RECOVERING ENERGY FROM WOOD WASTES IN A SEMI-CLOSED CYCLE POWER PLANT

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Rezumat. Se prezintă o soluţie de producere a energiei electrice, prin arderea deşeurilor din lemn într-o instalaţie energetică cu turbomotor cu aer cald. Se estimează parametrii funcţionali şi constructivi ai instalaţiei pentru diferite valori ale raportului de comprimare. Se analizează curbele de variaţie a acestor parametrii.
Cuvinte cheie: instalaţie energetică cu turbomotor cu aer cald, generator de aer cald, ciclu semi-închis, randament, putere, suprafaţă specifică de schimb de căldură.

Abstract. The paper presents a solution for the power generation in a Hot Air Turbine Power Plant using the wood wastes as fuel. The parameters for the estimated performances of the Power Plant and the overall specific heat exchange surface of the Hot Air Generator had been calculated for different values of the compressor pressure ratio. The resulted curves are presented and analyzed.
Keywords: Hot Air Turbine Power Plant, Hot Air Generator, semi-closed cycle, efficiency, power, specific heat exchange surface.

1 INTRODUCTION

A consequence of the processing of the raw wood material is the wood wastes generation. These wastes consist of sawdust, shavings, slab, edgings and other wastes from cutting. Because of both the storage requirements and, more important, the pollutant effect, to get rid of the wood wastes is an important need. The problem of the wood wastes is already solved in the Western Europe: these wastes are used as fuel, on a large scale. Unfortunately, in Romania the solution for the wood wastes problem is still far: there are just a few low power plants (electrical or thermal) that use the wood wastes as fuel. These plants solve the problem just to a slight degree and for small areas. In order to solve properly the problem of the wood wastes is necessary to conceive and develop power plants covering an output range of 1 to 5 MW. Because the wood wastes transportation is very expensive, it reduces considerably the profitability of the power plant. That is why this process must be avoided. It follows that the power plants must be conveniently placed for both the provider of the wood wastes and the consumer of energy.

The wood wastes can be used as primary energy source in a gasifier or can be directly burned in a furnace. An innovative solution for the wood wastes direct burning is the development of the mobile power plants with steam or hot air turbine. The use of the conventional gas turbine power plants is not possible because of the impossibility to develop wood wastes fueled combustion chambers. Because the most wood wastes providers are placed in locations with insignificant sources of water and without heat demand, the development of the power plants operating with low or zero water consumption is required. The steam turbine power plants (STPP) having the condensing systems with heat exchange surfaces and the hot air turbine power plants (HATPP) came as the properly solutions in this case. HATPP can be developed in two variants:

- in open cycle - fresh air passes continuously both the compressor and the Hot Air Generator (HAG); the hot air delivered by HAG is expanded through the turbine; the air exhausted from the turbine as well as the HAG flue gases are released in the atmosphere;
- in semi-closed cycle - fresh air passes the compressor only; the air exhausted from the turbine enters the HAG.

In the present paper a HATPP operating in semi-closed cycle is analysed.

2. PRESENTATION OF THE HOT AIR TURBINE POWER PLANT

The schematic for the studied HATPP is shown in fig. 1. The semi-closed cycle variant presents an important advantage: because of the high air exces coefficient, the highest temperature of the HAG burned gases and, consequently, the highest tube wall temperature are considerably lower than in the case of HATPP in opened cycle. It follows that in the case of HATPP in opened cycle can be used alloyed steels inferior to those used in the case of HATPP in semi-closed cycle.

