Seat Number

King Mongkut's University of Technology Thonburi
1st semester Midterm, academic year 2014

ChE 241 Thermodynamics 1 — Sophomore, Dept. of Chem. Eng.
September 29, 2014 — 9.00 am. - 12.00 pm.

Instruction

a) This examination paper has 13 pages and 5 problems.
b) Answer the questions in the space provided. If you run out of space for an answer, continue on the back of the page.
c) Lecture notes and textbooks are not permitted.
d) A calculator must be complied with the university regulation.
e) Do not take the examination out of the examination room.
f) Ask for permission to leave the examination room when finish.
g) Turn in neat, step-by-step solutions with enough explanation for someone else to follow what you have done.

Highest punishment for dishonesty is the expulsion from the university

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Problem No.	1	2	3	4	5	Total
Student's score						
Full score	15	30	15	20	20	100

The examination is written by

Assoc. Prof. Dr.Anawat Sungpet
(Tel. 9222 ext. 217)

This examination has been evaluated
by the department committee.

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(Assoc. Prof. Dr.Piyabutr Wanichpongpan)
(Head of the department)

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Mass balance

$$\frac{dm}{dt} = \sum_{j=1}^{J} \dot{m}_j$$

First law of thermodynamics

$$\frac{d\,(U + E_k + E_p)}{dt} = \sum_{j=1}^{J} \dot{m}_j(\hat{H} + \frac{v^2}{2} + gy) + \dot{Q} - \dot{W} \;:\; where\ \hat{H} = \hat{U} + P\hat{V}$$

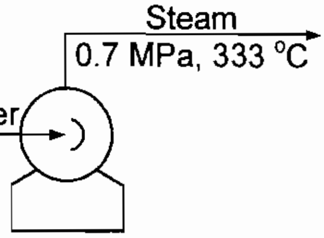
Entropy balance equation

$$\frac{dS}{dt} = \sum_{j=1}^{J} \dot{m}_j\,\hat{S}_j + \frac{\dot{Q}}{T} + \dot{S}_P$$

Problem 1 (15 points)

An inlet of a boiler is subcooled water at 0.1 MPa and 63 °C. The diameters of the inlet and outlet pipes are the same, 0.3636 m. The water flow rate is 5,000 kg/h. The steam produced is at 0.7 MPa and 333 °C. Determine the required heat rate for producing such steam

a) Neglect the change in kinetic energy
b) Include the change in kinetic energy
c) Discuss whether the change in kinetic energy can be omitted



Properties of water for problem 1

0.10 MPa (t_s = 99.606 °C)				
v	ρ	h	s	t, °C
1.012 11	988.03	209.42	0.703 77	**50**
1.014 52	985.69	230.33	0.767 98	**55**
1.017 09	983.20	251.25	0.831 25	**60**
1.019 84	980.55	272.18	0.893 61	**65**
1.022 74	977.76	293.12	0.955 09	**70**

0.70 MPa (t_s = 164.946 °C)				
v	ρ	h	s	t, °C
371.42	2.6924	3059.4	7.2995	**300**
378.33	2.6432	3080.4	7.3357	**310**
385.23	2.5959	3101.3	7.3713	**320**
392.10	2.5504	3122.3	7.4063	**330**
398.95	2.5066	3143.2	7.4407	**340**

$V \equiv$ cm^3/g, $\rho \equiv$ kg/m^3, $h \equiv$ kJ/kg, $s \equiv$ kJ/(kg.K), t_s = temperature at saturation

