

Gas Turbine and Water-Vapor Compressor

Integrated CCHP System

Contents

- 1. Combined Heat and Cooling and Power systems**
- 2. Load fluctuations in CCHP systems.**
- 3. Methods of water injection into Gas Turbines.**
- 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.

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

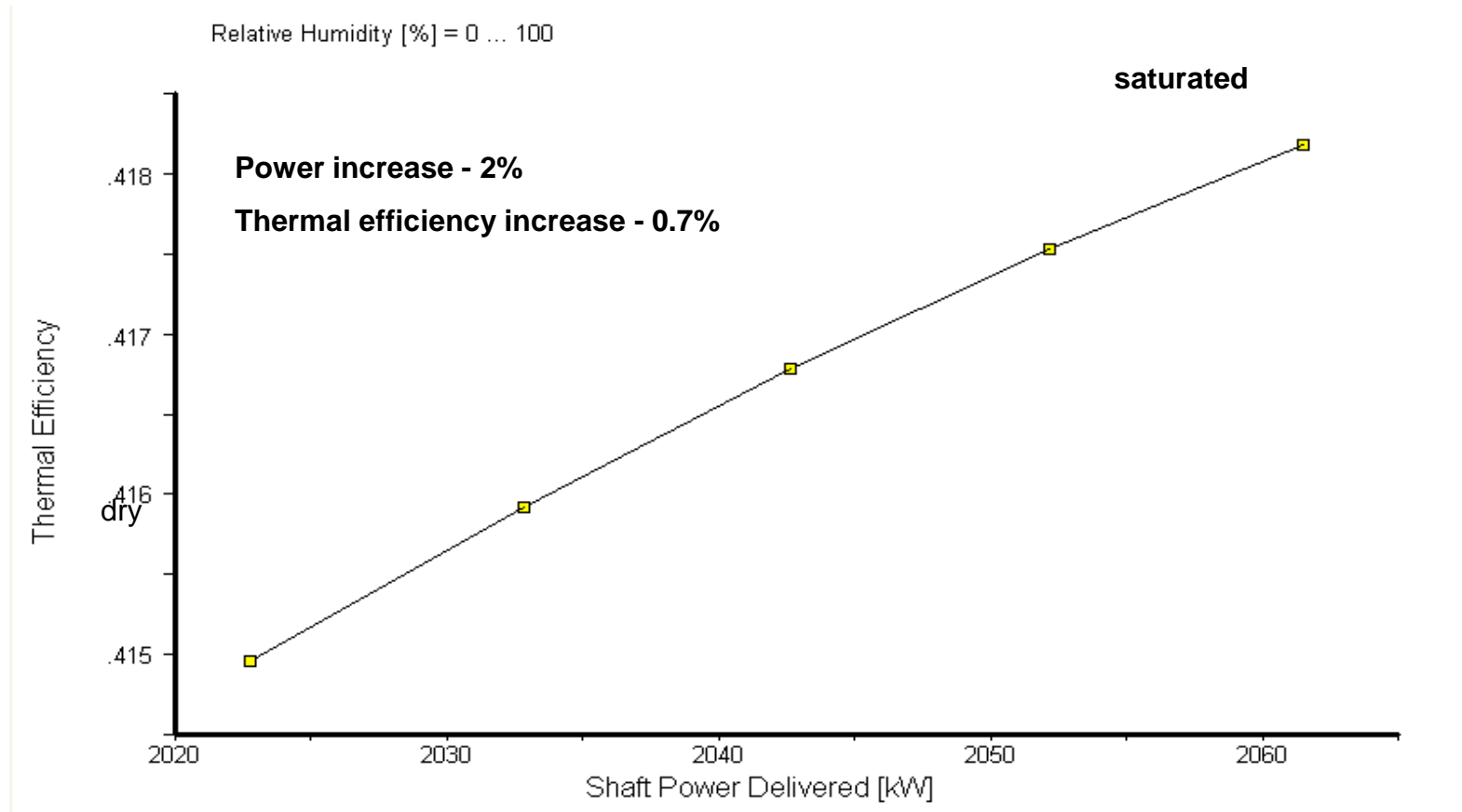
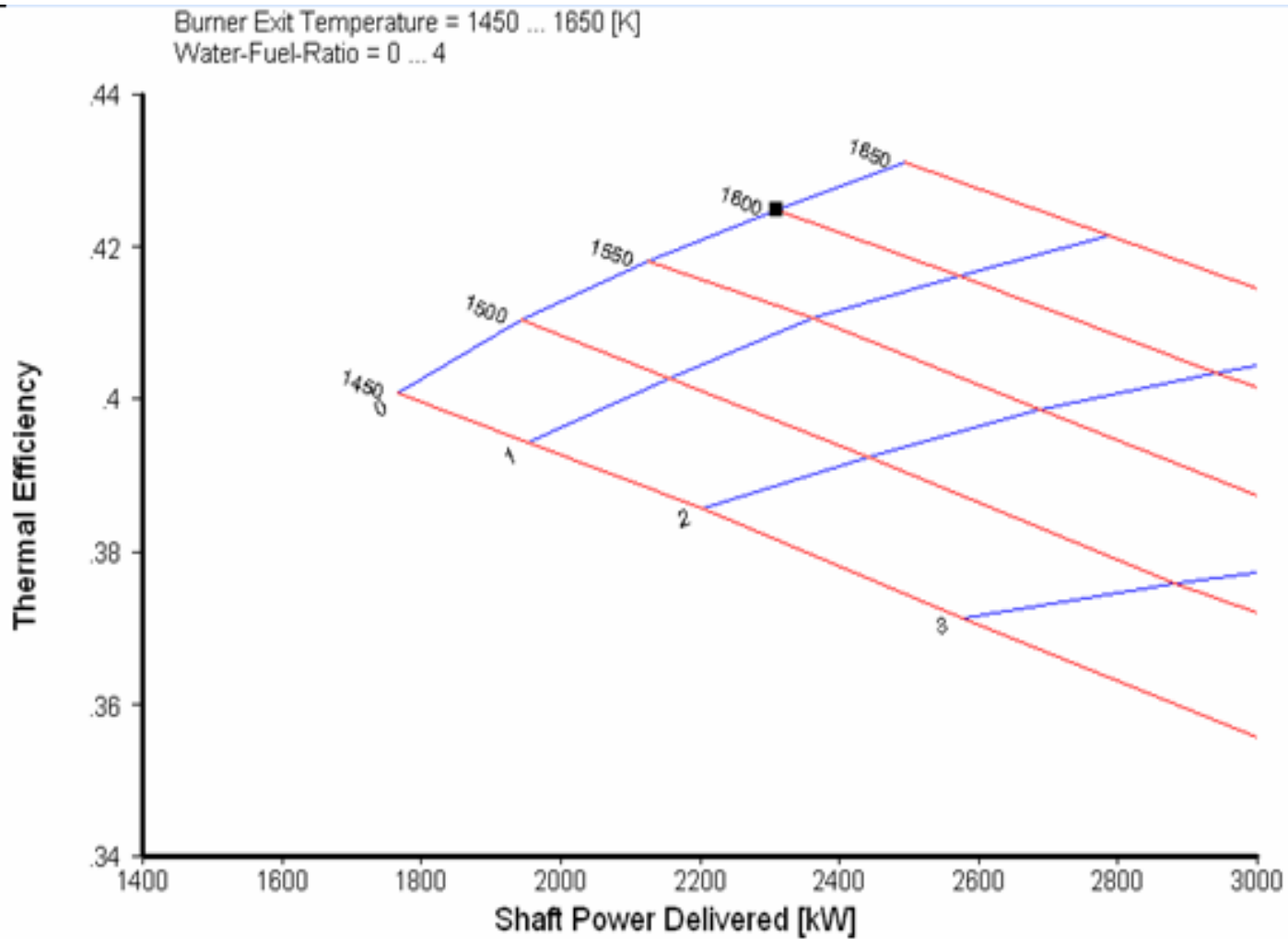


