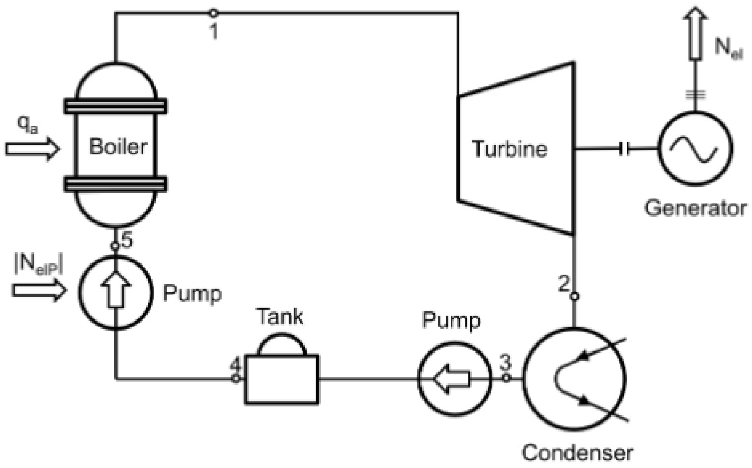
Q81: A Coal-fired boiler generates superheated steam with pressure 3.5 (MPa) and temperature 700 (K).



The Condenser pressure is p2 = p3 = 6 (kPa) and the steam mass flow rate is 13 (kg/s).
The Electric power of the generator is 11 (MW). Condensate leaving the condenser has a temperature 308 (K) and next is pumped into a vessel with pressure 0.1 (MPa).
The pump feeding the boiler pumps condensate from the tank and the discharge pressure is 3.5 (MPa).

The energy efficiency of the coal-fired boiler is 0.83. Pump's internal efficiency is 0.79, mechanical efficiency 0.97 and electric motor efficiency 0.9.

Calculate the energy efficiency of the electric power plant ηEEL

Ans:

```
% Conversion factors to units used by XSteam
%
Kelvin=-273.15;
bar=1.0;
MPa = 10.0;
kPa=0.01;
kg_s=1;
MW2kW=1.e3;
fromBar2Pa=1.e5;
fromW2kW=1.e-3;
fromJ_kg2kJ_kg=1.e-3;
%
% INPUT DATA
%
T1=713+Kelvin; % variation from 700 to 800 K
p1=3.5*MPa;
p2=6.0*kPa;
p3=p2;
```

```
T3=308+Kelvin;
p4=0.1*MPa;
p5=3.8*MPa;
etaB=0.82;  % variation from 0.80 to 0.85
etaiP=0.79; % variation from 0.75 to 0.80
etamP=0.95; % variation from 0.95 to 0.97
etaEM=0.88; % variation from 0.85 to 0.90
W=13*kg_s;
Nel_kW=11.0*MW2kW;
%
% SOLUTION
%
% Find electric power of pumps (in kW)
%
rho3=994.05; % =XSteam('rho_pT',p3,T3);
i3=146.02; % =XSteam('h_pT',p3,T3);
NelP1=W*(p4-p3)*fromBar2Pa/rho3/etaiP/etamP/etaEM;
NelP1_kW=NelP1*fromW2kW;
i4=i3+(p4-p3)*fromBar2Pa/rho3/etaiP * fromJ_kg2kJ_kg;
rho4=994.08; % =XSteam('rho_ph',p4,i4);
NelP2=W*(p5-p4)*fromBar2Pa/rho3/etaiP/etamP/etaEM;
NelP2_kW=NelP2*fromW2kW;
i5=i4+(p5-p4)*fromBar2Pa/rho4/etaiP * fromJ_kg2kJ_kg;
%
% Find fuel thermal power qF (in kW)
%
i1=3314.7; % =XSteam('h_pT',p1,T1);
qF_kW=W*(i1-i5)/etaB;
%
% Find energy efficiency of electric power plant
%
etaEEL=(Nel_kW - NelP1_kW - NelP2_kW)/qF_kW;
Answer = etaEEL;
```

Q82: A hydraulic turbine with known efficiency 0.86 is installed in a hydropower plant with penstock cross-section area 2.5 (m^2). The net head of the hydropower is 55 (m) and the water flow velocity in the penstock is 2 (m/s).

Calculate the mechanical power output of the turbine Nm (kW).
Assume water density rho = 1000 kg/m^3

Ans: % GIVEN

```
%
eta_t = 0.885; % changing from 0.8 to 0.96
Ap = 2.25;   % changing from 2 to 4 m^2
H = 20; % changing from 20 to 70 m
Up = 1; % changing from 1 to 2 m/s
rho = 1000;
%
% SOLUTION
% 1 Volumetric flow rate
Q = Ap*Up;
% 2 Mechanical power
Nm_W = eta_t*rho*Q*9.81*H;
Nm_kW = Nm_W/1000;
Answer = Nm_kW;
```

Q83: Measurements performed for a hydroulic turbine give the following results:
- rotor speed: 180 (rpm)
- torque measured on the shaft: 20.5 (kNm)
- volumetric flow 2.25 (m^3/s)
- net head 20 (m)

Calculate the turbine efficiency.

Assume water density rho = 1000 kg/m^3

Ans:
```
% GIVEN
%
n = 190; % changing from 180 to 195 rpm
Q = 2.25;   % fixed
Ts = 20.5; % changing from 19.5 to 20.5 kNm
H = 19.5; % changing from 19.5 to 21 m
rho = 1000;
%
% SOLUTION
% 1 Rotor mean angle speed
omega = n*pi/30;
% 2 Mechanical power
Nm = omega*Ts*1000;
% 3 Hydraulic power
Nh = rho*Q*9.81*H;
% 4 Efficiency
eta_t = Nm/Nh;
Answer = eta_t;
```

Q84: Turbine rotor rotates with speed of 170 rpm (revolutions per minute).

Express this in Hz (hertz)

Ans:
f = n/60;
Answer = f;

Q85: Turbine rotor rotates with speed of 220 rpm (revolutions per minute).

Express this in rad/s (radians per second)

omega = n*pi/30;
Answer = omega

Q86: Pelton turbine operates with volumetric water flow 0.75 (m^3/s).
The rotor has a mean radius 0.7 (m) and rotate with speed 190 (rpm).
The blade angle is 160 (deg).

Calculate the water jet radius Rj (m) for which the turbine will have the maximum power possible.

Assume water density rho = 1000 (kg/m^3)

Ans: % GIVEN
%
n = 200; % changing from 150 to 250 rpm
Q = 1;   % changing from 0.75 to 1.5 m^3/s
R = 0.5; % changing from 0.4 to 1 m
theta = 165; % changing from 160 to 175 deg
rho = 1000;
%
% SOLUTION
% 1 Rotor mean speed
Ur = R*n*pi/30;
% 2 Optimum jet mean speed
Uj = 2*Ur;
% 3 Jet radius
Aj = Q/Uj;
Rj = sqrt(Aj/pi);
Answer = Rj;

Q87: Pelton turbine operates with volumetric water flow 1.25 (m^3/s).
The rotor has a mean radius 0.45 (m) and rotate with speed 160 (rpm).
The blade angle is 160 (deg) and the water jet radius is 0.13 (m).

Calculate the turbine output power Nto (kW) assuming water density rho = 1000 (kg/m^3)

Ans: % GIVEN
%
n = 200; % changing from 150 to 250 rpm
Q = 1;   % changing from 0.75 to 1.5 m^3/s
R = 0.5; % changing from 0.4 to 1 m
theta = 165; % changing from 160 to 175 deg
Rj = 0.141; % changing from 130 to 160 mm
rho = 1000;
%
% SOLUTION
% 1 Rotor mean speed
Ur = R*n*pi/30;
% 2 Jet mean speed

```
Aj = pi*Rj**2;
Uj = Q/Aj;
% 3 Turbine output power
Nto_W = rho*Q*Ur*(Uj-Ur)*(1-cos(theta*pi/180));
Nto_kW = Nto_W/1000;
Answer = Nto_kW;
```

Q88: Consider a critical thermal reactor in which the neutron generation time is 0.001 (s), and moderator reactivity coefficient is 55 (pcm/K).

Assume one group of delayed neutrons (Lambda = 0.08 1/s, Beta = 6.5E-3).
At time t = 0 the moderator temperature decrease with 10 (K).

Find time T (s) at which the reactor power will change e-folds (e = 2.718...).
Neglect all reactivity feedbacks for t>0.

Ans:
```
pcm_K = 1.e-5;   % per-cent mill
%
% GIVEN
%
LAMBDA = 1.0e-4; % changing from 1.0e-3 to 1.0e-4 s
Lambda = 0.08;   % fixed value
Beta = 6.5e-3;   % fixed value
MRC = -50*pcm_K; % changing from -40 to -60
DTM = -5;        % changing from -5 to -25
%
% SOLUTION
% We find the reactivity increase
Rho = MRC*DTM;
% Find roots of the characteristic equation
aux1 = Beta/LAMBDA-Rho/LAMBDA+Lambda;
s1 = (-aux1+sqrt(aux1**2+4*Lambda*Rho/LAMBDA))/2;
s2 = (-aux1-sqrt(aux1**2+4*Lambda*Rho/LAMBDA))/2;
% Calculate the stable reactor period
% which is time when power changes e-folds
s = max(s1,s2);
if s>0
  T = 1/s;
  answer = T;
else
  answer = 'Reactor period is undefined'
endif
```

Q89: Consider a critical thermal reactor in which the neutron generation time is 8E-4 (s).
Assume one group of delayed neutrons (Lambda = 0.08 1/s, Beta = 0.003458).
Due to malfunction of control rods at time t = 0 the reactor became exactly prompt critical.
Find the stable reactor period T (s).

Ans:
```
% GIVEN
%
LAMBDA = 1.0e-4; % changing from 1.0e-3 to 1.0e-4 s
Lambda = 0.08;   % fixed value
Beta = 6.5e-3;   % changing from 6.4e-3 to 6.6e-5
%
% SOLUTION
% We find the reactivity increase
Rho = Beta; % Prompt
% Find roots of the characteristic equation
aux1 = Beta/LAMBDA-Rho/LAMBDA+Lambda;
```

```
s1 = (-aux1+sqrt(aux1**2+4*Lambda*Rho/LAMBDA))/2;
s2 = (-aux1-sqrt(aux1**2+4*Lambda*Rho/LAMBDA))/2;
% Calculate the stable reactor period
s = max(s1,s2);
if s>0
  T = 1/s;
  answer = T;
else
  answer = 'Reactor period is undefined'
endif
```

Q90: The reactivity in a steady-state thermal reactor with no external neutron sources, in which the neutron generation time is 1E-4 (s), is suddenly made positive and equal to 0.0065 such that the reactor is prompt critical.

Assuming one group of delayed neutrons (Lambda = 0.08 1/s, Beta = 6.5E-3)
determine the reactor power increase in percent of the initial power after time 0.1 (s).

