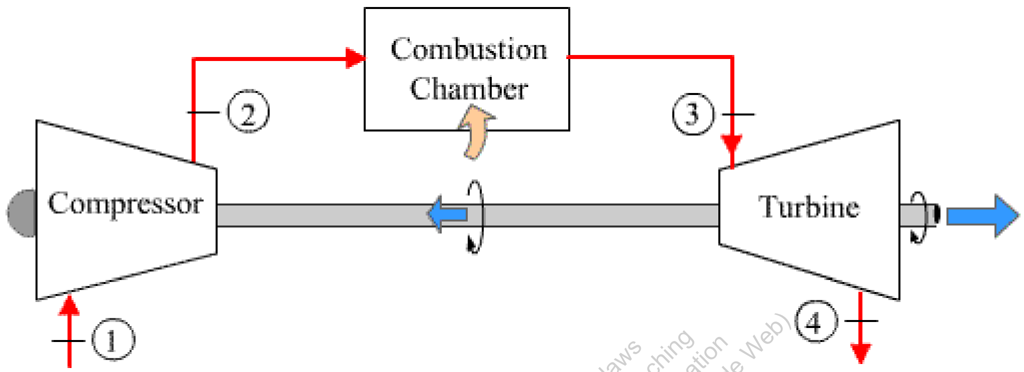
8-3-1 [OPS] In an air (use the PG model) standard Brayton cycle, air enters the compressor at 0.1 MPa, 20°C (atmospheric conditions), and a mass flow rate of 10 kg/s. The pressure leaving the compressor is 1 MPa, and the maximum temperature in the cycle is 1225°C. If the heat addition can be assumed to take place from a reservoir at 1500°C, (a) perform an exergy inventory and draw an exergy flow diagram for the cycle. Determine (b) the thermal efficiency ($\eta_{\text{th,Brayton}}$) and (c) the exergetic efficiency.

SOLUTION:



Heat Source at 1500 °C (1773 K)

Dead State: P0 = 0.1 MPa and T0 = 20 °C (293 K)

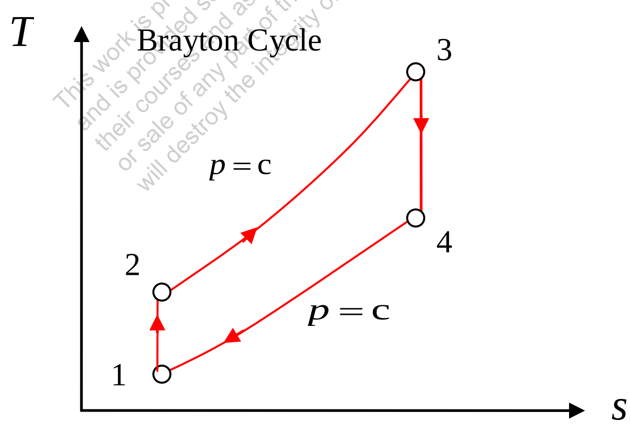


Table 1 Properties at various state points in the gas turbine plant at rated conditions

	p kPa	T K	$\dot{\Psi} = \dot{m}\psi$ MW	s kJ/(kg·K)	h kJ/kg
State 0	**100**	**293**	0	6.86972	-5.01747
State 1	**100**	**293**	0	6.86972	-5.01747
State 2	**1000**	566.33997	2.741	**6.86972**	269.127
State 3	**1000**	**1498**	9.230	7.84591	1204.1927
State 4	**100**	775	1.978	**7.84591**	478.99313

Note: Green quantities are given and black quantities are calculated.

Table 2 Device-specific analysis

Plant Component	Device	$\lvert \Delta\dot{\Psi} \rvert$ MW	$\dot{W}_u$ MW	Exergy Supplied from Reservoir MW	$\dot{I}$ MW	Exergetic Efficiency %
Compressor	A	2.741	- 2.741	0	0	100
Combustion Chamber	B	6.489	0	+ 7.80	1.316	83.19
Turbine	C	7.252	+ 7.252	0	0	100
----	D	1.979	0	0	1.979	
Total Plant			4.511	7.80	3.295	57.8

(a) Rate of exergy supplied by the reservoir at 1773 K,

$$\dot{Q}_{\text{in}} \times (1 - \frac{T_o}{T_R}) = 9.35\ \text{MW} \times (1\text{-}\frac{293\text{K}}{1773\text{K}}) = 7.80\ \text{MW}$$

(b) In order to determine the thermal efficiency, η_{th}, the Cycle Panel from TEST was used.

$$\dot{W}_{net} = 4510.552\ \text{kW}$$
$$\dot{Q}_{in} = 9350.658\ \text{kW}$$

$$\eta_{th} = \frac{\dot{W}_{net}}{\dot{Q}_{in}} = \frac{4510.552 \text{ kW}}{9350.658 \text{ kW}} = 0.482 = 48.2\%$$