Fig.2 Water Injection into Combustor - Performance



CCHP Systems

1. 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 - $T_4=1600\text{ }^\circ\text{K}$

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

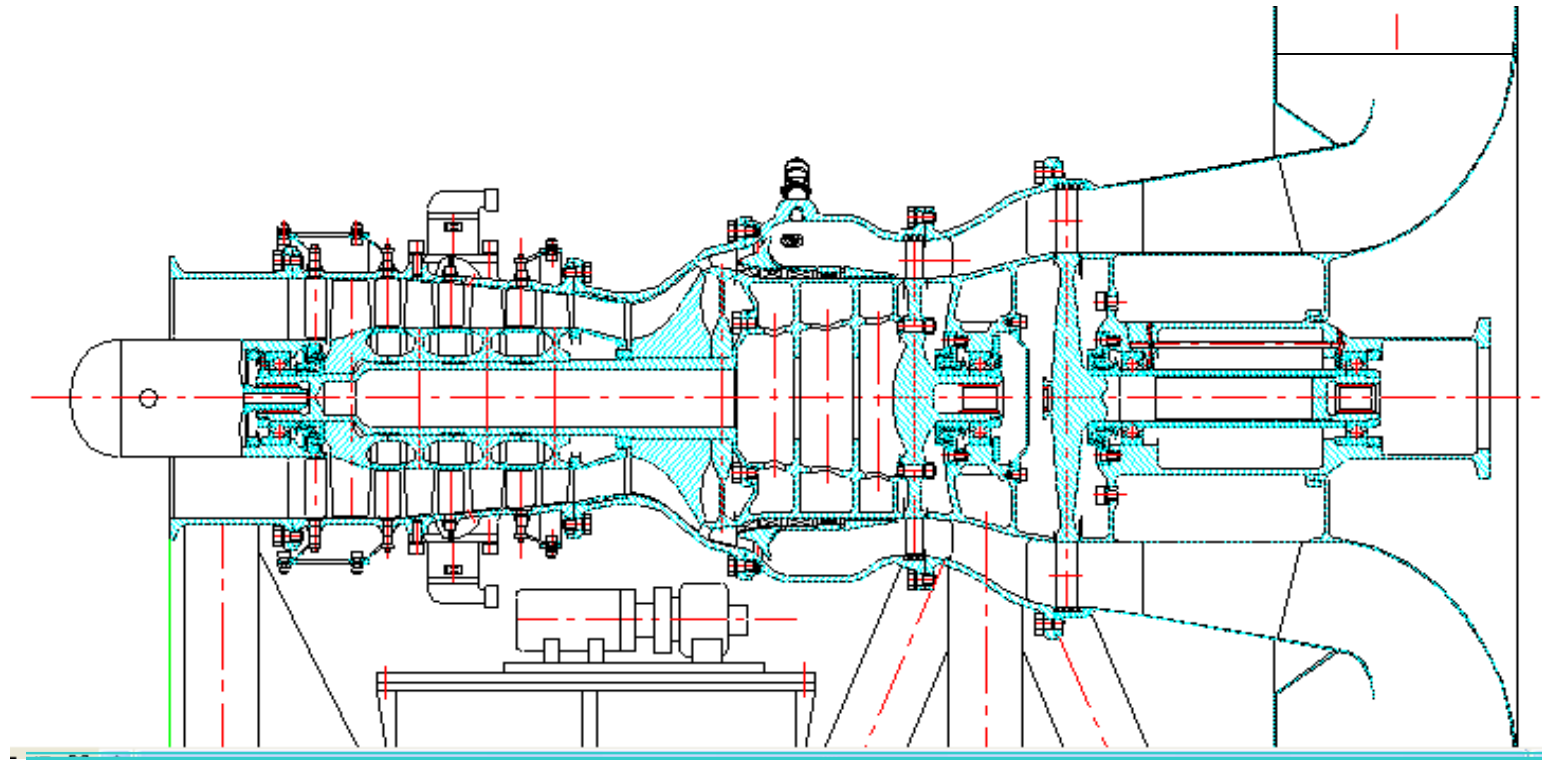


Fig. 4- Simple cycle performance

Station	W	T	P	WRstd	PWSD =	603.1
amb		288.15	101.325		PSFC =	0.21301
2	1.500	288.15	101.325	1.500	Therm Eff=	0.33992
24	1.500	500.71	543.102	0.369		
25	1.500	501.00	543.102	0.369	P2/P1 =	1.0000
3	1.500	701.10	1531.548	0.155	P25/P24 =	1.0000
31	1.500	701.10	1531.548		P3/P2 =	15.12
4	1.536	1600.00	1194.607	0.310	WF =	0.03568
41	1.536	1600.00	1194.607	0.310	Loading % =	100.00
44	1.536	1274.24	392.194		s NOx =	0.45393
45	1.536	1274.24	386.311	0.854	P45/P44 =	0.98500
49	1.536	953.86	102.451		Incidence =	0.00
5	1.536	953.86	102.451	2.787		
8	1.536	953.86	101.426	2.815	P7/P6 =	1.00000
					P8/Pamb =	1.00100
Efficiencies:	isent	polytr	RNI	P/P	A8 =	0.17880
Booster	0.8260	0.8611	1.000	5.360	TRQ [%] =	100.0
Compressor	0.8200	0.8430	2.102	2.820	ZWBld =	0.00000
Burner	0.9900			0.780	WBHD/W2 =	0.00000