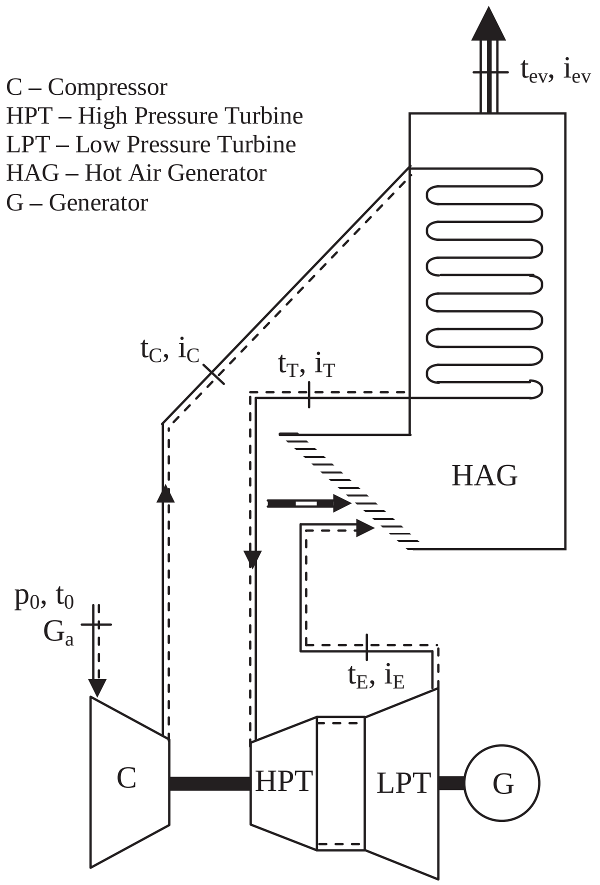

Fig.1 . *Schematic of HATPP*

Fresh air, compressed in C, is heated up in HAG. The hot air is then expanded in HPT (which drives the compressor) and in the power turbine LPT (which drives the generator G). The air exhausted from LPT enters the HAG where the wood wastes are burned. The burned gases are cooled by the compressed air delivered by C and

3. ANALYSIS OF THE HOT AIR TURBINE POWER PLANT

The most relevant technical parameters that indicate the performances of any power plant are the efficiency and output. Beside the performances, the economic aspects are also very important. The electricity cost price fixed by the investment and fuel costs decides the profitability of a power plant. The materials cost is an important constituent of the investment cost. Consequently, the overall specific heat exchange surface (S_{sp}) of HAG directly influences the electricity cost price and, therefore, was estimated in this study. Because the wood wastes have a very low price at present (still are cases when they are free), the fuel cost practically consists in the fuel transportation cost. Beside its importance as direct economic parameter, the specific fuel consumption (SFC) is an important factor in the power plant designing process: evaluating SFC, the power plant output is established function by the wood wastes resources. Taking into account these aspects, SFC estimation was included in the present study.

In order to perform the analysis, a home code has been made. In all calculations, the following parameters have constant values:

- atmospheric air temperature - t_0 = 15°C;
- atmospheric air pressure - p_0 = 1.013 bar;
- air mass flow rate - G_a = 6.05 kg/s;
- turbine inlet temperature (hot air temperature) - t_T = 777°C (1050 K)
- difference between the temperatures of the HATPP exhausted gases (t_{ev}) and compressed air (t_C) – Δt_{ev} = 30 grd;
- mechanical efficiency of the turbines - η_m = 0.995.

The calculations had been made considering dry wood wastes with the following elementary chemical composition, expressed in mass percents: C = 41%; H = 5%; O = 36%; N = 1%; A = 0.4%; W = 16.6%.

The parameters of the air turboengine are calculated according to the proceedures presented in [1] and [2].

The output of HATPP, expressed in kW, is given by

$$P_{ef} = \eta_m \cdot G_a \cdot \left(i_T - i_E\right), \qquad (1)$$

where i_T and i_E are the turbine inlet, respectively turbine exhaust enthalpies, in kJ/kg.

In order to determine the heat consumption (Q_{con}), were estimated [3], [4]:

- combustion loss - q_3 = 1%;
- unburned loss - q_4 = 4%;
- heat dissipation - q_5 = 2.65%;
- ash loss - q_6 = 0.002%.

The formula for Q_{con} calculation (in kW) is

$$Q_{con} = 100 \cdot \frac{Q_c + G_a \cdot \left(i_{ev} - i_0\right)}{100 - \sum_{i=3}^{6} q_i}, \qquad (2)$$

where i_{ev} and i_0 are the HAG exhausted gases, respectively atmospheric air enthalpies; Q_c represents the heat exchanged in HAG, in kW.

