45%. Waste heat from naval diesel generators represents a significant opportunity to drive bottoming organic Rankine cycles (ORCs) to increase their fuel efficiency. Waste heat streams include both high-temperature exhaust gases and low-temperature cooling loops. In this work, a comprehensive numerical analysis is carried out to compare different cycle architectures to maximize the ORC power output at both full- and part-load conditions. Both subcritical and transcritical cycle architectures with evaporators in-series or in-parallel have been investigated. Novel high-speed spinning scroll expanders have been considered as expansion devices. Parametric studies have been conducted to assess the trade-off between ORC size and effectiveness of operation to determine an optimum payback period.

Paper ID:1183 - Successful Application Examples of Industrial Heat Pumps in Switzerland

Arpagaus, Cordin*; Bertsch, Stefan S.,

***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 CO_2 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 CO_2.

Paper ID:1184 - Parametric Analysis on Novel Self-Water Supply ORC Power System for Hot-spring Thermal Energy Conversion

Yasunaga, Takeshi; Okuno, Tomoya*; Ikegami, Yasuyuki,

***Saga University, Japan**

Abstract: The self-water supply organic Rankine cycle (ORC) power system is a combination of distillation and hot spring thermal energy conversion; thus, it is able to produce the electric power and water to supply the cooling tower simultaneously. The cycle uses low-pressure steam as a warm heat source produced by the flash evaporation in the vacuumed condition instead of flowing the hot spring water. It acquires to prevent the performance degradation of the evaporator caused by the scaling due to the supersaturated Ca, Si, and so on. In this study, the parametric analysis of a novel hybrid ORC is conducted to show the basic performance (i.e., the power generation and water production to feed to cooling water). The analysis clarified the possibility of up to 3% of distillated water feeding to the cooling water.

Paper ID:1185 - Theoretical Model Construction for Renewable Low-Grade Thermal Energy Conversion: An Insight From Finite-Time Thermodynamics

Yasunaga, Takeshi*; Ikegami, Yasuyuki,

***Institute of Ocean Energy, Saga University (IOES), Japan**

Abstract: The power production from low-enthalpy geothermal energy and the ocean thermal gradient, which use the finite temperature and finite flow rate of the heat source, has unique thermodynamic characteristics. Finite-time thermodynamics is one of the keys to analyzing the basics of the cycles in terms of performance. This study summarizes the former research on finite-time thermodynamics applied to low-grade thermal energy, including the Rankine cycle, and discusses the application to the performance analysis of the total system, components, and optimum operation and design optima in terms of engineering. In addition, pilot test results using a 30-kW ocean thermal energy conversion pilot test bench are analyzed and compared with results of parametric analysis and finite-time thermodynamic basis analysis to verify the thermodynamics theory.

Paper ID:1189 - Effect of Waste Heat Utilization on the Performance of Low Temperature Rankine Cycle

Shahrooz, Mina*; Lundqvist, Per; Nekså, Petter,

***KTH Royal Institute of Technology, Sweden**

Abstract: Low temperature Rankine cycle is a prominent solution for power generation in Waste Heat Recovery (WHR) application. The performance of this cycle is affected by various parameters including characteristics of heat source, working fluid and constraints in the system. In cases where the heat source has a limited mass flux and therefore variable temperature, the amount of extracted heat affects the performance of the cycle including net power and efficiency which is also related to the working fluid. This is in the paper expressed in terms of a heat utilization factor, which shows the ratio of extracted heat to the maximum possible extraction rate in the specific case. This factor affects the performance of the cycle by moving the pinch point location in the evaporator. Results indicate that this factor has great impact on the performance of the cycle and the effect varies for different working fluids.

Paper ID:1194 - Test and Validation of a Control System for a Small-Scale Energy Recovery System Based on Sliding-Vane Technology

Costanzo, Ida*; Murgia, Stefano; Valenti, Gianluca; Fasani, Francesco; Fumagalli, Cristian,

***Ing. Enea Mattei SpA, Italy**

Abstract: A significant amount of the total waste thermal energy is dissipated at low temperature, from 30 °C to 200 °C. The most widely used solution to take advantage of these low-enthalpy thermal sources is the use of an Organic Rankine Cycle (ORC). This paper presents a fully automated ORC-based recovery system in recuperative configuration, equipped with sliding-vane rotary pump and expander, that exploits waste heat generated by large-scale air compressors to produce the net electric power of about 2.7 kW. The hot source is the water from the compressors cooling system. The working fluid employed is R1233zd. The expander generator and the pump motor are driven both by inverters in order to vary the rotational speed and guarantee the system flexibility. The control logic implemented in the system is presented in the paper. The approach for the start-up phase and the settings for the system damage prevention are described. In order to evaluate the thermodynamic conditions of every significant point of the cycle, temperature and pressure transducers are installed on the system.