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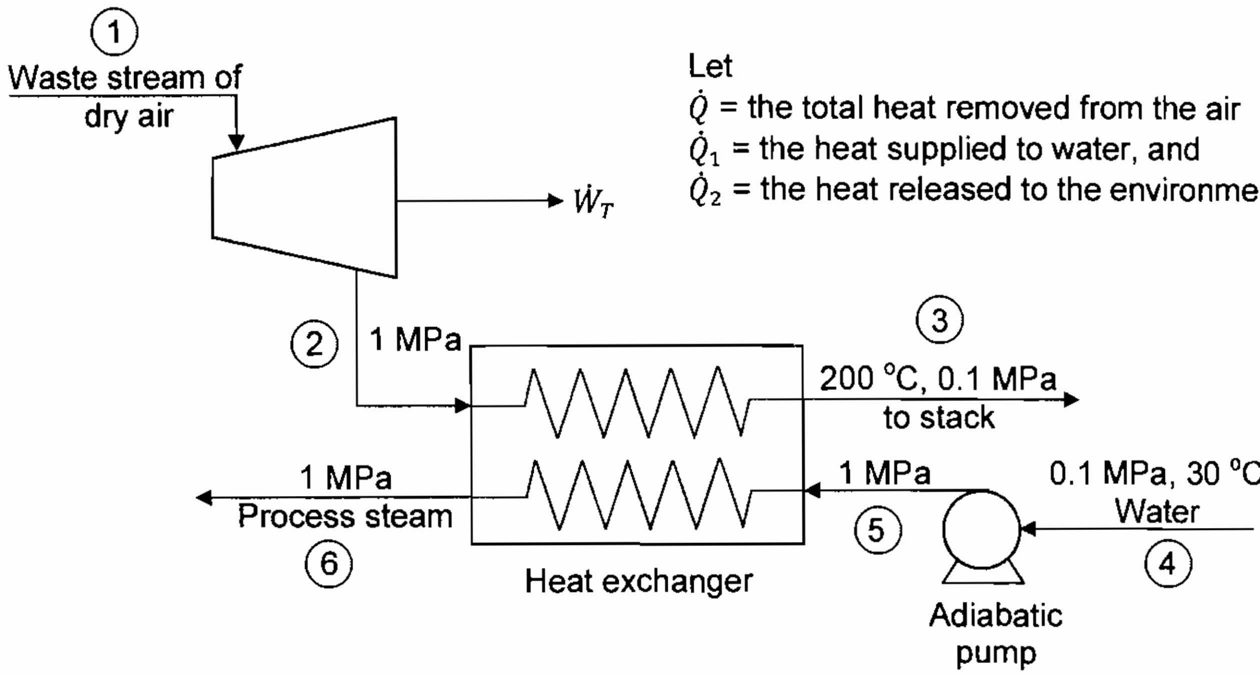
Problem 2 (30 points)

A chemical plant has a waste stream of dry air at 700 °C and 1 MPa, and a flow rate of 1.1×10^4 kg/h. An energy conservation proposal has been made to use this air in a turbine unit and a waste heat boiler to produce electricity and process steam. Efficiency of the turbine is 83.3 %. Only 80 % of the heat removed from the air in the heat exchanger is supplied to water. The rest of heat is released to the environment. The water flow rate is 500 kg/h. By using the properties of water the enthalpy-entropy diagram for dry air, determine

a) The power required by the adiabatic water pump ($\dot{W}_P$)
b) The power generated by the turbine ($\dot{W}_T$)
c) The temperature of the process steam

Let
$\dot{Q}$ = the total heat removed from the air
$\dot{Q}_1$ = the heat supplied to water, and
$\dot{Q}_2$ = the heat released to the environment



Properties of water for problem 2

0.10 MPa (t_s = 99.606 °C)				
v	ρ	h	s	t, °C
1.002 96	997.05	104.92	0.367 20	**25**
1.004 37	995.65	125.82	0.436 73	**30**
1.006 00	994.03	146.72	0.505 10	**35**
1.007 85	992.22	167.62	0.572 37	**40**
1.009 88	990.21	188.51	0.638 58	**45**

1.0 MPa (t_s = 179.878 °C)				
v	ρ	h	s	t, °C
1.127 23	887.13	762.52	2.1381	t_s(L)
194.36	5.1450	2777.1	6.5850	t_s(V)
1.120 63	892.35	741.08	2.0905	**175**
194.44	5.1431	2777.4	6.5857	**180**
197.42	5.0653	2790.7	6.6148	**185**
200.34	4.9916	2803.5	6.6427	**190**
203.20	4.9212	2816.0	6.6695	**195**

$V \equiv$ cm^3/g, $\rho \equiv$ kg/m^3, $h \equiv$ kJ/kg, $s \equiv$ kJ/(kg.K)
t_s = temperature at saturation