Ans: % GIVEN

```
%
LAMBDA = 1.0e-3; % changing from 1.0e-3 to 1.0e-4 s
Rho = 0.0075;     % changing from 0.0065 to 0.0085
Lambda = 0.08;   % fixed value
Beta = 6.5e-3;   % fixed value
t = 0.5;           % changing from 0.1 to 0.5 s
%
% SOLUTION
% We find roots of the characteristic equation
aux1 = Beta/LAMBDA-Rho/LAMBDA+Lambda;
s1 = (-aux1+sqrt(aux1**2+4*Lambda*Rho/LAMBDA))/2;
s2 = (-aux1-sqrt(aux1**2+4*Lambda*Rho/LAMBDA))/2;
% Calculate the relative power increase
aux2 = (s1+Lambda)/s1/(s1-s2);
aux3 = (s2+Lambda)/s2/(s2-s1);
x = Rho*(Lambda/s1/s2+aux2*exp(s1*t)+aux3*exp(s2*t))/LAMBDA;
% Answer: power increase in percent is x*100
answer = x*100;
```

Q91: What is the thermal utilization factor in a mixture of graphite and natural uranium with a carbon-to-uranium atomic ratio equal to 550?

Natural uranium contains three isotopes: U-234 (atomic abundance 0.0055%), U-235 (atomic abundance 0.72%) and U-238 (atomic abundance 99.2745%). Microscopic cross sections for absorption of these isotopes are 103.4 b, 687 b and 2.73 b, respectively.

Assume that graphite is pure C-12, with the microscopic cross section for absorption 0.0034 b.

Ans: % GIVEN;

```
550 = range(400,600,50); :% changing from 400 to 600;
103.4 = 103.4; :% fixed value;
687 = 687;   :% fixed value;
2.73 = 2.73;  :% fixed value;
0.0034 = 0.0034; :% fixed value;
5.5E-5 = 0.000055;    :% fixed value;
0.0072 = 0.007200;    :% fixed value;
0.992745 = 0.992745;    :% fixed value;
:% SOLUTION;
:% We assume that the atom number density;
:% of uranium is;
1 = 1;
:% Then atom number density of carbon is ;
```

550 = 1*550;

:% Macroscopic cross section for absorption for uranium;

7.662281 = 5.5E-5*103.4*1;
7.662281 = 7.662281+0.0072*687*1;
7.662281 = 7.662281+0.992745*2.73*1;
1.87 = 0.0034*550;

0.803824 = 7.662281/(7.662281+1.87);
0.803825 = 0.803824;

Q92: What is k-infinite of a homogeneous mixture of U-235 and graphite with an atomic-uranium-to-carbon ratio of 3.333333E-5?

For such a dilute mixture of fully enriched uranium and carbon:

(fast-fission factor)*(resonans escape probability) = epsilon * p=1,

so that k_inf = eta * f = (reproduction factor) * (thermal utilization factor).

Microscopic cross sections for absorption of U-235 and graphite (assuming C-12) are 687 b and 0.0034 b, respectively.

Microscopic cross sections for fission of U-235 is 587 b.

Ans: % GIVEN

```
%
U2Crat = 1/40000; % changing from 1/10000 to 1/100000
sigma_a_U235 = 687;   % fixed value
sigma_f_U235 = 587;   % fixed value
sigma_a_C12 = 0.0034; % fixed value
%
% SOLUTION
% We assume that the atom number density
% of uranium is
NU =1;
% Then atom number density of carbon is
NC = NU/U2Crat;
% Macroscopic cross section for absorption and fission
% for uranium
SIGMA_A_U = sigma_a_U235*NU;
SIGMA_F_U = sigma_f_U235*NU;
% Macroscopic cross section for absorption for carbon
SIGMA_A_C = sigma_a_C12*NC;
%
f = SIGMA_A_U/(SIGMA_A_U+SIGMA_A_C);
eta = 2.42*SIGMA_F_U/SIGMA_A_U;
k_inf = eta*f;
answer = k_inf;
```

Q93: What is k-infinite of a homogeneous mixture of U-235 and graphite with an atomic-uranium-to-carbon ratio of 3.333333E-5?

For such a dilute mixture of fully enriched uranium and carbon:

(fast-fission factor)*(resonans escape probability) = epsilon * p=1,

so that k_inf = eta * f = (reproduction factor) * (thermal utilization factor).

Microscopic cross sections for absorption of U-235 and graphite (assuming C-12) are 687 b and 0.0034 b, respectively.

Microscopic cross sections for fission of U-235 is 587 b.

Ans: % SOLUTION

```
% We find the reactivity increase
Rho = Beta; % Prompt reactor
% Find roots of the characteristic equation: thermal reactor
aux1 = Beta/LAMBDAT-Rho/LAMBDAT+Lambda;
s1 = (-aux1+sqrt(aux1**2+4*Lambda*Rho/LAMBDAT))/2;
s2 = (-aux1-sqrt(aux1**2+4*Lambda*Rho/LAMBDAT))/2;
% Calculate the stable reactor period for thermal reactor
s = max(s1,s2);
if s>0
  TT = 1/s;
else
  answerT = 'Reactor period is undefined for thermal reactor'
endif
% Find roots of the characteristic equation: fast reactor
aux1 = Beta/LAMBDAF-Rho/LAMBDAF+Lambda;
s1 = (-aux1+sqrt(aux1**2+4*Lambda*Rho/LAMBDAF))/2;
s2 = (-aux1-sqrt(aux1**2+4*Lambda*Rho/LAMBDAF))/2;
% Calculate the stable reactor period for fast reactor
s = max(s1,s2);
if s>0
  TF = 1/s;
else
  answerF = 'Reactor period is undefined for fast reactor'
endif
answer = TT/TF;
```

Q94: Calculate the reproduction factor eta for the enriched uranium.

Given: enrichment 3.7%, microscopic cross section for fission of U-235: 585 (barn), microscopic cross section for absorption in U-235: 684 (barn) and for absorption in U-238: 2.68 (barn).

Ans: % GIVEN

```
%
e = 0.0072; % changing from 0.007 to 0.05
sigma_f_U235 = 585;   % fixed value
sigma_a_U235 = 684;   % fixed value
sigma_a_U238 = 2.68;  % fixed value
%
% SOLUTION
%
eta = 2.42*e*sigma_f_U235/((1-e)*sigma_a_U238+e*sigma_a_U235);
answer = eta;
```

Q95: Calculate the total number of nuclei of U-238 in a sample containing pure U-238 isotope with density RHO=18.9 g/cm^3 and volume Vol = 6 cm^3

Ans: % SOLUTION

```
NA = 6.02e23;   % fixed value - Avogadro's number
A238 = 238;     % mass number for U-235
% We find the atomic number density
NU238 = 1000*RHO*NA/A238;
answer = NU238*Vol; %volume in m^3
```

Q96: The reactivity in a steady-state thermal reactor with no external neutron sources, in which the neutron generation time is 1E-4 (s), is suddenly made positive and equal to 0.0047.

Assuming one group of delayed neutrons (Lambda = 0.08 1/s, Beta = 6.5E-3)
determine the stable reactor period T (s).

Ans: % GIVEN

```
%
LAMBDA = 1.0e-4; % changing from 1.0e-3 to 1.0e-4 s
Rho = 0.0022;     % changing from 0.001 to 0.005
Lambda = 0.08;   % fixed value
Beta = 6.5e-3;   % fixed value
%
% SOLUTION
% We find roots of the characteristic equation
aux1 = Beta/LAMBDA-Rho/LAMBDA+Lambda;
s1 = (-aux1+sqrt(aux1**2+4*Lambda*Rho/LAMBDA))/2;
s2 = (-aux1-sqrt(aux1**2+4*Lambda*Rho/LAMBDA))/2;
% Calculate the stable reactor period
s = max(s1,s2);
if s>0
  T = 1/s;
  answer = T;
else
  answer = 'Reactor period is undefined'
endif
```

Q97: The reactivity in a steady-state thermal reactor with no external neutron sources, in which the neutron generation time is 4E-4 (s), is suddenly made positive and equal to 0.0025.

Assuming one group of delayed neutrons (Lambda = 0.08 1/s, Beta = 6.5E-3) determine the reactor power increase in percent of the initial power after time 2.4 (s).

Ans: % GIVEN

```
%
LAMBDA = 1.0e-3; % changing from 1.0e-3 to 1.0e-4 s
Rho = 0.0022;     % changing from 0.001 to 0.005
Lambda = 0.08;   % fixed value
Beta = 6.5e-3;   % fixed value
t = 1;           % changing from 0.1 to 3 s
%
% SOLUTION
% We find roots of the characteristic equation
aux1 = Beta/LAMBDA-Rho/LAMBDA+Lambda;
s1 = (-aux1+sqrt(aux1**2+4*Lambda*Rho/LAMBDA))/2;
s2 = (-aux1-sqrt(aux1**2+4*Lambda*Rho/LAMBDA))/2;
% Calculate the relative power increase
aux2 = (s1+Lambda)/s1/(s1-s2);
aux3 = (s2+Lambda)/s2/(s2-s1);
x = Rho*(Lambda/s1/s2+aux2*exp(s1*t)+aux3*exp(s2*t))/LAMBDA;
% Answer: power increase in percent is x*100
answer = x*100;
```

Q98: Calculate the specific energy (energy per unit air mass flowing through the area occupied by a single wind turbine rotor) for a wind turbine operating with the maximum efficiency given by the Betz limit, when the unperturbed wind speed is 5 m/s.

Ans: % GIVEN

```
%
U = 10; % changing from 5 to 25 m/s
%
% SOLUTION
% We find this ratio as N/W, where N is the maximum
```

```
% wind mill power: N=(1/2)*rho*U^3*A*4*a*(1-a)^2 and
% W = rho*A*U*(1-a); here W is mass flow rate, a is
% the interference factor
a=1/3; % interference factor at maximum power
ratio = 0.5*U*U*4*a*(1-a);
answer = ratio;
```

Q99: Calculate the maximum power (kW) that can be generated by the Savonius rotor with radius 2.5 (m) and height 5 (m) if wind speed is 5 (m/s) and air density is 1.2 (kg/m^3)

Ans: % GIVEN

```
%
U = 15; % changing from 5 to 25 m/s
R = 2;  % changing from 1 to 3 m
H = 3;  % changing from 2 to 5 m
RHO = 1.25; % changing from 1.15 to 1.30 kg/m^3
%
% SOLUTION
%
max_power = (16/27)*RHO*R*H*U**3;
answer = max_power/1000;
```

Q100: Wind speed was measured at a reference distance from the ground 40 (m) and was equal to 5 (m/s). Find the wind speed U (m/s) at the target distance above the ground 125 (m), knowing the ground roughness equal to 0.5264 (m).

Ans: % GIVEN

```
%
Uref = 15; % changing from 5 to 25 m/s
Zref = 35;  % changing from 25 to 50 m
Z = 100;  % changing from 75 to 150 m
z0 = 0.1; % changing from 0.0002 to 1.5 m
%
% SOLUTION
%
U=Uref*log(Z/z0)/log(Zref/z0);
answer = U;
```

Q101: Calculate solar time of the Sun on June 14 at 12:00 as seen from the AlbaNova building (coordinates: 59.3536 N, 18.0578 E)

Assume that the year has 365 days.