HP Turbine	0.9100	0.8988	0.676	3.046	WBld/W2 =	0.00000
LP Turbine	0.9300	0.9186	0.318	3.771	eta t-s =	0.92348
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			

◀ Power – 603 kW

◀ Thermal Efficiency - 34%

Fig.5 - Simple Inter-Cooled Cycle Performance

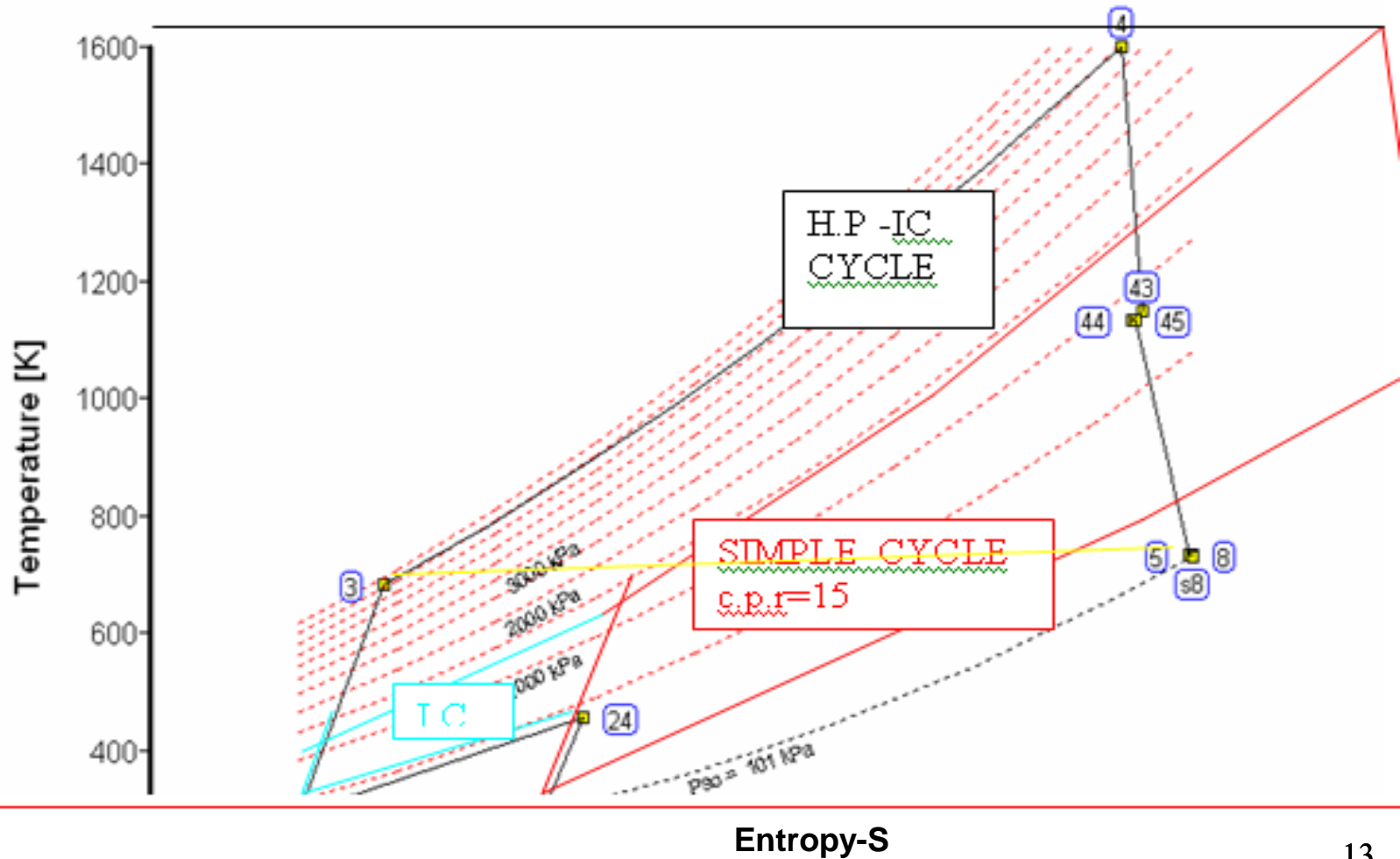
Station	W	T	P	WRstd	PWSD =	744.5
amb		288.15	101.325		PSFC =	0.22253
2	1.500	288.15	101.325	1.500	Therm Eff=	0.32537
24	1.500	500.71	543.102	0.280		
25	1.500	288.00	526.809	0.288	P2/P1 =	1.0000
3	1.500	408.55	1485.601	0.122	P25/P24 =	0.9700
31	1.500	408.55	1485.601		P3/P2 =	14.66
4	1.546	1600.00	1158.769	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
					P8/Pamb =	1.00100
					A8 =	0.18188
Efficiencies:	isent	polytr	RNI	P/P	TRQ [%] =	100.0
Booster	0.8260	0.8611	1.000	5.360	ZWBld =	0.00000
Compressor	0.8200	0.8439	5.204	2.820	WBHD/W2 =	0.00000
Burner	0.9900			0.780	WBld/W2 =	0.00000
HP Turbine	0.9100	0.9019	0.654	2.329	eta t-s =	0.92461
LP Turbine	0.9300	0.9166	0.367	4.783	WHcl/W25 =	0.00000
HP Spool mech	0.9950	Nominal Spd		0	WLcl/W25 =	0.00000
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			

