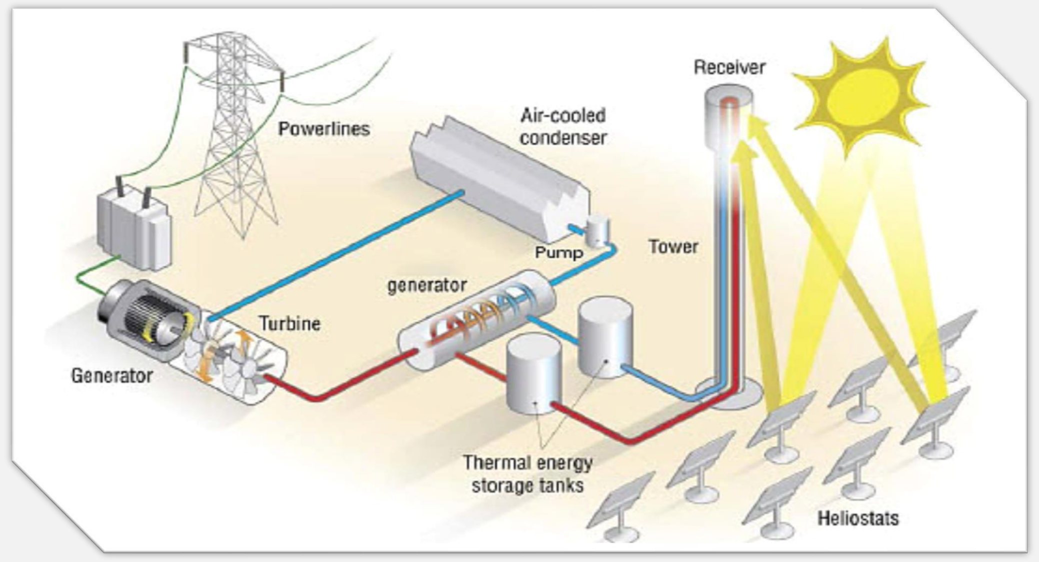
sCO_2 axial turbines: A review of loss mechanisms

AbdElRahman AbdElDayem

PhD. Researcher at City, University of London

Solar Thermal Power plant



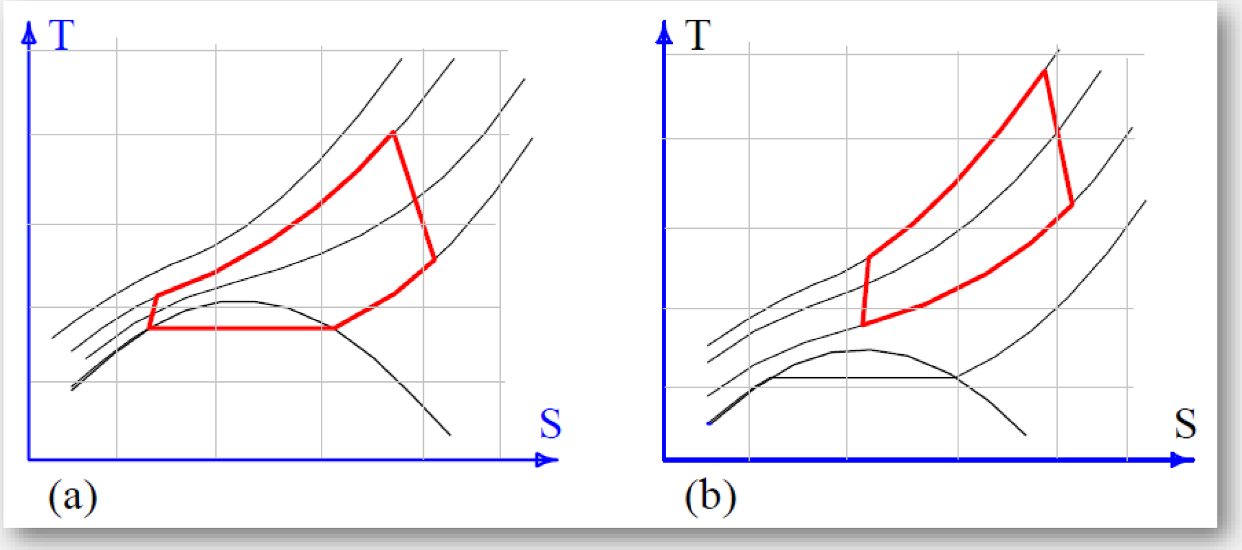
Solar energy is considered one of the most important and reliable sources of renewable energy which is widely used in power generation. The above picture shows the plant construction of concentrated solar power plant. The challenge facing CSP application in power generation is the high levelized cost of electricity (LCoE) which is currently as high as 150 €/MWh while the targeted LCoE of the SCARABEUS project is 100 €/MWh. To achieve this target, supercritical and transcritical carbon dioxide cycles are introduced as an alternative to traditional steam cycle.

