Design and modelling of innovative machinery systems for large ships - DTU Orbit
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Eighty percent of the growing global merchandise trade is transported by sea. The shipping industry is required to reduce the pollution and increase the energy efficiency of ships in the near future. There is a relatively large potential for approaching these requirements by implementing waste heat recovery (WHR) systems.

Studies of alternative WHR systems in other applications suggests that the Kalina cycle and the organic Rankine cycle (ORC) can provide significant advantages over the steam Rankine cycle, which is currently used for marine WHR.

This thesis aims at creating a better understanding of the Kalina cycle and the ORC in the application on board large ships; the thermodynamic performances of the mentioned power cycles are compared. Recommendations of suitable system layouts and working fluids for the marine applications are provided along with methodologies useful for the design and optimisation of the main engine and WHR system combined cycle.

Numerical models of a low-speed two-stroke diesel engine, turbochargers, and the mentioned types of WHR systems in various configurations, are used to achieve the mentioned objectives. The main engine is simulated using a zero-dimensional model consisting of a two-zone combustion and NOx emission model, a double Wiebe heat release model, the Redlich-Kwong equation of state and the Woschni heat loss correlation. A novel methodology is presented and used to determine the optimum organic Rankine cycle process layout, working fluid and process parameters for marine WHR. Using this mentioned methodology, regression models are derived for the prediction of the maximum obtainable thermal efficiency of ORCs. A unique configuration of the Kalina cycle, the Split-cycle, is analysed to evaluate the fullest potential of the Kalina cycle for the purpose. Integreated with three main engine waste heat streams, the Kalina cycle, the ORC and a dual-pressure steam cycle are compared with regards to the power outputs and other aspects. The part-load performances of four different WHR system configurations, including an exhaust gas recirculation system, are evaluated with regards to the fuel consumption and NOx emissions trade-off.

The results of the calibration and validation of the engine model suggest that the main performance parameters can be predicted with adequate accuracies for the overall purpose. The results of the ORC and the Kalina cycle optimisation efforts indicate that both cycles can achieve higher power outputs than the steam cycle; however, the results suggest that for the Kalina cycle to achieve such high power outputs, a relatively complex process layout and high working pressures are required. Conversely, the ORC can achieve superior power outputs with a much simpler process layout in comparison. The toxic ammonia-water working fluid of the Kalina cycle is problematic for the use in marine machinery rooms, and so are the highly flammable ORC working fluids.

Based on the analyses, no configuration of the Kalina cycle is recommended for marine WHR. An exhaust gas power turbine is recommended as an initial WHR system investment due its cost-effectiveness. For large ships, a dual-pressure steam cycle is recommended because it is well-known, proven, highly efficient and environmentally benign. The ORC is recommended for large and medium size ships and it is recommended to use the highly flammable working fluids and take the needed precautions. The main reasons are that the ORCs can achieve superior efficiencies with a simple process that can be operated fully automated. For the same reasons a WHR system consisting of a hybrid turbocharger and a recuperated ORC is recommended.

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