Gas Turbine and Water-Vapor Compressor

Integrated CCHP System
Contents

1. Combined **Heat** and **Cooling** and **Power** systems
2. Load fluctuations in CCHP systems.
4. The Brayton intercooled cycle.
5. OCN TS 2000 Intercooled Gas Turbine.
6. The IDE water vapor heating / cooling compressor.
7. The CCHP system -integration of the 2 systems.
8. The CCHP system-integration of the gas turbine as the compressor driver and heat booster -no electrical power.
Water injection methods

1. **Compressor Inlet Water Spray Evaporation Cooling Method**

   Used to restore degradation of power and thermal efficiency due to high temperature ambient conditions.

   Useful in dry and hot atmosphere.

   Limited by saturation conditions

2. **Wet Compression Method**

   Spraying excess water 5 microns drops which are vaporized during compression

   power boost-up to 20%

   Thermal efficiency increase by 1.5-3%

   Limited by saturation conditions in high pressure-risk of compressor blade damage.
3. **Water/Steam Spray Into Combustor**

   Direct water injection boosts power up to 20% but decreases efficiency.

   If heated and vaporized by exhaust boiler the thermal efficiency increases too by 20%.

4. **Inter Cooling by an Heat Exchanger**
Fig. 1. Engine inlet water injection performance
Ambient conditions – 35°C

Relative Humidity (%) = 0 ... 100

Power increase - 2%
Thermal efficiency increase - 0.7%
Fig. 2  Water Injection into Combustor - Performance
CCHP Systems

1. **Combined Cooling Heat and Power systems:**
   - 80% - total efficiency
   - 35% - power
   - 45% - heat and/or cooling

   Used in Distributed Energy applications: 100 – 10,000 kW

2. **Cogeneration system:**
   - Utilizes exhaust heat to generate steam and additional power
   - 60% total efficiency

   Used in large power stations-more than 100,000 KW
CCHP Systems Variable Energy Demands

1. Electrical load variable demands may be compensated by selling electricity back to the grid (assuming it exists) for an acceptable price.

2. Decreasing power for significant periods results in inefficient usage of the capital investment.

3. Heating/Cooling significant demand variations requires heat/cool storage facilities, as part load performance is not cost effective.
The Inter-Cooled Brayton Cycle - T4=1600 °K

1. Simple Cycle Performance
   C.P.R = 15
   Specific Power-- 400 kW/kg/sec
   Thermal Efficiency - 34%

2. Inter-Cooled Cycle
   C.P.R = 15
   Specific power - 496 kW/kg/sec
   Thermal efficiency - 32.5%

Conclusion:
20% power boost but thermal efficiency decrease of 1.5 points.
FIG.3 - OCN TS 600 Gas Turbine
Fig. 4- Simple cycle performance

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Efficiencies: isentr polytr RNI P/P
Booster  0.8260  0.8611  1.000  5.360
Compressor 0.8200  0.8430  2.102  2.820
Burner 0.9900 0.780
HP Turbine 0.9100 0.8988 0.676 3.046
LP Turbine 0.9300 0.9186 0.318 3.771
HP Spool mech 0.9950 Nominal Spd 0
LP Spool mech 0.9950 Nominal Spd 0
PT Spool Nominal Spd 0

Fuel   FHV  humidity war2
Natural Gas 49.721 0.0 0.00000

- Power – 603 kW
- Thermal Efficiency - 34%
## Fig. 5 - Simple Inter-Cooled Cycle Performance

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**Efficiencies:**
- isentr: 0.8260
- polytr: 0.8611
- RNI: 1.0000
- E/P: 5.360
- Booster: TRQ [%] = 100.0
- Compressor: ZWBld = 0.00000
- Burner: WBHD/W2 = 0.00000
- HP Turbine: WHcl/W2 = 0.00000
- LP Turbine: WLcl/W2 = 0.00000
- HP Spool mech: Nominal Spd = 0
- LP Spool mech: Nominal Spd = 0
- FT Spool: Nominal Spd = 0

**Fuel:** Natural Gas

- FHV: 49.721
- Humidity: 0.0
- war2: 0.0000

Power – 744.5 kW
Efficiency – 32.5%
Fig. 6 - Thermodynamics of an Inter-Cooled Cycle
The Boosted Inter-Cooled Cycle  G.E. – LMS 100

1. A compressor booster [4:1] delivers high pressure air into an inter-cooler and then flows into the same simple cycle gas turbine.

2. If cooled to ambient temperature:
   Mass flow increases 4 times
   Cycle pressure ratio increases to $80 = 4 \times 20$.
   Power increases 5 times.
   Thermal efficiency increases to 45%

3. A fin and plate large heat exchanger is used.
Fig. 7 - G.E LMS 100- Intercooled Gas Turbine
FIG.8 - Effect of Inter-Cooling On Performance

HP Compressor Pressure Ratio = 8 ... 16
Intercooler Exit Temp. = 288 ... 458 [K]

Operating line
Fig. 9 - Effect of Booster Pressure Ratio and Turbine Inlet Temperature On Performance

Burner Exit Temperature = 1450 ... 1650 [K]
Booster Press. Ratio = 2 ... 6
Fig.10 - Effect of Intercooler Parameters on Performance
OCN TS 2000 Gas Turbine

1. Based on the OCN TS 600 - Under Development (fig.3)

2. Boosted with a Booster of 4:1 P.R. Driven by an Additional Free Turbine.

3. Boosted Air Heated to $458 \, ^\circ K$ is Cooled in Air/Water Intercooler to $288-305 \, ^\circ K$ Depending on Water Inlet Temperature.

4. The Heat-Exchanger is a Direct Contact Technology with a Water Separator, Preventing water from entering compressor and low pressure drops.
Fig.11 - OCN TS 2000 Gas Turbine

Power - 2280 kW  Thermal Efficiency - 42.5%
**FIG. 12 - OCN TS 2000 Gas Turbine Design Point Inter-Cooled**

**Performance**

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**Efficiencies:**

- isentr
- polytr
- RNI
- P/P
- Booster: 0.8300
- Compressor: 0.7900
- Burner: 0.9950
- HP Turbine: 0.9150
- IP Turbine: 0.9400
- LP Turbine: 0.8950
- HP Spool mech: 0.9950
- IP Spool mech: 1.0000

**Power – 2280 kW**

**Thermal Efficiency – 42.5%**
Fig. 13 - CCHP System - Summer Module

68% Total Efficiency

Hot Water Users
70°C, 5 kg/sec
1150 kWth

1st Cooler

2nd Cooler

Gas Turbine

Alternator 2000 kW

Water Vapor condenser

100 kW

Heat pump

Cold water Sink 6°C

2 kg/sec-cold water to 2nd Cooler

Cold water supply & recirculation
11 kg/sec = 200 ton refrigeration

Return Water Inlet

40°C, 5 kg/sec
Fig. 14 - CHPC System - Winter Module

Output - 1900 kW Electrical + 1050 kW Heat Energy

Total Efficiency - 57%

- Gas Turbine
- Booster
- Alternator 2000 kW
- Heat pump
- Cold water sink
- Water Vapor condenser

1st Cooler:
- 70 °C, 5 kg/sec
- 1050 kW_{th}

2nd Cooler:
- 40 °C, 5 kg/sec

Water Inlet:
- 0 °C

1 kg/sec-cold water 0 °C to 2nd Cooler