◀ 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%**

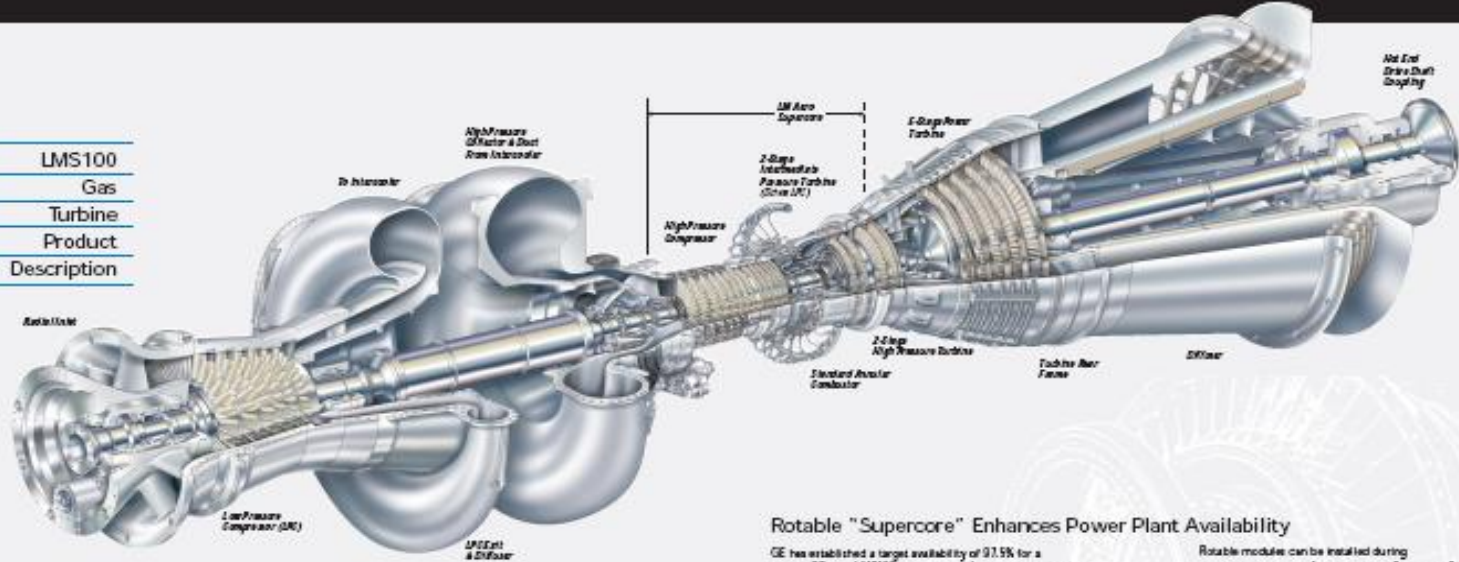
- 3. A fin and plate large heat exchanger is used.**

Fig. 7 - G.E LMS 100- Intercooled Gas Turbine

Designed for Availability and Maintainability.

LMS100

LMS100
Gas
Turbine
Product
Description



Air Inlet
 Low Pressure Compressor (LPC)
 Intercooler
 High Pressure Compressor
 High Pressure Compressor & Dual Flow Intercooler
 High Pressure Turbine (HPT)
 Standard Axial Combustor
 High Pressure Turbine
 2-Stage Intermediate Pressure Turbine (SIP/T)
 2-Stage High Pressure Turbine
 1-Stage Power Turbine
 Turbine Air Frame
 Exhaust
 Hot End Drive Shaft Assembly

Maintainability Features

- Modular construction permits replacement of the aero components without total disassembly
- Multiple borescope ports allow on-condition monitoring without turbine disassembly
- Condition based maintenance and remote diagnostics.
- Split casing construction of the LPC and aeroderivative compressor allows detailed on-site inspection and blade replacement.
- Hot section field maintenance can be done in several days.
- Accessories are externally mounted for ease of on-site replacement.