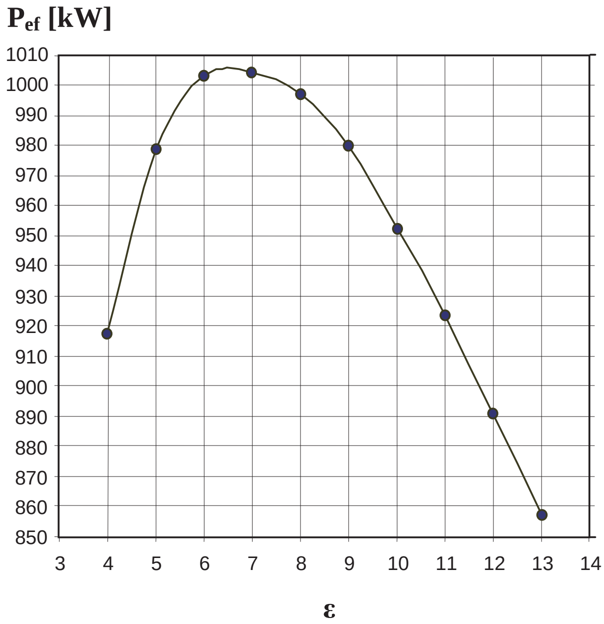

Fig.2 . *Variation of power plant output with the compressor pressure ratio*

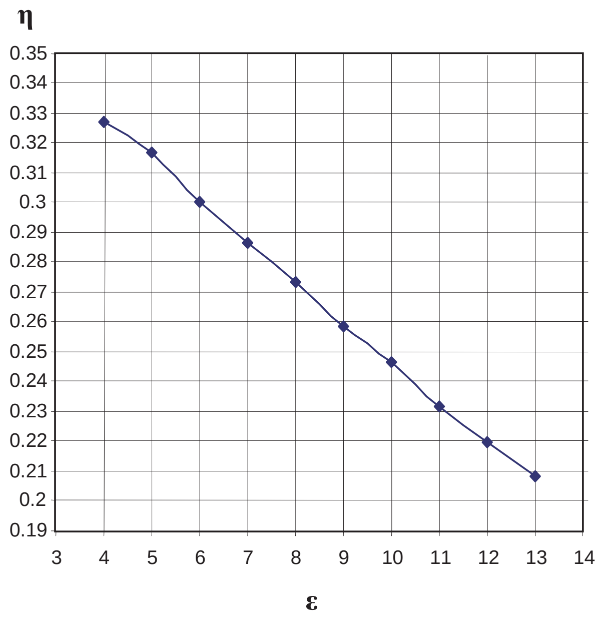

Fig.3 . *Variation of power plant efficiency with the compressor pressure ratio*

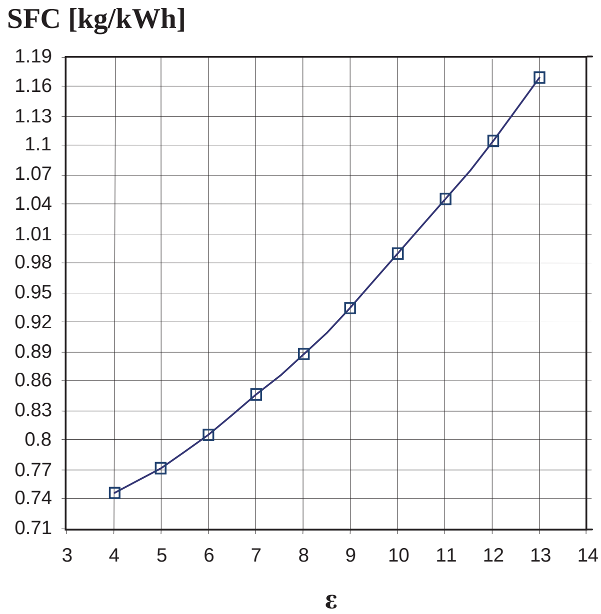

Fig.3 . *Variation of the power plant specific fuel consumption with the compressor pressure ratio*