Ans: % GIVEN

```
%
June_day = 21; % changing from 1 to 30 step 1
LT = 12; % local time
LAMBDA = 18.0578; % local longitude
FI = 59.3536;     % local latitude
%
% SOLUTION
% We find the day number Nd
Nd = 3*31+28+30+June_day;
% Equation of time
arg1_deg = 360*Nd/365+85.9;
arg2_deg = 2*360*Nd/365+108.9;
arg3_deg = 3*360*Nd/365+105.2;
arg1_rad = arg1_deg*pi/180; % in radians
arg2_rad = arg2_deg*pi/180; % in radians
arg3_rad = arg3_deg*pi/180; % in radians
```

ET=0.0066+7.3525*cos(arg1_rad)+9.9359*cos(arg2_rad);
ET=ET+0.3387*cos(arg3_rad); % in minutes
% Solar time
ST = LT - (4*(15-LAMBDA) + ET)/60; % note units! in h
answer = ST;

Q102: Calculate the Sun's surface temperature (K) knowing that due to fusion, the Sun is losing mass 4.18E9 (kg) during one second.

The Sun's radius is $R=6.955*10^{8}$ m.

Assume a black-body radiation from the Sun's surface.

Stefan-Boltzmann constant is sig = $5.67051*10^{-8}$ $W/m^2/K^4$

and the speed of light is c = 299792458 m/s.

Ans: % GIVEN
%
R=6.955e8;   % not changing
sig=5.67051e-8; % not changing
c=299792458;   % not changing
dM=4.3e9;   % changing from 4.1e9 to 4.3e9 step 0.02e9
%
% SOLUTION
% Total energy emitted by the Sun per second
q = dM*c**2;
% Heat flux from the Sun's surface
A = 4*pi*R**2;
q2p = q/A;
% The Sun's surface temperature
T=(q2p/sig)**0.25;
answer = T;

Q103: Calculate equation of time of the Sun on June 2.

Give answer in minutes.

Assume that the year has 365 days.

Ans: % GIVEN
%
June_day = 21; % changing from 1 to 30 step 1
%
% SOLUTION
% We find the day number Nd
Nd = 3*31+28+30+June_day;
% Equation of time
arg1_deg = 360*Nd/365+85.9;
arg2_deg = 2*360*Nd/365+108.9;
arg3_deg = 3*360*Nd/365+105.2;
arg1_rad = arg1_deg*pi/180; % in radians
arg2_rad = arg2_deg*pi/180; % in radians
arg3_rad = arg3_deg*pi/180; % in radians
ET=0.0066+7.3525*cos(arg1_rad)+9.9359*cos(arg2_rad);
ET=ET+0.3387*cos(arg3_rad); % in minutes
answer = ET;

Q104: Calculate azimuth of the Sun on June 20 at 12:00 as seen from the AlbaNova building (coordinates: 59.3536 N, 18.0578 E)

Assume that the year has 365 days.

The answer should be in angle degree.

Ans:
```
% GIVEN
%
June_day = 21; % changing from 1 to 30 step 1
LT = 12; % local time
LAMBDA = 18.0578; % local longitude
FI = 59.3536;     % local latitude
%
% SOLUTION
% We find the day number Nd
Nd = 3*31+28+30+June_day;
arg1_deg = 360*Nd/365+9.5;
arg2_deg = 2*360*Nd/365+5.4;
arg3_deg = 3*360*Nd/365+105.2;
arg1_rad = arg1_deg*pi/180; % in radians
arg2_rad = arg2_deg*pi/180; % in radians
arg3_rad = arg3_deg*pi/180; % in radians
% Declination of the Sun
d=0.3948-23.2559*cos(arg1_rad)-0.3915*cos(arg2_rad);
d=d-0.1764*cos(arg3_rad);
% Equation of time
arg1_deg = 360*Nd/365+85.9;
arg2_deg = 2*360*Nd/365+108.9;
arg3_deg = 3*360*Nd/365+105.2;
arg1_rad = arg1_deg*pi/180; % in radians
arg2_rad = arg2_deg*pi/180; % in radians
arg3_rad = arg3_deg*pi/180; % in radians
ET=0.0066+7.3525*cos(arg1_rad)+9.9359*cos(arg2_rad);
ET=ET+0.3387*cos(arg3_rad); % in minutes
% Solar time
ST = LT - (4*(15-LAMBDA) + ET)/60; % note units! in h
% Hour angle
w = (12 - ST)*15; % in degrees
% Altitude of the Sun
FI_rad = FI*pi/180;
w_rad = w*pi/180; % in radians
d_rad = d*pi/180; % in radians
arg_psi = cos(w_rad)*cos(FI_rad)*cos(d_rad)+sin(FI_rad)*sin(d_rad);
psi_rad = asin(arg_psi);
psi_deg = psi_rad*180/pi;
% Azimuth
arg_rad = sin(psi_rad)*sin(FI_rad)-sin(d_rad);
arg_rad = arg_rad/cos(psi_rad)/cos(FI_rad);
if ST > 12.00
  az = 180 + acos(arg_rad)*180/pi;
else
  az = 180 - acos(arg_rad)*180/pi;
end
answer = az;
```

Q105: Calculate altitude of the Sun on June 14 at 12:00 as seen from the AlbaNova building (coordinates: 59.3536 N, 18.0578 E)

Assume that the year has 365 days.

The answer should be in angle degree.

Ans: %
```
:% GIVEN
:%
June_day = 21; :% changing from 1 to 30 step 1
LT = 12; :% local time
LAMBDA = 18.0578; :% local longitude
```

```
FI = 59.3536;     :% local latitude
:%
:% SOLUTION
:% We find the day number Nd
Nd = 3*31+28+30+June_day;
arg1_deg = 360*Nd/365+9.5;
arg2_deg = 2*360*Nd/365+5.4;
arg3_deg = 3*360*Nd/365+105.2;
arg1_rad = arg1_deg*pi/180; :% in radians
arg2_rad = arg2_deg*pi/180; :% in radians
arg3_rad = arg3_deg*pi/180; :% in radians
:% Declination of the Sun
d=0.3948-23.2559*cos(arg1_rad)-0.3915*cos(arg2_rad);
d=d-0.1764*cos(arg3_rad);
:% Equation of time
arg1_deg = 360*Nd/365+85.9;
arg2_deg = 2*360*Nd/365+108.9;
arg3_deg = 3*360*Nd/365+105.2;
arg1_rad = arg1_deg*pi/180; :% in radians
arg2_rad = arg2_deg*pi/180; :% in radians
arg3_rad = arg3_deg*pi/180; :% in radians
ET=0.0066+7.3525*cos(arg1_rad)+9.9359*cos(arg2_rad);
ET=ET+0.3387*cos(arg3_rad); :% in minutes
:% Solar time
ST = LT - (4*(15-LAMBDA) + ET)/60; :% note units! in h
:% Hour angle
w = (12 - ST)*15; :% in degrees
:% Altitude of the Sun
FI_rad = FI*pi/180;
w_rad = w*pi/180; :% in radians
d_rad = d*pi/180; :% in radians
arg_psi = cos(w_rad)*cos(FI_rad)*cos(d_rad)+sin(FI_rad)*sin(d_rad);
psi_rad = asin(arg_psi);
psi_deg = psi_rad*180/pi;
answer = psi_deg;
```

Q106: Calculate the mean heat flux at Earth orbit resulting from solar irradiation on June 21st.
Assume the Sun constant Gcs = 1366 W/m^2 and that year has 365 days.

Ans: % GIVEN

```
%
June_day = 21; % changing from 1 to 30 step 1
Gsc = 1366;    % not changing
%
% SOLUTION
% We find variation of Sun irradiation as a
% function of day number Nd
Nd = 3*31+28+30+June_day;
arg_deg = 360*(Nd-3)/365;
arg_rad = arg_deg*pi/180; % in radians
Ie = Gsc*(1+0.033412*cos(arg_rad));
answer = Ie;
```

Q107: Calculate hour angle of the Sun on June 5 at 12:00 as seen from the AlbaNova building (coordinates: 59.3536 N, 18.0578 E)

Assume that the year has 365 days.

Ans: % GIVEN

```
%
```

```
June_day = 21; % changing from 1 to 30 step 1
LT = 12; % local time
LAMBDA = 18.0578; % local longitude
FI = 59.3536;     % local latitude
%
% SOLUTION
% We find the day number Nd
Nd = 3*31+28+30+June_day;
% Equation of time
arg1_deg = 360*Nd/365+85.9;
arg2_deg = 2*360*Nd/365+108.9;
arg3_deg = 3*360*Nd/365+105.2;
arg1_rad = arg1_deg*pi/180; % in radians
arg2_rad = arg2_deg*pi/180; % in radians
arg3_rad = arg3_deg*pi/180; % in radians
ET=0.0066+7.3525*cos(arg1_rad)+9.9359*cos(arg2_rad);
ET=ET+0.3387*cos(arg3_rad); % in minutes
% Solar time
ST = LT - (4*(15-LAMBDA) + ET)/60; % note units! in h
% Hour angle
w = (12 - ST)*15; % in degrees
answer = w;
```

Q108: Calculate declination of the Sun on June 30.
Give answer in angle degrees.
Assume that the year has 365 days.

Ans: % GIVEN

```
%
June_day = 21; % changing from 1 to 30 step 1
%
% SOLUTION
% We find the day number Nd
Nd = 3*31+28+30+June_day;
arg1_deg = 360*Nd/365+9.5;
arg2_deg = 2*360*Nd/365+5.4;
arg3_deg = 3*360*Nd/365+105.2;
arg1_rad = arg1_deg*pi/180; % in radians
arg2_rad = arg2_deg*pi/180; % in radians
arg3_rad = arg3_deg*pi/180; % in radians
% Declination of the Sun
d=0.3948-23.2559*cos(arg1_rad)-0.3915*cos(arg2_rad);
d=d-0.1764*cos(arg3_rad);
answer = d;
```

Q109: Electricity generating plant is typically built within 5 years with uniformly distributed expenditures per each year. A new construction schedule is considered in which the plant will be built within 4 years with uniformly distributed expenditures. The sum of expenditures in both cases will be the same.

Calculate the change of capital cost in percent using the original schedule as a reference. Use the following pattern for the answer: answer = (Co-Cn)/Co * 100 (%),

where:
Co - original schedule cost (5-year build)
Cn - new schedule cost (4-tear build).
The interest rate in both cases is the same
and equal to 7%.

Use the end of construction as the reference time point

Ans: % GIVEN

```
%
i = 0.05; % changing from 0.03 to 0.1, step 0.01
%
% SOLUTION
% We assume annual expenditure in original
% schedule:
Ex_o = 1;
% Then expenditures in new schedule will be:
Ex_n = 5*Ex_o/4;
% Capital cost for original schedule is now:
Co = Ex_o*(1+(1+i)+(1+i)**2+(1+i)**3+(1+i)**4);
% and for the new one
Cn = Ex_n*(1+(1+i)+(1+i)**2+(1+i)**3);
%
answer = (Co-Cn)/Co * 100;
```

Q110: Electricity generating plant was initially scheduled to operate N_o = 18 years, but this lifetime was extended to N_n = 33 years.

