How Does Two-Stage Expansion Affect Efficiency of a Gas Turbine?

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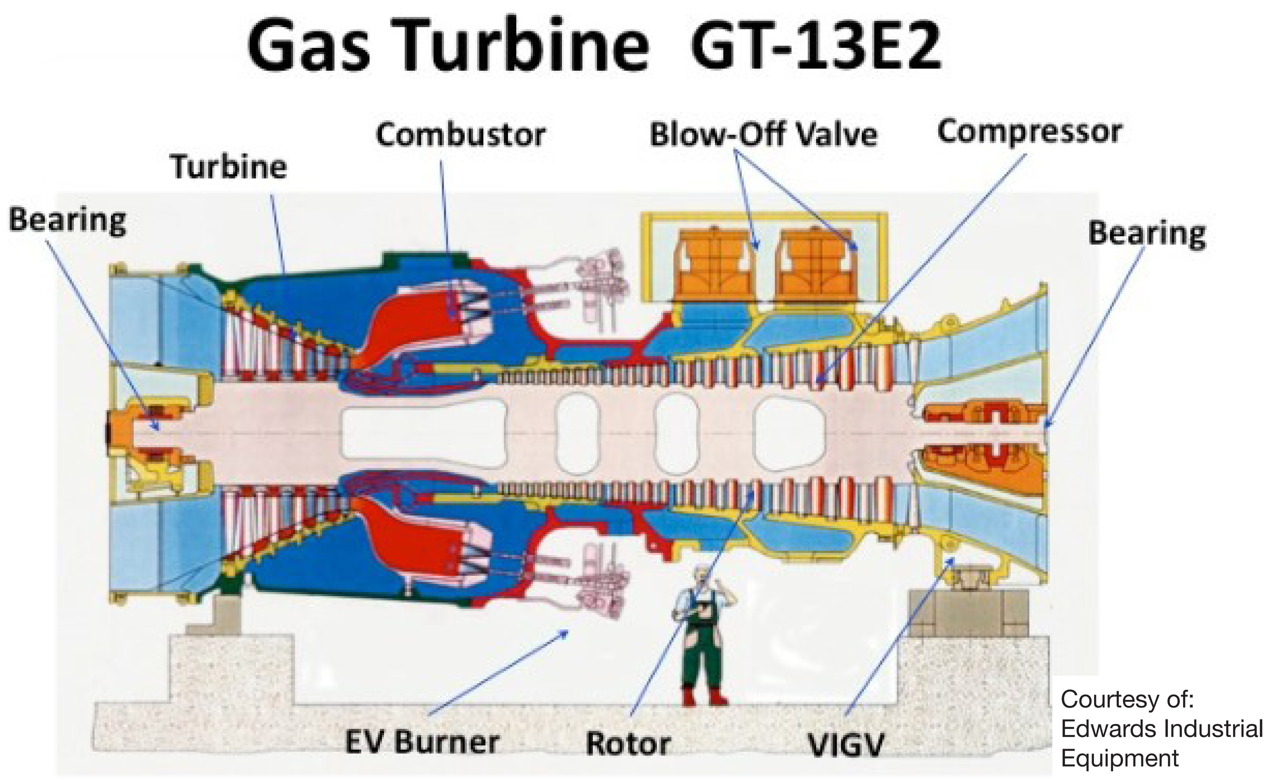
Introduction:

Today the world demands more energy than ever before. Because of the economic and environmental costs of electricity production, it is important that the most efficient methods are used. This project seeks to compare the gains in thermal efficiency of a 350 MW gas turbine by adding two-stage expansion. Both designs will have the same compressor inlet conditions, the same maximum temperature, and will both use regeneration.



Courtesy of: Edwards Industrial Equipment

Background Information:

The Brayton cycle is a thermodynamic cycle used in gas turbines such as those in aircraft or a natural gas power plant. Air is compressed then passes through a combustion chamber where it is heated. These hot, gases at very high pressure and temperature, then pass through a turbine which produces shaft work. In a power plant, this shaft work is used to power a generator and produce electricity.

As with all thermodynamic cycles, the process can be plotted on a temperature-entropy diagram. The enclosed area of the plot represents the net power output of the cycle per kilogram of air passing through the turbine. The numbers on the flow diagram correspond to the state on temperature entropy diagram.

Governing Equations:

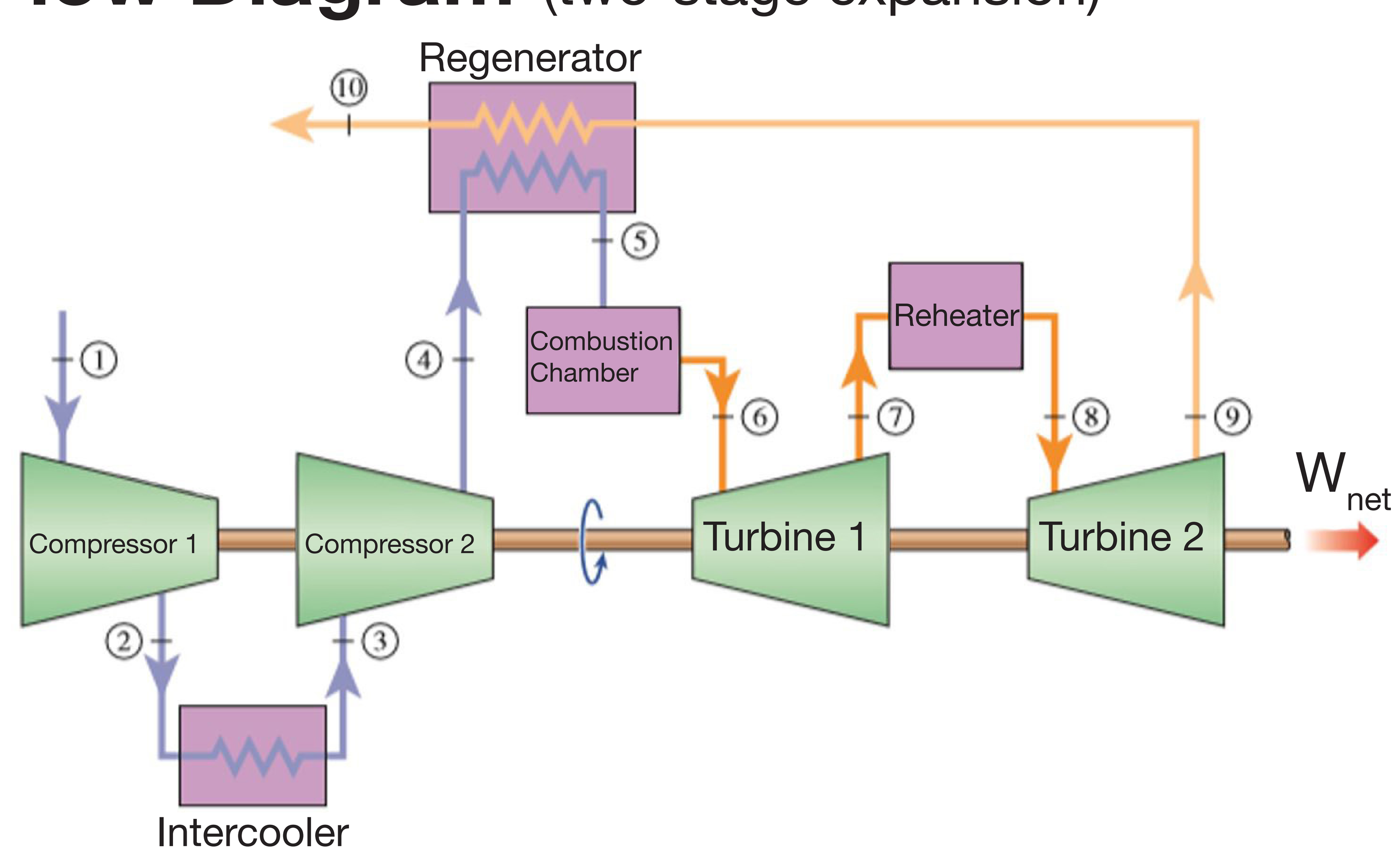
Compressor Power = (Mass Flow Rate) X (Enthalpy Difference)

Turbine Power = (Mass Flow Rate) X (Enthalpy Difference)

Net Power Output = Turbine Power – Compressor Power

Cycle Efficiency = Net Power Output / Heat Input

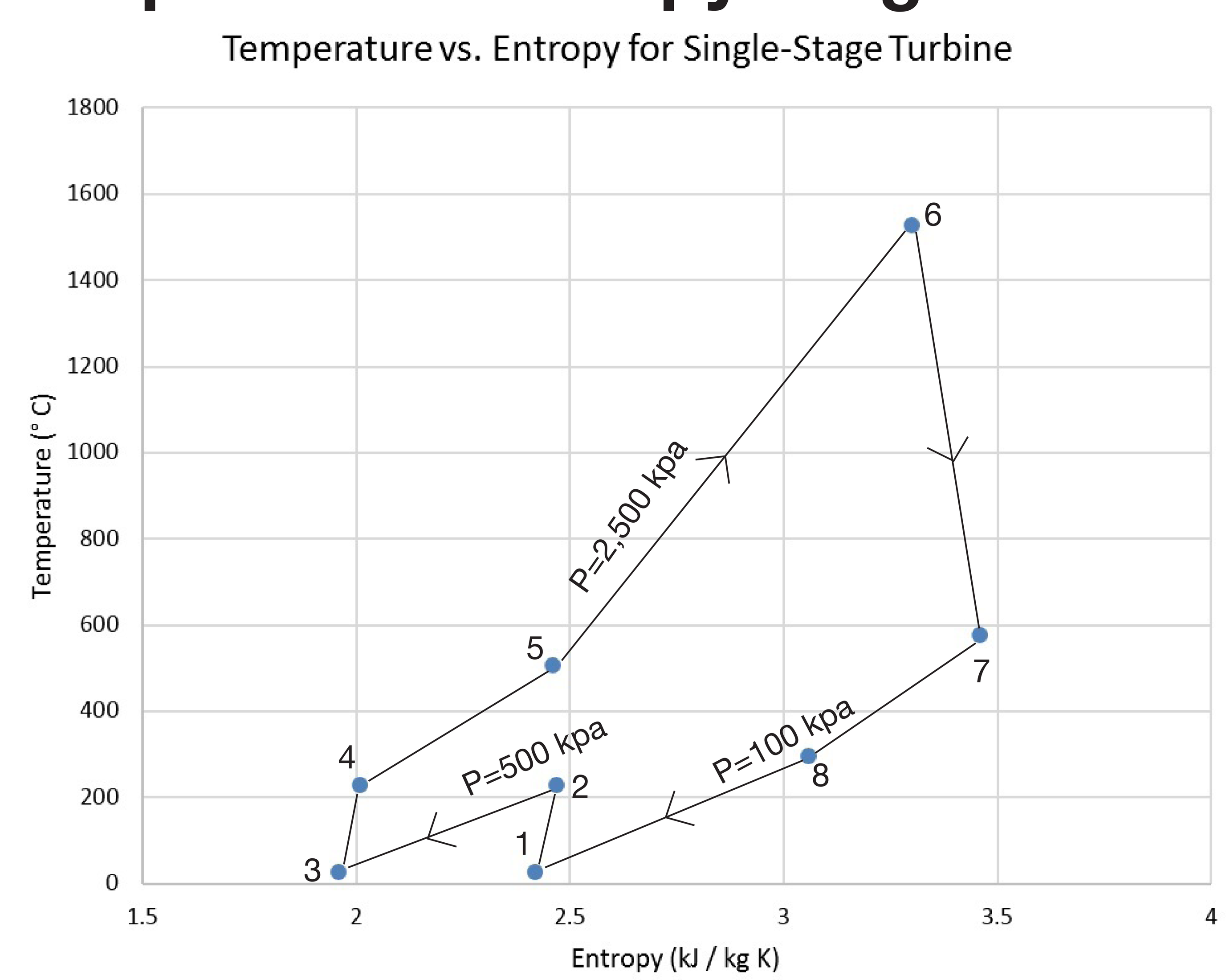
Flow Diagram (two-stage expansion)

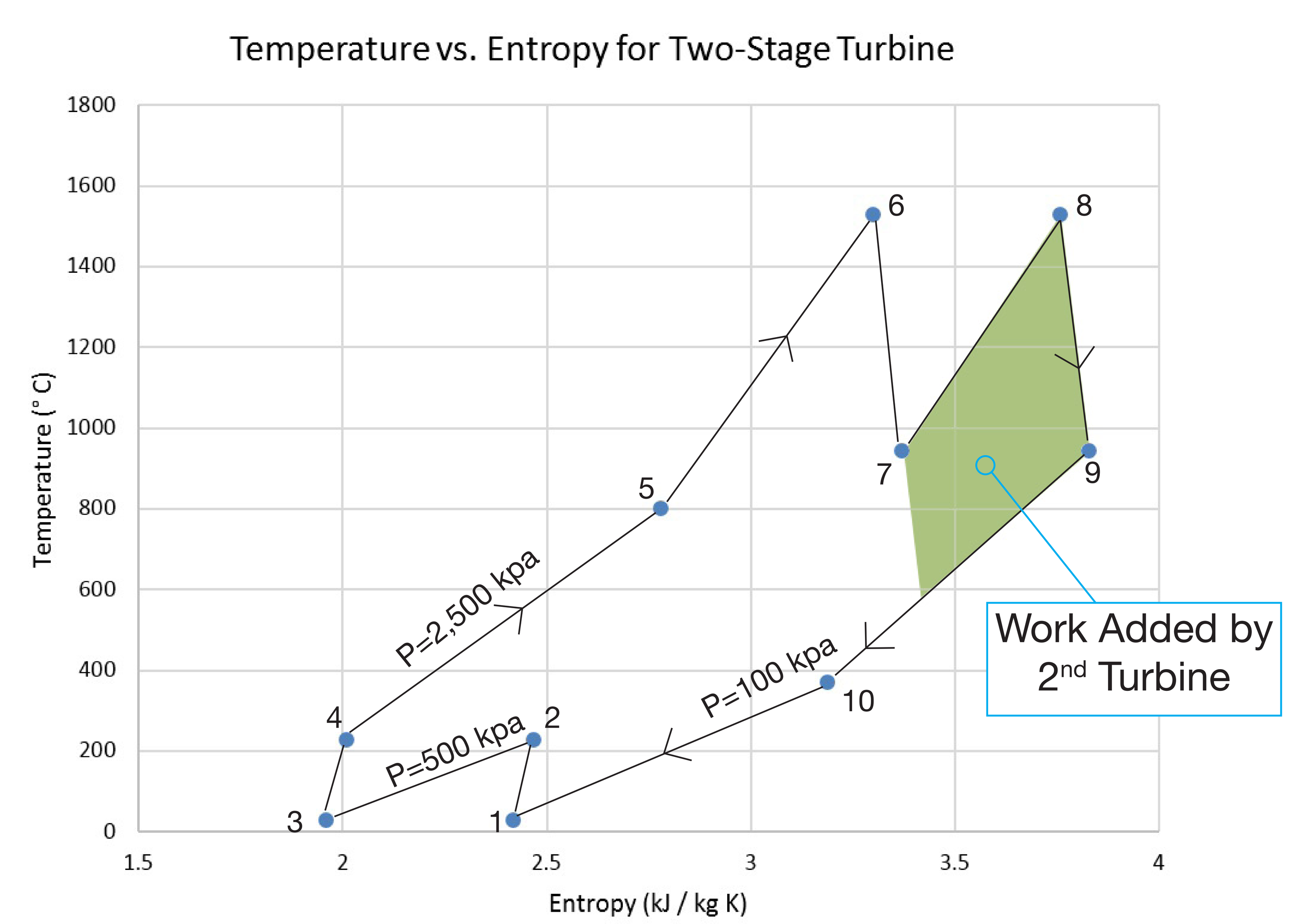


Conditions:

Brayton Cycle
Working Fluid: Air
Intended Net Power = 350 MW
Compressor Inlet = 100 kPa and 23°C
Turbine Inlet = 1527 °C
Overall Pressure Ratio = 25
Compressor Efficiency = 88%
Turbine Efficiency = 88%
Regenerator Effectiveness = 80%
Using CyclePad software

Comparison of Temperature-Entropy Diagrams:





Analysis:

	One Turbine	Two Turbines	Change
Thermal efficiency	54%	59%	+5%
Carnot efficiency	83%	83%	+0%
Net Power (kW)	350,000	350,000	0
Heat Input (kW)	646,000	596,000	-50,000
Mass Flow Rate (kg/s)	629	453	-176
Specific Heat Input (kJ/kg)	1,026	1,316	+290
Specific Net Work (kJ/kg)	556	772	+216

Observations:

- Adding the second turbine increases thermal efficiency by 5%.
- Although the heat input per kilogram is higher with two turbines (+28%), the net work increases by a greater percentage (+39%) which increases the overall efficiency.

Conclusion:

When using regereration, the overall efficiency of the Brayton Cycle can be improved by also adding a second turbine. In this analysis, the heat addition required to get 350 MW of power is reduced by 7% when using a second turbine. This reduction in heat requirement will also mean a reduction in carbon emissions.