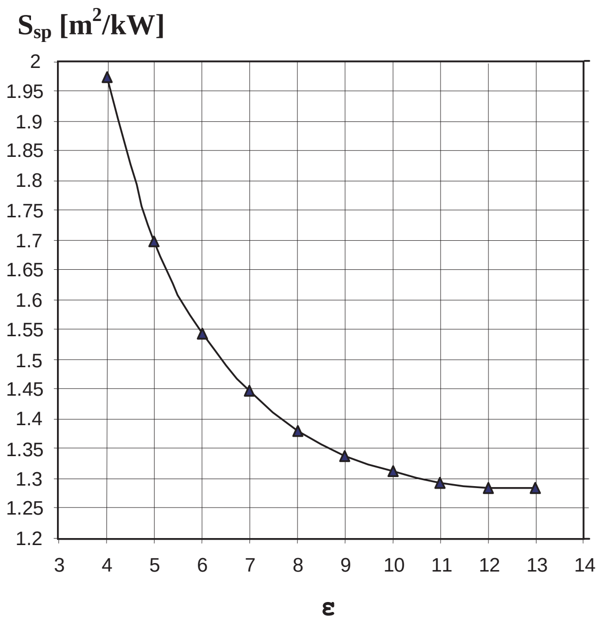

Fig.4 . *Variation of the specific heat exchange surface of the hot air generator with the compressor pressure ratio*

SFC, expressed in kg/kWh, is given by

$$SFC = 3600 \cdot \frac{Q_{con} - G_a \cdot (i_E - i_0)}{P_{ef} \cdot H_i} \qquad (3)$$

where H_i is the lower calorific value of the fuel. The overall efficiency of HATPP is estimated with the following formula:

$$\eta = \frac{3600}{SFC \cdot Hi} \qquad (4)$$

The procedure for the estimation of the heat exchange surface of HAG, in m^2, is the classic one used in the case of convective heat transfer and had been developed proceeding from [4] and [5]. The basic formula, well known, is

$$S = \frac{1000 \cdot Q_{HAG}}{k \cdot \Delta t_{lg}}, \qquad (5)$$

where Q_{HAG} [kW] is the heat exchanged in HAG, k [W/m^2·deg] is the heat transfer coefficient while Δt_{lg} [deg] is the logarithmic mean temperature difference.

Overall specific heat exchange surface of HAG, expressed in m^2/kW, is calculated as

$$S_{sp} = \frac{S}{P_{ef}}, \qquad (6)$$

Variations of the HATPP parameters (P_{ef}, η, SFC and S_{sp}) with the compressor pressure ratio (ε) is shown in fig. 2. Both SFC and η have linear variations. When ε increases from 4 to 13, SFC increases covering the range 0.75…1.17 kg/kWh, while η decreases from 0.33 to 0.21. The variation of S_{sp} from 1.97 m^2/kW to 1.28 m^2/kW is significantly only for low values of ε. This descendent variation is negligible when ε > 11. Unlike the others parameters, P_{ef} increases from 918 kW to the maximum value of 1007 kW, obtained for ε = 6.5, and decreases after to 857 kW.

4. CONCLUSIONS

For a conventional Gas Turbine Power Plant having fixed the value of T_T, the variation of the overall efficiency with ε always has a maximum. This maximum corresponds to the optimum design point of the power plant. Because of the continuous decreasing of η with ε, an optimum design point of the studied HATPP can't be established taking into account only technical criteria. In order to establish the optimum design point, an economic study must be developed. The optimum design point will be the one corresponding to the minimum cost price of the electricity. As can be seen in fig. 2, SFC and S_{sp} have opposite variations. If the investment price (varying directly with S_{sp}) could be established, the cost of the fuel is impossible to be estimated: at this moment still are providers of free wood wastes but their number decreases continuously; besides, a forthcoming increasing of the wood wastes price is expected. It follows that an economic study can't be perfected at this moment. It can be made only the mention that, for any fuel cost, the ε values higher than 11 are not justified because the increasings of SFC are important (that means higher fuel costs) but reductions of S_{sp} are negligible (that means insignificant reductions of the investment).

STPP with cooling tower is currently the usual power plant type with direct burning in a furnace. The overall efficiency of the existing STPP doesn't get over 30%, which is the overall efficiency of the studied HATPP for ε = 6.

The comparison of the studied HATPP with the existent wood wastes fueled STPP is helpfully but irrelevantly. The existent STPP are operating in favourable locations, with significant water sources. An adequate comparison could be made with STPP adapted to operate with low water consumption. These installations will be analysed in a further study.

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