Calculate the new levelized charge for electricity to cover capital expenditures if according to the initial schedule it would be equal to L_{cap}_o = 22 Euro/MWh

In both cases the invested amount and the number of electricity produced per year are the same and the interest rate is equal to i = 0.09 .

Ans: % GIVEN

```
%
i = 0.05; % changing from 0.03 to 0.1, step 0.01
Lcap_o = 25; % Changing from 20 to 40, step 2
No=20;    % changing from 10 to 20, step 1
Nn=30;    % changing from 30 to 40, step 1
%
% SOLUTION
% We find new levelized charge for electricity
% to cover capital expeditures directly
% from the relation between the two:
%
i1=1+i;
answer = Lcap_o*i1**(Nn-No) * (i1**No-1)/(i1**Nn-1);
```

Q111: An ideal gas mixture with known kappa = c_p/c_v = 1.33 undergoes in a closed system a frictionless process described with a linear function p(V).

Calculate the amonnt of heat Q_{12} (kJ) supplied to the mixture for known initial pressure p_1 = 400,000 (Pa) and volume V_1 = 0.05 (m^3) and final pressure p_2 = 280,000 (Pa) and volume V_2 = 0.3 (m^3).

Feedback

from the first law we have $Q_{12} = E_{I2} - E_{I1} + L_{12}$ where:

- $E_{I1,2}$ is the initial and final internal energy and
- L_{12} is the work done during the process.
- L_{12} = integral from V1 to V2 of p(V)dV. Since p(V) is linear,
- $L12 = \frac{(p_1+p_2)*(V_2-V_1)}{2}$ (mean pressure times volume change).

Hence,

$$E_{I2} - E_{I1} = m * c_v * (T_2 - T_1) = m\left(\frac{R}{(1-\kappa)}\right) * \frac{(p_1 * V_1 - p_2 * V_2)}{(m * R)} =$$

$$= \frac{(p_1 * V_1 - p_2 * V_2)}{(1-\kappa)}$$

.

We arrive at:

$$Q_{12} = \frac{(p_1 * V_1 - p_2 * V_2)}{(1-\kappa)} + \frac{(p_1 + p_2) * (V_2 - V_1)}{2}$$

Ans:

Q137: Steam turbine in a thermal power plant operates in a Rankine cycle and has an effective power 100 (MW), mechanical efficiency 0.99 and internal efficiency 0.79. Mass flow rate of cooling water in the condenser is 4,300 (kg/s) and its mean temperature increase is 10 (K). Specific heat of the cooling water is 4,190 (J/kg.K).

Assuming no heat losses in the system and neglecting the needed pumping power calculate the energy efficiency of the ideal Rankine cycle in the power plant.

Feedback

Solution:
(a) internal power of the turbine

$$N_i = \frac{N_e}{\eta_m};$$

(b) thermal power extracted in the condenser

$$q_e = W_w * c_{pw} * \Delta T_w$$

(c) theoretical power

$$N_{th} = \frac{N_i}{\eta_i}$$

(d) total added thermal power to the cycle

$$q_a = q_e + N_i$$

(e) efficiency of the ideal Rankine cycle

$$\eta_{EIR} = \frac{N_{th}}{q_a};$$

Ans:

Q138: A steam turbine operates at steady-state conditions and delivers effective (shaft) power N_e = 420 MW. Steam mass flow rate through the turbine is W = 499 kg/s. The inlet specific enthalpy and the mean velocity of the steam are i_{in} = 2,770 kJ/kg and U_{in} = 90 m/s, respectively. The corresponding parameters for steam at the outlet are i_{out} = 1,870 kJ/kg and U_{out} = 225 m/s.

Neglect potential energy of the steam streams. Calculate the turbine heat losses to the surroundings.

Feedback

Solution:

(a) internal power of the turbine

$N_i = W*(i_{in}+(U_{in}^2)/2-i_{out}-(U_{out}^2)/2);$

(b) thermal power loss

q_{loss} = Ni - Ne;

Ans:

Q139: A gear transmission in a windmil has an output power N_{ext} = 1,500,000 (W) and mechanical efficiency η_M = 0.95.

Calculate the amount of heat Q (kW) generated in the gear due to friction.

Feedback

The added power is $N_{add} = N_{ext}/eta$
and from the first law:

$Q = N_{add} - N_{ext} = N_{ext}*(1/eta-1)$

$Q = N_{ext}*(1.0/eta-1.0)$

Ans:

Q140: A tank with volume V = 15 (m^3) contains nitrogen (N_2) at pressure p_1 = 175,000 (Pa) and temperature T_1 = 330 (K).

An electrical heater with electrical power N_{el} = 7,000 (W) is installed inside the tank and heats up the gas to temperature T_2 = 840 (K). A fraction (0.1) of the heat provided by the heater is absorbed by the tank's walls.

Assuming:
(1) no heat accumulation in the heater
(2) ideal gas model for nitrogen

(3) Heat capacity ratio κκ = 1.4

(a) the heat absorbed by the gas Q_{12} (MJ)—10.142045

(b) the time needed to heat up the gas t_{12} (s)—1609.84848

Q141: Steam turbine in a thermal power plant has an effective power 75 (MW) and the mechanical efficiency 0.99. Specific steam usage in relation to the effective power is 6.7E-6 (kg/J of eff. power). Mass flow rate of cooling water in the condenser is 4,800 (kg/s) and its mean temperature increase is 8 (K). Specific heat of the cooling water is 4,190 (J/kg.K). Heat losses in the pipline between the boiler and the turbine are equal to 40,000 (J per kg of flowing steam).

Calculate the energy efficiency of the thermodynamic cycle in the power plant. Neglect the needed pumping power.

Feedback

Solution:

(a) internal power of the turbine

$$N_i = \frac{N_e}{\eta m}$$

(b) thermal power extracted in the condenser

$$q_e = W_w * cp_w * \Delta T_w$$

(c) mass flow of steam in the turbine

$$W = U_{st} * N_e$$

(d) thermal power loss in the pipeline

$$q_{loss} = Q_{loss} * W$$

(e) total added thermal power to the cycle

$$q_a = q_{loss} + q_e + N_i$$

(f) Energy efficiency of the cycle

$$eta_E = \frac{N_i}{q_a}$$

Ans:

Q162: Saturated water/steam mixture at temperature T=471.45 K flows upwards through a vertical pipe with diameter 110 mm and length 9 m.

Calculate the total pressure change Δp = p_2 - p_1 over the pipe length when the mass flow rate of water is 0.3 kg/s and the mass flow rate of steam is 1.33 kg/s.

Assume the same water/steam properties everywhere.
Assume wall roughness 0.1 mm.
Neglect the local inlet and outlet losses.

Ans: -273.15=-273.15;
10=10.;
0.001=1.E-3;
1=1.;
1=1.;
198.3=471.45+-273.15;
110 = range(100,200,10);
0.11=110*0.001;
0.1 = range(0.01,0.10,0.01);
1E-4=0.1*0.001;

9 = range(5,15,1);
9=9*1;
0.3 = range(0.1,2,0.1);
0.3=0.3*1;
1.33 = range(0.01,2,0.01);
1.33=1.33*1;

866.64=866.64;
7.5936=7.5936;

1.3554E-4=1.3554E-4;
1.5657E-5=1.5657E-5;
0.009503=3.141593*0.11^2/4;
1.63=0.3+1.33;
0.815951=1.33/1.63;
171.519006=1.63/0.009503;
139,199.429394 = 171.519006*0.11/1.3554E-4;: % Liquid-only Reynolds number;
6.893267=-1.8*log((1E-4/0.11/3.7)^1.11+6.9/139,199.429394);
0.005261=1/4/6.893267^2;
56.867485=(1+(866.64/7.5936-1)*0.815951)/(1+(1.3554E-4/1.5657E-5-1)*0.815951)^0.25;
-1,661.955459 = -56.867485 * (4*0.005261*9/0.11) * (171.519006^2/2/866.64);
0.998027=1/(1+(1-0.815951)/0.815951*(7.5936/866.64));
0.010717=1-(866.64-7.5936)/866.64*0.998027;
-820.044954 = -9.81*0.010717*866.64*9;
-2,482.000414 = -1,661.955459 + -820.044954;

Q163: Saturated water/steam mixture at temperature T=494.95 K flows upwards through a vertical uniformly heated pipe with diameter 140 mm and length 10 m.

Calculate the total pressure change $\Delta p = p_2 - p_1$ over the pipe length when the mass flow rate of saturated water at the inlet is 2.5 kg/s and the exit therodynamic equilibrium quality is x_{ex}=0.45.

Assume the same water/steam properties everywhere.
Assume wall roughness 0.02 mm.
Neglect the local inlet and outlet losses.

Ans: -273.15=-273.15;
10=10.;
0.001=1.E-3;
1=1.;
1=1.;

221.8=494.95+-273.15;

140 = range(100,200,10);
0.14=140*0.001;
0.02 = range(0.01,0.10,0.01);
2E-5=0.02*0.001;
10 = range(5,15,5);
10=10*1;
2.5 = range(1,5,0.25);
2.5=2.5*1;

837.91=837.91;

1.2049E-4=1.2049E-4;
0.015394=pi*0.14^2/4;
2.5=2.5;
162.403045=2.5/0.015394;
188,699.69541 = 162.403045*0.14/1.2049E-4; :% Liquid-only Reynolds number;
7.754603=-1.8*log((2E-5/0.14/3.7)^1.11+6.9/188,699.69541);
0.004157=1/4/7.754603^2;
15.5=15.5; :% found from figure (b);
-289.76464 = -15.5 * (4*0.004157*10/0.14) * (162.403045^2/2/837.91);
0.089=0.089; :% found from figure (c);
-7,315.708419 = -9.81*0.089*837.91*10;
37.6=37.6; :% found from figure (a);
-1,183.528736 = -37.6 * (162.403045^2/837.91);
-8,789.0018 = -289.76464 + -7,315.708419 + -1,183.528736;

Q164: Water steam at temperature T = 770 K and pressure 7.2 MPa flows through a sudden expansion with diameter change from 350 mm to 500 mm.

Calculate the total pressure change $\Delta p = p_2 - p_1$ over the sudden expansion when the volumetric flow rate of water steam is 0.9 m^3/s.

Assume the same water steam properties everywhere.