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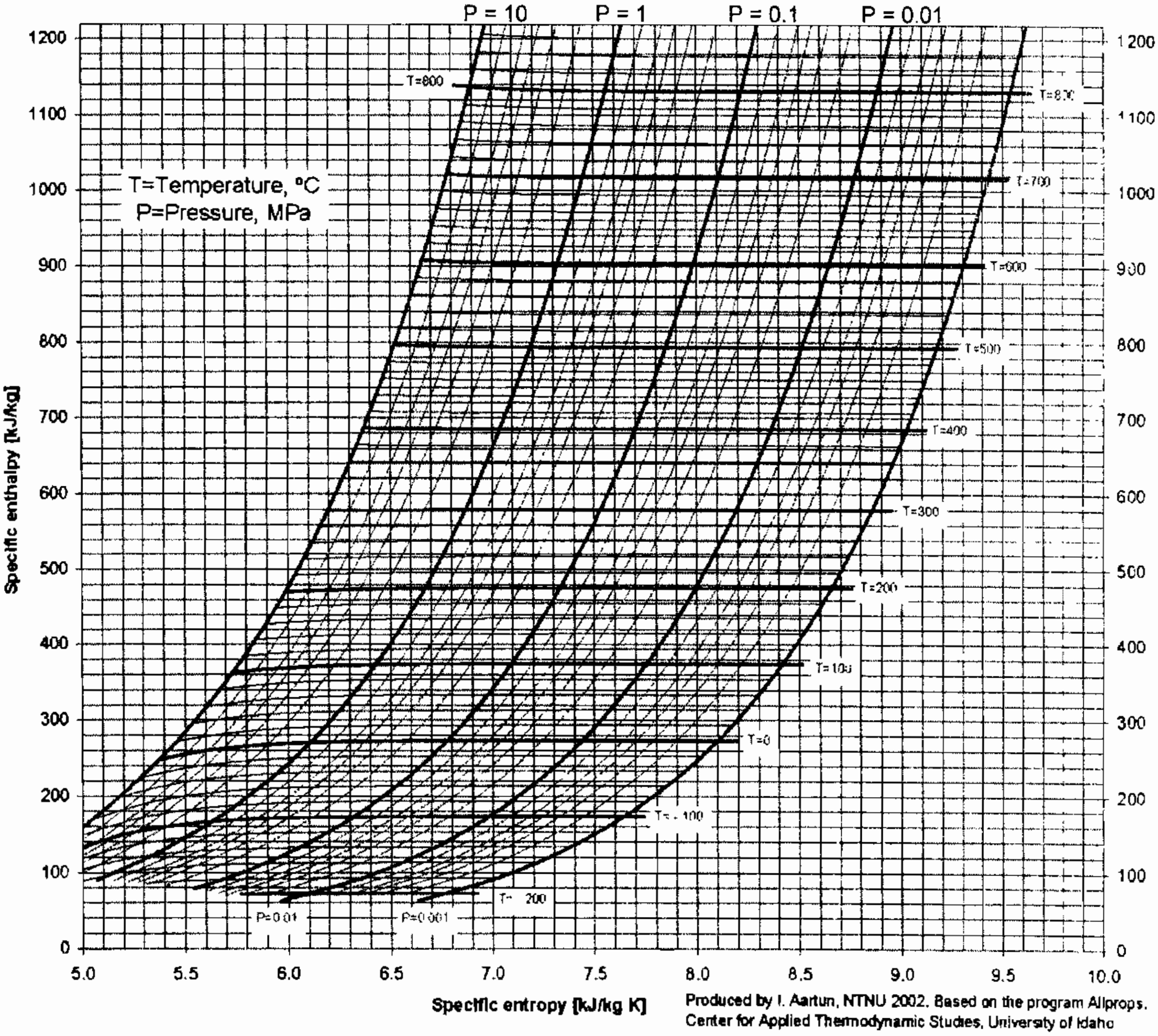

Produced by I. Aartun, NTNU 2002. Based on the program Allprops. Center for Applied Thermodynamic Studies, University of Idaho