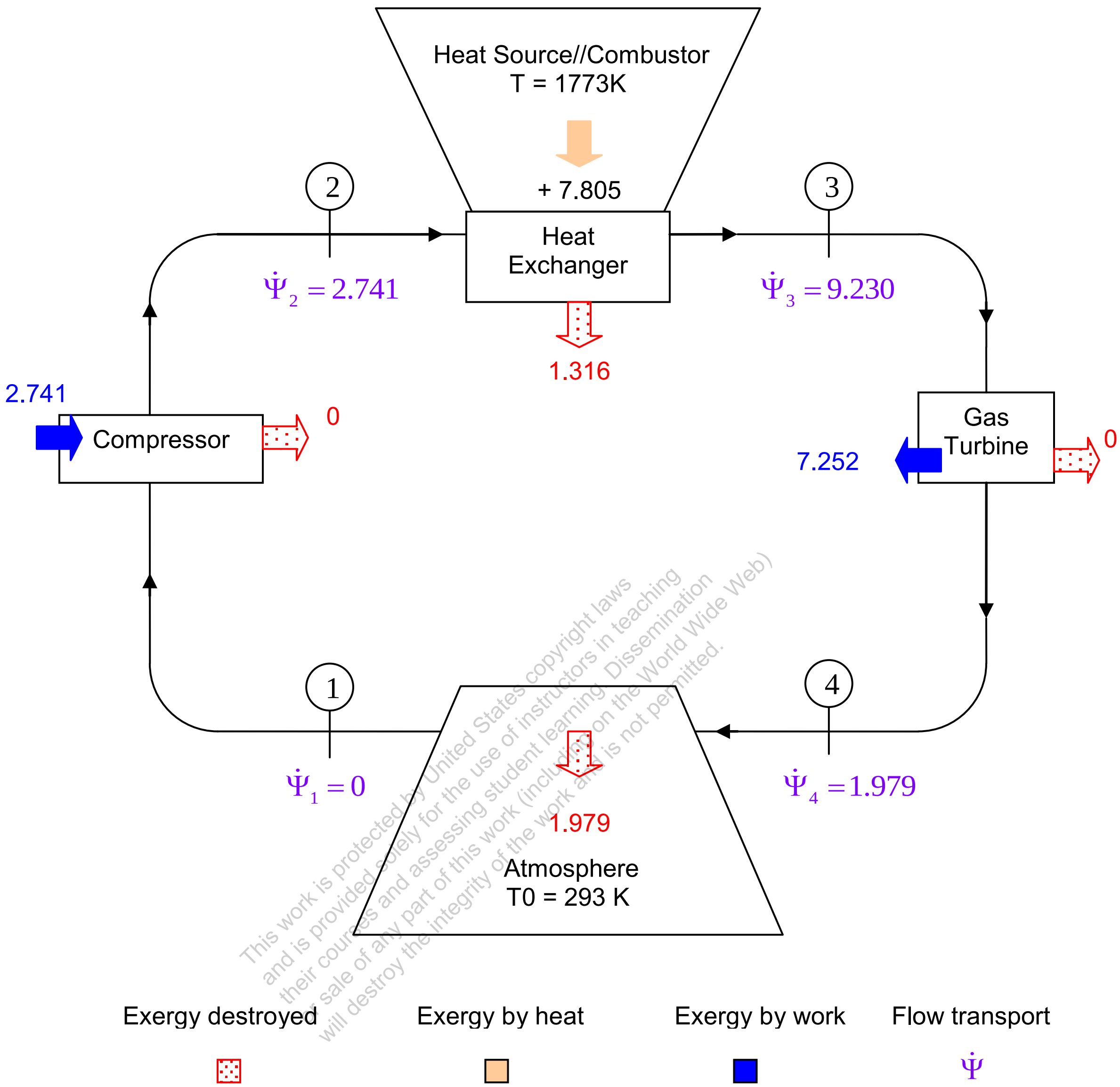
(c) To calculate the exergetic efficiency, η_{II} ,

$$\dot{W}_{net} = 4510.6 \text{ kW}$$

$$\dot{W}_{\max} = \dot{W}_{\text{rev}} = \dot{W}_{\text{net}} + \dot{I}$$

$$\dot{W}_{\max} = 4510.55 + 3295 = 7805.5 \text{ kW}$$

$$\eta_{II} = \frac{\dot{W}_{net}}{\dot{W}_{\max}} = \frac{4510.5 \text{ kW}}{7805.5 \text{ kW}} = 0.578 = 57.8\%$$

