The University of Melbourne

School of Engineering

Semester 2 Assessment 2011

ENGR30001 – Fluid Mechanics & Thermodynamics

Exam Duration: 3 hours

This paper has FOURTEEN (14) pages consisting of SEVEN (7) questions.

Authorized material:
Electronic calculators approved by the School of Engineering may be used.
Three tables, one chart and a table of formulae are attached.

Instructions to Invigilators:
Script books to be provided.

Instructions to Students:
All questions are to be attempted.
Full marks will be awarded for obtaining 100 marks of a potential 110 marks

THIS PAPER MUST NOT BE REMOVED FROM THE EXAMINATION ROOM

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Question 1

Perform the following using the attached steam tables as required.

i) Sketch a T - v diagram for H_20 showing the liquid, saturation and superheated regions and at least one isobar passing through each of these regions. Also indicate the region where the steam is most likely to behave like a perfect gas.

(3 marks)

ii) A sealed canister of strongly superheated H_20 initially has a specific volume of 2.536 m^3/kg and temperature of 600°C. The canister is then allowed to cool to 20°C. With reference to a $T - v$ diagram, describe the changes in state that will take place (if any) during the cooling and determine the temperature the changes will occur at.

(3 marks)

iii) Determine the final specific internal energy of the H_20 in part ii).

(2 marks)

iv) A steam power plant has a boiler that produces superheated steam at 400°C and 1 MPa. Determine the specific enthalpy.

(1 mark)

v) The steam is then passed through a turbine that extracts 550 kJ/kg of energy from the H_20 (note that this is an adiabatic process; ignore any velocity changes) and reduces the working fluid pressure to 0.1 MPa. In what state is the H_20 after leaving the turbine?

(1 mark)

vi) Would your answer to part v) change if the H_20 exit pressure from the turbine were 0.5 MPa? If so, what would be the state of the H_20?

(1 mark)

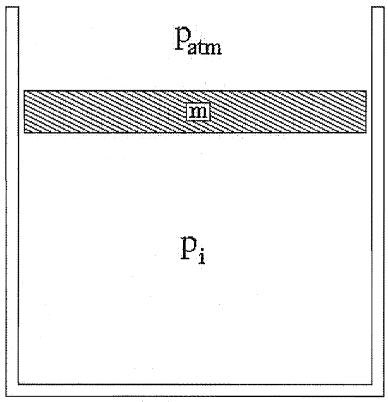
(Total for Question 1 = 11 marks)

Question 2

i) Define the four types of systems considered in Thermodynamics. **(2 marks)**

ii) Calculate the density of air at a gauge pressure of 100 kPa and temperature of 77.5°C. $R = 287$ J/kg K for air. **(1 mark)**

For the remaining questions, consider a cylinder of air capped by a leakproof, frictionless piston of mass, $m = 1$ kg, shown below. The cross-sectional area of the piston and cylinder is $A = 0.005$ m^2. The initial height of the piston above the internal base of the cylinder is $H = 0.1$ m.



iii) The internal pressure is initially p_i and the atmospheric pressure $p_{atm} = 101.3$ kPa. Determine the gauge pressure p_{ig} required to keep the mass from falling.

(2 marks)

iv) The density of the air is initially $\rho = 1.2$ kg/m^3. The temperature of the air is then raised by adding heat to the air. This causes the piston to rise by 0.01 m. The heat is added in such a way that the pressure rises linearly with volume. Sketch a graph of pressure versus volume and show a representation of the work done by the fluid, the work done on the atmosphere and the work done on the mass (it is recommended that you use three separate *p-v* diagrams; assume that the pressure is atmospheric if the volume of gas is zero). **(3 marks)**

v) Determine the work done by the fluid. **(2 marks)**

vi) Determine the heat transfer required to raise the piston. $C_v = 717$ J/kg K for air.

(2 marks)

(Total for Question 2 = 12 marks)

Question 3

i) Sketch a T - s property diagram illustrating the Carnot cycle using H_2O as the working fluid.

(1 mark)

ii) Sketch the Rankine cycle and explain why this cycle is used instead of the Carnot cycle for practical power generation.

(3 marks)

iii) Derive the thermal efficiency of an ideal steam power plant (i.e., using the Rankine cycle) in terms of the specific enthalpy changes. Neglect feed pump work.

(3 marks)

iv) Consider a steam power plant operating between maximum temperature of 773K and minimum temperature of 299K (dry saturated). If the maximum pressure is 4 MPa, calculate the specific work done by the isentropic turbine using the tables supplied. (Hint: the maximum and minimum temperatures are the turbine inlet and outlet temperatures, respectively).

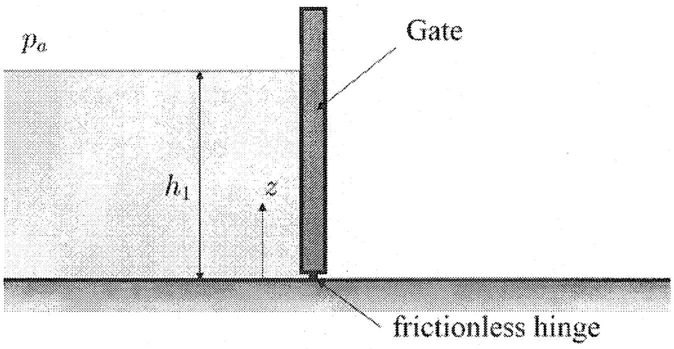
(3 marks)

v) Recalculate the specific work done by the turbine if the steam entering and exiting the turbine is assumed to be a perfect gas with C_p = 4.46 kJ/kg K (i.e., without reference to the steam tables). In one sentence explain why this calculation is inaccurate (compared with the more accurate calculation in part iv).

(2 marks)

(Total for Question 3 = 12 marks)

Question 4



A vertical gate of width w (into the page) forms the sidewall of a tank of liquid of depth h_1 and density ρ_1.