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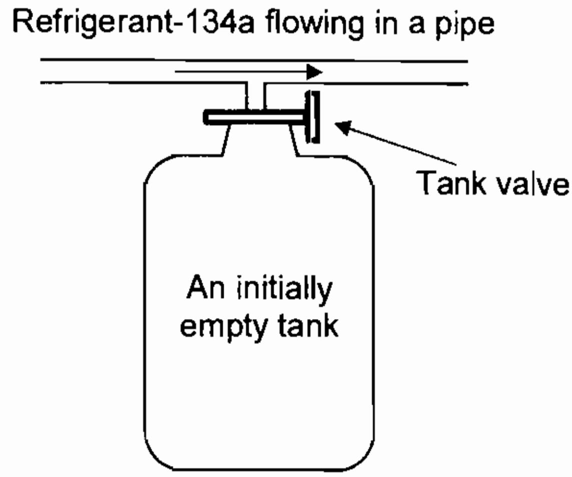
Problem 3 (15 points)
An initially empty tank is filled with refrigerant-134a at 0.5 MPa, 30 °C from a pipe line. The tank valve is closed once the pressure in the tank reaches the pipe line pressure. If the volume of tank is 0.25 m^3, what is the final temperature and the mass of the refrigerant in the tank? The tank is well insulated such that there is no heat transfer.

Superheated refrigerant-134a

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K
	P = 0.50 MPa (T_{sat} = 15.74°C)			
Sat.	0.04086	253.64	256.07	0.9117
20	0.04188	239.40	260.34	0.9264
30	0.04416	248.20	270.28	0.9597
40	0.04633	256.99	280.16	0.9918
50	0.04842	265.83	290.04	1.0229
60	0.05043	274.73	299.95	1.0531
70	0.05240	283.72	309.92	1.0825
80	0.05432	292.80	319.96	1.1114
90	0.05620	302.00	330.10	1.1397
100	0.05805	311.31	340.33	1.1675
110	0.05988	320.74	350.68	1.1949
120	0.06168	330.30	361.14	1.2218
130	0.06347	339.98	371.72	1.2484
140	0.06524	349.79	382.42	1.2746



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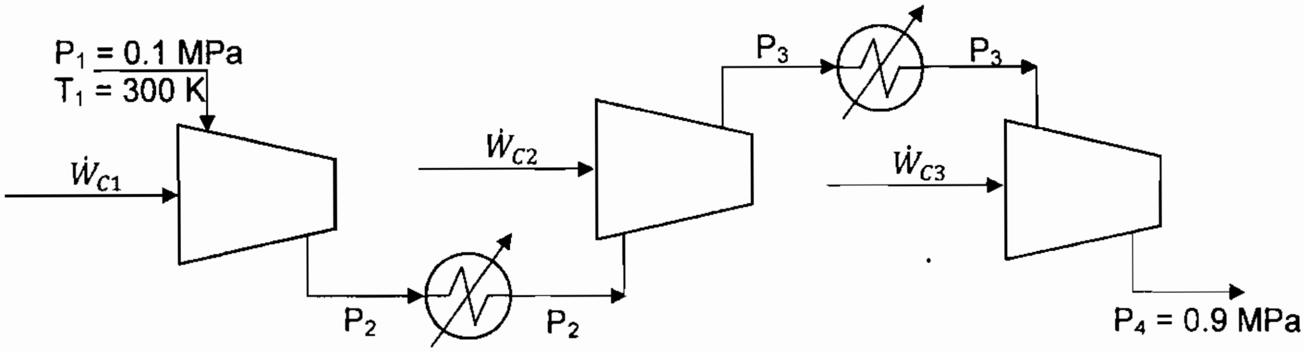
Problem 4 (20 points)
Methane is compressed by ***three*** reversible compressors from an inlet state of 0.1 MPa and 300 K to an exit pressure of 0.9 MPa. Assume that methane is an ideal gas.

