Gas Turbine and Water-Vapor Compressor

Integrated CCHP System

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8. The CCHP system-integration of the gas turbine as the compressor driver and heat booster -no electrical power.

Water injection methods

1. <u>Compressor Inlet Water Spray</u>
   <u>Evaporation Cooling Method</u>

   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 <u>Wet Compression Method</u>

   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.

Water injection methods (cont.)

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

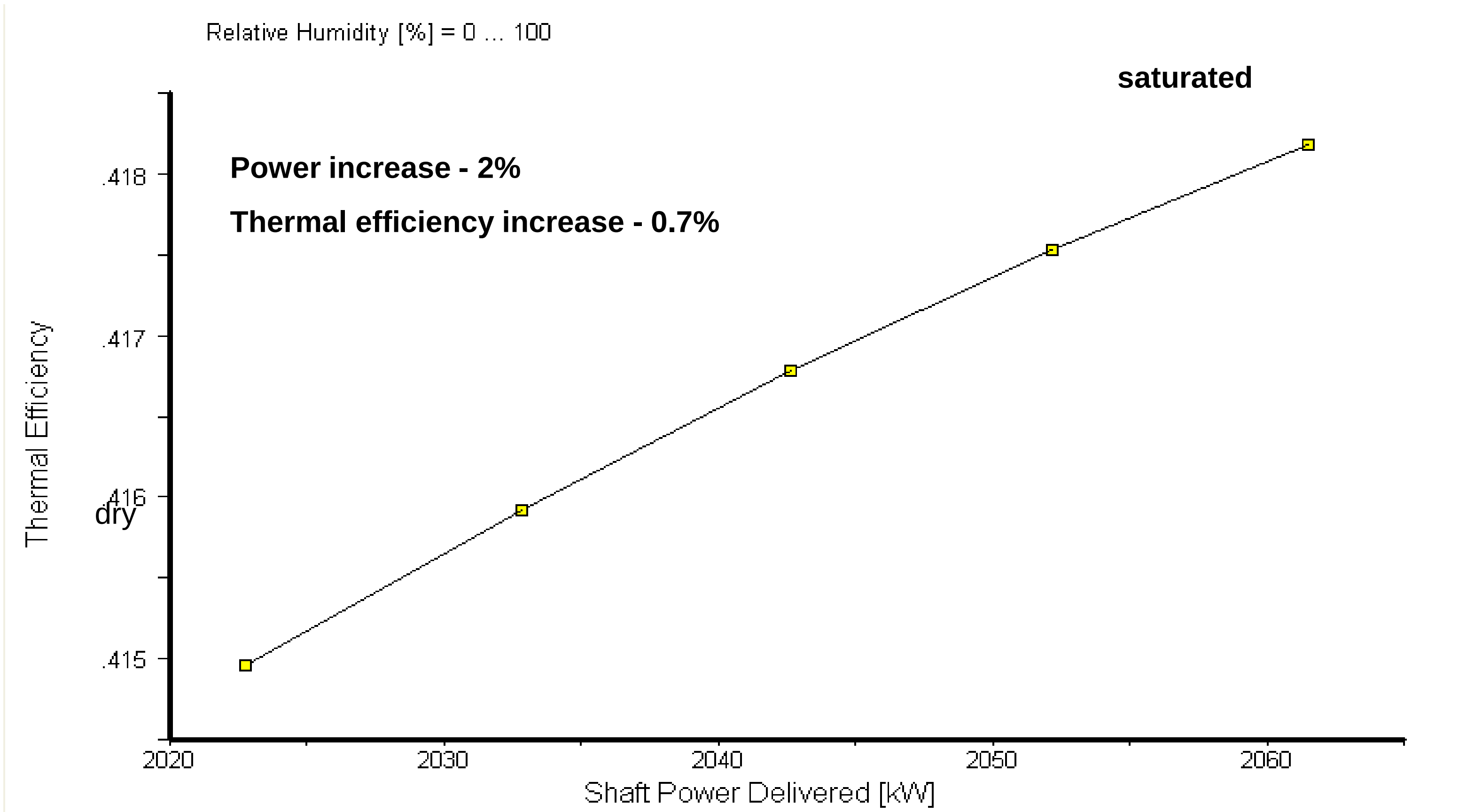
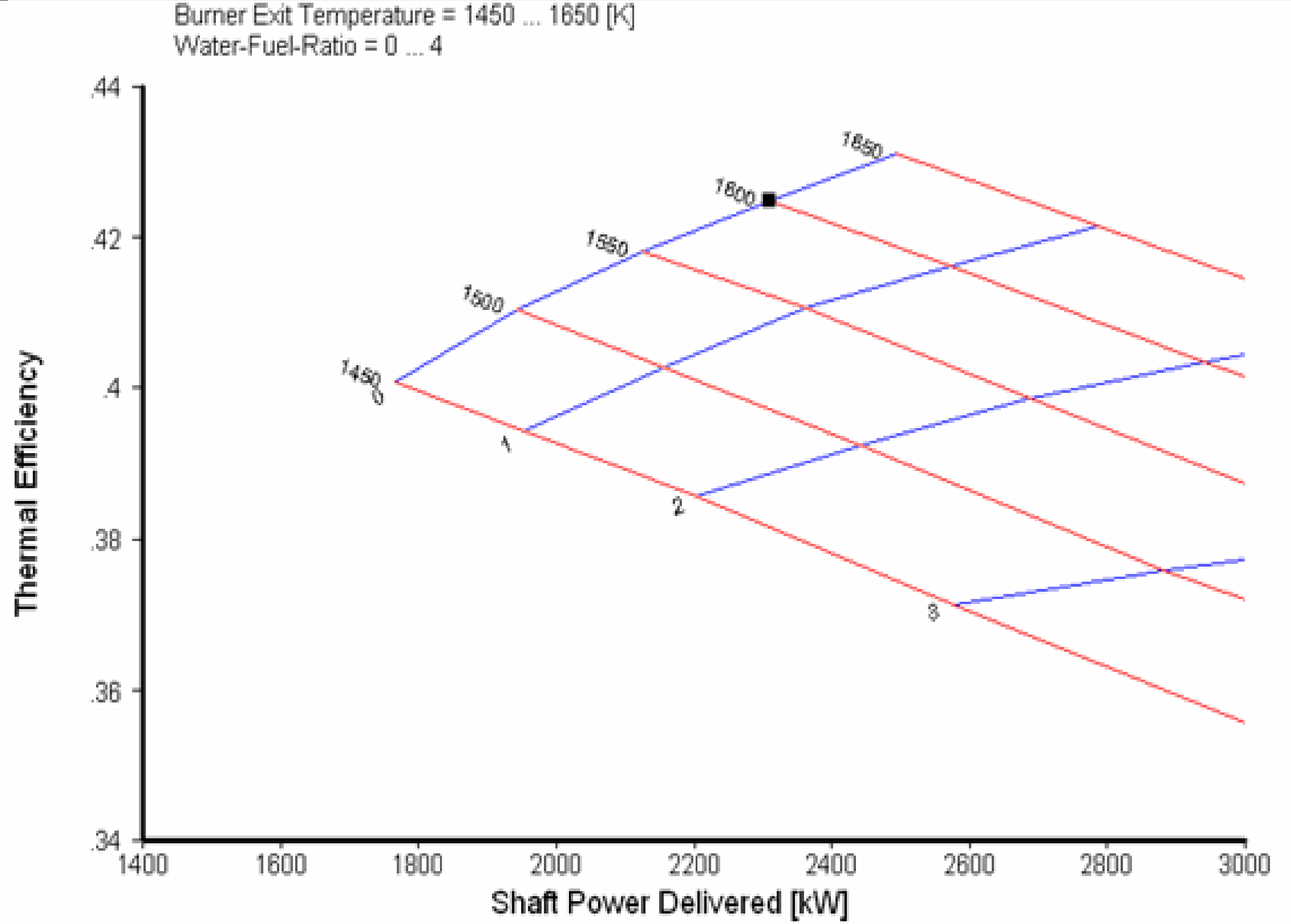


