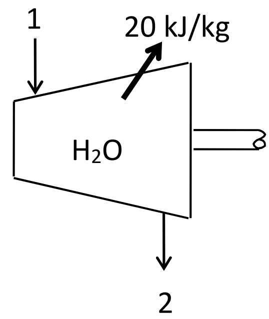
参考題

(注意：僅供參考，比賽時需加入更多說明及討論)

Steam enters a turbine steadily at 7 MPa and 600 °C with a velocity of 60 m/s and leaves at 25 kPa with a quality of 95 percent. A heat loss of 20 kJ/kg occurs during the process. The inlet area of the turbine is 150 cm^2, and the exit area is 1400 cm^2. (a) Determine the mass flow rate of the steam, the exit velocity, and the power output. (b) Investigate the effects of turbine exit area and turbine exit pressure on the exit velocity and power output of the turbine. Let the exit pressure vary from 10 to 50 kPa (with the same quality), and the exit area to vary from 1000 to 3000 cm^2. Plot the exit velocity and the power outlet against the exit pressure for the exit areas of 1000, 2000, and 3000 cm^2, and discuss the results.

(*a*)

Assumptions **1** This is a steady-flow process since there is no change with time. **2** Potential energy changes are negligible.



Properties From the steam tables (Tables A-4 through 6)

$$\left.\begin{array}{l} P_1 = 7\text{ MPa} \\ T_1 = 600°\text{C} \end{array}\right\} \begin{array}{l} v_1 = 0.05567\text{ m}^3/\text{kg} \\ h_1 = 3650.6\text{ kJ/kg} \end{array}$$

and

$$\left.\begin{array}{l} P_2 = 25\text{ kPa} \\ x_2 = 0.95 \end{array}\right\} \begin{array}{l} v_2 = v_f + x_2 v_{fg} = 0.00102 + (0.95)(6.2034 - 0.00102) = 5.8933\text{ m}^3/\text{kg} \\ h_2 = h_f + x_2 h_{fg} = 271.96 + (0.95)(2345.5) = 2500.2\text{ kJ/kg} \end{array}$$

Analysis The mass flow rate of the steam is

$$\dot{m} = \frac{1}{v_1} V_1 A_1 = \frac{1}{0.05567\text{ m}^3/\text{kg}} (60\text{ m/s})(0.015\text{ m}^2) = \mathbf{16.17\ kg/s}$$

There is only one inlet and one exit, and thus $\dot{m}_1 = \dot{m}_2 = \dot{m}$. Then the exit velocity is determined from

$$\dot{m} = \frac{1}{v_2} V_2 A_2 \longrightarrow V_2 = \frac{\dot{m} v_2}{A_2} = \frac{(16.17\text{ kg/s})(5.8933\text{ m}^3/\text{kg})}{0.14\text{ m}^2} = \mathbf{680.6\ m/s}$$

We take the turbine as the system, which is a control volume since mass crosses the boundary. The energy balance for this steady-flow system can be expressed in the rate form as

$$\underbrace{\dot{E}_{\text{in}} - \dot{E}_{\text{out}}}_{\substack{\text{Rate of net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta \dot{E}_{\text{system}}^{\nearrow 0\ \text{(steady)}}}_{\substack{\text{Rate of change in internal, kinetic,} \\ \text{potential, etc. energies}}} = 0$$

$$\dot{E}_{\text{in}} = \dot{E}_{\text{out}}$$

$$\dot{m}(h_1 + V_1^2/2) = \dot{W}_{out} + \dot{Q}_{out} + \dot{m}(h_2 + V_2^2/2) \quad (\text{since } \Delta pe \cong 0)$$

$$\dot{W}_{out} = -\dot{Q}_{out} - \dot{m}\left(h_2 - h_1 + \frac{V_2^2 - V_1^2}{2}\right)$$

Then the power output of the turbine is determined by substituting to be

$$\dot{W}_{out} = -(16.17 \times 20)\ \text{kJ/s} - (16.17\ \text{kg/s})\left(2500.2 - 3650.6 + \frac{(680.6\ \text{m/s})^2 - (60\ \text{m/s})^2}{2}\left(\frac{1\ \text{kJ/kg}}{1000\ \text{m}^2/\text{s}^2}\right)\right)$$