(a) Assume that the gate pivots at the bottom at a frictionless hinge. Integrate the distributed hydrostatic pressure force acting over the wetted surface of the gate to show that the net force acting on the gate is,

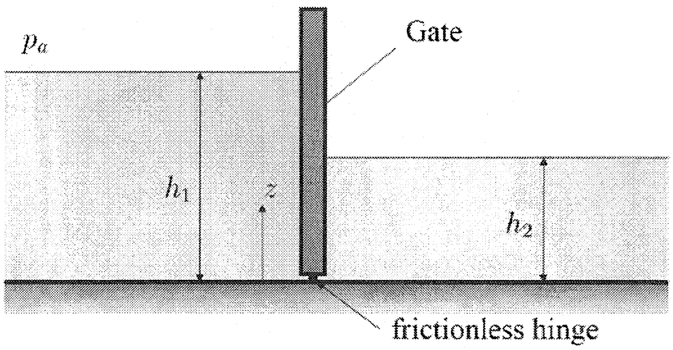
$$F_1 = \frac{\rho_1 g w h_1^2}{2}$$ **(4 marks)**

(b) Integrate the moment due to hydrostatic pressure forces at height z, to show that the total moment acting about the gate hinge is given by,

$$M_1 = \frac{\rho_1 g w h_1^3}{6}$$ **(4 marks)**

(c) State the vertical location $\hat{z}$ at which the resultant force F_1 can be considered to act.

(2 marks)

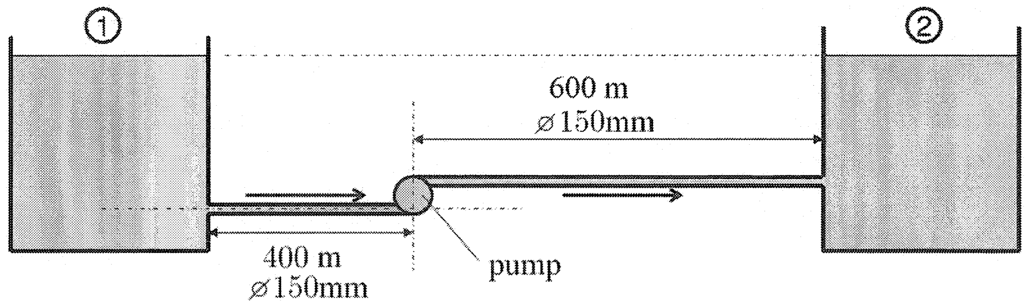


(d) The other side of the gate is filled to depth h_2 with a liquid of density ρ_2. Find an expression for the necessary ratio h_1/h_2 (in terms of ρ_1 and ρ_2) if the gate is to remain vertical. **(3 marks)**

(Total for Question 4 = 13 marks)

Question 5

Properties for oil at 15°C
$\rho = 850$ kg/m^3



Oil at 15°C having a density of 850 kg/m^3 is pumped between two large reservoirs (both of which are open to atmosphere and filled to the same height) through a pipe that has a total length L =1 km and diameter 150 mm. The volume flow rate through the system is 1.2 m^3/min. The mechanical brake power supplied to the pump is P_B = 4kW and the mechanical efficiency of the pump is $\eta = 0.65$.

(a) Assume that the Fanning friction factor for this flow is given by the analytical relationship,

$$f = \frac{16}{\text{Re}}$$

Starting from the Steady Flow Energy Equation, and ignoring minor losses, show that the viscosity of the oil can be determined from the following relationship,

$$\mu = \frac{\eta P_B}{8\pi V^2 L}$$

(8 marks)

(b) Hence calculate the Reynolds number and comment on whether the assumed relationship for friction factor f is valid for this problem.

(4 marks)

(Question 5 continues on next page)

Question 5 (continued)

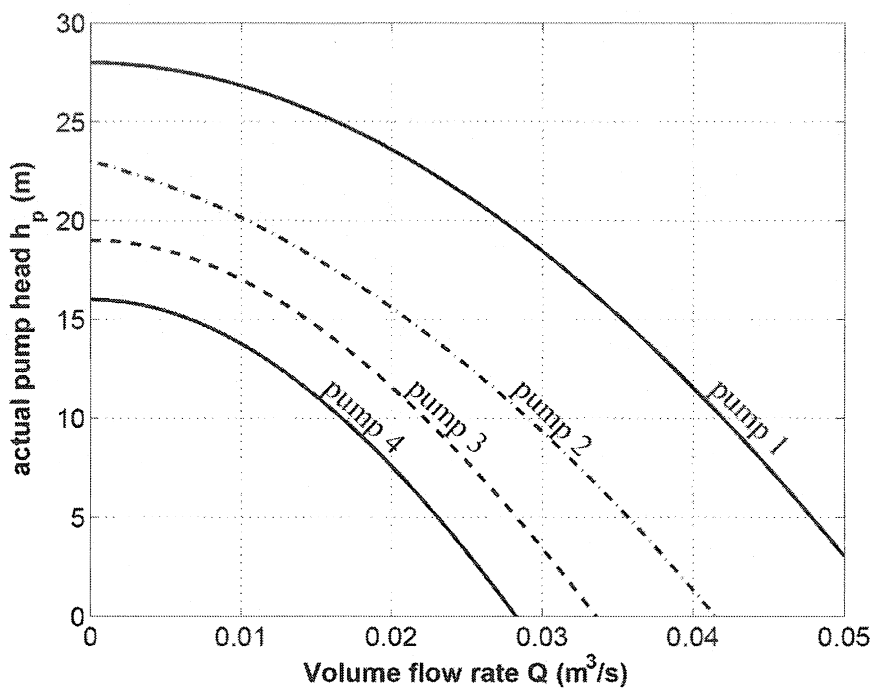
(c) For the system shown there would in fact be additional minor energy losses due to the sudden contraction at the inlet from reservoir 1, and the sudden expansion into reservoir 2. Estimate the percentage error in the calculated estimate of viscosity from part (a).

Minor Loss	Loss coefficient
Inlet loss	0.5
Exit loss	1.0

(5 marks)

(d) The actual pump head vs volume flow rate curves are provided by the manufacturer for a range of pumps as given in the figure below. Of the four pumps shown, which pump is being used in this system?

(5 marks)



(Total for Question = 22 marks)

Question 6

Nitrogen gas flows isothermally at 50 °C through a straight pipe of length 20m and uniform diameter 100 mm. The inlet pressure is 700kPa and the pressure outside the pipe exit is 300kPa. The flow is assumed to be horizontal, isothermal, ideal, and compressible. The Fanning friction factor is $f = 0.005$

The mechanical energy equation for this flow is

$$\frac{P_2^2 - P_1^2}{2(RT/M)} + \left(\frac{G}{A}\right)^2 \ln\left(\frac{P_1}{P_2}\right) + \frac{2fL}{D}\left(\frac{G}{A}\right)^2 = 0$$

and the critical pressure P_w is given by

$$\left(\frac{P_1}{P_w}\right)^2 - \ln\left(\frac{P_1}{P_w}\right)^2 - 1 = \frac{4fL}{D}$$

where all symbols have their usual meaning.