Fig.2 Water Injection into Combustor - Performance



CCHP Systems

1. **C**ombined **C**ooling **H**eat and **P**ower 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

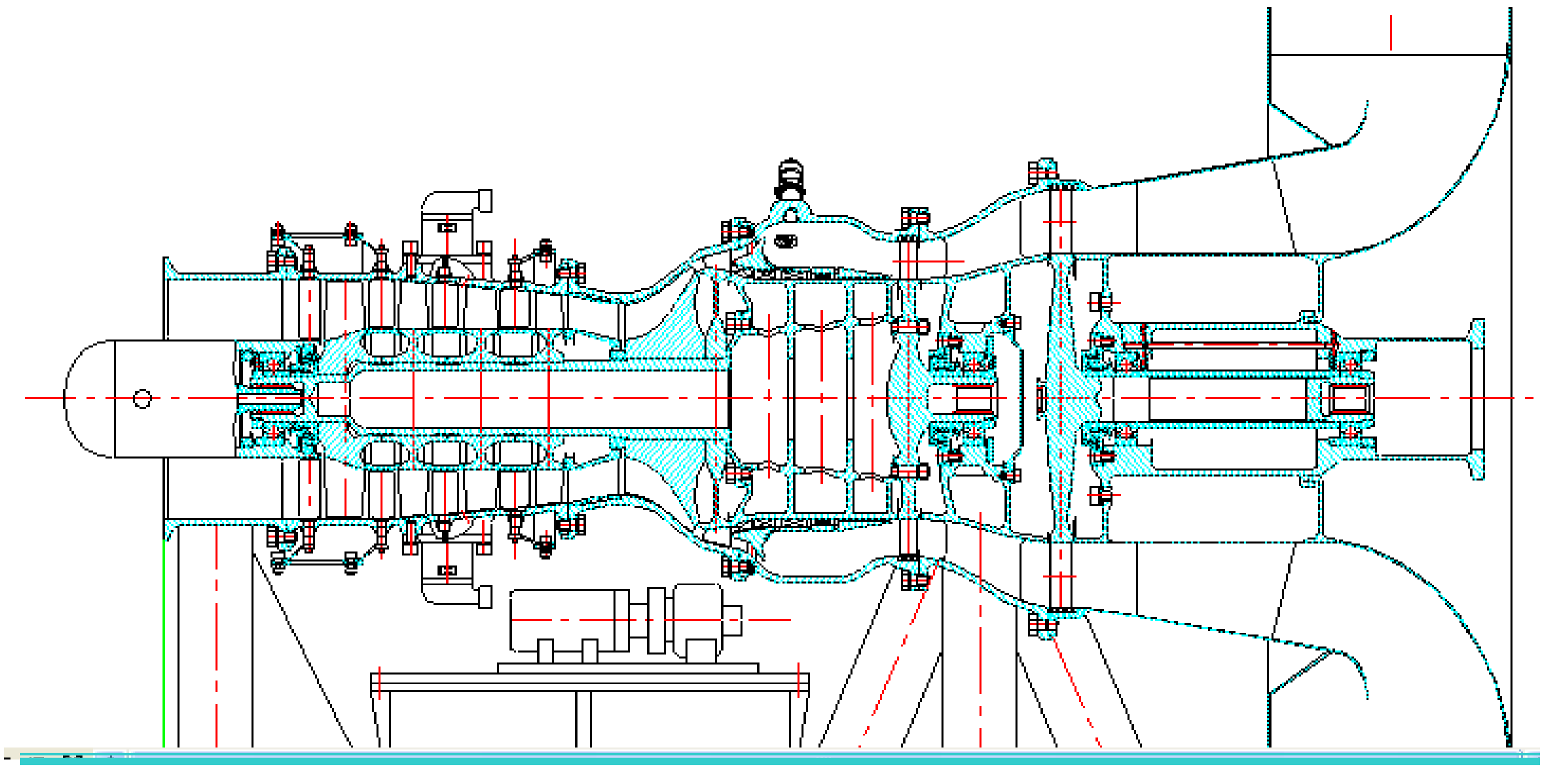


Fig. 4- Simple cycle performance

Station	W	T	P	WRstd
amb		288.15	101.325	
2	1.500	288.15	101.325	1.500
24	1.500	500.71	543.102	0.369
25	1.500	501.00	543.102	0.369
3	1.500	701.10	1531.548	0.155
31	1.500	701.10	1531.548	
4	1.536	1600.00	1194.607	0.310
41	1.536	1600.00	1194.607	0.310
44	1.536	1274.24	392.194	
45	1.536	1274.24	386.311	0.854
49	1.536	953.86	102.451	
5	1.536	953.86	102.451	2.787
8	1.536	953.86	101.426	2.815

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	0.0000

PWSD	=	603.1
PSFC	=	0.21301
Therm Eff	=	0.33992
P2/P1	=	1.0000
P25/P24	=	1.0000
P3/P2	=	15.12
WF	=	0.03568
Loading %	=	100.00
s NOx	=	0.45393
P45/P44	=	0.98500
Incidence	=	0.00
P7/P6	=	1.00000
P8/Pamb	=	1.00100
A8	=	0.17880
TRQ [%]	=	100.0
ZWBld	=	0.00000
WBHD/W2	=	0.00000
WBld/W2	=	0.00000
eta t-s	=	0.92348
WHcl/W25	=	0.00000
WLcl/W25	=	0.00000

◄ Power – 603 kW

◄ Thermal Efficiency - 34%

Fig.5 - Simple Inter-Cooled Cycle Performance

Station	W	T	P	WRstd			
amb		288.15	101.325		PSFC	=	0.22253
2	1.500	288.15	101.325	1.500	Therm Eff	=	0.32537
24	1.500	500.71	543.102	0.280			
25	1.500	288.00	526.809	0.288	P2/P1	=	1.0000
3	1.500	408.55	1485.601	0.122	P25/P24	=	0.9700
31	1.500	408.55	1485.601		P3/P2	=	14.66
4	1.546	1600.00	1158.769	0.322	WF	=	0.04602
41	1.546	1600.00	1158.769	0.322	Loading %	=	100.00
44	1.546	1349.48	497.510		s NOx	=	0.09956
45	1.546	1349.48	490.048	0.699	P45/P44	=	0.98500
49	1.546	965.82	102.451		Incidence	=	0.00
5	1.546	965.82	102.451	2.830			
8	1.546	965.82	101.426	2.859	P7/P6	=	1.00000

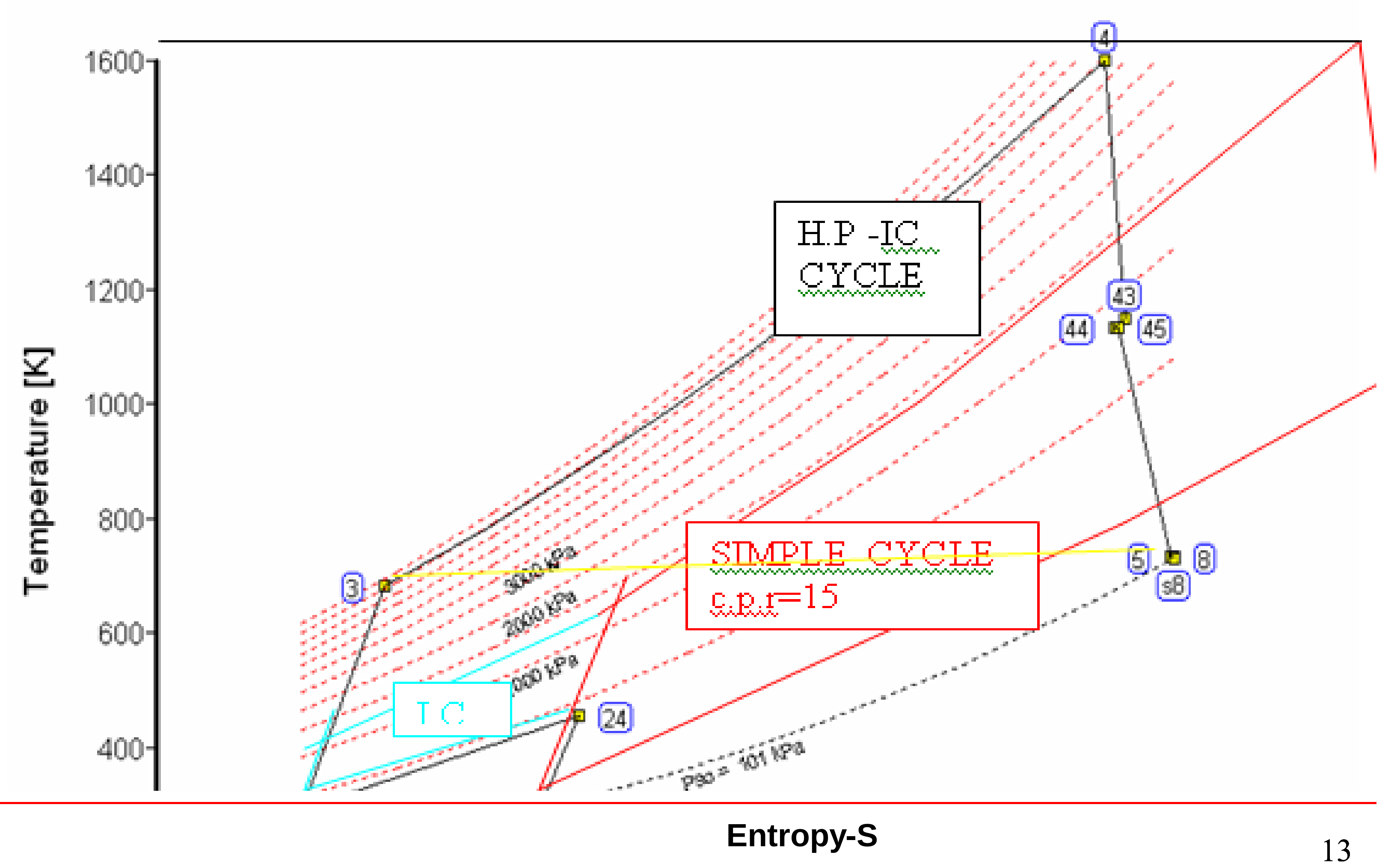
PWSD = 744.5 — Power – 744.5 kW

Therm Eff= 0.32537 — Efficiency – 32.5%

Efficiencies:	isentr	polytr	RNI	P/P			
					P8/Pamb	=	1.00100
					A8	=	0.18188
Booster	0.8260	0.8611	1.000	5.360	TRQ [%]	=	100.0
Compressor	0.8200	0.8439	5.204	2.820	ZWBld	=	0.00000
Burner	0.9900			0.780	WBHD/W2	=	0.00000
HP Turbine	0.9100	0.9019	0.654	2.329	WBld/W2	=	0.00000
LP Turbine	0.9300	0.9166	0.367	4.783	eta t-s	=	0.92461
HP Spool mech	0.9950	Nominal Spd		0	WHcl/W25	=	0.00000
LP Spool mech	0.9950	Nominal Spd		0	WLcl/W25	=	0.00000
PT Spool		Nominal Spd		0			

Fuel	FHV	humidity	war2
Natural Gas	49.721	0.0	0.0000

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 x 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

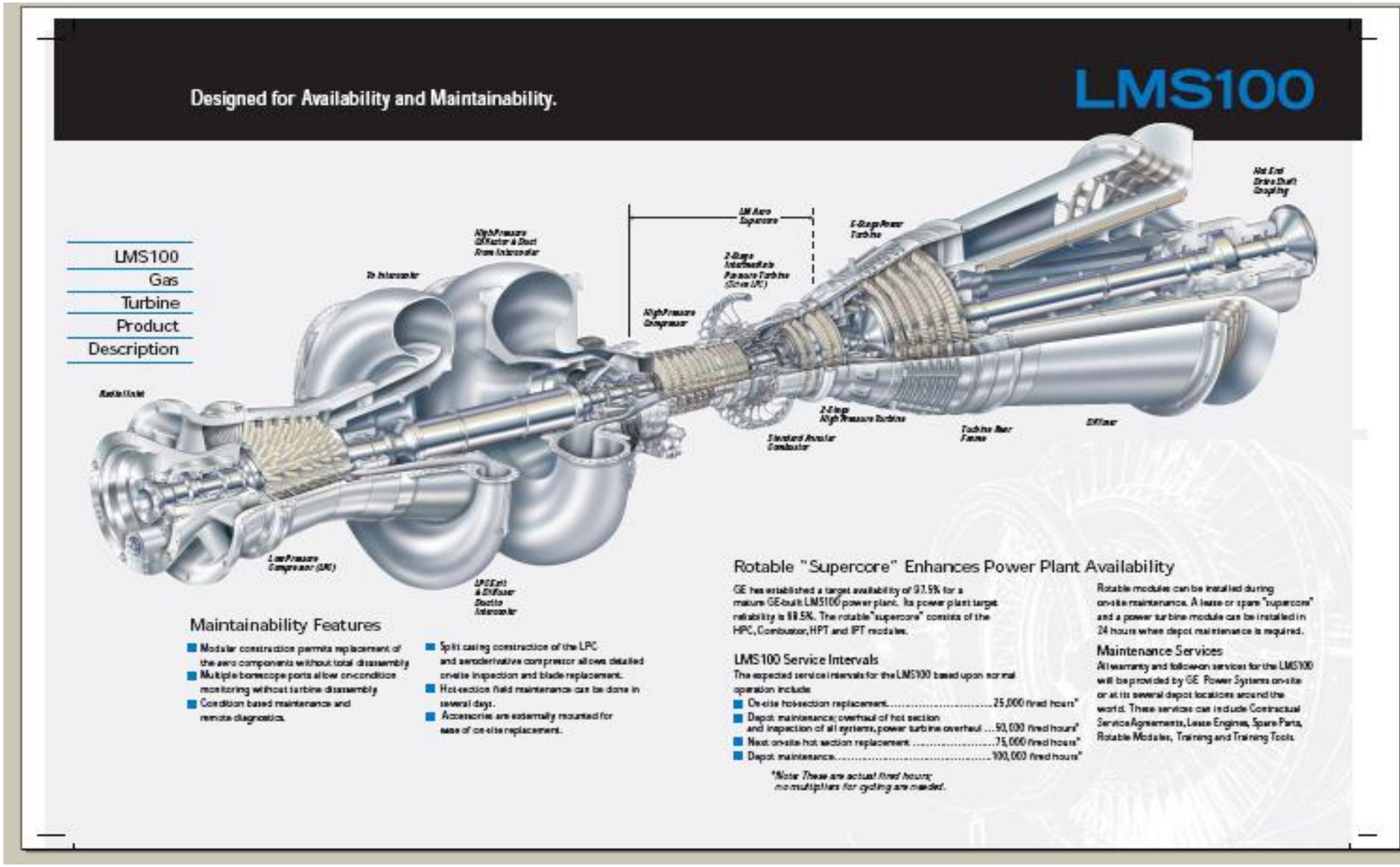


FIG.8 - Effect of Inter-Cooling On Performance

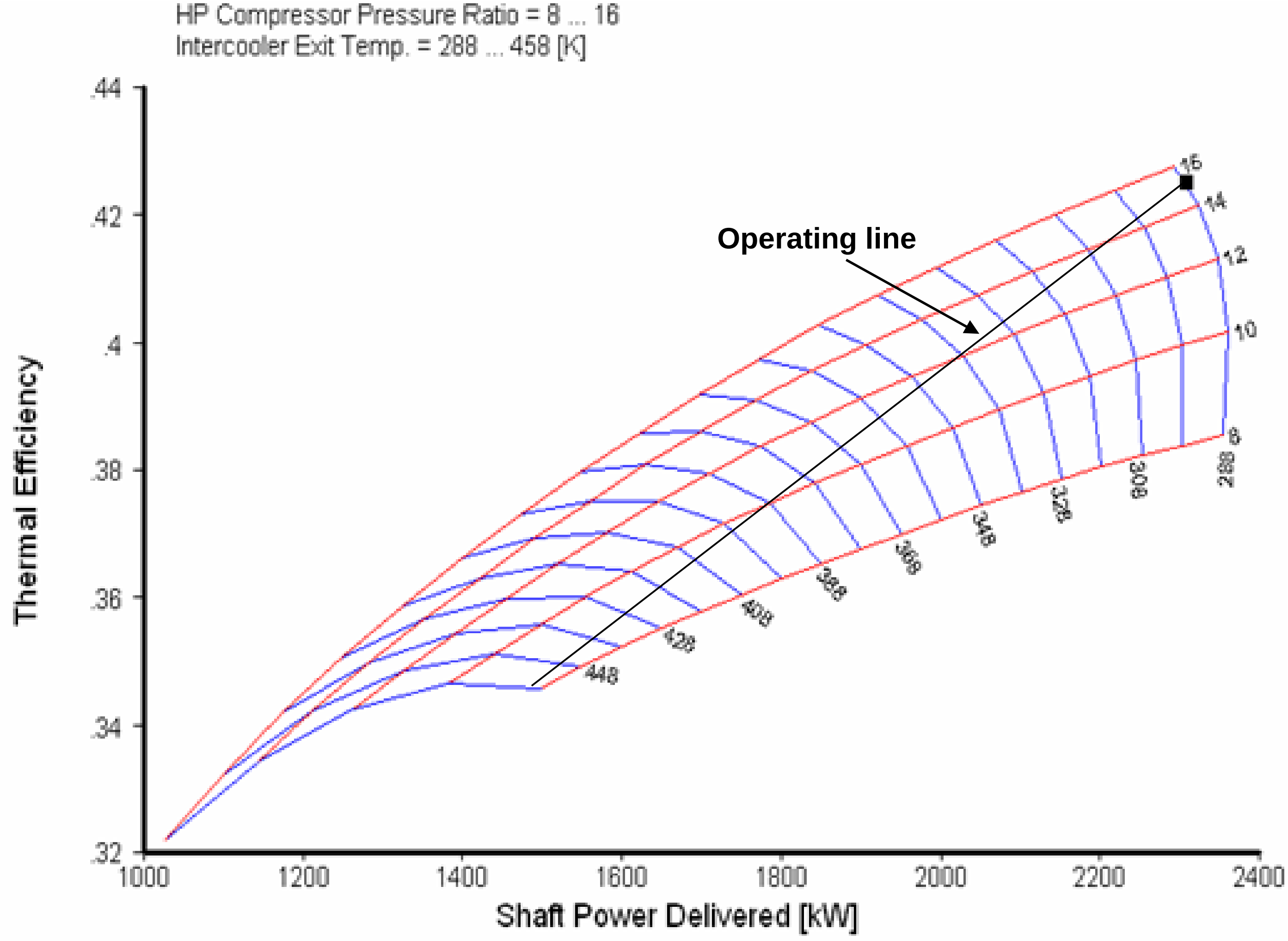


Fig.9 - Effect of Booster Pressure Ratio and Turbine Inlet Temperature On Performance

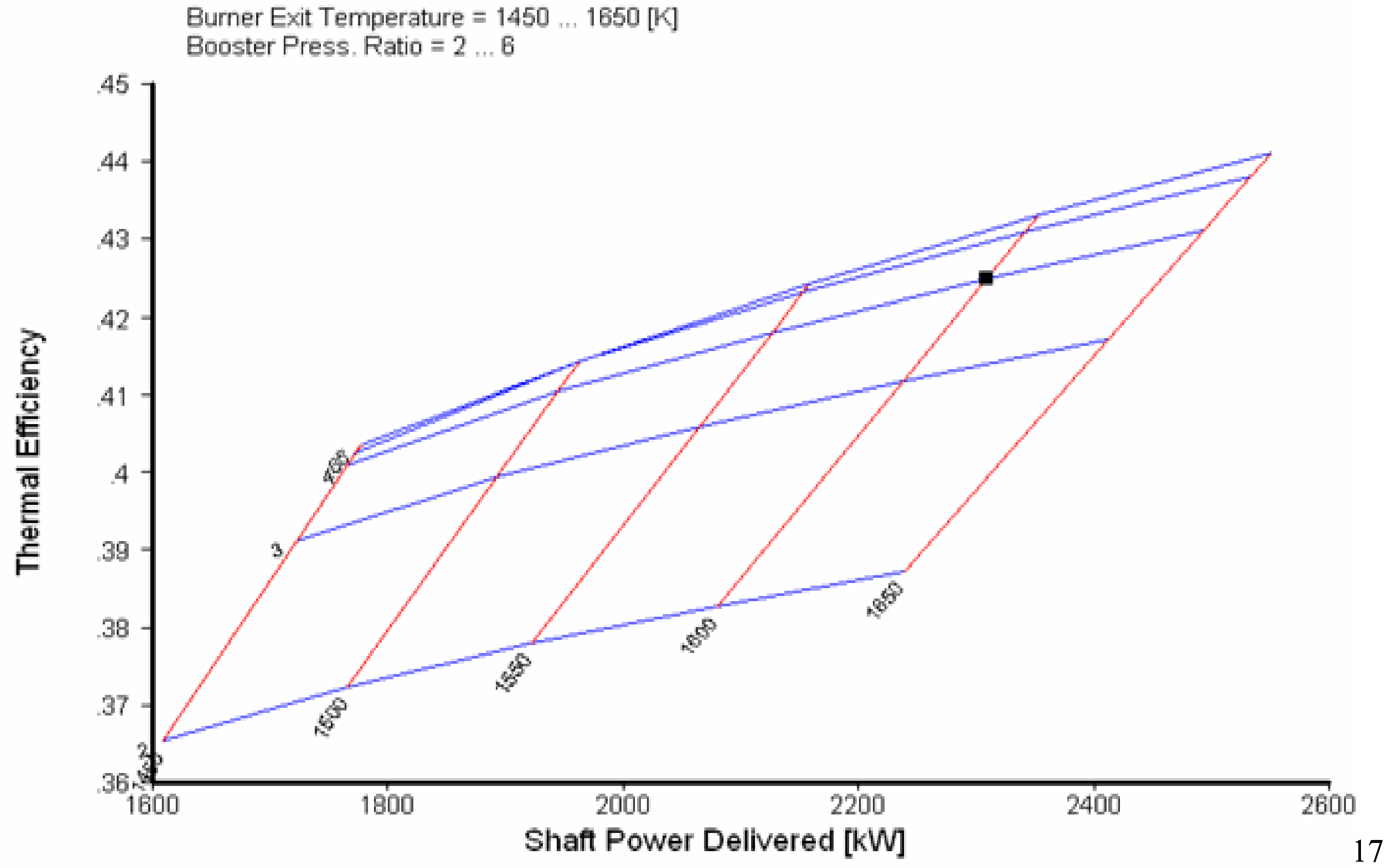
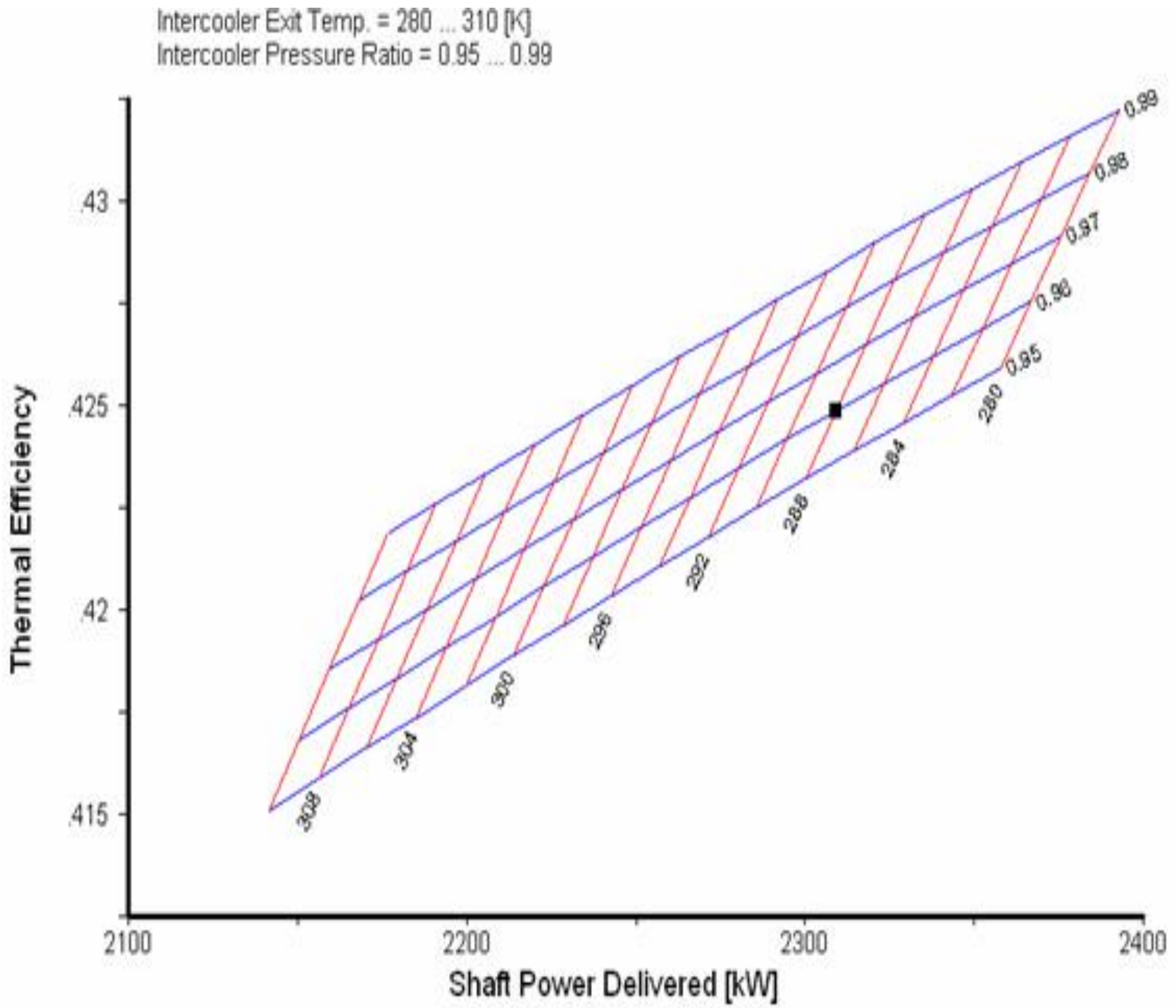


Fig.10 - Effect of Intercooler Parameters on Performance



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 ^{o}K is Cooled in Air/Water Intercooler to 288-305 ^{o}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%

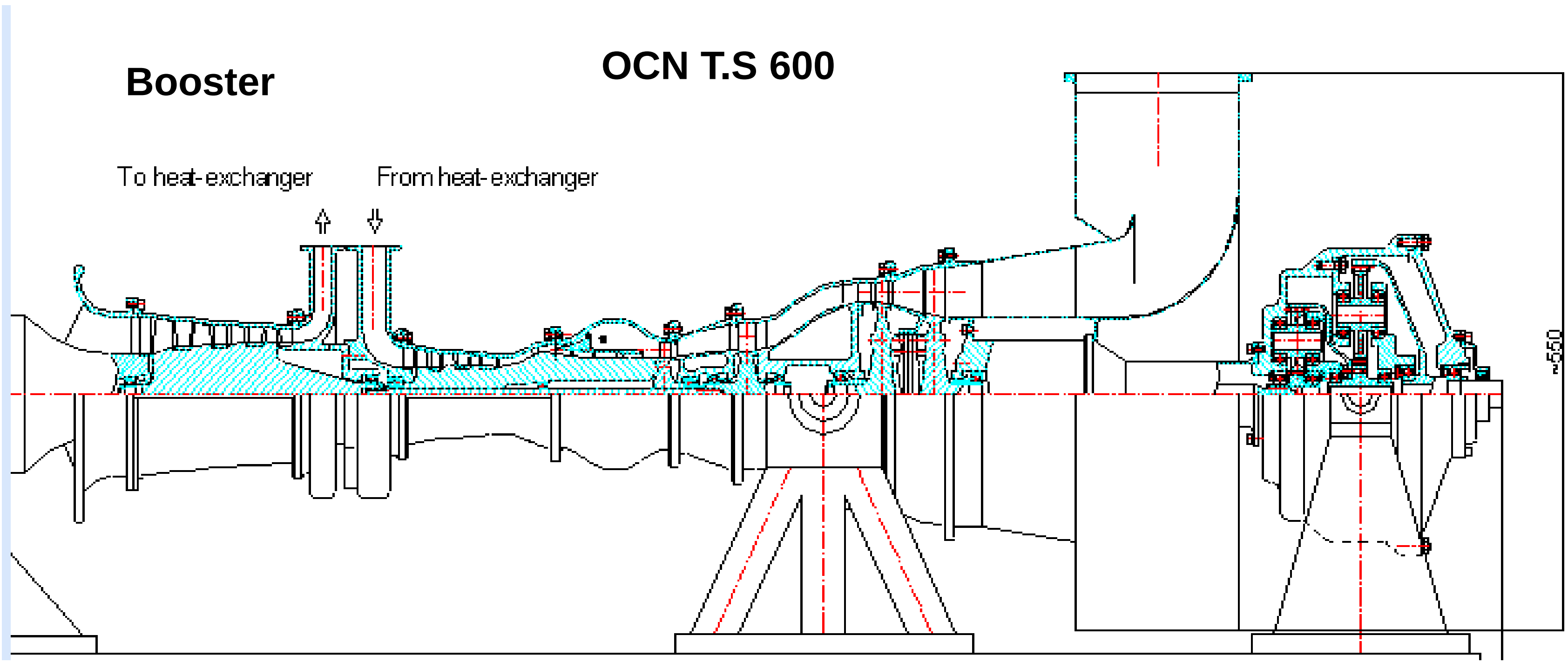


FIG.12 - OCN TS 2000 Gas Turbine Design Point Inter-Cooled

Performance Power-2280kw Thermal Efficiency-42.5%

Station	W	T	P	WRstd
amb		288.15	101.325	
2	4.700	288.15	101.325	4.700
24	4.700	455.53	405.300	1.175
25	4.700	288.00	381.306	1.249
3	4.700	700.76	5719.594	0.130
31	4.559	700.76	5719.594	
4	4.667	1600.00	4461.283	0.252
41	4.667	1600.00	4461.283	0.252
42	4.667	1264.10	1419.424	
43	4.808	1249.19	1419.424	
44	4.808	1249.19	1391.036	
45	4.808	1249.19	1391.036	0.735
46	4.808	1116.09	833.060	
47	4.808	1116.09	833.060	
48	4.808	1116.09	820.564	1.178
49	4.808	716.10	103.382	
5	4.808	716.10	103.382	7.490
8	4.808	716.10	101.832	7.604

Efficiencies:	isentr	polytr	RNI	P/P
Booster	0.8300	0.8591	1.000	4.000
Compressor	0.7900	0.8511	1.734	15.000
Burner	0.9950			0.780
HP Turbine	0.9150	0.9040	2.523	3.143
IP Turbine	0.9400	0.9365	2.523	1.670
LP Turbine	0.8950	0.8670	0.840	7.937
HP Spool mech	0.9950	Nominal Spd		0
IP Spool mech	1.0000	Nominal Spd		0

PWSD =	2280.0 ← Power – 2280 kW
PSFC =	0.17042
P2/P1 =	1.00000
P25/P24 =	0.94080
P3/P2 =	56.44800
WF =	0.10793
s NOx =	0.76759
Therm Eff=	0.42487 ← Thermal Efficiency
W_NGV/W25=	0.00000
WHcl/W25 =	0.03000
P44/P43 =	0.98000
WINcl/W25=	0.00000
WIcl/W25 =	0.00000
WLcl/W25 =	0.00000
P48/P47 =	0.98500
Incidence=	0.00
P8/Pamb =	1.00500
WBHD/W2 =	0.00000
WBld/W25 =	0.00000
Loading %=	100.00
WlkLP/W25=	0.00000
eta t-s =	0.88845
TRQ [%] =	100.00

Fig. 13 - CCHP System - Summer Module

68% Total Efficiency

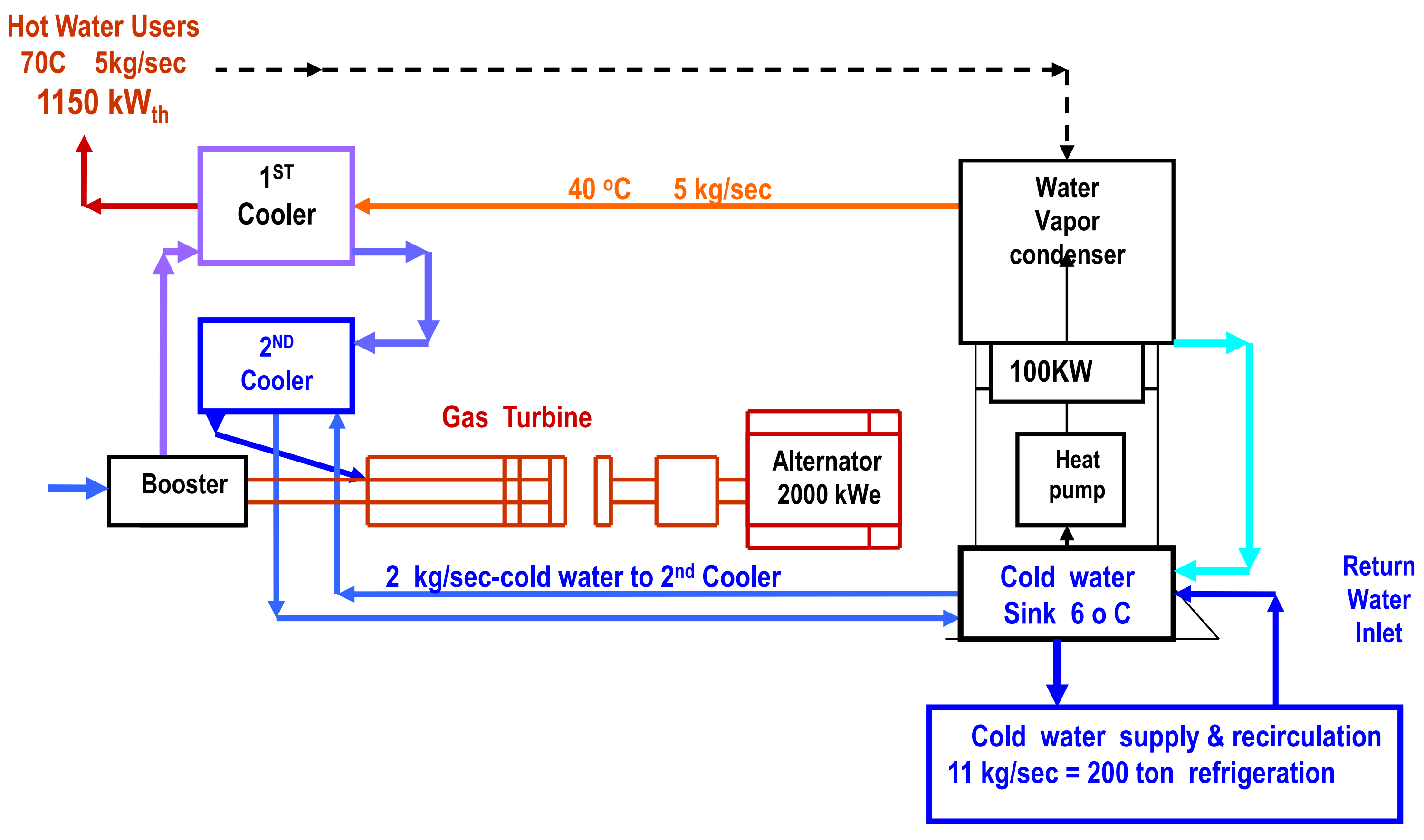


Fig. 14 - CHPC System - Winter Module

Output - 1900 kW Electrical + 1050 kW Heat Energy

Total Efficiency - 57%