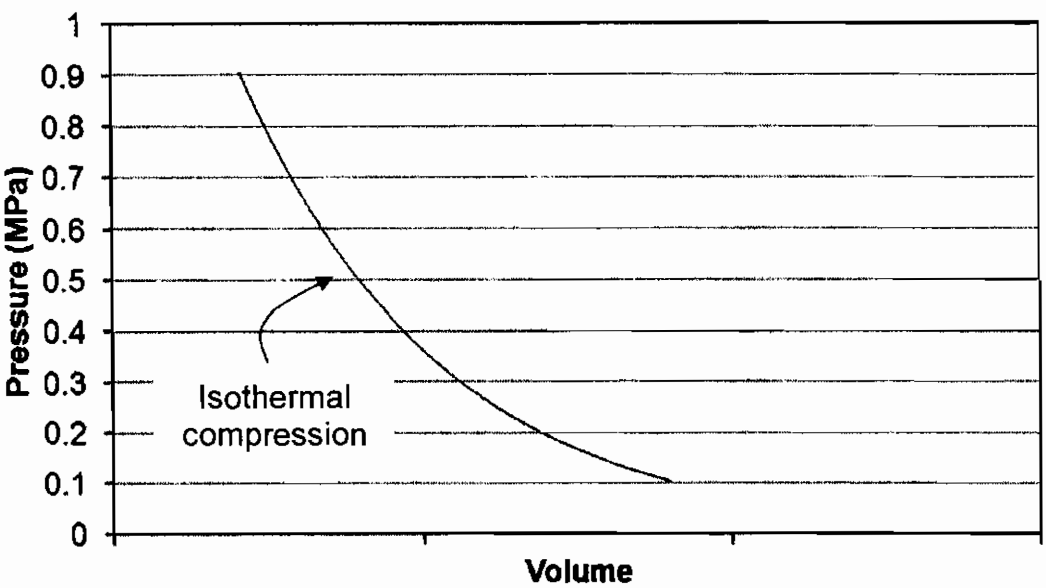


a) Determine the ***minimum*** compressor work per unit mass for the compression with isobaric intercooling with a polytropic exponent of 1.3. Given that the total work required by the polytropic compression is

$$W_{rev} = \frac{nRT_1}{n-1}\left[\left(\frac{P_2}{P_1}\right)^{(n-1)/n} - 1\right] + \frac{nRT_1}{n-1}\left[\left(\frac{P_3}{P_2}\right)^{(n-1)/n} - 1\right] + \frac{nRT_1}{n-1}\left[\left(\frac{P_4}{P_3}\right)^{(n-1)/n} - 1\right]; R = 0.287\ kJ/(kg.K)$$

Note that, to minimize the required work, the pressure ratio across each stage of the compressor must be the same.

b) Sketch the compression process relative to that of the isothermal compression on the given P-V diagram



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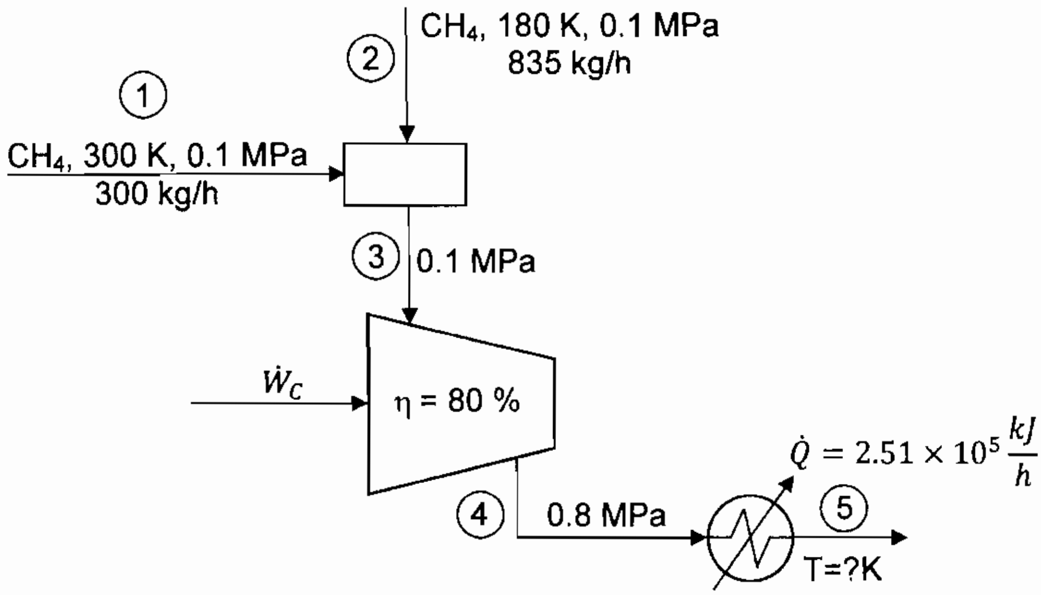
Problem 5 (20 points)

Methane at 300 K and 0.1 MPa is adiabatically mixed with methane at 180 K and 0.1 MPa. After mixing, it is compressed by an adiabatic compressor to 0.8 MPa. Efficiency of the compressor is 80 %. Methane is subsequently cooled by an isobaric cooler, which can remove heat from methane at a rate of 2.51×10^5 kJ/h. By using thermodynamic properties of methane diagram, determine the temperature of methane at the cooler exit?