(a) Determine whether the flow is choked or not. Give a reason for your conclusion.

(5 marks)

(b) Calculate the mass flow rate of nitrogen through the pipe **(8 marks)**

(c) Calculate the gas velocity at the pipe entrance as a percentage of the sonic velocity

(5 marks)

(d) If the value of the inlet pressure is doubled, would the flow then be choked or not choked? Give a reason for your conclusion.

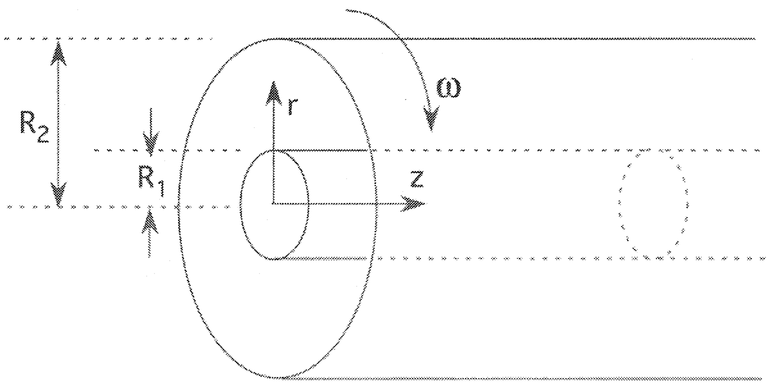
(3 marks)

Molecular weight of nitrogen	28 g/mol
Gas constant R	8.314 J mol^{-1} K^{-1}

(Total for Question 6 = 21 marks)

Question 7

An incompressible viscous Newtonian fluid is located in the space between two concentric cylinders having radii R_1 and R_2 as shown below. The inner cylinder is fixed but the outer cylinder is rotating with an angular velocity ω, thus imparting a swirling motion to the fluid. The fluid is also being driven in the z-direction due to a constant applied pressure gradient $\frac{\partial p}{\partial z} = -B$. The flow is steady, fully developed and axially symmetric.



(a) From the information provided, show that the velocity components v_z and v_θ in cylindrical polar coordinates are functions of r only. Also show that $v_r = 0$

(3 marks)

(b) Find an expression for the axial velocity (v_z) profile. **(8 marks)**

(c) Find an expression for the tangential velocity (v_θ) profile **(8 marks)**

(Total for Question 7 = 19 marks)

(Total for paper = 110 marks)

Table 2, Temperature Saturation

Saturated Water & Steam

Temperatures from 1 to 120 °C

°C	kN/m^2	m^3/kg	m^3/kg	kJ/kg	kJ/kg	kJ/kg	kJ/kg	kJ/kg	kJ/kg K	kJ/kg K	kJ/kg K	°C
T	p	v_f	v_g	u_f	u_g	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g	T
1	0.657	0.001000	192.6	4.174	2376.9	4.174	2499.2	2503.4	0.0153	9.116	9.131	**1**
2	0.705	0.001000	179.9	8.386	2378.3	8.387	2496.8	2505.2	0.0306	9.074	9.105	**2**
4	0.813	0.001000	157.3	16.80	2381.1	16.80	2492.1	2508.9	0.0611	8.992	9.053	**4**
6	0.935	0.001000	137.8	25.21	2383.8	25.21	2487.4	2512.6	0.0913	8.910	9.001	**6**
8	1.072	0.001000	121.0	33.60	2386.6	33.60	2482.6	2516.2	0.1213	8.830	8.951	**8**
10	1.227	0.001000	106.4	41.99	2389.3	41.99	2477.9	2519.9	0.1510	8.751	8.902	**10**
12	1.401	0.001000	93.84	50.38	2392.1	50.38	2473.2	2523.6	0.1805	8.673	8.854	**12**
14	1.597	0.001001	82.90	58.75	2394.8	58.75	2468.5	2527.2	0.2098	8.596	8.806	**14**
16	1.817	0.001001	73.38	67.12	2397.6	67.13	2463.8	2530.9	0.2388	8.521	8.759	**16**
18	2.062	0.001001	65.09	75.49	2400.3	75.50	2459.0	2534.5	0.2677	8.446	8.713	**18**
20	2.337	0.001002	57.84	83.86	2403.0	83.86	2454.3	2538.2	0.2963	8.372	8.668	**20**
22	2.642	0.001002	51.49	92.22	2405.8	92.23	2449.6	2541.8	0.3247	8.299	8.624	**22**
24	2.982	0.001003	45.93	100.6	2408.5	100.6	2444.9	2545.5	0.3530	8.228	8.581	**24**
26	3.360	0.001003	41.03	108.9	2411.2	108.9	2440.2	2549.1	0.3810	8.157	8.538	**26**
28	3.778	0.001004	36.73	117.3	2414.0	117.3	2435.4	2552.7	0.4088	8.087	8.496	**28**
30	4.241	0.001004	32.93	125.7	2416.7	125.7	2430.7	2556.4	0.4365	8.018	8.455	**30**
32	4.753	0.001005	29.57	134.0	2419.4	134.0	2425.9	2560.0	0.4640	7.950	8.414	**32**