Why CO_2?

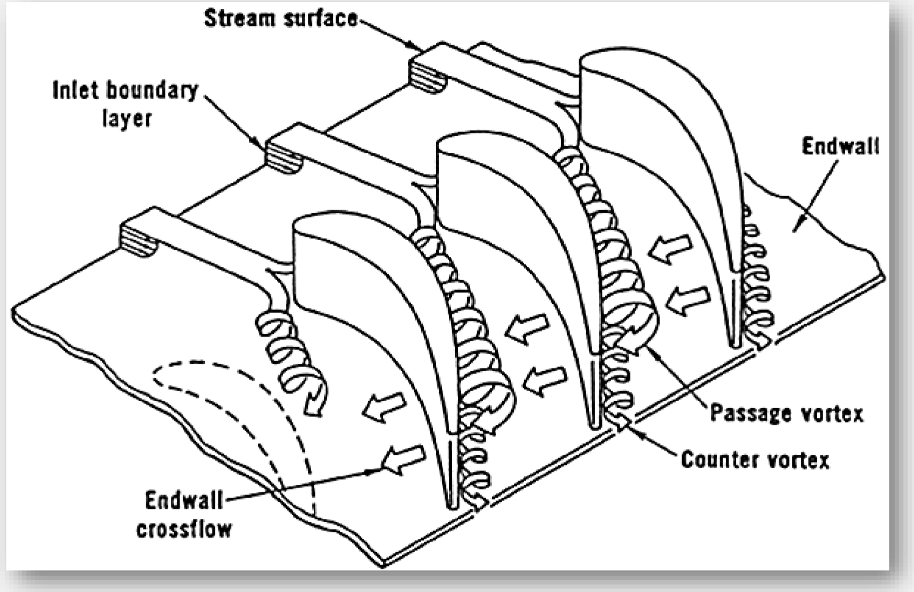
CO_2 has shown a great potential in performance enhancement along with reduced size of different cycle components. The performance of sCO2 power cycles can be further improved by converting the cycle from supercritical to transcritical through doping carbon dioxide with blends which elevate the critical temperature of the mixture to a value higher than the available cooling media, usually air, to allow condensation of the turbine exhaust.

Supercritical vs. Transcritical CO_2 Power cycle

In transcritical power cycles the compression process is adopted to start in the liquid phase using pumps instead of supercritical compressors which is similar to the performance of Rankine cycle achieving a significant efficiency enhancement through minimization of compression work required. The following shows the differences on T-S Diagram between supercritical and transcritical power cycles.



Loss sources in axial flow turbines



Loss estimation is considered an effective way in performance evaluation as it can lead to better understanding of the reasons for efficiency deterioration. The aerodynamic losses of a large-scale axial turbine are presented and defined in the following figures. The secondary flows through turbine passage are shown in the figure to the right.

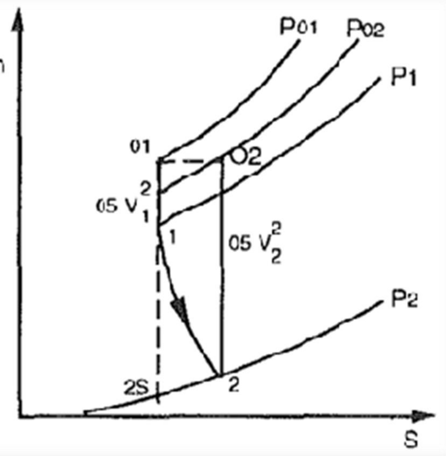
Mathematical representation of losses

Losses can be defined with various coefficients represented as loss in pressure, loss in enthalpy or increase in entropy. The following figure shows mathematical description of various loss coefficients.

$$\gamma = \frac{(P_{01}-P_{02})}{(P_{02}-P_2)}, \quad \xi = \frac{(h_2-h_{2s})}{(h_{02}-h_2)}, \quad \xi_s = \frac{T_2 \Delta S}{(h_{02}-h_2)}$$

where,

h	Enthalpy (J/kg)	S	Entropy (J/(kg.K))
P	Pressure (Pa)	T	Temperature (K)
γ	Pressure loss coefficient	ξ	Enthalpy loss coefficient
Δ	Change / Difference	ξ_s	Entropy loss coefficient
o1	Inlet state, total conditions	o2	Outlet state, total conditions
2	Actual outlet state.	2s	Isentropic outlet state.



Inlet losses

Incidence loss

Usually happens under off-design operating conditions leading to velocity vectors mismatch.

Partial admission loss

Controlling the mass flowrate through admission nozzles leading uneven distribution of flow.

External leakage

The clearance between the rotating shaft and the casing along with the pressure difference between the working fluid and the atmosphere

Exit losses

Trailing Edge loss

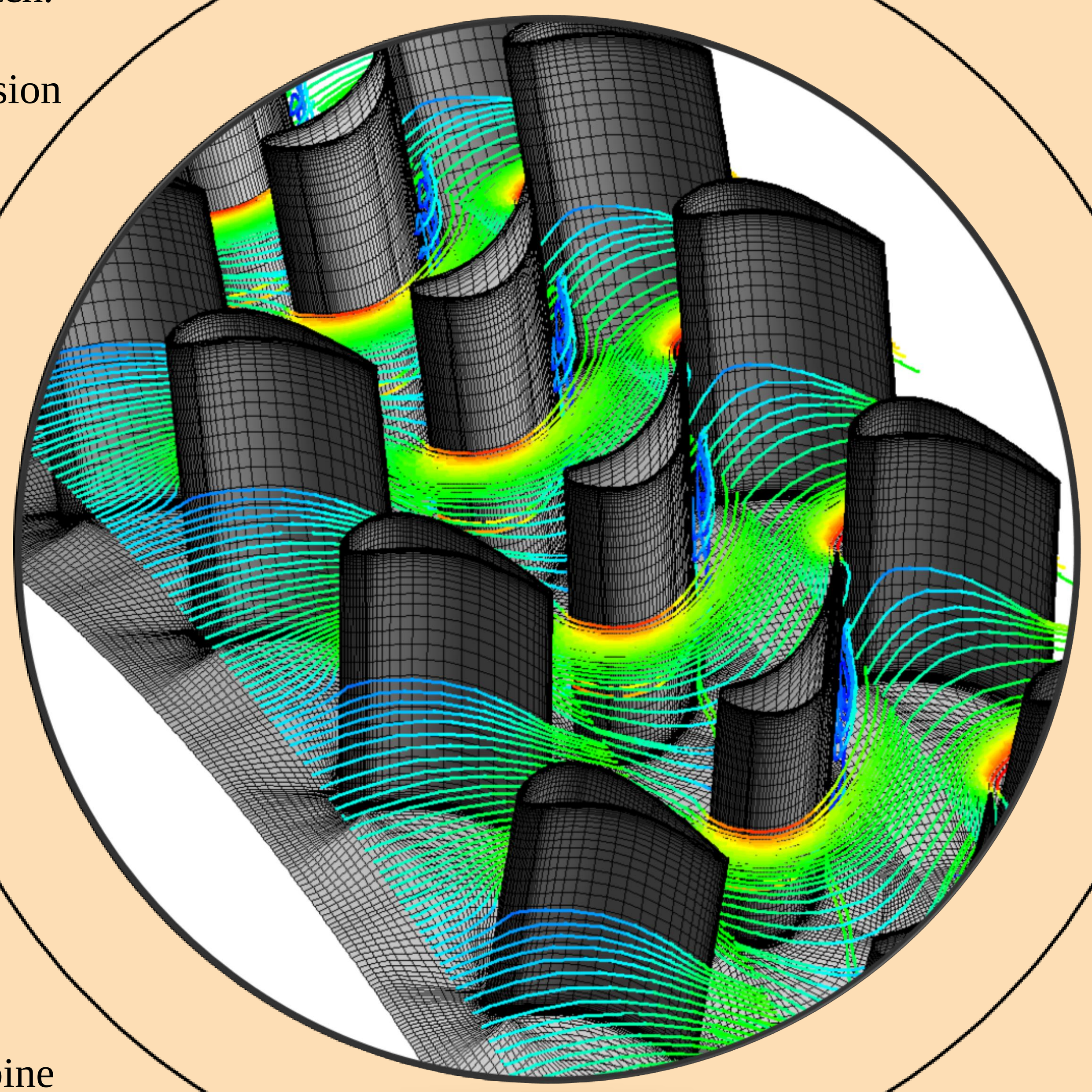
Sudden change in the flow passage area causing additional turbulence and vortices.

Shock wave losses

Insufficient upstream pressure fails to keep the fluid speed supersonic at the outlet and forms shock waves.

Exiting exergy

The amount of energy represented by the enthalpy and kinetic energy of the outlet fluid stream



Passage losses

Tip clearance loss

Internal leakage through the gap between moving blades tip and stator body due to pressure difference across the rotor blades.

Secondary flows losses

Undesired flow streams passing between turbine blades causing turbulence and vortices. The secondary flows can be controlled through airfoil geometry modifications, endwall fences and endwall contouring

Other losses

Windage loss

Friction between the rotating shaft and the working media

Heat loss

Thermal energy lost due to the difference in temperature between the working media and the turbine surroundings.