Paper ID:1198 - Refrigerant Lubricant Interaction In High-Temperature Heat Pump And Organic Rankine Cycle Systems

Cotter, Donal F*; Shah, Nikhilkumar; Hewitt, Neil; Huang, Ming J,

***Ulster University, United Kingdom**

Abstract: High-Temperature Heat Pumps (HTHPs) and Organic Rankine Cycles (ORCs) are well defined technologies used in energy conversion. Ongoing research and development of equipment and processes is enabling the operating envelope of these technologies to be extended to achieve higher temperatures and pressures. Lubricant plays a key functional role within primary plant, namely compressors and expanders preventing damage and wear, while also sealing, preventing corrosion and reducing energy requirements. These lubricant oils need to interact with low global warming potential refrigerant combinations without negating operational performance or damaging plant and equipment. An evaluation of these refrigerant lubricant compositions through testing is essential to ensure optimum performance is maintained within operational limits. This study is linked to an EU project CHESTER (Compressed Heat Energy STorage for Energy from Renewable sources) and reviews research based on HTHPs and ORCs that serves to provide a bases to understand integration of lubricant basestocks and working fluids to meet the demands of high temperature applications.

Paper ID:1200 - Scalability of Chemical Looping Heat Pump Technology

Kim, Junyoung*; James, Nelson A.; Groll, Eckhard A.; Braun, James E.; Ziviani, Davide,

***Purdue University-West Lafayette, United States of America**

Abstract: Air conditioning, space heating, and refrigeration account for approximately 40% of the electricity usage in the U.S. residential and commercial building sector. To improve energy utilization and reduce energy consumption, novel heat pumping technologies are needed. The concept of a chemical looping heat pump (CLHP) system has been previously investigated by of a CLHP system by means of a detailed thermodynamic model coupled with a 2D-discretized electrochemical cell model. Parametric studies on the cell size as well as flow ratthe authors and shown to have the potential for significant performance improvement compared with conventional vapor compression systems. The current work investigates the scalabilitye of the working fluids (IPA/Acetone) are performed to identify requirements for meeting target cooling capacities for residential and

commercial building applications under different operating conditions. Based on the simulation results, trade-offs between system performance and cell sizes are identified. For a 7 kW residential heat pump with a target COPc of 4.0, a minimum of 3000 stacks having a surface of 8,000 cm2 per stack is required.

Paper ID:1201 - Test Stand to Investigate a Vapor Compression Cycle at Varying Orientation and First Experimental Results

Brendel, Leon P. M.*; Braun, James E.; Groll, Eckhard A.,

***Purdue University, United States of America**

Abstract: Varying the orientation of a vapor compression cycle and describing observed effects is a research field that has received very little attention. This paper presents the design of a test stand that is dedicated to the investigation of body-force effects on a vapor compression cycle and is able to rotate 360° around one axis. Results could be useful for transport and microgravity applications and contribute to the understanding of two-phase flow in general. It is shown that at certain operating conditions, inclining the system can lead to a sudden decrease of subcooling.

Paper ID:1202 - An LNG-based System for the Combined Production of Power and Cooling

Atienza-Márquez, Antonio*; Bruno, Joan Carles; Coronas, Alberto,

***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.

Paper ID:1204 - A Dynamic Simulation of a Cryogenic Power Generation System on an LNG Fueled Vessel Based on ORC Technology technology

Li, Yi*; Wu, Dawei,

***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℃. 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.

Paper ID:1205 - Working Fluid Selection of a Novel Chemical Reactive Power Cycle for Different Heat Source Temperature

Kim, Junyoung*; James, Nelson A.; Groll, Eckhard A.; Braun, James E.; Ziviani, Davide,

***Purdue University-West Lafayette, United States of America**

Abstract: Waste heat and solar energy are viable alternative sources to generate electricity and reduce power production by conventional fuel burning thermal cycle power plants. On the one hand, Organic Rankine cycles (ORCs) are widely used to harness waste heat sources especially in the low- to medium temperature ranges, but they are characterized by relatively low thermal efficiency. On the other hand, steam Rankine cycles and supercritical CO_2Brayton cycles represent the state-of-the-art of solar concentrated power systems with peak thermal efficiencies of approximately 40%. To further improve energy conversion efficiency, a novel chemical reactive power cycle with a system layout similar to that of a basic ORC has been proposed by authors. The working fluid is allowed to undergo chemical reactions and useful work is extracted from both the expansion process and a fuel cell. In this work, the working fluid selection for different temperature ranges and applications is discussed.