34	5.318	0.001006	26.60	142.4	2422.1	142.4	2421.2	2563.6	0.4913	7.883	8.374	**34**
36	5.940	0.001006	23.97	150.7	2424.8	150.7	2416.4	2567.2	0.5184	7.816	8.335	**36**
38	6.624	0.001007	21.63	159.1	2427.5	159.1	2411.7	2570.8	0.5453	7.751	8.296	**38**
40	7.375	0.001008	19.55	167.4	2430.2	167.5	2406.9	2574.4	0.5721	7.686	8.258	**40**
42	8.198	0.001009	17.69	175.8	2432.9	175.8	2402.1	2577.9	0.5987	7.622	8.221	**42**
44	9.100	0.001009	16.04	184.2	2435.6	184.2	2397.3	2581.5	0.6252	7.559	8.184	**44**
46	10.09	0.001010	14.56	192.5	2438.3	192.5	2392.5	2585.1	0.6514	7.497	8.148	**46**
48	11.16	0.001011	13.23	200.9	2440.9	200.9	2387.7	2588.6	0.6776	7.435	8.113	**48**
50	12.34	0.001012	12.05	209.2	2443.6	209.3	2382.9	2592.2	0.7035	7.374	8.078	**50**
52	13.61	0.001013	10.98	217.6	2446.2	217.6	2378.1	2595.7	0.7293	7.314	8.043	**52**
54	15.00	0.001014	10.02	226.0	2448.9	226.0	2373.2	2599.2	0.7550	7.254	8.009	**54**
56	16.51	0.001015	9.159	234.3	2451.5	234.4	2368.4	2602.7	0.7804	7.195	7.976	**56**
58	18.15	0.001016	8.381	242.7	2454.1	242.7	2363.5	2606.2	0.8058	7.137	7.943	**58**
60	19.92	0.001017	7.679	251.1	2456.8	251.1	2358.6	2609.7	0.8310	7.080	7.911	**60**
62	21.84	0.001018	7.044	259.4	2459.4	259.5	2353.7	2613.2	0.8560	7.023	7.879	**62**
64	23.91	0.001019	6.469	267.8	2462.0	267.8	2348.8	2616.6	0.8809	6.967	7.848	**64**
66	26.15	0.001020	5.948	276.2	2464.5	276.2	2343.9	2620.1	0.9057	6.911	7.817	**66**
68	28.56	0.001022	5.476	284.6	2467.1	284.6	2338.9	2623.5	0.9303	6.856	7.786	**68**
70	31.16	0.001023	5.046	292.9	2469.7	293.0	2334.0	2626.9	0.9548	6.802	7.756	**70**
72	33.96	0.001024	4.656	301.3	2472.2	301.4	2329.0	2630.3	0.9792	6.748	7.727	**72**
74	36.96	0.001025	4.300	309.7	2474.8	309.7	2324.0	2633.7	1.003	6.695	7.698	**74**
76	40.19	0.001027	3.976	318.1	2477.3	318.1	2318.9	2637.1	1.027	6.642	7.669	**76**
78	43.65	0.001028	3.680	326.5	2479.8	326.5	2313.9	2640.4	1.051	6.590	7.641	**78**
80	47.36	0.001029	3.409	334.9	2482.3	334.9	2308.8	2643.8	1.075	6.538	7.613	**80**
82	51.33	0.001031	3.162	343.3	2484.8	343.3	2303.8	2647.1	1.099	6.487	7.586	**82**
84	55.57	0.001032	2.935	351.7	2487.3	351.7	2298.6	2650.4	1.123	6.436	7.559	**84**
86	60.11	0.001033	2.727	360.1	2489.7	360.1	2293.5	2653.6	1.146	6.386	7.532	**86**
88	64.95	0.001035	2.536	368.5	2492.2	368.5	2288.4	2656.9	1.169	6.336	7.506	**88**
90	70.11	0.001036	2.361	376.9	2494.6	376.9	2283.2	2660.1	1.193	6.287	7.480	**90**
92	75.61	0.001038	2.200	385.3	2497.0	385.4	2278.0	2663.4	1.216	6.239	7.454	**92**
94	81.46	0.001039	2.052	393.7	2499.4	393.8	2272.8	2666.6	1.239	6.190	7.429	**94**
96	87.69	0.001041	1.915	402.1	2501.8	402.2	2267.5	2669.7	1.261	6.143	7.404	**96**
98	94.30	0.001042	1.789	410.5	2504.1	410.6	2262.2	2672.9	1.284	6.095	7.380	**98**
100	101.3	0.001044	1.673	419.0	2506.5	419.1	2256.9	2676.0	1.307	6.049	7.355	**100**
105	120.8	0.001048	1.419	440.0	2512.3	440.2	2243.6	2683.7	1.363	5.933	7.296	**105**
110	143.3	0.001052	1.210	461.2	2518.0	461.3	2230.0	2691.3	1.418	5.820	7.239	**110**
115	169.1	0.001056	1.036	482.3	2523.5	482.5	2216.2	2698.7	1.473	5.710	7.183	**115**
120	198.5	0.001061	0.892	503.5	2529.0	503.7	2202.2	2706.0	1.528	5.602	7.129	**120**