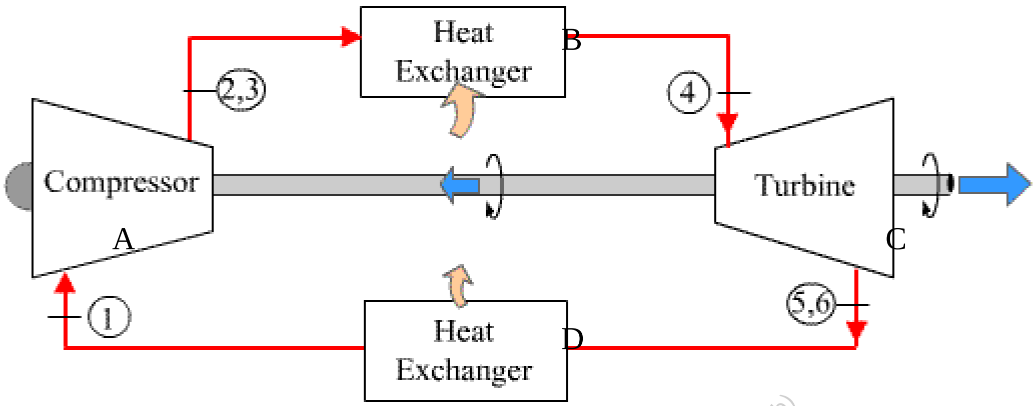


Exergy diagram for the total plant (*on MW basis*)

TEST Solution Use the PG (or IG based on problem statement) gas-power cycle TESTcalc to verify the solution. The TEST-code for this problem can be found in the problem module of the professional TEST site at www.thermofluids.net.

8-3-2 [OPH] Repeat problem 8-3-1 [OPS] assuming a compressor efficiency of 80% and a turbine efficiency of 80%.

Analysis



Heat Source at 1500 °C (1773 K)

Dead State: P0 = 0.1 MPa and T0 = 20 °C (293 K)

Compressor efficiency, $\eta_c = 80\%$

Turbine efficiency, $\eta_t = 80\%$

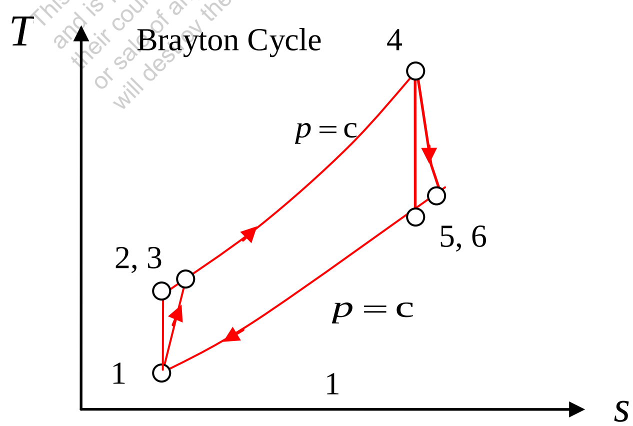


Table 1 Properties at various state points in the gas turbine plant at rated conditions

	p kPa	T K	$\dot{\Psi} = \dot{m}\psi$ MW	s $\text{kJ}/(\text{kg}\cdot\text{K})$	h kJ/kg
State 1	**100**	**293**	0	6.86972	-5.01747
State 2	**1000**	566.33997	2.741	**6.86972**	269.127
State 3	**1000**	634.637	3.092	6.98398	**337.663**
State 4	**1000**	**1498**	9.230	7.84591	1204.1927
State 5	**100**	**775**	1.978	**7.84591**	478.99313
State 6	**100**	920	2.926	8.0774	**624.0331**

Note: Green quantities are given and black quantities are calculated.

Table 2. Device-specific analysis

Plant Component	Device	$\lvert\Delta\dot{\Psi}\rvert$ MW	$\dot{W}_u$ MW	Exergy Supplied from Reservoir MW	$\dot{I}$ MW	Exergetic Efficiency %
Compressor	A	3.092	- 3.4268	0	0.3348	90.22
Combustion Chamber	B	6.138	0	+ 7.233	1.095	84.86
Turbine	C	6.304	+ 5.802	0	0.5024	92.03
Hx	D	2.926	0	0	2.926	0
Total Plant			2.3752	7.233	4.8582	32.8

(a) Rate of exergy supplied by the reservoir at 1773 K,

$$\dot{Q}_{in} \times (1 - \frac{T_o}{T_R}) = 8.6653\text{ MW} \times (1\text{-}\frac{293\text{K}}{1773\text{K}}) = 7.233\text{ MW}$$

