Example – steam turbine

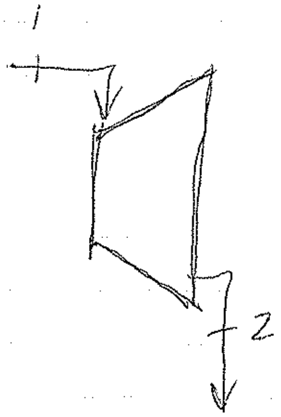
A steam turbine receives steam at a pressure of 1 MPa, 300 C. The steam leaves the turbine at a pressure of 15 kPa. The work output of the turbine is measured and found to be 600 kJ/kg of steam flowing through the turbine.

a) Sketch the system & boundary and classify the system.
b) Show initial state and final state isobars on a Ts diagram.
   Sketch the ideal and real process on the Ts diagram.
c) Use the steam tables to find real and ideal final state conditions.
d) What is the quality at the turbine outlet (both real and ideal)?
e) Write the conservation of energy for this process.
f) What is the specific work for an ideal turbine with these conditions?
g) What is the isentropic efficiency of the turbine?
h) What is the specific entropy production for the real turbine?

STEAM TURBINE PROBLEM

$T_1 = 300\ C$

$P_1 = 1 MPa$

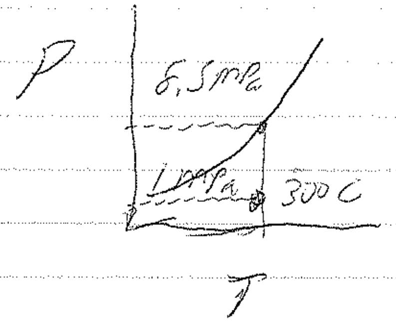


OPEN SYSTEM
STEADY FLOW

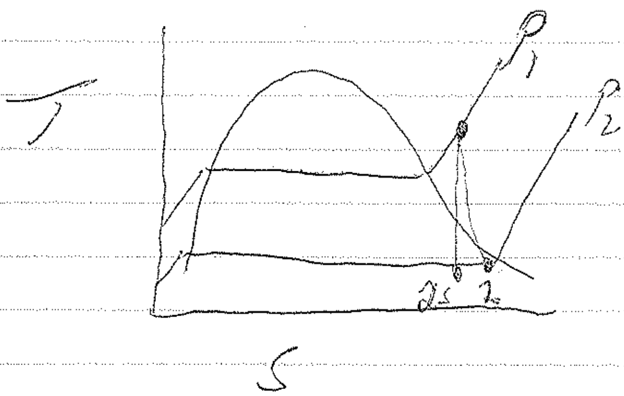
$W_{REAL} = 600\ KJ/kg$

$\eta_T = ?$

$P_2 = 15\ KPa$



STATE 1 IS SUPERHEATED VAPOR



PROPERTIES:

INLET $h_1 = 3051\ KJ/kg$

$S_1 = 7.123\ KJ/kg\text{-}K$

OUTLET $h_2 = 3051 - 600 = 2451\ KJ/kg$

$S_{2s} = S_1 \quad X_e = .938$

$h_{2s} = ?$

AS 15 KPa

$S_{2s} = S_1 = 7.123\ KJ/Kg\text{-}K = .7549 + X_{2s}\ 7.2836$

$X_{2s} = .878$

$h_{2s} = 225.9 + .878(2373) = 2309\ KJ/Kg$

↑ Interpolating Between .014 and .016 MPa

1st LAW

$\dot{Q}^{0} - W + (h_1 + V_1^2/2g + Z_1 g/g_c) - (h_2 + V_2^2/2g + Z_2 g/g_c) = dE_{cv}/dt^{0}$

$W = h_2 - h_1$ SO $W_s = 3051 - 2309 = 741\ KJ/Kg$

$\eta_t = W_{REAL}/W_s = 600/741 = 81\%$

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"TURBINE EFFICIENCY PROBLEM"

"Real Turbine"
f$ = 'STEAM_IAPWS'
T[1] = 300[C]
P[1] = 1000[kPa]
h[1] = Enthalpy(f$, P=P[1], T=T[1])
s[1] = Entropy(f$, P=P[1], T=T[1])
x[1] = Quality(f$, P=P[1], T=T[1])

P[2] = 15[kPa]
h[2] = h[1] - 600[kJ/kg]
T[2] = Temperature(f$, P=P[2], h=h[2])
s[2] = Entropy(f$, P=P[2], h=h[2])
x[2] = Quality(f$, P=P[2], h=h[2])

"Ideal Turbine"
hs[1] = h[1]
ss[1] = s[1]
xs[1] = Quality(f$, P=P[2], h=hs[1])

ss[2] =s[1]
hs[2] = Enthalpy(f$, P=P[2], s=s[1])
xs[2] = Quality(f$, P=P[2], h=hs[2])

"Efficiency Calculation"
wa = h[1]-h[2]
ws = h[1]-hs[2]
efficiency = wa/ws
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SOLUTION