°C T \ p (MN/m²)	0.001	0.01	0.02	0.05	0.1	0.5	1	2	4	6	8	10	15	20	25	30	35	40	45	50	60	80	100	T
0	0.043	0.052	0.063	0.093	0.144	0.554	1.065	2.086	4.124	6.156	8.183	10.20	15.23	20.22	25.17	30.09	34.97	39.82	44.64	49.43	58.91	77.58	95.97	0
5	21.02	21.03	21.04	21.07	21.12	21.52	22.02	23.02	25.01	27.00	28.98	30.96	35.88	40.76	45.62	50.45	55.24	60.01	64.74	69.45	78.79	97.17	115.3	5
10	2520	42.00	42.01	42.04	42.09	42.48	42.97	43.94	45.89	47.83	49.77	51.71	56.52	61.31	66.07	70.81	75.51	80.19	84.85	89.48	98.66	116.8	134.5	10
20	2539	83.87	83.88	83.91	83.95	84.33	84.80	85.74	87.62	89.49	91.36	93.23	97.88	102.5	107.1	111.7	116.3	120.8	125.4	129.9	138.9	156.6	174.0	20
25	2548	104.8	104.8	104.8	104.9	105.2	105.7	106.6	108.5	110.3	112.1	114.0	118.6	123.1	127.7	132.2	136.7	141.2	145.7	150.2	159.1	176.6	193.9	25
30	2557	125.7	125.7	125.7	125.8	126.1	126.6	127.5	129.3	131.1	132.9	134.7	139.3	143.8	148.3	152.7	157.2	161.6	166.1	170.5	179.3	196.6	213.8	30
40	2576	167.5	167.5	167.5	167.5	167.9	168.3	169.2	171.0	172.7	174.5	176.3	180.7	185.1	189.4	193.8	198.2	202.5	206.8	211.2	219.8	236.9	253.8	40
50	2595	2593	209.3	209.3	209.3	209.7	210.1	211.0	212.7	214.4	216.1	217.8	222.1	226.4	230.7	235.0	239.2	243.5	247.7	251.9	260.4	277.2	293.9	50
60	2613	2612	251.1	251.1	251.2	251.5	251.9	252.7	254.4	256.1	257.8	259.4	263.6	267.8	272.0	276.1	280.3	284.5	288.6	292.8	301.1	317.6	334.0	60
70	2632	2631	2629	293.0	293.0	293.4	293.8	294.6	296.2	297.8	299.5	301.1	305.2	309.3	313.3	317.4	321.5	325.6	329.6	333.7	341.8	358.0	374.2	70
80	2651	2650	2648	334.9	335.0	335.3	335.7	336.5	338.1	339.6	341.2	342.8	346.8	350.8	354.8	358.7	362.7	366.7	370.7	374.7	382.6	398.5	414.4	80
90	2670	2669	2667	2663	377.0	377.3	377.7	378.4	380.0	381.5	383.1	384.6	388.5	392.4	396.2	400.1	404.0	407.9	411.8	415.7	423.5	439.1	454.7	90
100	2689	2688	2686	2683	2676	419.4	419.7	420.5	422.0	423.5	425.0	426.5	430.3	434.0	437.8	441.6	445.4	449.2	453.0	456.8	464.5	479.7	495.1	100
125	2736	2735	2734	2731	2726	525.2	525.5	526.2	527.6	529.0	530.4	531.8	535.3	538.8	542.3	545.8	549.4	552.9	556.5	560.1	567.3	581.7	596.3	125
150	2784	2783	2782	2780	2776	632.2	632.5	633.1	634.3	635.6	636.8	638.1	641.3	644.4	647.7	650.9	654.2	657.4	660.7	664.1	670.7	684.3	698.0	150
175	2832	2831	2831	2829	2826	2800	741.2	741.7	742.8	743.8	744.9	746.0	748.8	751.6	754.4	757.3	760.2	763.1	766.1	769.1	775.2	787.6	800.4	175
200	2880	2880	2879	2878	2875	2855	2827	852.6	853.4	854.2	855.1	855.9	858.1	860.4	862.8	865.2	867.7	870.2	872.8	875.4	880.8	891.9	903.5	200
225	2929	2928	2928	2927	2925	2909	2886	2834	967.3	967.8	968.3	968.9	970.3	971.9	973.6	975.4	977.3	979.3	981.3	983.4	987.9	997.4	1008	225
250	2978	2977	2977	2976	2975	2961	2943	2902	1086	1086	1086	1086	1086	1087	1087	1088	1090	1091	1092	1094	1097	1104	1113	250
275	3027	3027	3027	3026	3024	3013	2998	2965	2886	1211	1210	1209	1208	1207	1206	1206	1206	1206	1206	1207	1208	1213	1220	275
300	3077	3077	3076	3076	3074	3065	3052	3025	2962	2885	2787	1343	1338	1334	1331	1329	1327	1325	1324	1324	1323	1325	1329	300
325	3127	3127	3127	3126	3125	3116	3106	3083	3031	2970	2899	2810	1487	1476	1468	1461	1456	1452	1449	1446	1442	1439	1439	325
350	3177	3177	3177	3177	3176	3168	3159	3139	3095	3046	2990	2926	2695	1647	1625	1610	1599	1590	1582	1576	1567	1556	1550	350
375	3228	3228	3228	3228	3227	3220	3211	3194	3156	3115	3069	3018	2861	2594	1865	1793	1763	1743	1728	1717	1700	1681	1672	375
400	3280	3280	3279	3279	3278	3272	3264	3249	3216	3180	3142	3100	2979	2820	2582	2162	1993	1934	1901	1878	1847	1814	1798	400
425	3331	3331	3331	3331	3330	3325	3317	3303	3274	3243	3209	3174	3075	2957	2808	2613	2374	2209	2121	2068	2009	1952	1924	425
450	3384	3384	3383	3383	3382	3377	3371	3358	3331	3303	3274	3244	3160	3064	2954	2826	2676	2516	2384	2293	2187	2094	2051	450
475	3436	3436	3436	3436	3435	3430	3424	3412	3388	3363	3337	3310	3237	3157	3068	2969	2859	2742	2624	2522	2380	2242	2181	475
500	3489	3489	3489	3489	3488	3484	3478	3467	3445	3422	3399	3375	3311	3241	3166	3085	2998	2907	2814	2723	2571	2397	2316	500
550	3597	3596	3596	3596	3596	3592	3587	3578	3559	3539	3520	3500	3448	3394	3337	3277	3215	3152	3087	3021	2896	2708	2594	550
600	3706	3706	3705	3705	3705	3702	3697	3689	3673	3656	3640	3623	3580	3536	3490	3443	3395	3346	3297	3248	3152	2980	2857	600
650	3816	3816	3816	3816	3816	3813	3809	3802	3788	3774	3759	3745	3708	3671	3633	3595	3556	3517	3478	3439	3362	3220	3105	650
700	3929	3929	3929	3929	3928	3926	3923	3916	3904	3892	3879	3867	3835	3804	3772	3740	3707	3675	3642	3610	3547	3429	3324	700
750	4043	4043	4043	4043	4042	4040	4038	4032	4021	4011	4000	3989	3962	3935	3908	3880	3853	3825	3798	3771	3717	3617	3526	750
800	4159	4159	4159	4159	4158	4156	4154	4149	4140	4131	4121	4112	4089	4065	4042	4018	3995	3972	3948	3925	3880	3793	3714	800
T_{sat}	6.98	45.83	60.09	81.35	99.63	151.8	179.9	212.4	250.3	275.5	295.0	311.0	342.1	365.7										
h_f	29.34	191.8	251.5	340.6	417.5	640.1	762.6	908.6	1087	1214	1317	1408	1611	1826										
h_g	2514	2585	2610	2646	2675	2748	2776	2797	2800	2785	2760	2728	2615	2418										