$= \mathbf{14{,}560\ kW}$

EES

```
A[1]=150   [cm^2]
T[1]=600 [C]
P[1]=7000 [kPa]
Vel[1]= 60 [m/s]
A[2]=1400 [cm^2]
P[2]=25 [kPa]
q_out = 20 [kJ/kg]
m_dot = A[1]*convert(cm^2, m^2)*Vel[1]/v[1]
v[1]=volume(steam_iapws, T=T[1], P=P[1]) "specific volume of steam at state 1"
Vel[2]=m_dot*v[2]/(A[2]*Convert(cm^2, m^2))
v[2]=volume(steam_iapws, x=0.95, P=P[2])   "specific volume of steam at state 2"
T[2]=temperature(steam_iapws, P=P[2], v=v[2])   "not required, but good to know"

"Conservation of Energy for steady-flow:
Ein_dot - Eout_dot = DeltaE_dot   -   For steady-flow, DeltaE_dot = 0"
DELTAE_dot=0
"For the turbine as the control volume, neglecting the PE of each flow steam:"
E_dot_in=E_dot_out
h[1]=enthalpy(steam_iapws,T=T[1], P=P[1])
E_dot_in=m_dot*(h[1]+ Vel[1]^2/2*convert(J, kJ) )
h[2]=enthalpy(steam_iapws, x=0.95, P=P[2])
E_dot_out=m_dot*(h[2]+ Vel[2]^2/2*convert(J, kJ))   + m_dot *q_out+ W_dot_out
Power=W_dot_out*Convert(kW, MW)
Q_dot_out=m_dot*q_out
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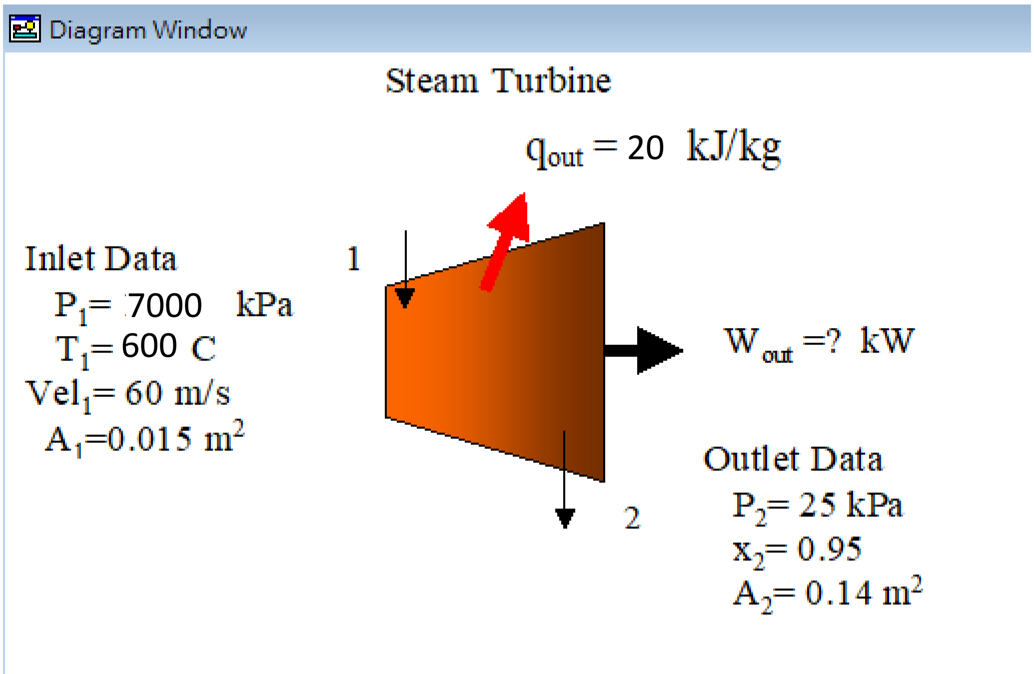

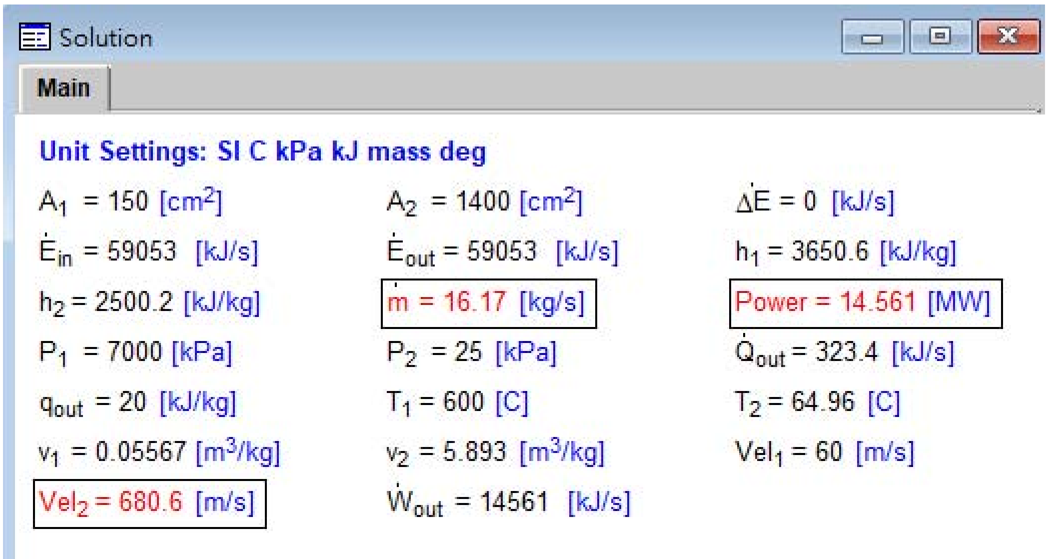

(b)