Paper ID:1209 - Heat Transfer Assessment of the Low GWP Substitutes for R245fa in ORC

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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.

Paper ID:1214 - A Compact Reverse Rankine Cycle Combines Surface Enhancement and Jet Impingement to Remove High Heat Fluxes

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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.

Paper ID:1215 - A R744 Transcritical Refrigeration Test Rig Equipped With A Transparent Two-phase Ejector For Flow Visualisation: Experimental Study

Haida, Michal*; Fingas, Rafal; Szwajnoch, Wojciech; Smolka, Jacek; Palacz, Michal; Bodys, Jakub; Nowak, Andrzej J.,

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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.

Paper ID:1217 - High-Performance Air-Conditioning Refrigerants With Low GWP

Low, Robert Elliott*,

***Koura Global (Mexichem), United Kingdom**

Abstract: The average Global Warming Potential (GWP) of all refrigerants used must reduce to about 300 if international regulatory requirements are to be met. Yet as GWP reduces so must the focus be maintained on ensuring that the energy efficiency of any new refrigerant does not result in a perverse increase in indirect emissions of CO_2 from added power consumption. Koura Global has new air-conditioning refrigerants in active development which offer comparable cooling capacity with energy efficiency increased compared to R-410A whilst having a GWP of 300 or lower. This paper covers the refrigerants' properties and performance by cycle modelling and practical testing in systems. Initial results of lubricant and materials compatibility will also be presented and discussed.

Paper ID:1218 - Pushing The Envelope: Extending The Range And Performance Of R-744

Low, Robert Elliott*,

***Koura Global (Mexichem), United Kingdom**

Abstract: Refrigerant R-744 is finding increasing favour as a non-flammable refrigerant in a range of cold-chain refrigeration and other applications. Its physical properties however constrain its application: its triple point of -57°C sets a lower practical operating limit, while the very high operating pressures and reduced energy efficiency in high ambient climates limit its attraction for air-conditioning applications. Koura Global has in development a range of hybrid R-744-fluorocarbon refrigerants which are non-flammable but which offer significantly improved energy efficiency, reduced operating pressure and extended operational temperature range compared to R-744, whilst also having low Global Warming Potentials. The paper will present a suitable thermodynamic model for these fluids and share property and performance test data on two selected applications: air-conditioning with fluids having GWP below 300; and refrigeration to achieve product temperatures below -60°C.

Paper ID:1221 - Case study of integration of energy systems for low grade waste heat utilization based on pinch method

Du, S*; Yang, C; Wang, RZ,

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Abstract: Efficient integration of energy systems is important for utilization of low grade waste heat to achieve high primary energy efficiency. This paper presents a thermodynamic method for integration of energy systems, including ORC, heat pump, refrigeration and thermal storage systems by using the pinch technology. The integration analysis is conducted through temperature matching between the waste heat source and the energy systems according to the practical energy demands. A case study is introduced to demonstrate how to use this method and how to obtain the optimal integration directly. The temperature-enthalpy diagram, problem table and gridding method are applied to obtain the optimal heat exchanger network. This method is applied to a practical project. The pressurized water, which is originally used to preheat processing water, is optimized so as to be used for producing cooling effect by an absorption chiller and preheat the processing water. The energy efficiency of the optimized system is improved by 42.3% compared to the existing system.

Paper ID:1222 - The Electrification Of Heat - Opportunities And Challenges for Vapour Compression Heat Pumps

Hewitt, Neil James*,

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Abstract: A possibility for decarbonisation in the UK is the electrification of heating through vapour compression heat pumps. However, it is becoming recognised that the electrical demand especially at peak times will exceed our electricity distribution network capacities. This will be especially challenging when combined with a parallel electrification of transport policy. This paper will explore global best practice in the management of heat pumps and their integration with energy storage and explore alternative thinking through technology coupling to mitigate local electricity network challenges. The impacts of thermal storage, electricity storage (fixed battery and electric vehicle) and hybrid heat pumps (ultimately operating of net-zero carbon gas) supported in building integrated or local renewable energy will be examined, along with the impacts of future low temperature heat networks and building fabric improvements.