Specific Enthalpy of Water & Steam   kJ/kg

Table 4, Enthalpy

p (MN/m^2), T (°C)

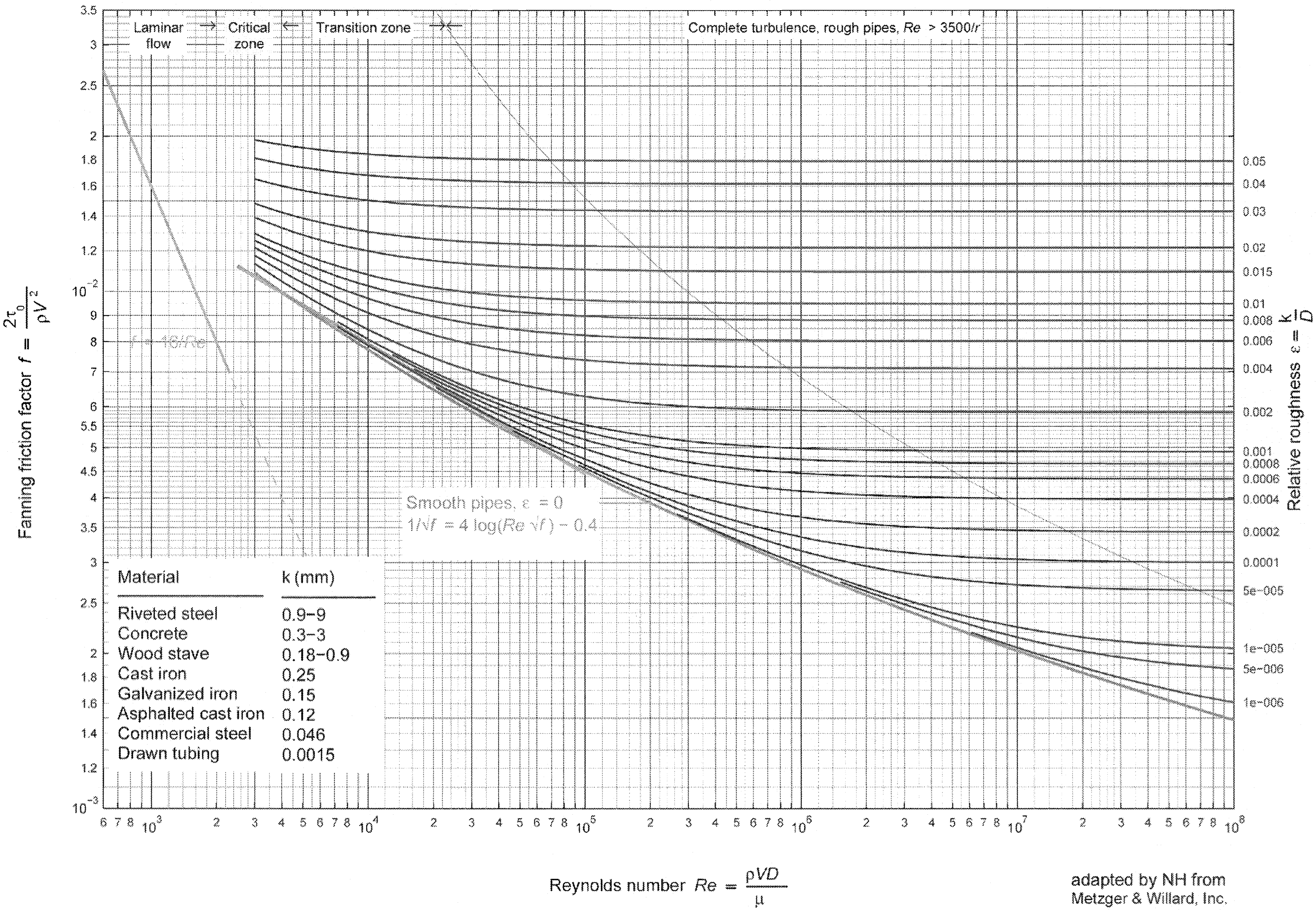
T \ p	0.001	0.01	0.02	0.05	0.1	0.5	1	2	4	6	8	10
0	999.8	999.8	999.8	999.8	999.8	1000	1000	1001	1002	1003	1004	1005
5	999.9	999.8	999.8	999.8	999.8	1000	1000	1001	1002	1003	1004	1005
10	0.00766	999.8	999.8	999.8	999.8	1000	1000	1001	1002	1003	1004	1004
20	0.00739	998.3	998.3	998.3	998.3	998.5	998.7	999.2	1000	1001	1002	1003
25	0.00727	997.0	997.0	997.0	997.0	997.2	997.4	997.9	998.8	999.7	1001	1001
30	0.00715	995.7	995.7	995.7	995.8	995.9	996.2	996.6	997.5	998.4	999.2	1000
40	0.00692	992.3	992.3	992.3	992.3	992.5	992.7	993.1	994.0	994.9	995.7	996.6
50	0.00671	0.0673	988.0	988.0	988.1	988.2	988.5	988.9	989.8	990.6	991.5	992.4
60	0.00651	0.0652	981.9	983.2	983.2	983.4	983.6	984.0	984.9	985.8	986.6	987.5
70	0.00632	0.0633	0.1269	977.7	977.7	977.9	978.1	978.5	979.4	980.3	981.2	982.1
80	0.00614	0.0615	0.1232	971.6	971.7	971.8	972.1	972.5	973.4	974.3	975.2	976.1
90	0.00597	0.0598	0.1197	0.301	965.1	965.3	965.5	966.0	966.9	967.9	968.8	969.7
100	0.00581	0.0582	0.1165	0.293	0.590	958.3	958.6	959.0	960.0	960.9	961.9	962.8
125	0.00544	0.0545	0.1091	0.274	0.550	938.8	939.1	939.6	940.6	941.7	942.7	943.7
150	0.00512	0.0512	0.1026	0.257	0.516	916.8	917.1	917.7	918.8	920.0	921.1	922.2
175	0.00484	0.0484	0.0968	0.243	0.487	2.504	892.1	892.8	894.1	895.4	896.7	898.0
200	0.00458	0.0458	0.0917	0.230	0.460	2.353	4.856	865.0	866.6	868.1	869.6	871.1
225	0.00435	0.0435	0.0871	0.218	0.437	2.223	4.554	9.643	835.1	837.0	838.8	840.6
250	0.00414	0.0414	0.0829	0.207	0.416	2.108	4.296	8.973	799.2	801.5	803.8	806.1
275	0.00395	0.0395	0.0791	0.198	0.396	2.006	4.073	8.429	18.34	759.3	762.2	765.2
300	0.00378	0.0378	0.0756	0.189	0.379	1.914	3.876	7.968	17.00	27.67	41.21	715.4
325	0.00362	0.0362	0.0725	0.181	0.363	1.830	3.700	7.569	15.94	25.42	36.54	50.40
350	0.00348	0.0348	0.0696	0.174	0.348	1.754	3.541	7.217	15.05	23.68	33.39	44.60
375	0.00334	0.0334	0.0669	0.167	0.335	1.685	3.396	6.902	14.29	22.29	31.04	40.76
400	0.00322	0.0322	0.0644	0.161	0.322	1.620	3.263	6.617	13.63	21.11	29.15	37.87
425	0.00310	0.0310	0.0621	0.155	0.311	1.561	3.141	6.357	13.04	20.09	27.57	35.55
450	0.00300	0.0300	0.0599	0.150	0.300	1.506	3.028	6.119	12.51	19.19	26.22	33.62
475	0.00290	0.0290	0.0579	0.145	0.290	1.455	2.923	5.900	12.02	18.39	25.03	31.97
500	0.00280	0.0280	0.0561	0.140	0.280	1.407	2.825	5.696	11.58	17.67	23.98	30.53
550	0.00263	0.0263	0.0527	0.132	0.263	1.320	2.649	5.331	10.80	16.41	22.17	28.09
600	0.00248	0.0248	0.0496	0.124	0.248	1.244	2.494	5.012	10.13	15.34	20.66	26.10
650	0.00235	0.0235	0.0469	0.117	0.235	1.176	2.356	4.731	9.537	14.42	19.38	24.41
700	0.00223	0.0223	0.0445	0.111	0.223	1.115	2.233	4.481	9.017	13.61	18.26	22.96
750	0.00212	0.0212	0.0424	0.106	0.212	1.060	2.123	4.256	8.555	12.89	17.28	21.70
800	0.00202	0.0202	0.0404	0.101	0.202	1.011	2.023	4.054	8.140	12.26	16.41	20.58
T_{sat}	6.98	45.83	60.09	81.35	99.63	151.8	179.9	212.4	250.3	275.5	295.0	311.0
ρ_f	999.9	989.9	983.1	970.8	958.4	915.0	887.0	849.9	798.7	758.3	722.4	688.4
ρ_g	0.00774	0.0681	0.1307	0.309	0.590	2.669	5.147	10.05	20.10	30.83	42.51	55.43