Rotable "Supercore" Enhances Power Plant Availability

GE has established a target availability of 97.5% for a mature GE-built LMS100 power plant. Its power plant target reliability is 99.5%. The rotable "supercore" consists of the HPC, Combustor, HPT and IPT modules.

LMS 100 Service Intervals

The expected service intervals for the LMS100 based upon normal operation include:

On-site inspection replacement.....	25,000 fired hours*
Depot maintenance; overhaul of hot section and inspection of all systems, power turbine overhaul ...	50,000 fired hours*
Next on-site hot section replacement	75,000 fired hours*
Depot maintenance.....	100,000 fired hours*

*Note: These are actual fired hours; no multipliers for cycling are needed.

Maintenance Services

At warranty and follow-on services for the LMS100 will be provided by GE Power Systems on-site or at its several depot locations around the world. These services can include Contractual Service Agreements, Lease Engines, Spare Parts, Rotable Modules, Training and Training Tools.

FIG.8 - Effect of Inter-Cooling On Performance

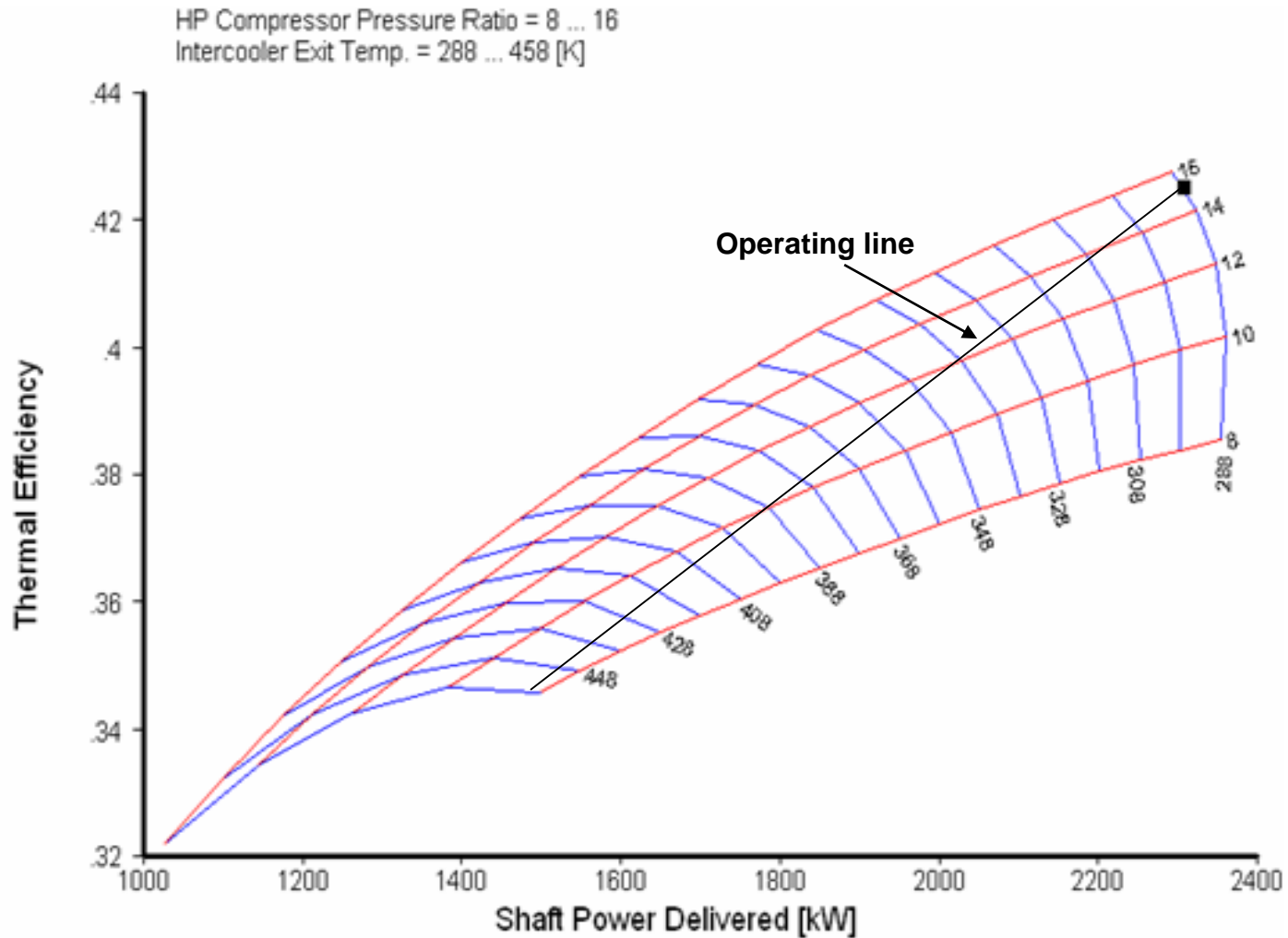


Fig.9 - Effect of Booster Pressure Ratio and Turbine Inlet Temperature On Performance