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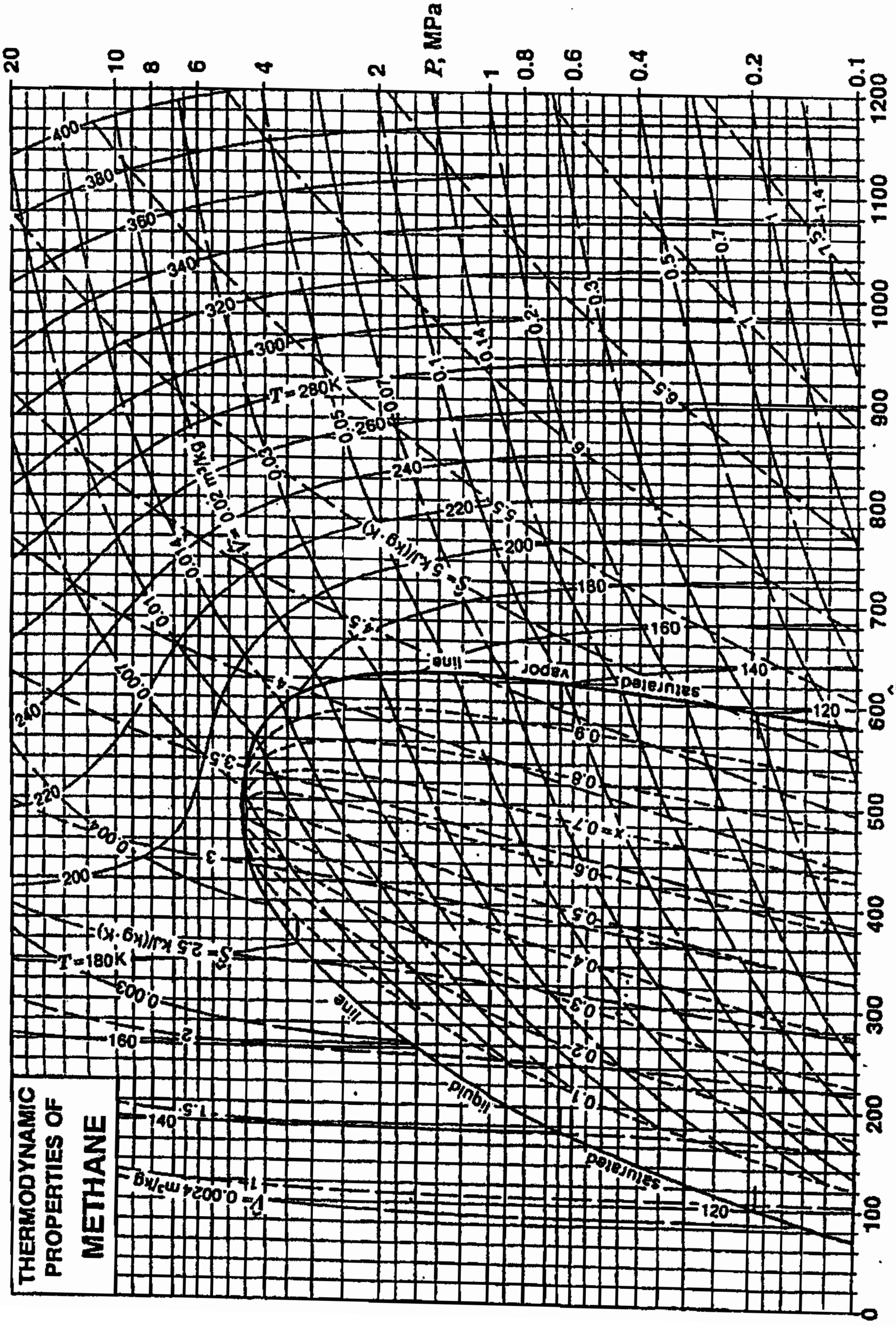

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