

Closed Cycle Microturbines for CHP **Market**

1. Introduction

Recently, there is a growing requirement for distributed/decentralized energy installations for C.H.P (Combined Heat and Power) applications, in which micro turbines are competing against natural gas piston engines .

Many advantages exist to micro turbines against the piston engines ,such as low pollution , compactness and total efficiency but their major disadvantage is a high price currently twice compared the piston engine., mostly in the low power range (up to 500 kw).

Micro Turbines advantages so far has been recognized mostly in the western world and won recently considerable support from governments such as Germany, Great Britain and recently U.S.A . by activating high incentive programs.

There are a few micro turbines manufacturers for the C.H.P market in the world i.e -Capston, Turbec, which generate less than 250kw of electric power. A cluster of several micro turbines is delivered whenever a higher power is required.

At present the above design features are limited to 200kw mainly due to the alternator rotor stresses occurring at typical high speeds.

Another disadvantage is the power electronics size and cost.

Their size is similar to a 200kw synchronous alternator turning at 1500 rpm and the cost is twice as much.

Large industrial gas turbines continue are designed with 1500 rpm of alternator speed and install a reduction transmission between gas turbine shaft and alternator.

The energy losses due to adding a transmission is less (4%) than the power electronic losses (8%) so there is an opportunity to design a micro turbine driving a conventional alternator with a mechanical transmission.

The above design is not sufficient to reduce the total cost. The gas turbine cost itself has to be reduced to match piston engine cost.

A closed cycle design is presented that intends to reduce micro turbines cost.

2. Closed cycle CHP micro turbine design-fig.1

The closed cycle design has the following advantages -

- Avoiding fouling of engine from fuel pollution products thus attaining multi-fuel combustion thus avoiding contamination of combustor, ducts and turbines.
- Control of internal fluid pressure determines total power, thus bleeding or pressurizing of internal closed fluid allows constant speed operation and variable power.

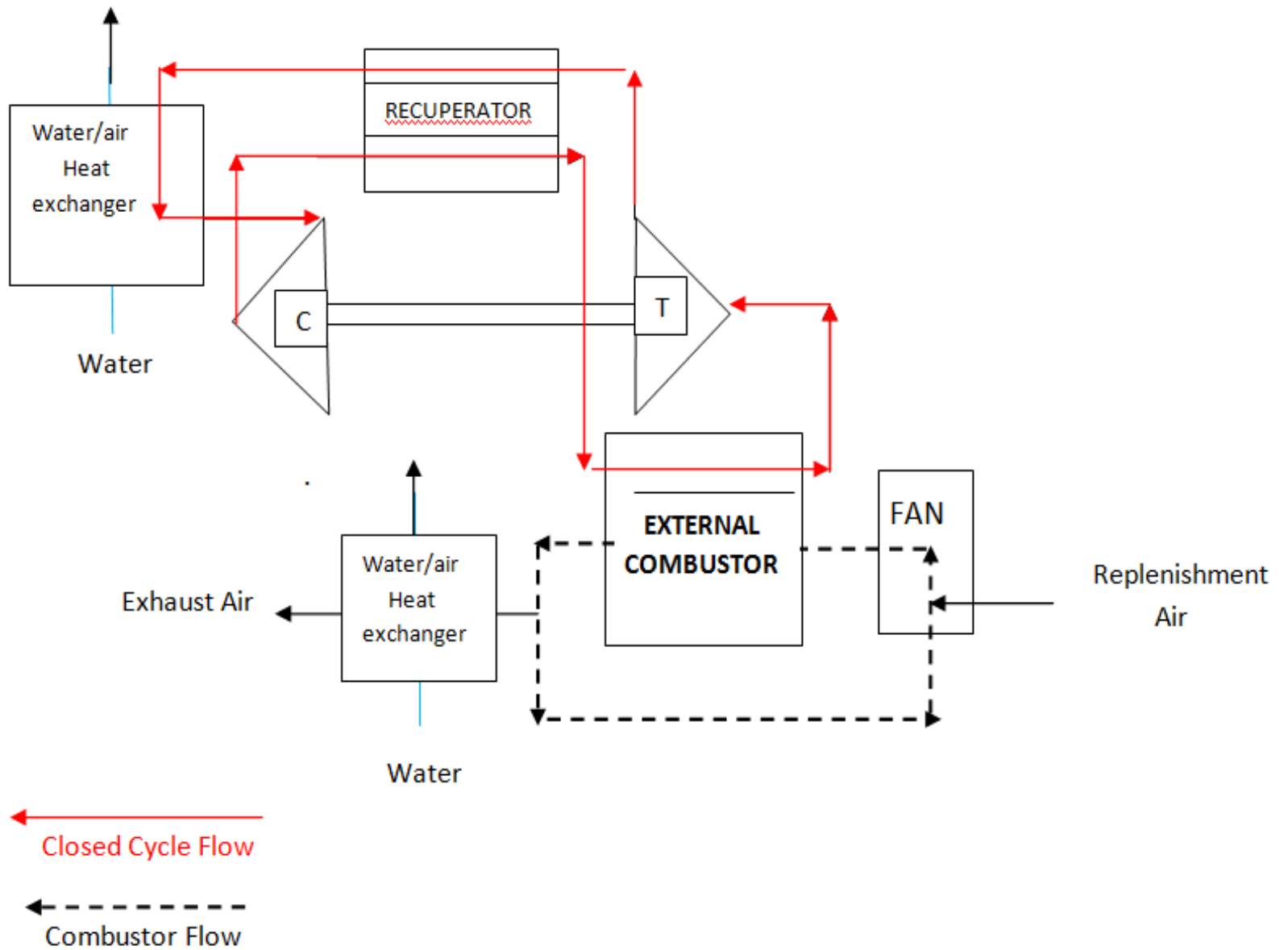


FIG.1-CLOSED CYCLE MICRO TURBINE CYCLE

By increasing the mass flow and the inlet pressure simultaneously the corrected flow is kept constant and the same micro turbine is thus adaptable to increase its power which will be limited only by its structural strength.

The recuperator heat transfer capacity increases when its cold and hot mass flows increase due to higher heat transfer factors.

Using Helium or CO₂ as circulating fluid result in higher performance -power and thermal efficiency.

The disadvantages of the micro turbine closed cycle are-

- increased cost and size due to two heat exchangers at external flow exit and at compressor inlet.

- Pressure and heat loss in the external combustor.

A fan is used to circulate the air through the combustor and its heat exchanger.

3. Closed cycle design concepts

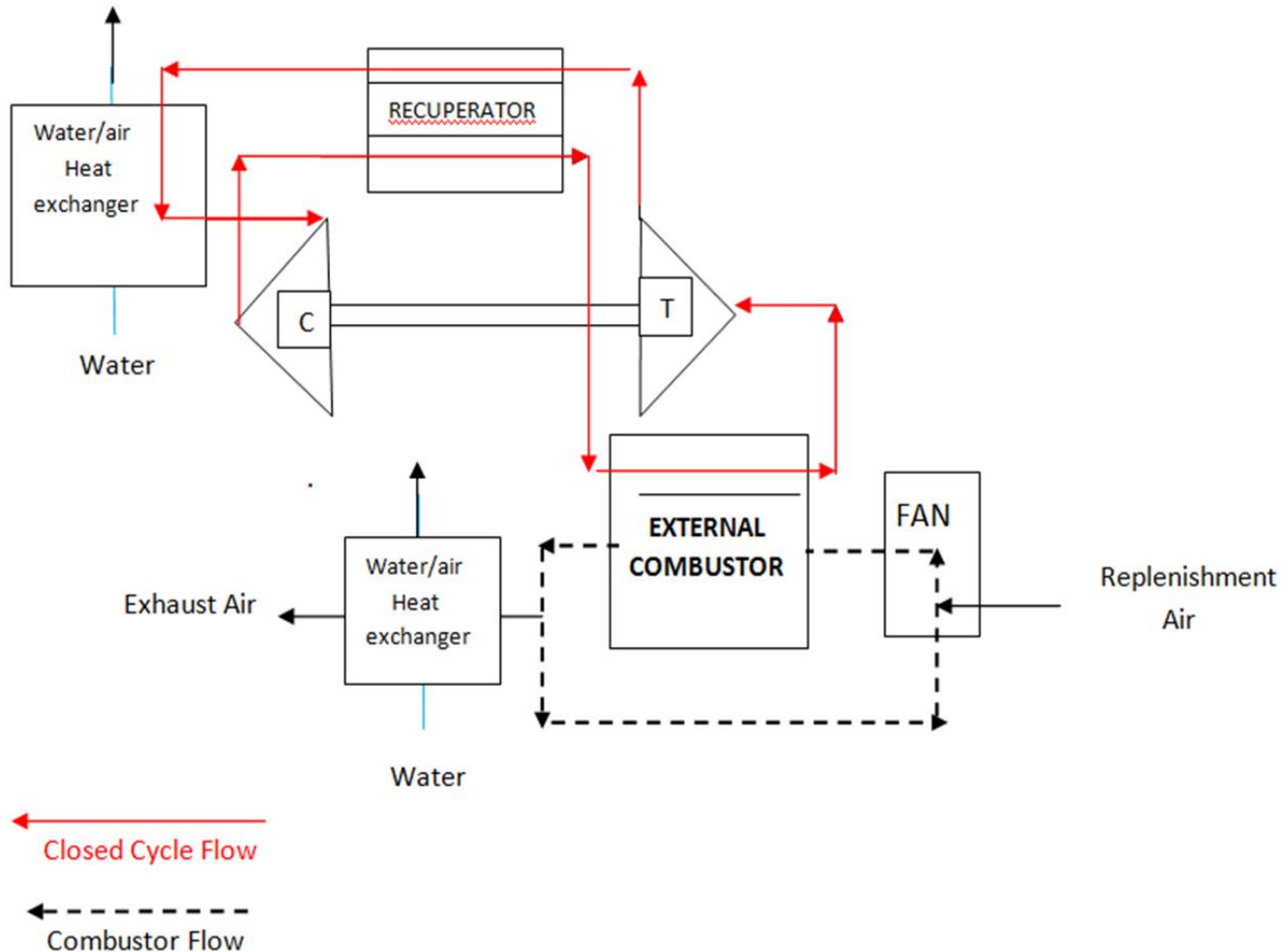


FIG.1-CLOSED CYCLE MICRO TURBINE CYCLE

Closed cycle design- see fig.1

- The closed cycle differs from the open cycle in the combustor design which is external to the pressurized air flow. The heat energy is transmitted by conduction.

- The external ambient air is first heated by the combustor exhaust gas and then fuel is added to attain the desired air temperature .

- The external combustor is insulated to avoid heat losses through its external envelop.

A fan is provided to provide fresh air an to overcome the external combustor pressure loss.

(calculated as 20kpa for an external air flow of 3.5 kg/hr.)

- Heat output is generated in both heat exchangers one at compressor inlet and the second at combustor outlet.

3.1 -The TG-40 micro turbine performance is evaluated when modifying it to a closed cycle design and boosting its inlet air pressure to 1000 kpa. The results are presented in TABLE A as:

Thermal power -472kw, Thermal efficiency-37.15%

Unfortunately at a speed of 80000 rpm the existing high speed alternator technology is limited to 40kw at 80000 rpm (Calnetix), 100kw at 70000 rpm (ABB) and 200kw at 60000 rpm (Capstone).The limiting barrier is the stress at the permanent magnet rotor.

TABLE A—THEMODYNAMIC OF TG-500 CYCLE -
INLET PRESSURE BOOSTED TO 1000 KPA
POWER=472KW at 80000 rpm

| | W | T | P | WRstd | | |
|---------------|------------------|---------|-------------|----------|------------------|-------------------------|
| Station | kg/s | K | kPa | kg/s | PWSD | = 472 kW |
| amb | | | | | | |
| 1 | 3.038 | 288.00 | 1000.130 | | PSFC | = 0.1948 kg/(kW*h) |
| 2 | 3.038 | 288.00 | 980.127 | 0.314 | Heat Rate= | 9690.6 kJ/(kW*h) |
| 3 | 3.038 | 421.67 | 2940.382 | 0.127 | ThermEff= | 0.3715 |
| 31 | 3.038 | 421.67 | 2940.382 | | WF | = 0.02505 kg/s |
| 35 | 2.856 | 979.02 | 2896.276 | | P35/P3 | = 0.98500 |
| 4 | 2.881 | 1310.00 | 2780.425 | 0.225 | P7/P6 | = 0.98000 |
| 41 | 3.063 | 1291.13 | 2780.425 | 0.237 | s NOx | = 2.44674 |
| 49 | 3.063 | 1051.43 | 1030.849 | | incidence= | 0.00000 ° |
| 5 | 3.063 | 1051.43 | 1030.849 | 0.577 | XM8 | = 2.201E-4 |
| 6 | 3.063 | 1051.43 | 1020.541 | | A8 | = 4.5843 m ² |
| 7 | 3.063 | 518.34 | 1000.130 | | | |
| 8 | 3.063 | 518.34 | 1000.130 | 0.417 | P8/Ps8 | = 1.00000 |
| Bleed | 0.000 | 421.67 | 2940.376 | | WBld/W2 | = 0.00000 |
| Efficiencies: | isentrpolytr | RNI | P/P | W_NGV/W2 | | = 0.06000 |
| Compressor | 0.7900 | 0.8194 | 9.679 | 3.000 | WCL/W2 | = 0.00000 |
| Burner | 0.9600 | | 0.960 | | Loading | = 100.00 % |
| Turbine | 0.8700 | 0.8555 | 4.745 | 2.697 | e45 th | = 0.86853 |
| Heat Exch. | 0.8800 | | | | | |
| Generator | 0.96 | | | | | |
| Transmission | 0.96 | | | | | |
| PW_gen | = 425 Kw- | | | | | |
| Spool mechEff | 0.9950 | Nom Spd | 80000 rpm | P6/P5 | | = 0.9900 |
| hum [%] | war0 | FHV | Fuel | | | |
| 0.0 | 0.00000 | 49.736 | Natural Gas | | | |

4. Competitive Cost closed cycle design.- boosting to 750 kpa

Thermal efficiency-37.7% Thermal Power-522kw Design Speed-50Krpm-see Table B

a. Application of the following large gas turbine architecture –

- Synchronic alternator generating 50/60 HZ turning at 1500/1800 rpm.

- Planetary transmission 33:1 for 1500 , 27:1 for1800 rpm

Electric starter driving transmission exit shaft.

TABLE B—THEMODYNAMIC OF TG-500 CYCLE

INLET PRESSURE BOOSTED TO 1000 KPA

POWER=522 kW at 50000 rpm

| | W | T | P | WRstd | |
|------------------------|---------------|---------|-----------|-------------|-----------------------------|
| Station | kg/s | K | kPa | kg/s | PWSD = 522.4 kW |
| amb | 300.00 | 750.000 | | | |
| 1 | 3.555 | 300.00 | 750.000 | | PSFC = 0.1921 kg/(kW*h) |
| 2 | 3.555 | 300.00 | 735.000 | 0.500 | ThermEff= 0.37673 |
| 24 | 3.555 | 300.01 | 735.073 | 0.500 | Heat Rate= 9556.0 kJ/(kW*h) |
| 25 | 3.555 | 300.01 | 735.073 | 0.500 | P2/P1 = 0.9800 |
| 3 | 3.555 | 437.24 | 2205.220 | 0.201 | P25/P24 = 1.0000 |
| 31 | 3.555 | 437.24 | 2205.220 | | P3/P2 = 3.00 |
| 35 | 3.341 | 963.76 | 2172.142 | 0.285 | P35/P3 = 0.98500 |
| 4 | 3.369 | 1290.00 | 2150.421 | 0.337 | WF = 0.02788 kg/s |
| 41 | 3.582 | 1271.31 | 2150.421 | 0.356 | Loading = 100.00 % |
| 42 | 3.582 | 1156.03 | 1360.771 | | s NOx = 2.01613 |
| 43 | 3.582 | 1156.03 | 1360.771 | | |
| 44 | 3.582 | 1156.03 | 1360.771 | | |
| 45 | 3.582 | 1156.03 | 1360.771 | 0.536 | P45/P43 = 1.00000 |
| 49 | 3.582 | 1032.61 | 796.543 | | |
| 5 | 3.582 | 1032.61 | 796.543 | 0.865 | |
| 6 | 3.582 | 1032.61 | 780.612 | | P6/P5 = 0.98000 |
| 8 | 3.582 | 527.83 | 765.000 | 0.644 | P7/P6 = 0.98000 |
| Efficiencies: | isent | polytr | RNI | P/P | A8 = 0.00933 m ² |
| Compressor | 0.8000 | 0.8279 | 6.916 | 3.000 | |
| Burner | 0.9900 | | 0.990 | | |
| HP Turbine | 0.8700 | 0.8635 | 3.735 | 1.580 | |
| LP Turbine | 0.8700 | 0.8624 | 2.632 | 1.708 | eta t-s = 0.78767 |
| Heat Exch | .8800 | | | | |
| Generator | 0.96 | | | | |
| Transmission | 0.96 | | | | |
| PW_gen = 483 Kw | ----- | | | | |
| HP Spool | mechEff0.9950 | NomSpd | 50000 rpm | | |
| LP Spool | mechEff1.0000 | NomSpd | 50000 rpm | | |
| PT Spool | | Nom Spd | 50000 rpm | | |
| hum [%] | war0 | FHV | Fuel | | |
| | 0.0 | 0.00000 | 49.736 | Natural Gas | |

5. SUMMARY

A closed cycle design of micro turbines is presented as a cost effective solution which is competitive to gas piston engines cost and performance for the CHP markets.

This design allows to use efficiently the same core engine for variable power.

This design will result in a total energy (Power and Heat) efficiency of 85%-92%.