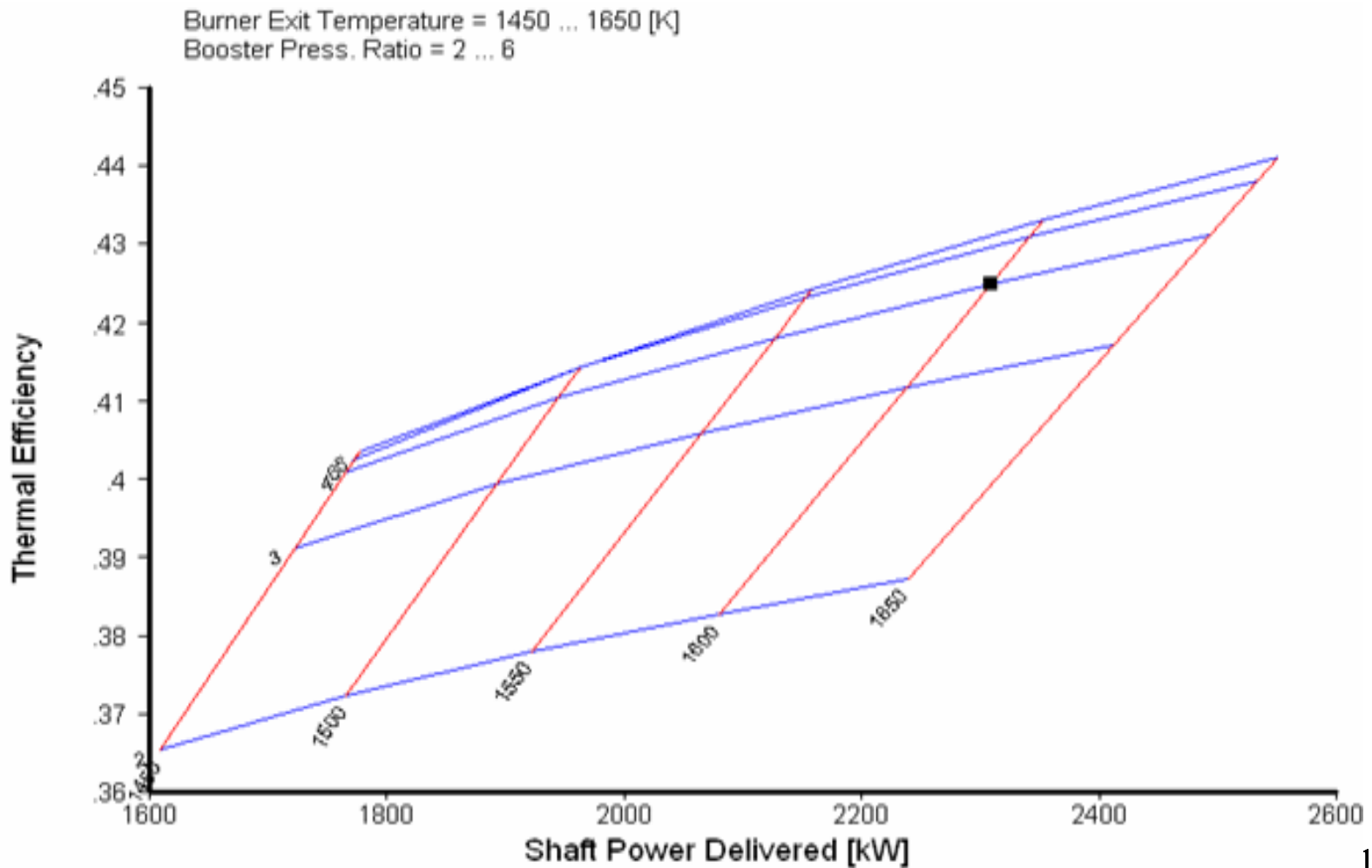
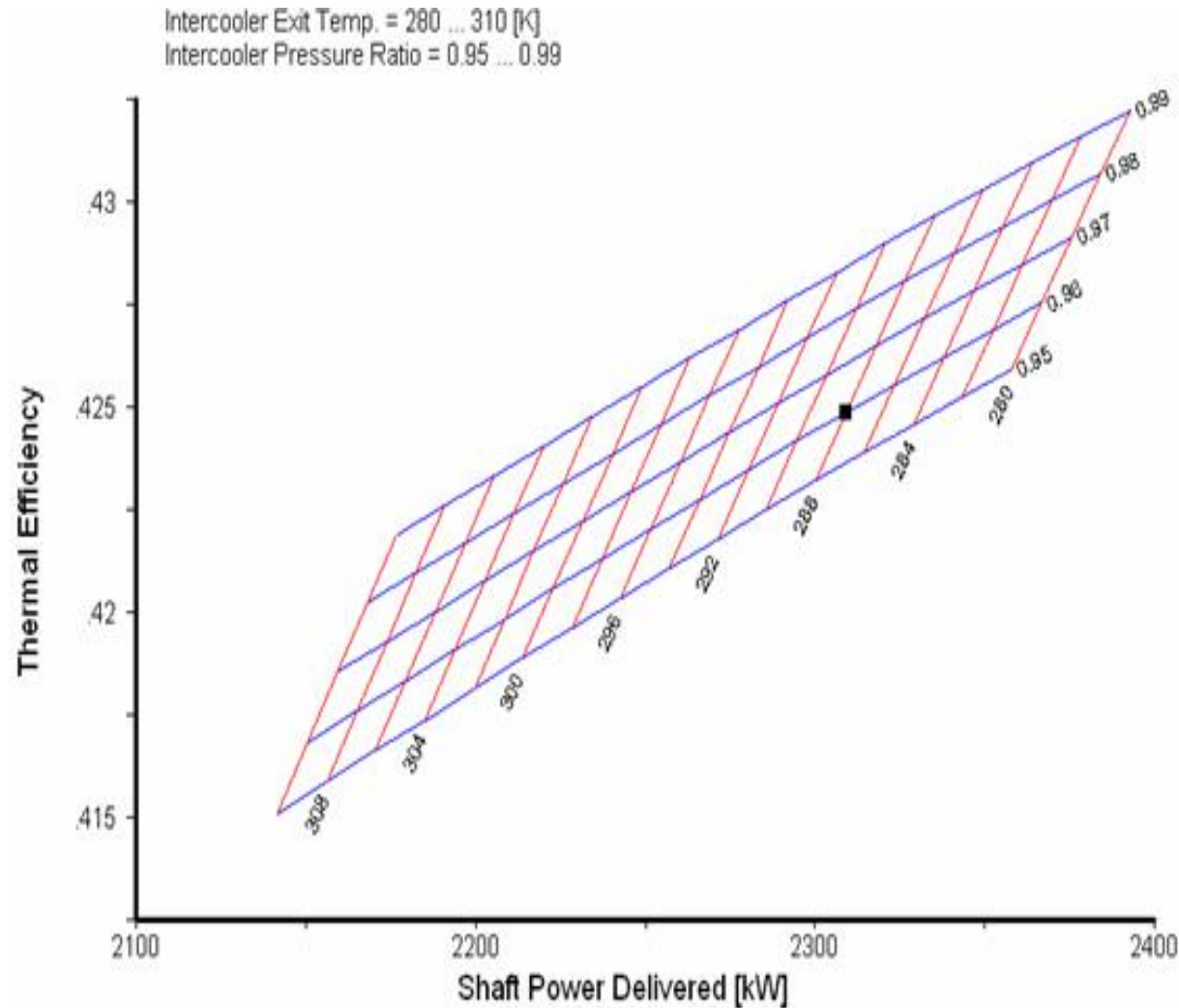