Ans: -273.15=-273.15;
10=10.;
0.001=1.E-3;
1=1.;

496.85=770+-273.15;
72=7.2*10;
350 = range(100,450,50);
0.35=350*0.001;
500 = range(500,750,50);
0.5=500*0.001;
0.9 = range(0.10,1.00,0.10);
0.9=0.9*1;

21.505=21.505;
0.096211=pi*0.35^2/4;
0.19635=pi*0.5^2/4;
9.354413=0.9/0.096211;
4.583662=0.9/0.19635;
714.988461 = 21.505*(9.354413^2-4.583662^2)/2;
0.2601=(1-0.096211/0.19635)^2;
-244.727605 = -0.2601*21.505*9.354413^2/2;
470.260856 = 714.988461 + -244.727605;

Q165: Water steam at temperature T=750 K and pressure 7.0 MPa flows through a horizontal pipe with diameter 140 mm and length 19 m.

Calculate the total pressure change Δp = p2-p1 over the pipe length when the mass flow rate of water steam is 20 kg/s.

Assume the same water steam properties everywhere.
Assume wall roughness 0.08 mm.
Neglect the local inlet and outlet losses.

Ans: -273.15=-273.15;
10=10.;
0.001=1.E-3;
1=1.;
1=1.;

476.85=750+-273.15;
70=7.0*10;

140 = range(100,500,10);
0.14=140*0.001;   :% variation from 100 to 500 mm;
0.08= range(0.01,0.10,0.01);
8E-5=0.08*0.001;   :% variation from 0.01 to 0.1 mm;
19 = range(10,50,1);
19=19*1;   : % variation from 10 to 50 m;
20 = range(5,25,5);
20=20*1;   :% variation from 5 to 25 kg/s;

21.577=21.577;
2.7767E-5=2.7767E-5;
0.015394=pi*0.14^2/4;
60.213392=20/(21.577*0.015394);
6,550,632.437423 = 60.213392*0.14*21.577/2.7767E-5;
7.600982=-1.8*log((8E-5/0.14/3.7)^1.11+6.9/6,550,632.437423);
0.004327=1/4/7.600982^2;
-91,882.70192 = -(4*0.004327*19/0.14) * (20^2/2/21.577/0.015394^2);

Q166: Water steam at temperature T=750 K and pressure 7.0 MPa flows upwards through a vertical pipe with diameter 220 mm and length 18 m.

Calculate the total pressure change Δp = p2-p1 over the pipe length when the mass flow rate of water steam is 25 kg/s.

Assume the same water steam properties everywhere.
Assume wall roughness 0.04 mm.
Neglect the local inlet and outlet losses.

Ans: -273.15=-273.15;
10=10.;
0.001=1.E-3;
1=1.;
1=1.;

476.85=750+-273.15;
70=7.0*10;

220 = range(100,500,10);
0.22=220*0.001;   :% variation from 100 to 500 mm;
0.04= range(0.01,0.10,0.01);
4E-5=0.04*0.001;   :% variation from 0.01 to 0.1 mm;
18 = range(10,50,1);
18=18*1;   : % variation from 10 to 50 m;
25 = range(5,25,5);
25=25*1;   :% variation from 5 to 25 kg/s;

21.577=21.577;
2.7767E-5=2.7767E-5;
0.038013=pi*0.22^2/4;
30.479913=25/(21.577*0.038013);
5,210,729.150338 = 30.479913*0.22*21.577/2.7767E-5;
8.548166=-1.8*log((4E-5/0.22/3.7)^1.11+6.9/5,210,729.150338);
0.003421=1/4/8.548166^2;
-11,222.561943 = -(4*0.003421*18/0.22) * (25^2/2/21.577/0.038013^2);
-3,810.06666 = -9.81*21.577*18;
-15,032.62856 = -11,222.561943 + -3,810.06666;

Q167: Water steam at temperature T=750 K and pressure 7.0 MPa flows downwards through a vertical pipe with diameter 330 mm and length 14 m.

Calculate the total pressure change Δp = p2-p1 over the pipe length when the mass flow rate of water steam is 5 kg/s.

Assume the same water steam properties everywhere.
Assume wall roughness 0.08 mm.
Neglect the local inlet and outlet losses.

Water-steam properties:

Density of water steam at temperature T=750 K and pressure 7.0 MPa is 21.577 kg/m^3;

Viscosity of water steam at temperature T=750 K and pressure 7.0 MPa is 2.777x10^{-5} Pas

Ans: -273.15=-273.15;
10=10.;
0.001=1.E-3;
1=1.;
1=1.;

476.85=750+-273.15;
70=7.0*10;

330 = range(100,500,10);
0.33=330*0.001;   :% variation from 100 to 500 mm;
0.08= range(0.01,0.10,0.01);

8E-5=0.08*0.001;   :% variation from 0.01 to 0.1 mm;
14 = range(10,50,1);
14=14*1;   : % variation from 10 to 50 m;
5 = range(5,25,5);
5=5*1;   :% variation from 5 to 25 kg/s;

21.577=21.577;
2.7767E-5=2.7767E-5;
0.08553=pi*0.33^2/4;
2.709325=5/(21.577*0.08553);
694,763.865057 = 2.709325*0.33*21.577/2.7767E-5;
8.075268=-1.8*log((8E-5/0.33/3.7)^1.11+6.9/694,763.865057);
0.003834=1/4/8.075268^2;
-51.520915 = -(4*0.003834*14/0.33) * (5^2/2/21.577/0.08553^2);
2,963.38518 = 9.81*21.577*14;
2,911.864265 = -51.520915 + 2,963.38518;

Q168: Saturated water/steam mixture at temperature T=537.09 K flows through a horizontal uniformly heated pipe with diameter 110 mm and length 35 m.

Calculate the total pressure change Δp = p_2 - p_1 over the pipe length when the mass flow rate of saturated water at the inlet is 4.5 kg/s and exit thermodynamic equilibrium quality is x_{ex}=0.65.

Assume the same water/steam properties everywhere.
Assume wall roughness 0.03 mm.
Neglect the local inlet and outlet losses.

Ans: -273.15=-273.15;
10=10.;
0.001=1.E-3;
1=1.;
1=1.;

263.94=537.09+-273.15;

110 = range(100,200,10);
0.11=110*0.001;
0.03 = range(0.01,0.10,0.01);
3E-5=0.03*0.001;
35 = range(10,50,5);
35=35*1;
4.5 = range(2,5,0.25);
4.5=4.5*1;

777.36=777.36;

1.0001E-4=1.0001E-4; : =XSteam('my_pT',psat,T-0.01) to get liquid viscosity;
0.009503=pi*0.11^2/4;
4.5=4.5;
473.518728=4.5/0.009503;
520,818.518948 = 473.518728*0.11/1.0001E-4; : Liquid-only Reynolds number;
7.933526=-1.8*log((3E-5/0.11/3.7)^1.11+6.9/520,818.518948);
0.003972=1/4/7.933526^2;
8.4=8.4; : found from figure for given xex and pressure;
19.3=19.3; : found from figure for given xex and pressure;
-11,690.970857 = -(8.4 * (4*0.003972*35/0.11) + 2*19.3) * (473.518728^2/2/777.36);

Q169: Water steam at temperature T=790 K and pressure 7.5 MPa flows through a sudden contraction with diameter change from 650 mm to 450 mm.

Calculate the total pressure change Δp = p_2 - p_1 over the sudden contraction when the volumetric flow rate of water is 0.05 m^3/s.

Assume the same water properties everywhere.

Ans:
-273.15=-273.15;
10=10.;

0.001=1.E-3;
1=1.;
516.85=790+-273.15;
75=7.5*10;
450 = range(100,450,50);
0.45=450*0.001;
650 = range(500,750,50);
0.65=650*0.001;
0.05 = range(0.05,0.20,0.05);
0.05=0.05*1;

21.75=21.75;
0.331831=pi*0.65^2/4;
0.159043=pi*0.45^2/4;
0.150679=0.05/0.331831;
0.31438=0.05/0.159043;
-0.827921 = 21.75*(0.150679^2-0.31438^2)/2;
0.661839 = 0.62 + 0.38*(0.159043/0.331831)^3;
0.261062=(1/0.661839-1)^2;
-0.280597 = -0.261062*21.75*0.31438^2/2;
-1.108517 = -0.827921 + -0.280597;

Q170: Water at temperature T=350 K and pressure 0.25 MPa flows downwards through a vertical pipe with diameter 290 mm and length 27 m.

Calculate the total pressure change $\Delta p = p_2 - p_1$ over the pipe length when the mass flow rate of water is 50 kg/s.
Assume the same water properties everywhere.
Assume wall roughness 0.02 mm.
Neglect the local inlet and outlet losses

Ans: -273.15=-273.15;
10=10.;
0.001=1.E-3;
1=1.;
1=1.;
76.85=350+-273.15;

290 = range(100,500,10);
0.29=290*0.001;   :% variation from 100 to 500 mm;
0.02= range(0.01,0.10,0.01);
2E-5=0.02*0.001;   :% variation from 0.01 to 0.1 mm;
27 = range(10,50,1);
27=27*1;   : % variation from 10 to 50 m;
50 = range(50,250,25);
50=50*1;   :% variation from 50 to 250 kg/s;
973.81=973.81;
3.6883E-4=3.6883E-4;
0.066052=pi*0.29^2/4;
0.777338=50/(973.81*0.066052);
595,190.313185 = 0.777338*0.29*973.81/3.6883E-4;
8.575202=-1.8*log((2E-5/0.29/3.7)^1.11+6.9/595,190.313185);
0.0034=1/4/8.575202^2;
-372.512236 = -(4*0.0034*27/0.29) * (50^2/2/973.81/0.066052^2);
257,933.0547 = 9.81*973.81*27;
257,560.542764 = -372.512236 + 257,933.0547;

Q171: Saturated water/steam mixture at temperature T=522.01 K flows downwards through a vertical pipe with diameter 200 mm and length 9 m.

Calculate the total pressure change $\Delta p = p_2 - p_1$ over the pipe length when the mass flow rate of water is 1 kg/s and the mass flow rate of steam is 1.41 kg/s.

Assume the same water/steam properties everywhere.
Assume wall roughness 0.07 mm.
Neglect the local inlet and outlet losses.

Ans: -273.15=-273.15;
10=10.;
0.001=1.E-3;
1=1.;
1=1.;
248.86=522.01+-273.15;
200 = range(100,200,10);
0.2=200*0.001;
0.07 = range(0.01,0.10,0.01);
7E-5=0.07*0.001;
9 = range(5,15,1);
9=9*1;
1 = range(0.1,2,0.1);
1=1*1;
1.41 = range(0.01,2,0.01);
1.41=1.41*1;
800.58=800.58;
19.573=19.573;
1.0664E-4=1.0664E-4;
1.7452E-5=1.7452E-5;
0.031416=3.141593*0.2^2/4;
2.41=1+1.41;
0.585062=1.41/2.41;
76.712674=2.41/0.031416;
143,872.231995 = 76.712674*0.2/1.0664E-4;: % Liquid-only Reynolds number;
7.354229=-1.8*log((7E-5/0.2/3.7)^1.11+6.9/143,872.231995);
0.004622=1/4/7.354229^2;
17.225567=(1+(800.58/19.573-1)*0.585062)/(1+(1.0664E-4/1.7452E-5-1)*0.585062)^0.25;
-52.675805 = -17.225567 * (4*0.004622*9/0.2) * (76.712674^2/2/800.58);
0.982956=1/(1+(1-0.585062)/0.585062*(19.573/800.58));
0.041076=1-(800.58-19.573)/800.58*0.982956;
2,903.360841 = 9.81*0.041076*800.58*9;
2,850.685035 = -52.675805 + 2,903.360841;

Q172: Water at temperature T=350 K and pressure 0.25 MPa flows
through a horizontal pipe with diameter 380 mm and length 33 m.
Calculate the total pressure change $\Delta p = p_2 - p_1$ over the pipe length when the mass flow rate of water is 50 kg/s.
Assume the same water properties everywhere.
Assume wall roughness 0.04 mm.
Neglect the local inlet and outlet losses.