Unit Settings: SI C kPa kJ mass deg

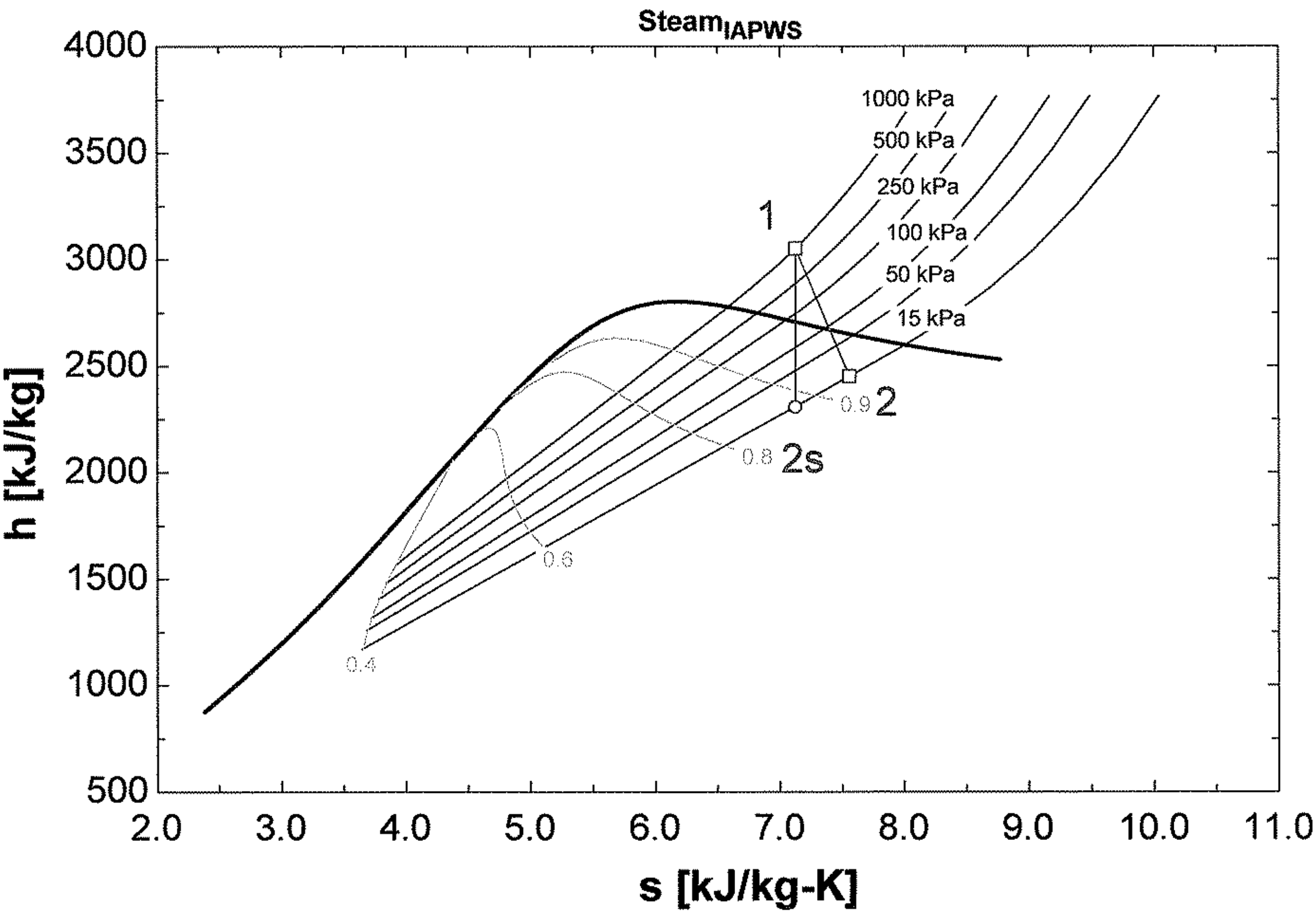
efficiency = 0.8086 f$ = 'STEAM_IAPWS' wa = 600 [kJ/kg]

ws = 742 [kJ/kg]

No unit problems were detected.

Arrays Table: Main

	h_i	hs_i	P_i	s_i	T_i	x_i	xs_i	ss_i
	[kJ/kg]	[kJ/kg]	[kPa]	[kJ/kg-C]	[C]	[dim]	[dim]	[kJ/kg-C]
1	3052	3052	1000	7.125	300	100	100	7.125
2	2452	2310	15	7.559	53.97	0.9382	0.8783	7.125


Steam$_{IAPWS}$
h [kJ/kg]
s [kJ/kg-K]
4000
3500
3000
2500
2000
1500
1000
500
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
1000 kPa
500 kPa
250 kPa
100 kPa
50 kPa
15 kPa
1
2
2s
0.9
0.8
0.6
0.4

REFLECTION:

1) Mollier diagrams (h-s) are often used in the power industry to calculate initial state and final state enthalpies given superheated inlet conditions and saturated outlet conditions.

2) In creating the property diagram with initial and final endpoints, implement the property plot first and select a relevant pressure range. Then use the 'Overlay Plot' feature under the plot dropdown to select real state and ideal state property pairs. Special hs and ss columns in the array table were used to define the ideal turbine conditions.