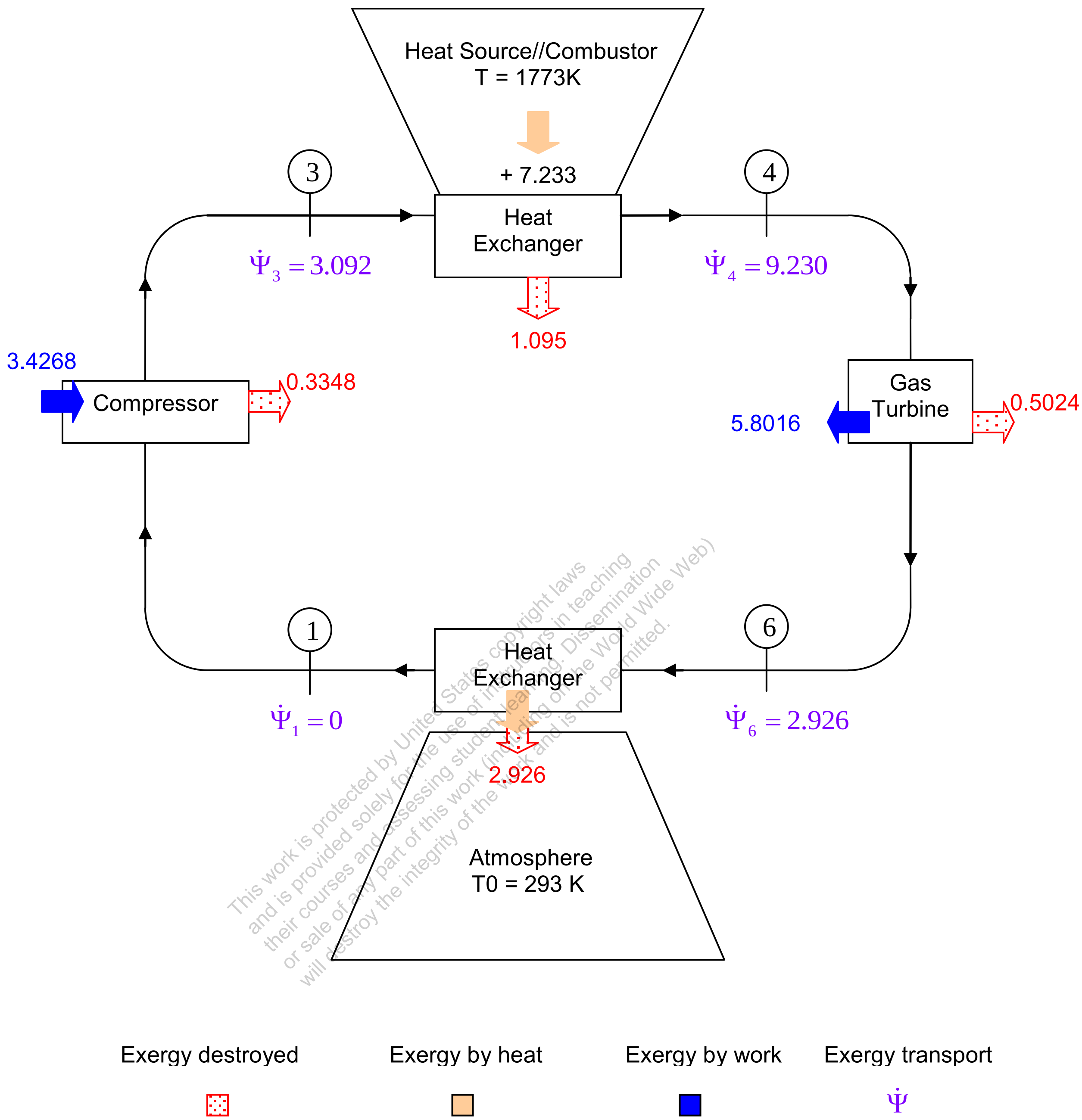
(b) In order to determine the thermal efficiency, η_{th}, the Cycle Panel from TEST was used.

$$\dot{W}_{net} = 2374.79\text{ kW}$$
$$\dot{Q}_{in} = 8665.29\text{ kW}$$

$$\eta_{th} = \frac{\dot{W}_{net}}{\dot{Q}_{in}} = \frac{2374.79 \text{ kW}}{8665.29 \text{ kW}} = 0.274 = 27.4\%$$

(c) To calculate the exergetic efficiency, η_{II} ,

$$\dot{W}_{net} = 2374.79 \text{ kW}$$
$$\dot{W}_{\max} = \dot{W}_{\text{rev}} = \dot{W}_{\text{net}} + \dot{I}$$
$$\dot{W}_{\max} = 2374.79 + 4858.2 = 7232.99 \text{ kW}$$
$$\eta_{II} = \frac{\dot{W}_{net}}{\dot{W}_{\max}} = \frac{2374.79 \text{ kW}}{7232.99 \text{ kW}} = 0.328 = 32.8\%$$