Ans: -273.15=-273.15;
10=10.;
0.001=1.E-3;
1=1.;
1=1.;
76.85=350+-273.15;
2.5=0.25*10;
380 = range(100,500,10);
0.38=380*0.001; :% variation from 100 to 500 mm;
0.04= range(0.01,0.10,0.01);
4E-5=0.04*0.001; :% variation from 0.01 to 0.1 mm;
33 = range(10,50,1);
33=33*1; : % variation from 10 to 50 m;
50 = range(50,250,25);
50=50*1; :% variation from 50 to 250 kg/s;
973.81=973.81;

3.6883E-4=3.6883E-4;
0.113411=pi*0.38^2/4;
0.452729=50/(973.81*0.113411);
454,224.198315 = 0.452729*0.38*973.81/3.6883E-4;
8.309579=-1.8*log((4E-5/0.38/3.7)^1.11+6.9/454,224.198315);
0.003621=1/4/8.309579^2;
-125.514435 = -(4*0.003621*33/0.38) * (50^2/2/973.81/0.113411^2);

Q173: Saturated water/steam mixture at pressure 3 MPa flows downwards through a vertical uniformly heated pipe with diameter 110 mm and length 15 m.

Calculate the total pressure change $\Delta p = p_2 - p_1$ over the pipe length when the mass flow rate of saturated water at the inlet (x_{in}=0) is 2.5 kg/s and the exit therodynamic equilibrium quality is x_{ex}=0.4.

Assume the same water/steam properties everywhere.
Assume wall roughness 0.05 mm.

Use Haaland's Correlation for friction factor.
Neglect the local inlet and outlet losses.

Water-steam properties:

Density of saturated water at 3 MPa is 821.8949 kg/m^3;

Density of saturated steam at 3 MPa is 15.0006 kg/m^3;

Viscosity of saturated water at 3 MPa is 1.1395x10^{-4} Pas;

Viscosity of saturated steam at 3 MPa is 1.6903x10^{-5} Pas.

Ans: -273.15=-273.15;
10=10.;
0.001=1.E-3;
1=1.;
1=1.;

110 = range(100,200,10);
0.11=110*0.001;
0.05 = range(0.01,0.10,0.01);
5E-5=0.05*0.001;
15 = range(5,15,5);
15=15*1;
2.5 = range(1,5,0.25);
2.5=2.5*1;
821.8949=821.8949;
1.1395E-4=1.1395E-4;
0.009503=pi*0.11^2/4;
2.5=2.5;
263.06596=2.5/0.009503;
253,946.955682 = 263.06596*0.11/1.1395E-4; :% Liquid-only Reynolds number;
7.448202=-1.8*log((5E-5/0.11/3.7)^1.11+6.9/253,946.955682);
0.004506=1.0/4.0/7.448202^2;
9.5=9.5; :% found from figure (b);
-983.111209 = -9.5 * (4*0.004506*15/0.11) * (263.06596^2/2/821.8949);
0.14=0.14; :% found from figure (c);
16,931.856835 = 9.81*0.14*821.8949*15;
22=22.0; :% found from figure (a);
-1,852.403981 = -22 * (263.06596^2/821.8949);
14,096.341611 = -983.111209 + 16,931.856835 + -1,852.403981;

:test
((a)*(a))*(a) = log10(100);
2 = log(100);
4.60517 = ln(100);

Q174: Water at temperature T=390 K and pressure 0.29 MPa flows through a sudden contraction with diameter change from 500 mm to 350 mm.

Calculate the total pressure change $\Delta p = p_2 - p_1$ over the sudden contraction when the volumetric flow rate of water is 0.05 m^3/s.

Assume the same water properties everywhere.

Water-steam properties:

Density of water at temperature T=390 K and pressure 0.29 MPa is 945.68 kg/m^3;

Viscosity of water at temperature T=390 K and pressure 0.29 MPa is 2.39×10^{-4} Pas.

Ans: -273.15=-273.15;
10=10.;
0.001=1.E-3;
1=1.;

116.85=390+-273.15;
2.9=0.29*10;
350 = range(100,450,50);
0.35=350*0.001;
500 = range(500,750,50);
0.5=500*0.001;
0.05 = range(0.05,0.20,0.05);
0.05=0.05*1;

945.68=945.68;
0.19635=pi*0.5^2/4;
0.096211=pi*0.35^2/4;
0.254648=0.05/0.19635;
0.51969=0.05/0.096211;
-97.041787 = 945.68*(0.254648^2-0.51969^2)/2;
0.664707 = 0.62 + 0.38*(0.096211/0.19635)^3;
0.254443=(1/0.664707-1)^2;
-32.493188 = -0.254443*945.68*0.51969^2/2;
-129.534975 = -97.041787 + -32.493188;

Q175: Water at temperature T=370 K and pressure 0.27 MPa flows through a sudden expansion with diameter change from 300 mm to 650 mm.

Calculate the total pressure change $\Delta p = p_2 - p_1$ over the sudden expansion when the volumetric flow rate of water is 0.5 m^3/s.

Assume the same water properties everywhere.

Water-steam properties:

Density of water at temperature T=370 K and pressure 0.27 MPa is 960.68 kg/m^3;

Viscosity of water at temperature T=370 K and pressure 0.27 MPa is 2.91×10^{-4} Pas.

Ans: Feedback

-273.15=-273.15;
10=10.;
0.001=1.E-3;
1=1.;

96.85=370+-273.15;
2.7=0.27*10;
300 = range(100,450,50);
0.3=300*0.001; :% variation from 100 to 450 mm;
650 = range(500,750,50);
0.65=650*0.001; :% variation from 500 to 750 mm;

0.5 = range(0.1,1,0.1);
0.5=0.5*1;   :% variation from 0.1 to 1 m3/s;
960.68=960.68; :% =XSteam('rho_pT',p,T);
0.070686=pi*0.3^2/4;
0.331831=pi*0.65^2/4;
7.073553=0.5/0.070686;
1.506792=0.5/0.331831;
22,943.313214 = 960.68*(7.073553^2-1.506792^2)/2;
0.619341=(1-0.070686/0.331831)^2;
-14,885.174355 = -0.619341*960.68*7.073553^2/2;
8,058.1388 = 22,943.313214 + -14,885.174355;

Q176: Saturated water/steam mixture at temperature T=453.04 K flows through a horizontal pipe with diameter 120 mm and length 30 m.

Calculate the total pressure change $\Delta p = p_2 - p_1$ over the pipe length when the mass flow rate of water is 2 kg/s and the mass flow rate of steam 1.5 kg/s.

Assume the same water/steam properties everywhere.

Assume wall roughness 0.04 mm.

Neglect the local inlet and outlet losses.

Ans: -273.15=-273.15;
10=10.;
0.001=1.E-3;
1=1.;
1=1.;
179.89=453.04+-273.15;
120 = range(100,200,10);
0.12=120*0.001;
0.04 = range(0.01,0.10,0.01);
4E-5=0.04*0.001;
30 = range(10,50,5);
30=30*1;
2 = range(1,2,0.25);
2=2*1;
1.5 = range(1,2,0.25);
1.5=1.5*1;
887.12=887.12;
5.1459=5.1459;
:psat=XSteam('psat_T',T) % saturation pressure, bar;
1.5024E-4=1.5024E-4; :% =XSteam('my_pT',psat,T-0.01) % to get liquid viscosity;
1.5022E-5=1.5022E-5; :% =XSteam('my_pT',psat,T+0.01) % to get vapor viscosity;
0.01131=pi*0.12^2/4;
3.5=2+1.5;
0.428571=1.5/3.5;
309.468042=3.5/0.01131;
247,178.947284 = 309.468042*0.12/1.5024E-4; :% Liquid-only Reynolds number;
7.596059=-1.8*log((4E-5/0.12/3.7)^1.11+6.9/247,178.947284);
0.004333=1/4/7.596059^2;
50.151311=(1+(887.12/5.1459-1)*0.428571)/(1+(1.5024E-4/1.5022E-5-1)*0.428571)^0.25;
-11,729.112859 = -50.151311 * (4*0.004333*30/0.12) * (309.468042^2/2/887.12);

Q177: Water at temperature T=350 K and pressure 0.25 MPa flows upwards through a vertical pipe with diameter 470 mm and length 23 m.

Calculate the total pressure change $\Delta p = p_2 - p_1$ over the pipe length when the mass flow rate of water is 250 kg/s.

Assume the same water properties everywhere.
Assume wall roughness 0.03 mm.
Neglect the local inlet and outlet losses

Ans: -273.15=-273.15;
10=10.;
0.001=1.E-3;
1=1.;
1=1.;
76.85=350+-273.15;

470 = range(100,500,10);
0.47=470*0.001; :% variation from 100 to 500 mm;
0.03= range(0.01,0.10,0.01);
3E-5=0.03*0.001; :% variation from 0.01 to 0.1 mm;
23 = range(10,50,1);
23=23*1; : % variation from 10 to 50 m;
250 = range(50,250,25);
250=250*1; :% variation from 50 to 250 kg/s;
973.81=973.81;
3.6883E-4=3.6883E-4;
0.173494=pi*0.47^2/4;
1.479722=250/(973.81*0.173494);
1,836,225.61641 = 1.479722*0.47*973.81/3.6883E-4;
9.089313=-1.8*log((3E-5/0.47/3.7)^1.11+6.9/1,836,225.61641);
0.003026=1/4/9.089313^2;
-631.498209 = -(4*0.003026*23/0.47) * (250^2/2/973.81/0.173494^2);
-219,720.7503 = -9.81*973.81*23;
-220,352.248209 = -631.498209 + -219,720.7503;

Q198: Water at pressure p = 11.98 MPa and average inlet subcooling dT_{subi} = 10.3 K flows in a uniformly heated pipe with inner diameter 11 (mm).

Assuming turbulent convective heat transfer, calculate the inner wall surface temperature at the pipe exit, Twex (K), knowing that the avearge exit water temperature is T_{ex} = 596.15 K, the pipe length is 0.9 (m) and the water mass flux in the pipe is 2,410 (kg/m^2.s).

Neglect pressure changes in the pipe.

Use the Dittus-Boelter correlation.

