Organic Rankine Cycles (ORC) for Mobile Applications: Economic Feasibility in Different Transportation Sectors

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Abstract : Internal combustion engines (ICE) are today the most common energy system to drive vehicles and transportation systems. Numerous studies state that 50-60% of the fuel energy content is lost to the ambient as sensible heat. ORC offers a valuable alternative to recover such waste heat from ICE, leading to fuel energy savings and reduced emissions. In contrast, the additional weight of the ORC affects the net energy balance of the overall system and the ORC occupies additional volume that competes with vehicle transportation capacity. Consequently, a lower income from delivered freight or passenger tickets can be achieved. The economic feasibility of integrating an ORC into an ICE and the resulting economic impact of weight and volume have not been analyzed in open literature yet. This work intends to define such a benchmark for ORC applications in the transportation sector and investigates the current situation on the market. The applied methodology refers to the freight market, but it can be extended to passenger transportation as well. The economic parameter X is defined as the ratio between the variation of the freight revenues and the variation of fuel costs when an ORC is installed as a bottoming cycle for an ICE with respect to a reference case without ORC. A good economic situation is obtained when the reduction in fuel costs is higher than the reduction of revenues for the delivered freight, i.e. $X<1$. Through this constraint, a maximum allowable change of transport capacity for a given relative reduction in fuel consumption is determined. The specific fuel consumption is influenced by the ORC in two ways. Firstly because the transportable freight is reduced and secondly because the total weight of the vehicle is increased. Note, that the generated electricity of the ORC influences the size of the ICE and the fuel consumption as well. Taking the above dependencies into account, the limiting condition $X = 1$ results in a second order equation for the relative change in transported cargo. The described procedure is carried out for a typical city bus, a truck of 24-40 t of payload capacity, a middle-size freight train (1000 t), an inland water vessel (Va RoRo, 2500 t) and handysize-like vessel (25000 t). The maximum allowable mass and volume of the ORC are calculated in dependence of its efficiency in order to satisfy $X < 1$. Subsequently, these values are compared with weight and volume of commercial ORC products. For ships of any size, the situation appears already highly favorable. A different result is obtained for road and rail vehicles. For trains, the mass and the volume of common ORC products have to be reduced at least by 50%. For trucks and buses, the situation looks even worse. The findings of the present study show a theoretical and practical approach for the economic application of ORC in the transportation sector. In future works, the potential for volume and mass reduction of the ORC will be addressed, together with the integration of an economic assessment for the ORC.

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