ASME ORC 2013 Conference Rotterdam
Oral presentation in Turbo Expander II session, Tuesday October 8th 2013

COMPARISON OF AXIAL AND RADIAL OUTFLOW TURBINES IN A MEDIUM-HIGH ENTHALPY WASTE HEAT RECOVERY ORC APPLICATION

Luca G. Xodo, Claudio Spadacini, Marco Astolfi, Ennio Macchi

ABSTRACT

In the wide range of applications of the ORC, the medium-high enthalpy heat recovery applications are acquiring a growing importance, as energy efficiency and primary energy savings are becoming a focus for most of the industrial world. Medium-high enthalpy applications are defined as those applications in which the waste heat is available at a considerable peak temperature (higher than 250 °C), e.g. industrial waste heat from glass mills, steel mills or cement factories and simple cycle power production applications such as gas/oil/biogas engines and gas turbines. The ORC becomes an option in specific applications: medium size, need for remote control and isolated environment; nevertheless the overall heat recovery efficiency is the first parameter to consider in order to give a competitive solution to the market. Overall heat recovery efficiency can be defined as the maximum amount of high-valued energy, in this case electrical power, can be obtained from the available heat source. This means a right balance between thermal power recovery, lowering the minimum temperature to which the gas should be cooled down, and the cycle conversion efficiency. In fact, once the heat sink temperature level has been set, the ORC efficiency, together with the theoretical Lorenz efficiency, is bound to the average temperature level of the heat source. For a supercritical or a subcritical superheated cycle once the maximum temperature is selected the other optimization variable is the operating pressure of the cycle which directly affects both the enthalpy drop and the volume flow ratio along the expansion. In particular the total volume flow ratio is another limit that has to be carefully considered and it is strictly related to the thermodynamic properties of the fluid. Organic fluids commonly used for medium high enthalpy applications are long chain alkanes, perflourated fluids and siloxanes, which are characterized by an high molecular weight and an high molecular complexity. For a fixed turbine pressure ratio this kind of fluids shows a small enthalpy drop along the expansion which allow designing the turbine with just few stages (at limit just one) with small load coefficients, low peripheral speed and low mechanical stresses. However the design of this kind of turbine is not trivial: several difficulties arise because of the low speed of sound (high Mach numbers) and because the whole volume flow ratio has to be managed in a little number of stages. This last aspect entails a challenging design of turbine blades and big flaring angles are commonly used with the formation of radial fluxes in blade channels and reduction of the stage efficiency. Economic concerns suggest to limit the number of stages to at maximum 3-4 and so any technological solution able to guarantee an high efficiency with a limited number of stages is crucial in ORC field. The use of a radial outflow turbine might solve most of the over mentioned problems. In fact increasing the blade mean diameter along the expansion allows to obtain a better and easier design of turbine blades which can have small

flaring angles and they don’t need to be twisted in the last turbine stages. Where this kind of advanced turbine is adopted, it is possible to relax the constrain related to the maximum volume ratio along the expansion, to increase the maximum operating pressure and to reach an higher efficiency. The study compares the application of a 3-stage axial turbine and a 3+ stages radial outflow turbine on a case study of heat recovery from industrial process, comparing isentropic efficiency, overall cycle efficiency and operational parameters of the different configurations. Finally an analysis of turbine design is presented in order to appreciate the advantages of the proposed solution.