Analysis The problem is solved using EES, and the results are tabulated and plotted below.

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Fluid$='Steam_IAPWS'

A[1]=150 [cm^2]
T[1]=550 [C]
P[1]=10000 [kPa]
Vel[1]= 60 [m/s]
A[2]=1400 [cm^2]
```
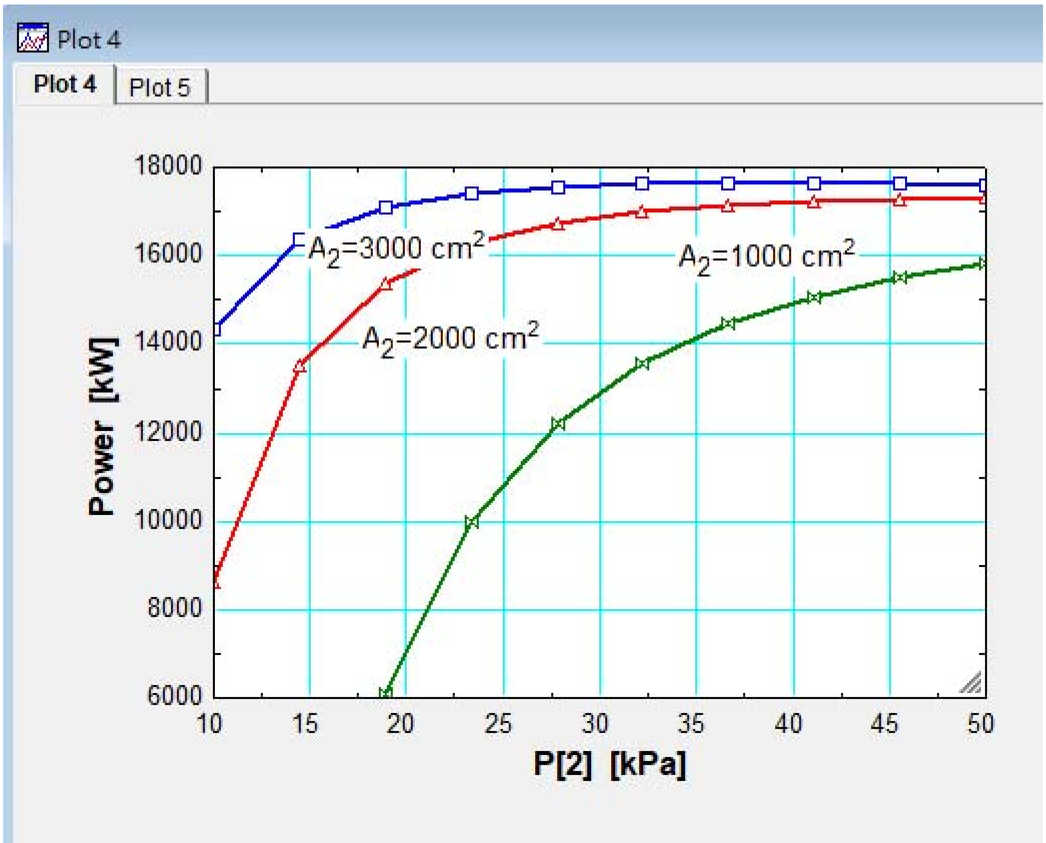

```
P[2]=25 [kPa]
q_out = 30 [kJ/kg]
m_dot = A[1]*Vel[1]/v[1]*convert(cm^2,m^2)
v[1]=volume(Fluid$, T=T[1], P=P[1]) "specific volume of steam at state 1"
Vel[2]=m_dot*v[2]/(A[2]*convert(cm^2,m^2))
v[2]=volume(Fluid$, x=0.95, P=P[2]) "specific volume of steam at state 2"
T[2]=temperature(Fluid$, P=P[2], v=v[2]) "[C]" "not required, but good to know"

"[conservation of Energy for steady-flow:"
"Ein_dot - Eout_dot = DeltaE_dot"    "For steady-flow, DeltaE_dot = 0"
DELTAE_dot=0 "[kW]"
"For the turbine as the control volume, neglecting the PE of each flow steam:"
E_dot_in=E_dot_out
h[1]=enthalpy(Fluid$,T=T[1], P=P[1])
E_dot_in=m_dot*(h[1]+ Vel[1]^2/2*Convert(m^2/s^2, kJ/kg))
h[2]=enthalpy(Fluid$,x=0.95, P=P[2])
E_dot_out=m_dot*(h[2]+ Vel[2]^2/2*Convert(m^2/s^2, kJ/kg))+ m_dot *q_out+
W_dot_out
Power=W_dot_out
Q_dot_out=m_dot*q_out
```