Ans: mm = 1.e-3;
m = 1;
MPa = 10;
Kelvin = -273.15;
%
% INPUT DATA
%
p = 11.98*MPa; % constant pressure
dTsubi= 10.3; % constant inlet subcooling
Tex = 596.15+Kelvin; % constant exit temperature
di = 10*mm; % changing from 8 to 12 mm
L = 1*m; % changing from 0.5 to 1.0 m
G = 2493.3; % changing from 2400 to 2550 kg/m^2.s
%
% SOLUTION
%
Tsat=324.55; % =XSteam('Tsat_p',p);
Tin = Tsat-dTsubi;
rho=660.39; % =XSteam('rho_pT',p,Tex);

```
iin=1424182; % = XSteam('h_pT',p,Tin)*1000;
iex=1480065; % = XSteam('h_pT',p,Tex)*1000;
A = pi*di^2/4;  % Pipe flow area
U = G/rho;  % Mean flow velocity
my=7.7397e-5; % = XSteam('my_pT',p,Tex); % Dynamic viscosity
Re = rho*U*di/my;  % Reynolds number
tcex=0.50093; % = XSteam('tc_pT',p,Tex); % thermal cond. at ex.
cpex=6678.2; % = XSteam('cp_pT',p,Tex)*1000; % thermal capacity
Pr = cpex*my/tcex;  % Prandtl number
Nu = 0.023*Re**0.8*Pr**0.4;  % Dittus-Boelter correlation
hex = tcex*Nu/di; % heat transfer coeff. at exit
q = (iex-iin)*G*A; % energy balance
q2p = q/(L*pi*di); % heat flux
Twex = Tex + q2p/hex; % Found wall temp. (K)
Answer = Twex;
```

Q199: A pipe with outer diameter 0.03 (m), inner diameter 0.019 (m) and length 17 (m) is made of steel with heat thermal conductivity 53 (W/m.K). Water/steam mixture flows inside the pipe and exhaust gases flow outside the pipe. The inner surface temperature of the pipe is 460 (K) and the outside surface temperature is 550 (K).

Calculate the heat flux q_{2p} (W/m^2) from exhaust gases to the pipe wall outer surface.

Find thermal resistance

$$R_{th} = \frac{\log \frac{D_{out}}{D_{in}}}{(2 \cdot \pi \cdot L \cdot H_{con})}$$

Find heat flow rate

$$q = \frac{(T_{out} - T_{in})}{R_{th}}$$

Find heat flux on the outer surface

$$q_{2p} = \frac{q}{(\pi \cdot D_{out} \cdot L)}$$

Ans:

Q200: A plane wall with thickness 29 (m) and area 17 (m^2) is made of material with heat thermal conductivity 1.4 (W/m.K). The air on one side of the wall has temperature 290 (K) and heat transfer coefficient from the air to the wall surface is 4 (W/m^2 K). On the other side of the wall there is an insulation layer with thickness 0.25 (m) made of styrofoam with thermal conductivity 0.05 (W/m.K). The air temperature outside the insulated wall is 255(K) and the heat transfer coefficient is 15 (W/m^2 K).

Calculate the temperature T_{cs} (K) of the contact surface between the wall and the insulation.

Find thermal resistance

$$R_{th} = \frac{(\frac{1.0}{h_1} + \frac{L}{H_{con}} + \frac{L_{ins}}{H_{cins}} + \frac{1.0}{h_2})}{A}$$

Find heat flow rate

$$q = \frac{(T_1 - T_2)}{R_{th}}$$

Find heat flux

$$q_{2p} = \frac{q}{A}$$

Find the temperature at the contact surface

$$T_{cs} = T_1 - \frac{q_{2p}}{h_1} - q_{2p} * \frac{L}{H_{con}}$$

Ans:

Q201: A copper pipe with outer diameter 6 (mm) and wall thickness 1.8 (mm) contains flowing hot water with temperature 355 (K). The pipe is insulated with material that has thermal conductivity 0.06 W/(m.K). The inner heat transfer coefficient is 525 W/(m^2.K) and the outer heat transfer coefficient (the same for uninsulated and insulated pipe) is 5 W/(m^2.K).
Ambient temperature is 265 (K).

Calculate the change of heat loss from the pipe per unit length q (W/m) when an uninsulated copper pipe is covered with an insulation layer that has the critical thickness.
Note that this change should be negative if the loss increases for insulated pipe ($q_{changeofheatloss}$qchangeofheatloss = $q_{uninsulated}$quninsulated - $q_{insulated}$qinsulated).
Copper thermal conductivity is 400 W/(m.K).

Ans: -5.387164

Q202: A plane wall with thickness 2.4 (m) and area 20 (m^2) is made of material with heat thermal conductivity 1.5 (W/m.K). The air on one side of the wall has temperature 295 (K) and heat transfer coefficient from the air to the wall surface is 9 (W/m^2 K). On the other side of the wall there is an insulation layer with thickness 0.25 (m) made of styrofoam with thermal conductivity 0.02 (W/m.K). The air temperature outside the insulated wall is 270(K) and the heat transfer coefficient is 19 (W/m^2 K).

Calculate the rate of heat q (W) transfered through the insulated wall from side (1) to side (2).

Find thermal resistance

$$R_{th} = \frac{(\frac{1.0}{h_1} + \frac{L}{H_{con}} + \frac{L_{ins}}{H_{cins}} + \frac{1.0}{h_2})}{A}$$

Find heat flow rate

$$q = \frac{(T_1 - T_2)}{R_{th}}$$

Ans:

Q203: Water at pressure p = 11.98 MPa and average inlet subcooling dT_{subi} = 10.3 K flows in a uniformly heated pipe with inner diameter 10 (mm).

Calculate the heat flux value q_{2p} (W/m^2) for which the exit quality will be equal to the critical quality, knowing that the water mass flux in the pipe is 2,550 (kg/m^2.s) and the pipe length is 6 (m).

Neglect pressure changes in the pipe.

Use the Levitan-Lantsman correlation for dryout.

Use steam and water saturation properties in the whole pipe.

Water-steam properties:

Saturated temperature of water-steam at 11.98 MPa is 324.55C;

Density of saturated water at 11.98 MPa is 655.5 kg/m^3;

Density of saturated steam at 11.98 MPa is 69.9 kg/m^3;

Viscosity of saturated water at 11.98 MPa is 7.67x10^{-5} Pas;

Viscosity of saturated steam at 11.98 MPa is 2.12x10^{-5} Pas;

Thermal conductivity of saturated water at 11.98 MPa is 0.497 W/(mK);

Thermal conductivity of saturated steam at 11.98 MPa is 0.091 W/(mK);

Specific heat of saturated water at 11.98 MPa is 6804.6 J/(kgK);

Specific heat of saturated steam at 11.98 MPa is 8799.2 J/(kgK);

Specific enthalpy of saturated water at 11.98 MPa is 1.4905x10^6 J/kg;

Specific enthalpy of saturated steam at 11.98 MPa is 2.6860x10^6 J/kg;

Specific enthalpy of water at 11.98 MPa and 314.25C is 1.4242x10^6 J/kg.

```
Ans: mm = 1.e-3;
m  = 1;
MPa = 10;
kW_m2 = 1e3;
%
% INPUT DATA
%
p    = 11.98*MPa;   %   constant pressure
dTsubi= 10.3;       % constant inlet subcooling
di   = 10*mm;     %  changing from 8 to 12 mm
G    = 2493.3;    %  changing from 2400 to 2550 kg/m^2.s
L    = 7*m;       %  changing from 3 to 6 m
%
% SOLUTION
% Find properties
  Tsat = 324.55; % =XSteam('Tsat_p',p);
  Tin  = Tsat - dTsubi;
  IV   = 2686017; % =XSteam('hV_p',p)*1000;
  IL   = 1490517; % =XSteam('hL_p',p)*1000;
  IFG  = IV-IL;
  IIN  = 1424182; % =XSteam('h_pT',p,Tin)*1000;
% Flow area
  A = pi*di^2/4;
%
  P = p/98;
  xcr = (0.39+P*(1.57+P*(-2.04+0.68*P)))*(G/1000)^(-0.5);
  if (di ~= 0.008)
    xcr = xcr*(0.008/di)^0.15;
  endif
  IEX = IL + xcr*IFG;
  q = G*A*(IEX-IIN);
  q2p = q/(L*pi*di);

  Answer = q2p;
```

Q204: A plane wall with thickness 1 (m) and area 13 (m²) is made of material with heat thermal conductivity 2 (W/m.K). The air on one side of the wall has temperature 296 (K) and heat transfer coefficient from the air to the wall surface is 3 (W/m² K). On the other side of the wall the air temperature is 270(K) and the heat transfer coefficient is 19 (W/m² K).

Calculate the wall surface temperature T_{s1}(K) on side 1 (facing air with temperature T_1).

Ans:

Find thermal resistance

$$R_{th} = \frac{\left(\frac{1.0}{h_1} + \frac{L}{H_{con}} + \frac{1.0}{h_2}\right)}{A}$$

Find heat flow rate

$$q = \frac{(T_1 - T_2)}{R_{th}}$$

Find heat flux

$$q_{2p} = \frac{q}{A}$$

Wall surface temperature on side 1

$$T_{s1} = T_1 - \frac{q_{2p}}{h1}$$

Q205: A plane wall with thickness 1.5 (m) and area 12 (m²) is made of material with heat thermal conductivity 1.6 (W/m.K). The air on one side of the wall has temperature 295 (K) and heat transfer coefficient from the air to the wall surface is 10 (W/m² K). On the other side of the wall the air temperature is 250(K) and the heat transfer coefficient is 15 (W/m² K).

Calculate the rate of heat q (W) transfered through the wall from side (1) to side (2).

Find thermal resistance

$$R_{th} = \frac{\left(\frac{1.0}{h_1} + \frac{L}{H_{con}} + \frac{1.0}{h_2}\right)}{A}$$

Find heat flow rate

$$q = \frac{(T_1 - T_2)}{R_{th}}$$

Ans:

Q206: Water at pressure p = 11.98 MPa and average inlet subcooling dT_{subi} = 10.3 K flows in a uniformly heated pipe with inner diameter 11 (mm).

Calculate the critical heat flux value q_{2pcr} (W/m²) at distance 2 (m) from the inlet knowing that the water mass flux in the pipe is 2,525 (kg/m².s) and the heat flux is 365 (kW/m²).

Neglect pressure changes in the pipe.

Use the Levitan-Lantsman correlation for DNB.

Use steam and water saturation properties in the whole pipe.

Water-steam properties:
Saturated temperature of water-steam at 11.98 MPa is 324.55C;
Density of saturated water at 11.98 MPa is 655.5 kg/m^3;
Density of saturated steam at 11.98 MPa is 69.9 kg/m^3;
Viscosity of saturated water at 11.98 MPa is 7.67x10^{-5} Pas;
Viscosity of saturated steam at 11.98 MPa is 2.12x10^{-5} Pas;
Thermal conductivity of saturated water at 11.98 MPa is 0.497 W/(mK);
Thermal conductivity of saturated steam at 11.98 MPa is 0.091 W/(mK);
Specific heat of saturated water at 11.98 MPa is 6804.6 J/(kgK);
Specific heat of saturated steam at 11.98 MPa is 8799.2 J/(kgK);
Specific enthalpy of saturated water at 11.98 MPa is 1.4905x10^6 J/kg;
Specific enthalpy of saturated steam at 11.98 MPa is 2.6860x10^6 J/kg;
Specific enthalpy of water at 11.98 MPa and 314.25C is 1.4242x10^6 J/kg.