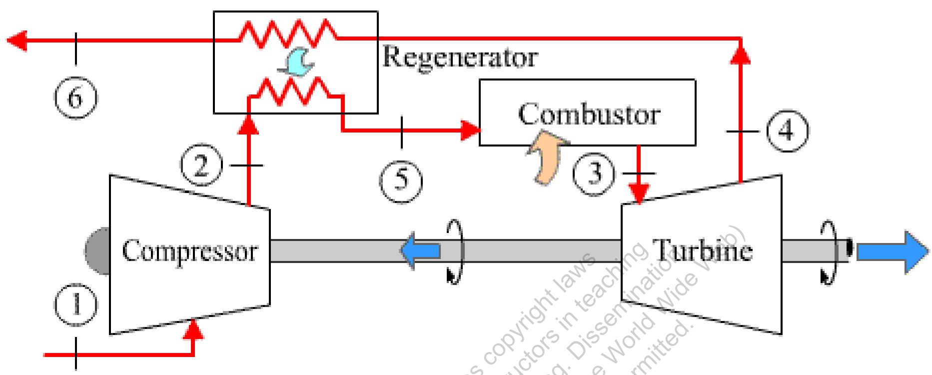


Exergy diagram for the entire plant (*on MW basis*)

TEST Solution Use the PG (or IG based on problem statement) gas-power cycle TESTcalc to verify the solution. The TEST-code for this problem can be found in the problem module of the professional TEST site at www.thermofluids.net.

8-3-3 [OPN] Air (use the IG model) enters the compressor of an ideal air standard Brayton cycle at 100 kPa, 290 K (atmospheric conditions) and a mass flow rate ($\dot{m}$) of 6 kg/s. The compressor pressure ratio is 10. The turbine inlet temperature is 1500 K. A regenerator with an effectiveness of 70% is incorporated in the cycle. If the heat addition can be assumed to take place from a reservoir at 1800 K, (a) perform an exergy inventory and draw an exergy flow diagram for the cycle. Determine (b) the thermal efficiency ($\eta_{th,Brayton}$) and (c) the exergetic efficiency. (d) Calculate the rate of exergy destruction ($\dot{I}$) in the regenerator.

Analysis



Heat Source at 1800 K

Dead State: p0 = 100 kPa and T0 = 290 K – Assume

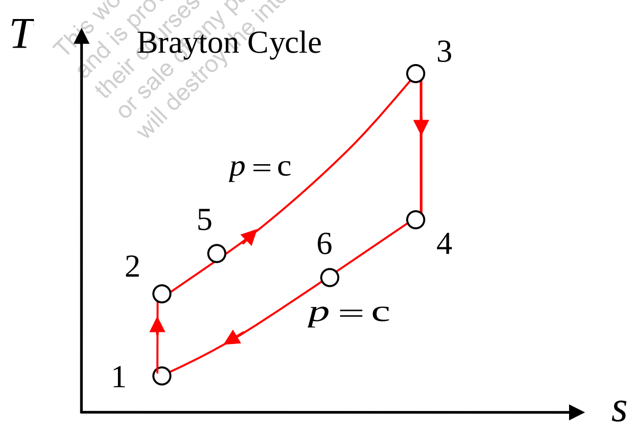


Table 1 Properties at various state points in the gas turbine plant at rated conditions

	p kPa	T K	$\dot{\Psi} = \dot{m}\psi$ MW	s $\text{kJ}/(\text{kg}\cdot\text{K})$	h kJ/kg
State 0	**100**	**290**	0	6.85888	-8.16232
State 1	**100**	**290**	0	6.85888	-8.16232
State 2	**1000**	553.80	1.6205	**6.85888**	261.9332
State 3	**1000**	**1500**	6.1337	7.97851	1338.8127
State 4	**100**	848.916	1.578	**7.97851**	579.54
State 5	**1000**	762.065	2.362	7.19931	**484.258**
State 6	**100**	644.02	0.7652	7.67905	**357.215**

Note: Green quantities are given and black quantities are calculated.

Table 2 Device-specific analysis

Plant Component	Device	$\lvert\Delta\dot{\Psi}\rvert$ MW	$\dot{W}_u$ MW	Exergy Supplied from Reservoir MW	$\dot{I}$ MW	Exergetic Efficiency %
Compressor	A	1.6205	- 1.6205	0	0	100
Regenerator *Air Side*	B	0.7415	0	0	0.0713	91.22
Exhaust Side		0.8128	0			
Combustion Chamber	C	3.772	0	4.301	0.5293	87.70
Turbine	D	4.5557	+4.5557	0	0	100
	E	0.7652	0	0	0.7652	0
Total Plant			2.9352	4.301	1.3658	68.242

(a) Rate of exergy supplied by the reservoir at 1800 K,

$$\dot{Q}_{in} \times (1 - \frac{T_o}{T_R}) = 5.127 \text{ MW} \times (1\text{-}\frac{290\text{K}}{1800\text{K}}) = 4.301 \text{ MW}$$

(b) In order to determine the thermal efficiency, η_{th}, the Cycle Panel from TEST was used.

$$\dot{W}_{net} = 2935.06 \text{ kW}$$
$$\dot{Q}_{in} = 5127.325 \text{ kW}$$
$$\eta_{th} = \frac{\dot{W}_{net}}{\dot{Q}_{in}} = \frac{2935.06 \text{ kW}}{5127.32 \text{ kW}} = 0.5724 = 57.24\%$$

(c) To calculate the exergetic efficiency, η_{II},

$$\dot{W}_{net} = 2935.06 \text{ kW}$$

Wmax = Wnet + Total Exergy Destroyed

Wmax = 2935.02 + 1365.8 = 4301 kW

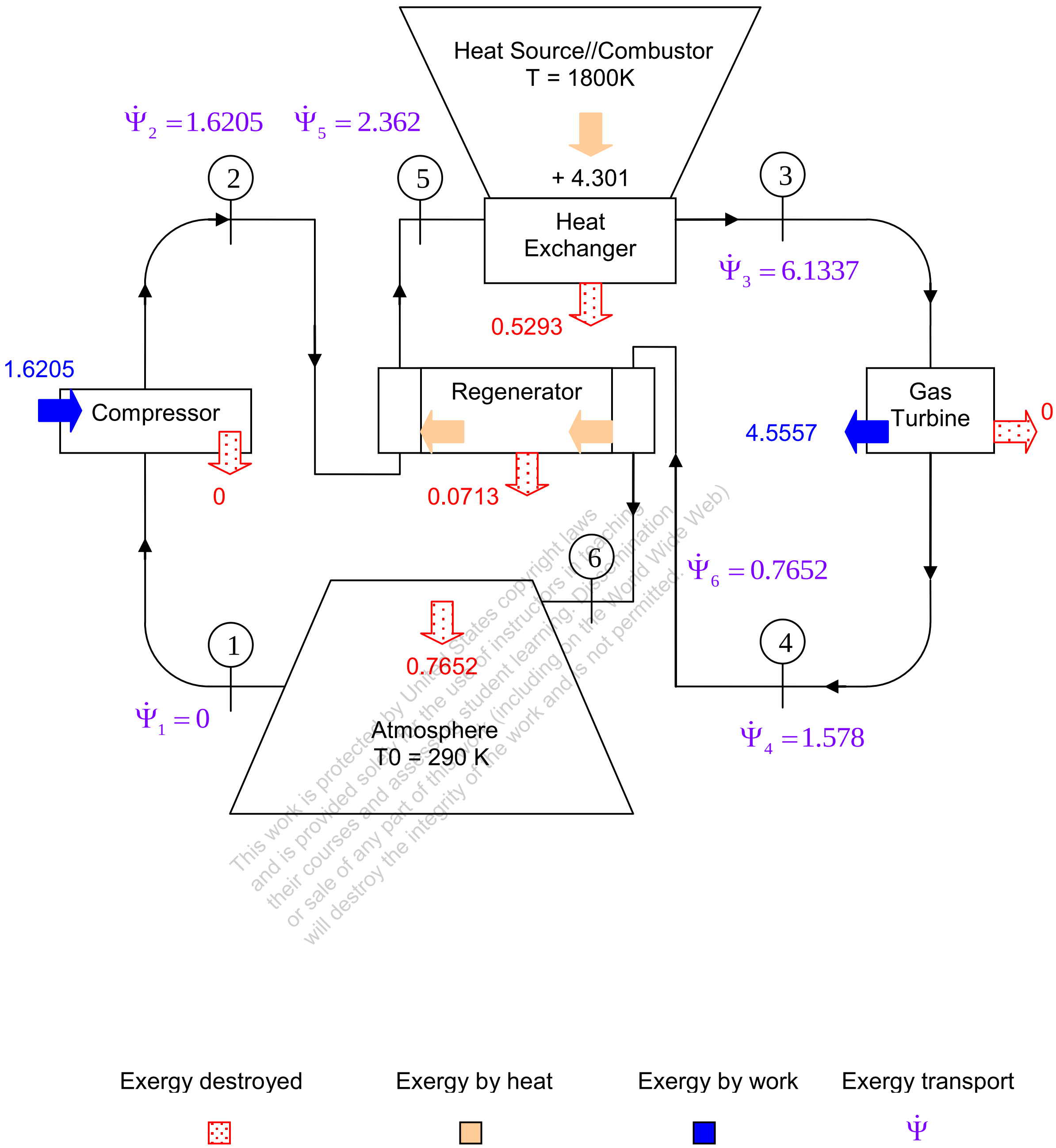
$$\eta_{II} = \frac{\dot{W}_{net}}{\dot{W}_{\max}} = \frac{2935.06 \text{ kW}}{4301 \text{ kW}} = 0.6824 = 68.24\%$$

Check:

η_{II} = 1 - % Total Exergy Destroyed

η_{II} = 1 - 0.31758=0.68242, 68.24 %

(d) Exergy destroyed in regenerator = 71.3 kW (which is negligible)

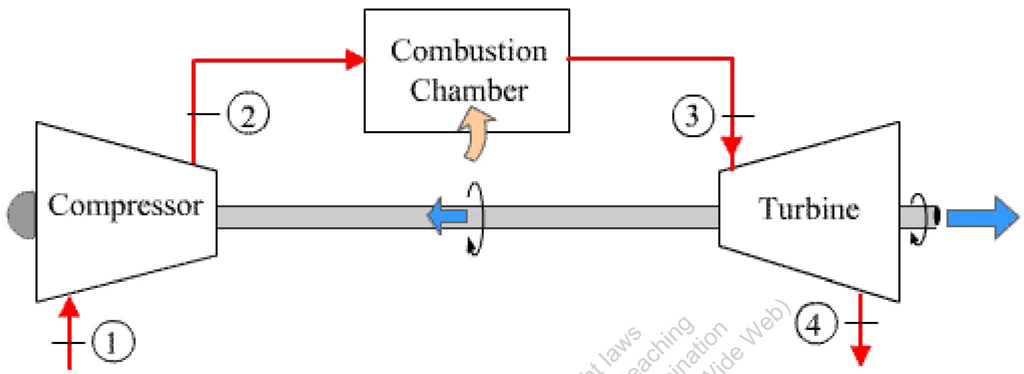


Exergy diagram for the entire plant (*on MW basis*)

TEST Solution Use the PG (or IG based on problem statement) gas-power cycle TESTcalc to verify the solution. The TEST-code for this problem can be found in the problem module of the professional TEST site at www.thermofluids.net.

8-3-4 Repeat problem *8-3-3* without having the regenerator.
Air enters the compressor of an ideal air standard Brayton cycle 100 kPa, 290 K, with a mass flow rate of 6 kg/s. The compressor pressure ratio is 10. The turbine inlet temperature is 1500 K If the heat addition can be assumed to takes place from a reservoir at 1800 K, (a) perform an exergy inventory and draw an exergy flow diagram for the cycle. Determine (b) the thermal efficiency and (c) the exergetic efficiency.

Analysis



Heat Source at 1800 K

Dead State: P0 = 100 kPa and T0 = 290 K – Assume

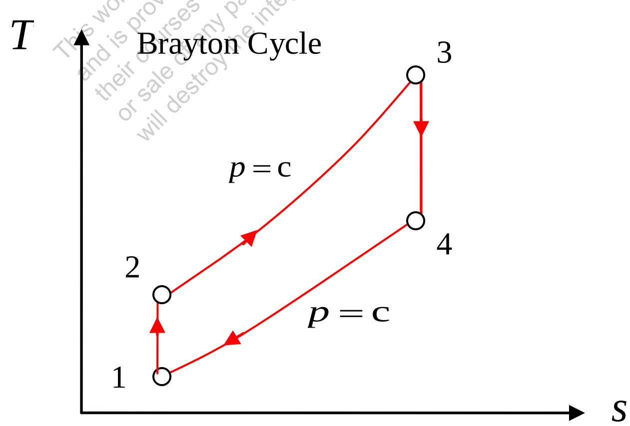


Table 1, Property values, exergy flows and entropy production rates at various state points in the gas turbine plant at rated conditions

	p kPa	T K	$\dot{\Psi} = \dot{m}\psi$ MW	s kJ/(kg·K)	h kJ/kg
State 0	**100**	**290**	0	6.85888	-8.16232
State 1	**100**	**290**	0	6.85888	-8.16232
State 2	**1000**	553.80	1.6205	**6.85888**	261.9332
State 3	**1000**	**1500**	6.1337	7.97851	1338.8127
State 4	**100**	848.916	1.578	**7.97851**	579.54

Note: Green quantities are given and black quantities are calculated.

Table 2 Device-specific analysis

Plant Component	Device	$\lvert\Delta\dot{\Psi}\rvert$ MW	$\dot{W}_u$ MW	Exergy Supplied from Reservoir MW	$\dot{I}$ MW	Exergetic Efficiency %
Compressor	A	1.6205	- 1.6205	0	0	100
Combustion Chamber	B	4.5132	0	5.420	0.9068	83.27
Turbine	C	4.5557	+4.5557	0	0	100
	D	1.578	0	0	1.578	0
Total Plant			2.9352	5.420	2.4848	54.155

(a) Rate of exergy supplied by the reservoir at 1800 K,

$$\dot{Q}_{\text{in}} \times (1 - \frac{T_o}{T_R}) = 6.461\ \text{MW} \times (1\text{-}\frac{290\text{K}}{1800\text{K}}) = 5.42\ \text{MW}$$

(b) In order to determine the thermal efficiency, η_{th}, the Cycle Panel from TEST was used.

$$\dot{W}_{net} = 2935.06 \text{ kW}$$
$$\dot{Q}_{in} = 6461 \text{ kW}$$
$$\eta_{th} = \frac{\dot{W}_{net}}{\dot{Q}_{in}} = \frac{2935.06 \text{ kW}}{6461 \text{ kW}} = 0.4542 = 45.42\%$$

(c) To calculate the exergetic efficiency, η_{II},

$$\dot{W}_{net} = 2935.06 \text{ kW}$$

Wmax = Wnet + Total Exergy Destroyed

Wmax = 2935.02 + 2484.8 = 5420 kW

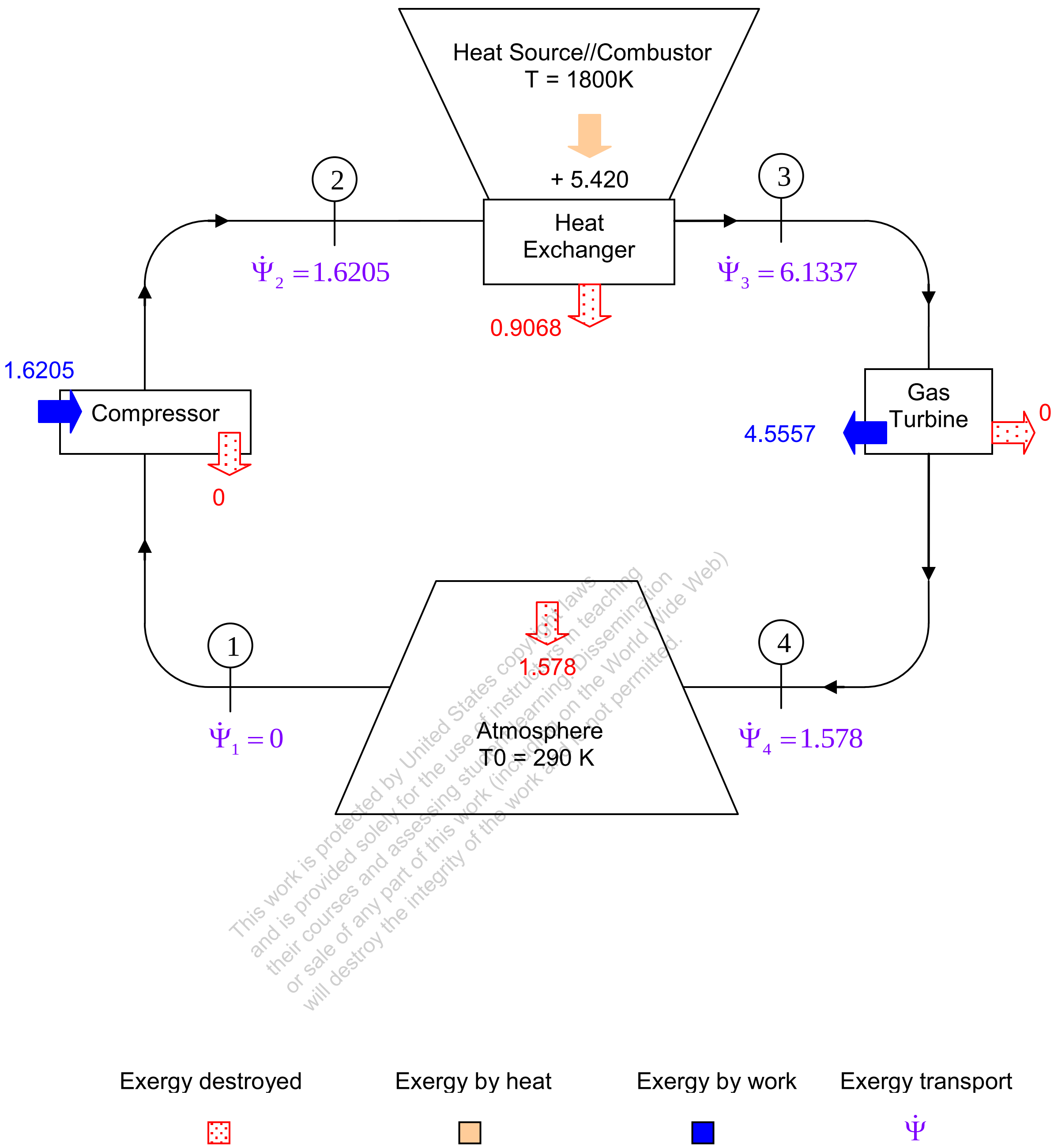
$$\eta_{II} = \frac{\dot{W}_{net}}{\dot{W}_{\max}} = \frac{2935.06 \text{ kW}}{5420 \text{ kW}} = 0.5415 = 54.15\%$$

Check:

η_{II} = 1 - % Total Exergy Destroyed

η_{II} = 1 - 0.45844=0.54155, 54.155 %

TEST Solution Use the PG (or IG based on problem statement) gas-power cycle TESTcalc to verify the solution. The TEST-code for this problem can be found in the problem module of the professional TEST site at www.thermofluids.net.



Exergy diagram for the entire plant (*on MW basis*)

TEST Solution Use the PG (or IG based on problem statement) gas-power cycle TESTcalc to verify the solution. The TEST-code for this problem can be found in the problem module of the professional TEST site at www.thermofluids.net.