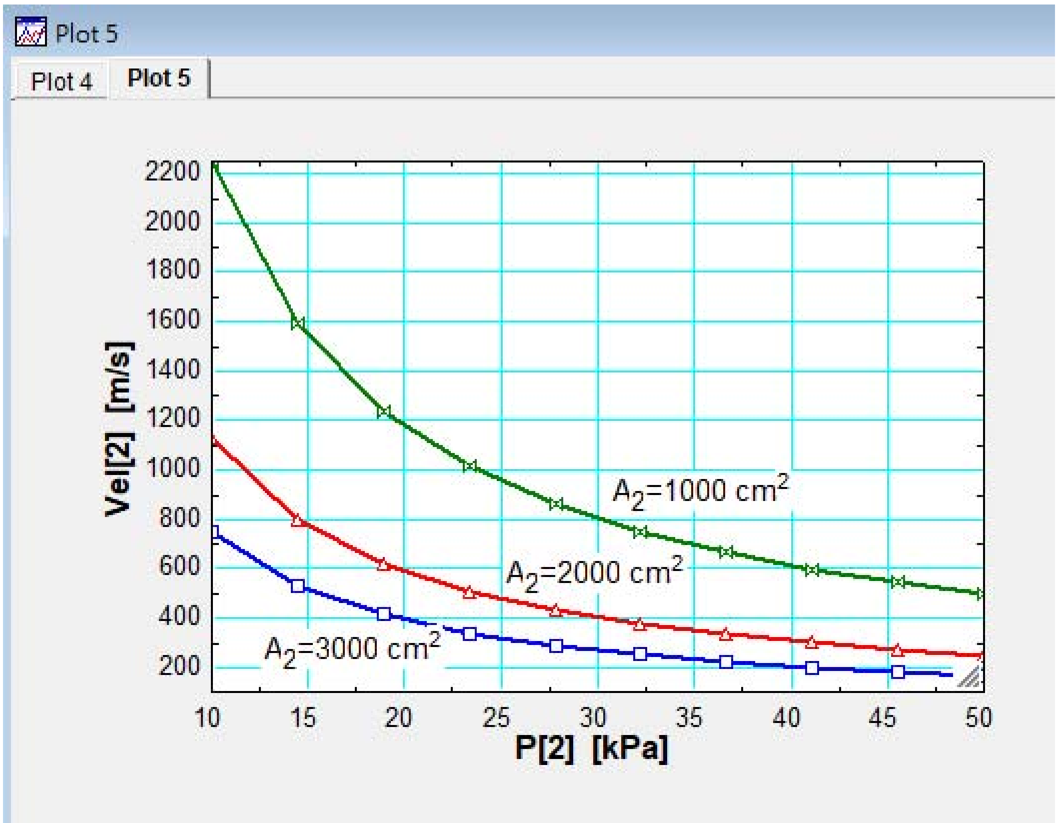
Parametric Table

Table 1

1..10	P_2 [kPa]	Power [kW]	Vel_2 [m/s]
Run 1	10	-22158	2253
Run 2	14.44	-1895	1595
Run 3	18.89	6071	1239
Run 4	23.33	9998	1017
Run 5	27.78	12212	863.2
Run 6	32.22	13573	751.1
Run 7	36.67	14464	665.4
Run 8	41.11	15075	597.8
Run 9	45.56	15507	543
Run 10	50	15821	497.7

Table values are for A[2]=1000 [cm^2]


Plot 4
Plot 4
Plot 5
Power [kW]
P[2] [kPa]
A_2=3000 cm^2
A_2=2000 cm^2
A_2=1000 cm^2
18000
16000
14000
12000
10000
8000
6000
10
15
20
25
30
35
40
45
50


Plot 5
Plot 4
Plot 5
Vel[2] [m/s]
P[2] [kPa]
A_2=1000 cm^2
A_2=2000 cm^2
A_2=3000 cm^2
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
10
15
20
25
30
35
40
45
50