Fig.10 - Effect of Intercooler Parameters on Performance



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 °K is Cooled in Air/Water Intercooler to 288-305 °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%

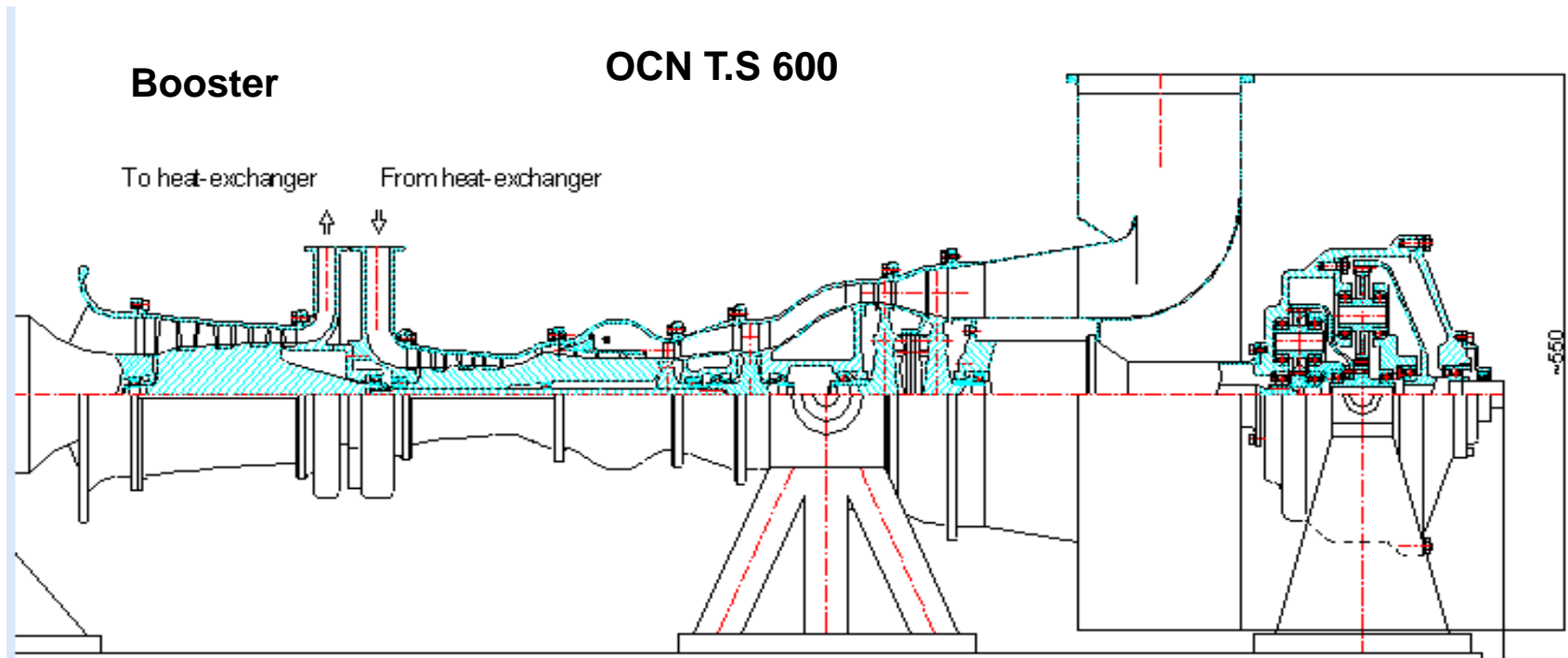


FIG.12 - OCN TS 2000 Gas Turbine Design Point Inter-Cooled

Performance

Power-2280kw

Thermal Efficiency-42.5%

Station	W	T	P	WRstd			
amb		288.15	101.325		PWSD =	2280.0	← Power – 2280 kW
2	4.700	288.15	101.325	4.700	PSFC =	0.17042	
24	4.700	455.53	405.300	1.175	P2/P1 =	1.00000	
25	4.700	288.00	381.306	1.249	P25/P24 =	0.94080	
3	4.700	700.76	5719.594	0.130	P3/P2 =	56.44800	
31	4.559	700.76	5719.594		WF =	0.10793	
4	4.667	1600.00	4461.283	0.252	s NOx =	0.76759	
41	4.667	1600.00	4461.283	0.252	Therm Eff=	0.42487	← Thermal Efficiency
42	4.667	1264.10	1419.424		W_NGV/W25=	0.00000	
43	4.808	1249.19	1419.424		WHcl/W25 =	0.03000	
44	4.808	1249.19	1391.036		P44/P43 =	0.98000	