Paper ID:1223 - Optimization Of Organic Rankine Cycle Using Low-GWP Refrigerants With Multi-objective Optimization Algorithm

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Abstract: Organic Rankine cycle enables to recover low-grade waste heat and generates electricity. Conventional refrigerants HFCs will be phased out because of impact on climate change. Screening of alternatives to HFCs is necessary to reduce the carbon dioxide and maintain cycle efficiency. For low-temperature ORC, environmental-friendly refrigerants are proposed as potential replacements such as R1233zd(E), R1234ze(Z), R1224yd(Z), DR2, DR12, R1234yf and mixtures. This paper is targeted to present a comparison of afore-mentioned refrigerants in ORC, where both thermodynamic and economic indicators are taken into consideration. Furthermore, multi-objective optimization of ORC using different refrigerants is implemented based on NSGA-II. Four decision variables are examined including evaporator outlet temperature, condensing temperature, pinch-point temperature and superheat. Thermal efficiency and levelized electricity cost are two objectives. The obtained pareto-optimum frontiers are sorted by TOPSIS to determine the optimum pareto-solution. The results indicate that R1233zd(E) and R1234ze(Z) exhibits better thermo-economic performance. The proposed comprehensive evaluation method provides a reference for prior selection of refrigerants in ORC.

Paper ID:1224 - Heat Exchanger for ORC, Adaptability and Optimization Potentials

Haugg, Albert Thomas*; Kreyer, Jörg Otto; Kemper, Hans; Hatesuer, Katerina; Esch, Thomas,

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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.

Paper ID:1226 - Heat Transfer under Pulse Heating of Liquids: the Case of Solution with Lower Critical Solution Temperature

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Abstract: Following the pioneering work of James Joule in solving heat transfer enhancement problems, by the beginning of the 21st century these issues had come to the forefront of thermophysical research. One of the approaches to this problem consists in the search for partially

soluble additives to the liquid heat carrier and optimising the thermal conditions in which these additives provide a significant effect. In this report, the characteristic features of a thermal response of a water/PPG-425 solution with LCST to powerful heat release are discussed. The method of controlled pulse heating of a wire probe was applied. An analysis of the values of the energy transferred from the probe to the substance under comparable conditions has shown that, in one of the heat release modes, these values for a solution with 20-30% content of PPG exceed the corresponding values for pure water by an order of magnitude. This result can serve as a practical basis for the search of a new generation of coolants for processes in which powerful local heat generation is possible.

Paper ID:1227 - Simulation of Absorption Power Cycle and Organic Rankine Cycle Using Evacuated Tube Solar Collectors

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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.

Paper ID:1229 - Power Generation And Heat Recovery From Biomass With Advanced CO_2 Thermodynamic Power Cycles: Modelling Development And Simulation

Ge, Yunting*; Zhang, Xinyu; Ling, Changming; Lang, Pingyuan,

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Abstract: A small-scale power generation system with biomass and CO_2 transcritical Brayton cycles has been designed with purposely selected system components. These include a biomass boiler, a CO_2 supercritical heater, a CO_2 turbine simulator, a CO_2 recuperator, a CO_2 gas cooler, and a CO_2 transcritical compressor. The designed performance specifications of each component include the biomass flue gases parameters, the heat exchanger UA values and the compressor performance curves. Accordingly, the system component models are developed and therefore integrated together under TRNSYS simulation platform to establish a model for the biomass- CO_2 power generation system. The developed system model is then applied to predict the system performance at different design and operation conditions. These consist of heat source and sink temperatures, turbine inlet and outlet pressures, heat exchanger UA values and working fluid mass flow rates. The simulation results are essential and significant in understanding the system operations and can contribute significantly to optimal system designs, component selections and controls.

Paper ID:1230 - The Environmental Impact and Performance of HFO R454A in Retail Supermarkets

Cameron, Sam CAMERON; Cook, Nabil*; Churchyard, Brian,

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Abstract: This paper firstly provides an overview of technical and safety considerations associated with HFO refrigerants. It then presents the performance of what is considered to be the world's first supermarket HFO refrigeration system operating in a traditional direct expansion application, with comparisons made against other available refrigerant technologies. Based on a blend of theoretical and monitored data, the paper identifies the wider environmental potential of adopting HFO R454A against other technologies from both a direct and indirect emissions perspective.

The foundations of this trial supermarket system will pave the way for a significant uptake in low GWP, next generation synthetic refrigerants. This paper demonstrates tangible performance and environmental benefits over current and other emerging environmentally friendly refrigeration systems, whilst offering the end user the most cost effective and future-proof solution of all available technologies.