T \ p	15	20	25	30	35	40	45	50	60	80	100
0	1007	1010	1012	1014	1017	1019	1022	1024	1028	1037	1046
5	1007	1009	1012	1014	1016	1019	1021	1023	1028	1036	1044
10	1007	1009	1011	1014	1016	1018	1020	1022	1027	1035	1043
20	1005	1007	1009	1012	1014	1016	1018	1020	1024	1032	1040
25	1004	1006	1008	1010	1012	1014	1016	1018	1022	1030	1038
30	1002	1004	1007	1009	1011	1013	1015	1017	1021	1029	1036
40	998.7	1001	1003	1005	1007	1009	1011	1013	1017	1025	1032
50	994.5	996.6	998.7	1001	1003	1005	1007	1009	1013	1020	1027
60	989.6	991.8	993.8	995.9	997.9	999.9	1002	1004	1008	1015	1023
70	984.2	986.4	988.5	990.6	992.6	994.7	996.7	998.6	1003	1010	1017
80	978.3	980.5	982.7	984.8	986.9	988.9	990.9	993.0	996.9	1005	1012
90	972.0	974.2	976.4	978.5	980.7	982.8	984.8	986.9	990.9	998.7	1006
100	965.1	967.4	969.7	971.9	974.1	976.2	978.3	980.4	984.5	992.5	1000
125	946.2	948.7	951.1	953.5	955.9	958.2	960.4	962.7	967.0	975.5	983.5
150	925.0	927.7	930.4	933.0	935.6	938.1	940.5	943.0	947.7	956.7	965.3
175	901.1	904.2	907.2	910.1	912.9	915.7	918.4	921.1	926.3	936.2	945.5
200	874.7	878.2	881.6	884.9	888.1	891.3	894.3	897.3	903.1	914.0	924.1
225	844.9	849.0	853.0	856.9	860.6	864.3	867.8	871.2	877.7	889.9	901.1
250	811.4	816.5	821.3	826.0	830.4	834.7	838.8	842.7	850.3	864.1	876.6
275	772.3	778.9	785.1	790.9	796.4	801.6	806.6	811.3	820.2	836.2	850.4
300	725.7	735.0	743.3	751.0	758.1	764.7	770.9	776.7	787.5	806.4	822.7
325	663.6	679.0	691.8	703.0	712.9	721.8	729.9	737.5	751.0	773.9	792.9
350	87.24	600.1	625.0	643.5	658.6	671.4	682.6	692.6	710.0	738.1	760.6
375	72.04	132.0	488.7	555.4	586.5	608.5	625.9	640.4	664.2	699.7	726.5
400	63.85	100.5	166.3	353.3	473.8	523.8	555.1	578.3	612.6	658.8	691.4
425	58.37	87.21	127.0	189.3	292.3	390.6	455.0	497.2	551.1	613.6	653.9
450	54.20	78.70	109.0	148.5	201.8	272.1	343.2	401.3	479.9	564.3	613.9
475	50.87	72.54	97.92	128.3	165.4	210.5	262.9	315.9	403.9	510.8	571.2
500	48.09	67.70	89.86	115.2	144.4	178.1	216.2	257.6	338.8	457.0	528.2
550	43.65	60.43	78.61	98.37	119.9	143.2	168.5	195.6	253.3	361.8	445.3
600	40.19	55.06	70.79	87.44	105.0	123.6	143.2	163.6	206.8	295.9	374.8
650	37.36	50.83	64.87	79.48	94.68	110.5	126.8	143.7	178.7	251.6	322.0
700	34.98	47.37	60.13	73.28	86.80	100.7	115.0	129.5	159.5	221.3	282.8
750	32.94	44.45	56.21	68.24	80.52	93.04	105.8	118.8	145.2	199.3	253.0
800	31.17	41.94	52.89	64.03	75.33	86.80	98.42	110.2	134.0	182.5	230.4
T_{sat}	342.1	365.7									
ρ_f	603.2	490.9									
ρ_g	96.71	170.2									

Density of Water & Steam kg/m^3

Table 6, Density

Moody Diagram



Continuity and Navier-Stokes equations for incompressible homogeneous fluids in Cartesian, cylindrical, and spherical coordinates