45	4.808	1249.19	1391.036	0.735	WINcl/W25=	0.00000	
46	4.808	1116.09	833.060		WIcl/W25 =	0.00000	
47	4.808	1116.09	833.060		WLcl/W25 =	0.00000	
48	4.808	1116.09	820.564	1.178	P48/P47 =	0.98500	
49	4.808	716.10	103.382		Incidence=	0.00	
5	4.808	716.10	103.382	7.490			
8	4.808	716.10	101.832	7.604	P8/Pamb =	1.00500	
Efficiencies:		isent	polytr	RNI	P/P		
Booster		0.8300	0.8591	1.000	4.000	WBHD/W2 =	0.00000
Compressor		0.7900	0.8511	1.734	15.000	WBld/W25 =	0.00000
Burner		0.9950			0.780	Loading %=	100.00
HP Turbine		0.9150	0.9040	2.523	3.143		
IP Turbine		0.9400	0.9365	2.523	1.670	WkLP/W25=	0.00000
LP Turbine		0.8950	0.8670	0.840	7.937	eta t-s =	0.88845
HP Spool mech		0.9950	Nominal Spd		0	TRQ [%] =	100.00
IP Spool mech		1.0000	Nominal Spd		0		

Fig. 13 - CCHP System - Summer Module

68% Total Efficiency

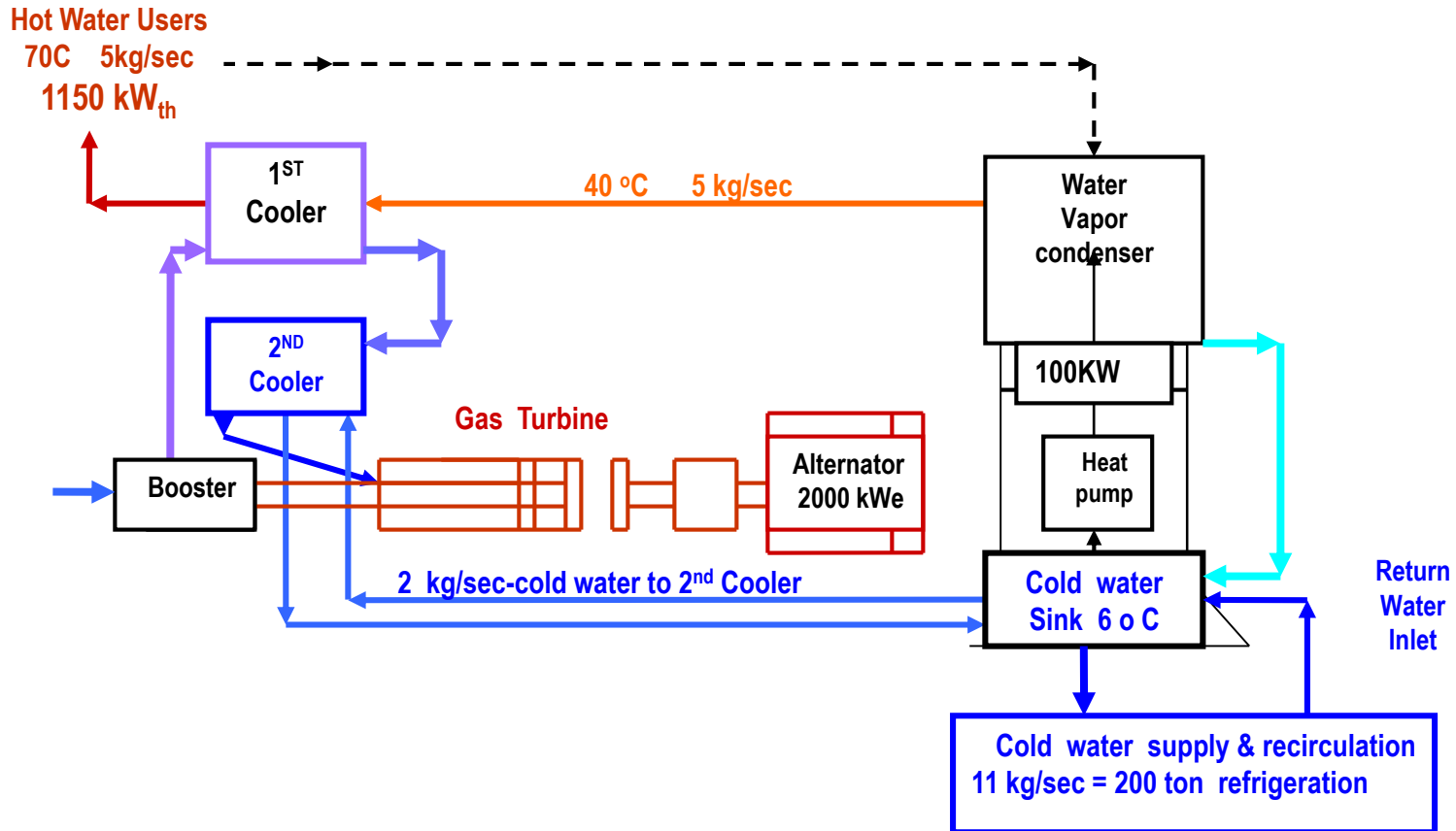


Fig. 14 - CHPC System - Winter Module

Output - 1900 kW Electrical + 1050 kW Heat Energy

Total Efficiency - 57%