Ans:
```
mm = 1.e-3;
m  = 1;
MPa = 10;
kW_m2 = 1e3;
%
% INPUT DATA
%
p    = 11.98*MPa;   %   constant pressure
dTsubi= 10.3;       % constant inlet subcooling
di   = 10*mm;     %  changing from 7 to 12 mm
G    = 2493.3;    %  changing from 2400 to 2550 kg/m^2.s
L    = 3*m;       %  changing from 1 to 4 m
q2p  = 350*kW_m2; %  changing from 320 to 370 kW/m^2
%
% SOLUTION
% Find properties
  Tsat = 324.55; % =XSteam('Tsat_p',p);
  Tin  = Tsat - dTsubi;
  IV   = 2686017; % =XSteam('hV_p',p)*1000;
  IL   = 1490517; % =XSteam('hL_p',p)*1000;
  IFG  = IV-IL;
  IIN  = 1424182; % =XSteam('h_pT',p,Tin)*1000;
% Energy balance
  A = pi*di^2/4;
  ILOC = IIN + q2p*L*pi*di/G/A;
  x = (ILOC-IL)/IFG;
%
  P = p/98;
  ex = 1.2*((P-1)/4.-x);
  q2pcr = (10.3+P*(-7.8+1.6*P))*(G/1000)^(ex)*exp(-1.5*x);
  if (di ~= 0.008)
    q2pcr = q2pcr*sqrt(0.008/di);
  endif
  Answer = q2pcr*1e6;
```

Q207: Water at pressure p = 11.98 MPa and average inlet subcooling dT_{subi} = 10.3 K flows in a uniformly heated pipe with inner diameter 10 (mm).

Calculate the wall temperature at inner surface T_w (K) at distance 3 (m) from the inlet, knowing that the heat flux is 345 (kW/m^2) and the water mass flux in the pipe is 2,475 (kg/m^2.s).
Neglect pressure changes in the pipe.

Use the Chen correlation for convective boiling heat transfer. Use the following approximation to calculate saturated pressure ps (bar) as a function of the wall temperature Tw (C): ps = 113.37 + 1.5145*(Tw - 320.36)

HINT: iterate wall temperature until convergence.

Ans:
```
mm = 1.e-3;
m  = 1;
MPa = 10;
kW_m2 = 1e3;
%
% INPUT DATA
%
p    = 11.98*MPa;   %   constant pressure
dTsubi= 10.3;       % constant inlet subcooling
di   = 10*mm;     %  changing from 8 to 12 mm
q2p  = 348*kW_m2; %  changing from 330 to 360 kW/m^2
G    = 2493.3;    %  changing from 2400 to 2550 kg/m^2.s
L    = 5*m;       %  changing from 3 to 6 m
%
% SOLUTION
% Find properties
  Tsat = 3.245506605846990e+02;  %XSteam('Tsat_p',p);
  Tin  = Tsat - dTsubi;
  RHOL = 6.555002172822931e+02;  %XSteam('rhoL_p',p);
  RHOV = 69.925776024162350;     %XSteam('rhoV_p',p);
  VISL = 7.666935902283314e-05;  %XSteam('my_pT',p,Tsat-0.01);
  VISV = 2.117364057284995e-05;  %XSteam('my_pT',p,Tsat+0.01);
  CPL  = 6.804592996635221e+03;  %XSteam('cpL_p',p)*1000;
  CONL = 0.496816348037341;      %XSteam('tcL_p',p);
  CONV = 0.090794755477667;      %XSteam('tcV_p',p);
  SIG  = 0.008871693100245;      %XSteam('st_p',p);
  IV   = 2.686016748218022e+06;  %XSteam('hV_p',p)*1000;
  IL   = 1.490516858836635e+06;  %XSteam('hL_p',p)*1000;
  IFG  = IV-IL;
  IIN  = 1.424181972369010e+06;  %XSteam('h_pT',p,Tin)*1000;
% Energy balance
  A = pi*di^2/4;
  ILOC = IIN + q2p*L*pi*di/G/A;
  x = (ILOC-IL)/IFG;
%
  DTguess = 5;
  eps = 100;
  Xtt = ((1-x)/x)^0.9*(RHOV/RHOL)^0.5*(VISL/VISV)^0.1;
  Rel = G*(1-x)*di/VISL;
  if 1/Xtt <= 0.1
    F = 1;
  else
    F = 2.35*(0.213+1/Xtt)^0.736;
  end
  S = 1/(1+2.56e-6*F^1.463*Rel^1.17);
  Prl = CPL*VISL/CONL;
  hmac = 0.023*CONL*Rel^0.8*Prl^0.4*F/di;
  iter = 1;
  ConstHmic = 0.00122*CONL^0.79*CPL^0.45*RHOL^0.49*S/SIG^0.5/VISL^0.29/IFG^0.24/RHOV^0.24;
  while iter <=100 & eps>=0.01
    DTsup = DTguess;
    Tw   = Tsat + DTsup;
%    PsTw = XSteam('psat_T',Tw);  % exact
    PsTw = 113.37 + 1.5145*(Tw - 320.36); % Approximation
    hmic = ConstHmic*DTsup^(0.24)*((PsTw-p)*1e5)^(0.75);
    htc = hmic + hmac;
```

```
  DTnew = q2p/htc;
  DTguess = 0.85*DTnew + 0.15*DTsup;
  eps = abs(DTnew-DTsup);
  iter= iter+1;
end
Answer = Tsat + DTguess + 273.15;  % wall temperature (K)
```

Q208: Water at pressure p = 11.98 MPa and average inlet subcooling dT_{subi} = 10.3 K flows in a uniformly heated pipe with inner diameter 8 (mm).

Calculate the distance from the inlet to the ONB point, zONB (m) knowing that the heat flux is 360 (kW/m^2) and the water mass flux in the pipe is 2,475 (kg/m^2.s).
Neglect pressure changes in the pipe and, use all water properties as at inlet.
Use the Dittus-Boelter and the Thom et al. correlations.

Water-steam properties:
Saturated temperature of water-steam at 11.98 MPa is 324.55C;
Density of water at 11.98 MPa and 314.25C is 685.38 kg/m^3;
Viscosity of water at 11.98 MPa and 314.25C is 8.13x10^{-5} Pas;
Thermal conductivity of water at 11.98 MPa and 314.25C is 0.52 W/(mK);
Specific heat of water at 11.98 MPa and 314.25C is 6136 J/(kgK).

Ans: 0.14767

Q209: A pipe with outer diameter 0.034 (m), inner diameter 0.021 (m) and length 29 (m) is made of steel with heat conductivity 38 (W/m.K). Water/steam mixture flows inside the pipe and exhaust gases flow on outside the pipe. The inner surface temperature of the pipe is 480 (K) and the outside wall surface temperature is 570 (K).

Calculate the total heat flow rate q (W) transferred from exhaust gases to the water/steam mixture.

Find thermal resistance

$$R_{th} = \frac{\log \frac{D_{out}}{D_{in}}}{(2 \cdot \pi \cdot L \cdot H_{con})}$$

Find heat flow rate

$$q = \frac{(T_{out} - T_{in})}{R_{th}}$$

Ans:

Q210: Water at pressure p = 2.5 MPa and average inlet temperature T_{in} = 380 K flows in a uniformly heated pipe with inner diameter 140 (mm).

Assuming laminar, convective heat transfer, calculate the inner wall surface temperature at the pipe exit, T_{wex} (K), knowing that the avearge exit water, temperature is T_{ex} = 390 K, the pipe length is 6 (m) and the water mass flow rate in the pipe is 0.05 (kg/s).
Neglect pressure changes in the pipe.

Ans: mm = 1.e-3;
m = 1;

```
MPa = 10;
Kelvin = -273.15;
```

INPUT DATA

```
p    = 2.5*MPa;    %   constant pressure
Tin  = 380+Kelvin; % constant inlet temperature
Tex  = 390+Kelvin; % constant exit temperature
di   = 100*mm;  %    changing from 100 to 150 mm
L    = 8*m;     %    changing from 3 to 8 m
W    = 0.04;    %    changing from 0.04 to 0.06 kg/s
```

SOLUTION

```
iin = XSteam('h_pT',p,Tin)*1000;
iex = XSteam('h_pT',p,Tex)*1000;
my = XSteam('my_pT',p,Tin);
tcex = XSteam('tc_pT',p,Tex); % thermal cond. at ex.
Nu = 4.364;
hex = tcex*Nu/di; % heat transfer coeff. at exit
q = (iex-iin)*W;

q2p = q/(L*pi*di); % heat flux
Twex = Tex + q2p/hex; % Found wall temp. (K)
Answer = Twex;
```

Q211: A pipeline with outer wall diameter 200 (mm), wall thickness 17 (mm) and length 55 (m) is made of material with thermal conductivity 50 (W/(m.K)). The pipeline is insulated with a layer with thickness 10 (cm) and thermal conductivity 0.08 (W/(m.K)). A fluid with mean temperature 660 (K) flows inside the pipeline and heat transfer coefficient on the inside is 525 (W/(m^2.K)). The air temperature outside the pipeline is 270 (K) and the heat transfer coefficient is 12 (W/(m^2.K)).

Calculate the total thermal losses q_{loss} (W) of the pipeline.

Ans: Find thermal resistance

```
ri = d/2 - wth;                  % inner pipe wall radius
rwo= d/2;                        % outer pipe wall radius
ro = rwo + ith;                  % outer insulation radius
Rthi = 1.0/hi/ri;                % inner resistance
Rthw = log(rwo/ri)/wthc;         % wall resistance
Rthil = log(ro/rwo)/ithc;        % insulation resistance
Rtho = 1.0/ho/ro;                % outer resistance
Rth = (Rthi+Rthw+Rthil+Rtho)/(2*pi*L);
```

Find heat flow rate (loss)

```
q = (Tfi-Tfo)/Rth;
```

Q212: A pipe with outer diameter 0.035 (m), inner diameter 0.02 (m) and length 20 (m) is made of steel with heat thermal conductivity 51 (W/m.K). Water/steam mixture flows inside the pipe and exhaust gases flow outside the pipe. The inner surface temperature of the pipe is 455 (K) and the outside surface temperature is 565 (K).

Calculate the heat flux q_{2p} (W/m^2) to water/steam mixture from the pipe wall inner surface.

Find thermal resistance

$$R_{th} = \frac{\log \frac{D_{out}}{D_{in}}}{(2 \cdot \pi \cdot L \cdot H_{con})}$$

Find heat flow rate

$$q = \frac{(T_{out} - T_{in})}{R_{th}}$$

Find heat flux on the inner surface

$$q_{2p} = \frac{q}{(\pi \cdot D_{in} \cdot L)}$$

Ans: