SEMI-CLOSED CYCLE TURBINE ENGINES IN U.S. ARMY APPLICATIONS WITH WATER HARVESTING

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1. INTRODUCTION

Gas turbine power requirements for the U.S. Army vary tremendously depending upon the specific application, spanning the power range from a few Watts for individual soldier power supplies to Megawatt-scale engines for heavy land vehicles and air transport. Each application has its own set of key drivers which constrain the selection of an engine technology and in optimizing the design, the objective function dependencies vary widely. Hence, although the desire for compactness, efficiency, lightness, low observables, etc. is universal among the common Army applications, their relative importance is not. In addition, certain applications may require an engine attribute which is wholly unimportant in other cases, such as the need for heat and/or air conditioning in a distributed generation unit. Thus flexibility in the design of any type of engine is a significant advantage if it is to find a niche in several applications, an obvious benefit to minimizing Army inventories and costs.

Rare is the application for which a single attribute dominates the engine selection and design process. If, for instance, design-point efficiency were the sole consideration, then the designer should select amongst engine types – gas turbine, Diesel, fuel cell, etc. – optimized for the power class required, and choose the most efficient. However, the true objective function is never that simple, as other factors such as size, weight, life-cycle costs, reliability, maintainability, observables, fuel requirements, and operational flexibility must also be considered. Furthermore, the end use of the power may involve auxiliary systems, such as air conditioning, desalinization, or heating. It is advantageous to design an optimal overall system, including the auxiliaries, rather than accept the penalties inherent in a modular approach.

The current paper describes an ongoing Army program to explore the potential use of a novel gas turbine engine called the High Pressure Recuperative Turbine Engine (HPRTE) in U.S. Army applications requiring multiple end products, specifically any combination of power, cooling, heat, and fresh water. The HPRTE is a semi-closed cycle engine which is inherently more flexible in its design for such applications than traditional turbine or other engine types. In its simplest form it offers the advantages of high design point and part load efficiency, compactness, low emissions, low observables, and high specific power. In a combined cycle mode, it is still quite compact relative to competing technologies, while demonstrating higher efficiency and the thermodynamic integration of a combined heat/cooling/power/fresh water plant. This technology further has advantages in low exhaust temperature, greatly reduced airflow, and very low emissions of NO_x, CO, and soot. The current study is motivated by this potential for a more efficient, more compact, and simpler-to-operate plant.

2. HPRTE DESCRIPTION

The HPRTE may be best used in simple-cycle mode for some applications, or in a combined cycle for those cases in which performance is more important than size and weight. Shown in Figure 1 is one version of the HPRTE combined cycle, in which the second cycle is a vapor absorption refrigeration cycle, rather than an additional power cycle. A simple-cycle version of this system would eliminate the refrigeration cycle (bottom half of Figure 1) and the generator and evaporator in the gas turbine cycle (top half of Figure 1).

Several potential applications of the HPRTE appear attractive; however, in the current paper, only those which utilize water production coupled with high efficiency (on and off design) are considered, which include distributed generation and ground transportation.

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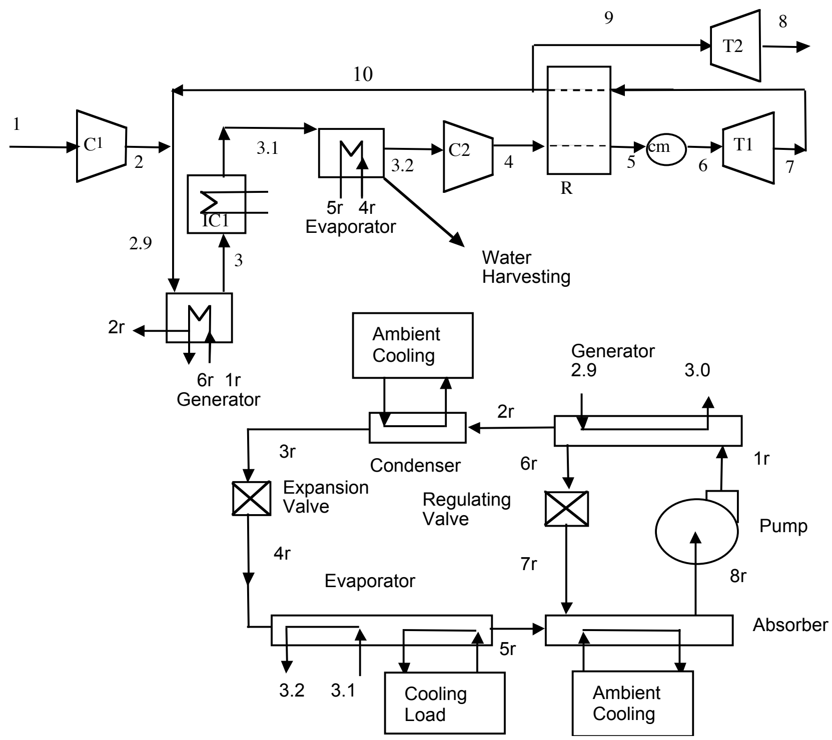

Figure 1. High Pressure Recuperative Turbine Engine and absorption combined cycle.

3. RESULTS AND CONCLUSIONS

Initial experiments have been conducted in simple-cycle mode on a 60 HP HPRTE. A total of 1.3 liters of water was extracted for about 20 liters of fuel consumed. The cycle has also been modeled using traditional one-dimensional steady-state thermodynamics, with the actual values of the efficiency and pressure drops for the turbo-machinery and heat exchangers. Excellent agreement with the experimental data was observed. The model was then used to design the absorption combined system. The evaporator is predicted to cool the recirculated gases to about 4.0 ºC to extract about 1.25 kg of water per kg of fuel consumed with the current experimental setup, which uses old technology.

Using the same model but with state-of-the-art component efficiencies as inputs yields highly promising results. Typical hot-day efficiency is on the order of 10 points higher than the state of the art engines, while delivering refrigeration or air conditioning at a energy rate equal to the power delivery. Water extraction rates approach the theoretical maximum for the water production in the combustor. This is predicted in a package which is about one-third the size of competing technologies and which reduces exhaust temperatures by approximately 200 degrees. Hence this approach appears attractive for a variety of Army applications.