Cartesian	Cylindrical	Spherical
	Continuity equation	
$\frac{\partial v_x}{\partial x}+\frac{\partial v_y}{\partial y}+\frac{\partial v_z}{\partial z}=0$	$\frac{1}{r}\frac{\partial (r v_r)}{\partial r}+\frac{1}{r}\left(\frac{\partial v_\theta}{\partial \theta}\right)+\frac{\partial v_z}{\partial z}=0$	$\frac{1}{r^2}\frac{\partial (r^2 v_r)}{\partial r}+\frac{1}{r\sin\theta}\frac{\partial (v_\theta \sin\theta)}{\partial \theta}+\frac{1}{r\sin\theta}\frac{\partial v_\phi}{\partial \phi}=0$
	Navier-Stokes equation	
$\rho\left(\frac{\partial v_x}{\partial t}+v_x\frac{\partial v_x}{\partial x}+v_y\frac{\partial v_x}{\partial y}+v_z\frac{\partial v_x}{\partial z}\right) = -\frac{\partial p}{\partial x}+\mu\left(\frac{\partial^2 v_x}{\partial x^2}+\frac{\partial^2 v_x}{\partial y^2}+\frac{\partial^2 v_x}{\partial z^2}\right)$	$\rho\left(\frac{\partial v_r}{\partial t}+v_r\frac{\partial v_r}{\partial r}+\frac{v_\theta}{r}\frac{\partial v_r}{\partial \theta}-\frac{v_\theta^2}{r}+v_z\frac{\partial v_r}{\partial z}\right) = -\frac{\partial p}{\partial r}+\mu\left[\frac{\partial}{\partial r}\left(\frac{1}{r}\frac{\partial}{\partial r}(r v_r)\right)+\frac{1}{r^2}\frac{\partial^2 v_r}{\partial \theta^2}-\frac{2}{r^2}\frac{\partial v_\theta}{\partial \theta}+\frac{\partial^2 v_r}{\partial z^2}\right]$	$\rho\left(\frac{\partial v_r}{\partial t}+v_r\frac{\partial v_r}{\partial r}+\frac{v_\theta}{r}\frac{\partial v_r}{\partial \theta}+\frac{v_\phi}{r\sin\theta}\frac{\partial v_r}{\partial \phi}-\frac{v_\theta^2+v_\phi^2}{r}\right) = -\frac{\partial p}{\partial r}+\mu\left[\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial v_r}{\partial r}\right)+\frac{1}{r^2\sin\theta}\frac{\partial}{\partial \theta}\left(\sin\theta\frac{\partial v_r}{\partial \theta}\right) +\frac{1}{r^2\sin^2\theta}\frac{\partial^2 v_r}{\partial \phi^2}-\frac{2v_r}{r^2}-\frac{2}{r^2}\frac{\partial v_\theta}{\partial \theta}-\frac{2v_\theta\cot\theta}{r^2}-\frac{2}{r^2\sin\theta}\frac{\partial v_\phi}{\partial \phi}\right]$
$\rho\left(\frac{\partial v_y}{\partial t}+v_x\frac{\partial v_y}{\partial x}+v_y\frac{\partial v_y}{\partial y}+v_z\frac{\partial v_y}{\partial z}\right) = -\frac{\partial p}{\partial y}+\mu\left(\frac{\partial^2 v_y}{\partial x^2}+\frac{\partial^2 v_y}{\partial y^2}+\frac{\partial^2 v_y}{\partial z^2}\right)$	$\rho\left(\frac{\partial v_\theta}{\partial t}+v_r\frac{\partial v_\theta}{\partial r}+\frac{v_\theta}{r}\frac{\partial v_\theta}{\partial \theta}+\frac{v_r v_\theta}{r}+v_z\frac{\partial v_\theta}{\partial z}\right) = -\frac{1}{r}\frac{\partial p}{\partial \theta}+\mu\left[\frac{\partial}{\partial r}\left(\frac{1}{r}\frac{\partial}{\partial r}(r v_\theta)\right)+\frac{1}{r^2}\frac{\partial^2 v_\theta}{\partial \theta^2}+\frac{2}{r^2}\frac{\partial v_r}{\partial \theta}+\frac{\partial^2 v_\theta}{\partial z^2}\right]$	$\rho\left(\frac{\partial v_\theta}{\partial t}+v_r\frac{\partial v_\theta}{\partial r}+\frac{v_\theta}{r}\frac{\partial v_\theta}{\partial \theta}+\frac{v_\phi}{r\sin\theta}\frac{\partial v_\theta}{\partial \phi}+\frac{v_r v_\theta}{r}-\frac{v_\phi^2\cot\theta}{r}\right) = -\frac{1}{r}\frac{\partial p}{\partial \theta}+\mu\left[\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial v_\theta}{\partial r}\right)+\frac{1}{r^2\sin\theta}\frac{\partial}{\partial \theta}\left(\sin\theta\frac{\partial v_\theta}{\partial \theta}\right) +\frac{1}{r^2\sin^2\theta}\frac{\partial^2 v_\theta}{\partial \phi^2}+\frac{2}{r^2}\frac{\partial v_r}{\partial \theta}-\frac{v_\theta}{r^2\sin^2\theta}-\frac{2\cos\theta}{r^2\sin^2\theta}\frac{\partial v_\phi}{\partial \phi}\right]$
$\rho\left(\frac{\partial v_z}{\partial t}+v_x\frac{\partial v_z}{\partial x}+v_y\frac{\partial v_z}{\partial y}+v_z\frac{\partial v_z}{\partial z}\right) = -\frac{\partial p}{\partial z}+\mu\left(\frac{\partial^2 v_z}{\partial x^2}+\frac{\partial^2 v_z}{\partial y^2}+\frac{\partial^2 v_z}{\partial z^2}\right)$	$\rho\left(\frac{\partial v_z}{\partial t}+v_r\frac{\partial v_z}{\partial r}+\frac{v_\theta}{r}\frac{\partial v_z}{\partial \theta}+v_z\frac{\partial v_z}{\partial z}\right) = -\frac{\partial p}{\partial z}+\mu\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial v_z}{\partial r}\right)+\frac{1}{r^2}\frac{\partial^2 v_z}{\partial \theta^2}+\frac{\partial^2 v_z}{\partial z^2}\right]$	$\rho\left(\frac{\partial v_\phi}{\partial t}+v_r\frac{\partial v_\phi}{\partial r}+\frac{v_\theta}{r}\frac{\partial v_\phi}{\partial \theta}+\frac{v_\phi}{r\sin\theta}\frac{\partial v_\phi}{\partial \phi}+\frac{v_r v_\phi}{r}+\frac{v_\theta v_\phi\cot\theta}{r}\right) = -\frac{1}{r\sin\theta}\frac{\partial p}{\partial \phi}+\mu\left[\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial v_\phi}{\partial r}\right)+\frac{1}{r^2\sin\theta}\frac{\partial}{\partial \theta}\left(\sin\theta\frac{\partial v_\phi}{\partial \theta}\right) +\frac{1}{r^2\sin^2\theta}\frac{\partial^2 v_\phi}{\partial \phi^2}-\frac{v_\phi}{r^2\sin^2\theta}+\frac{2}{r^2\sin\theta}\frac{\partial v_r}{\partial \phi}+\frac{2\cos\theta}{r^2\sin^2\theta}\frac{\partial v_\theta}{\partial \phi}\right]$