Appendix (A)

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LUBRICATION SYSTEM

GENERAL

The lubricating requirements for the gas turbine power plant are furnished by a common forced-feed lubrication system. This lubrication system, complete with tank, pumps, coolers, filters, valves and various control and protection devices, furnishes normal lubrication and absorption of heat rejection load of the gas turbine. Lubricating fluid is circulated to the two main turbine bearings, generator bearings, reduction gear, and to the turbine accessory gear. Additionally, a portion of the pressurized fluid is diverted and filtered again for use by hydraulic control devices as control fluid and as a supply to other systems.

Refer to "Hydrocarbon Base Lubricating Oil Recommendations for Gas Turbines" in the FLUID SPECIFICATIONS section of this manual for the lubricating oil requirements.

The lubrication system is designed to provide an ample supply of filtered lubricant at the proper temperature and pressure for operation of the turbine and its associated equipment. The lubrication system including all major components is shown in the system schematic diagram in the Reference Drawings Section. Major system components include:

a. Lube reservoir in the turbine base.

b. Main lube pump (shaft driven from the accessory gear).

c. Auxiliary lube pump.

d. Emergency lube pump.

e. Pressure relief valve VR1 in the main pump discharge.

f. Lube fluid heat exchangers.

g. Main lube filters.

h. Bearing header pressure regulator VPR2.

For turbine starting, a maximum of 800 SSU is specified for reliable operation of the control system and for bearing lubrication. A temperature switch, 26QN-1, prevents turbine startup if the temperature of the lubricant decreases to a point where oil viscosity is 800 SSU.

Lubricating fluid for the main, the auxiliary and the emergency pumps is supplied from the reservoir, while lubricating fluid used for control is supplied from the bearing header. This lubricant must be regulated to the proper, predetermined pressure to meet the requirements of the main bearings and the accessory lube system, as well as the hydraulic control and trip circuits. Regulating devices are shown on the Lube System Schematic Diagram. All lubricating fluid is filtered and cooled before being piped to the bearing header.

FUNCTIONAL DESCRIPTION

GENERAL

The system is a closed loop, forced feed system including a lube oil supply reservoir. The reservoir for the lubrication system is the 3300-gallon tank which is fabricated as an integral part of the turbine base. Lubricating fluid is pumped from the reservoir by the main shaft driven pump (part of the accessory gear) or auxiliary or emergency pumps to the bearing header, the accessory gear and the hydraulic supply system.

The lube pumps take their suction from the oil tank and discharge into a common header. All lubricant pumped from the lube

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reservoir to the bearing header flows through the lube fluid heat exchanger to remove excess heat and then through the cartridge type filter providing five-micron filtration. After lubricating the bearings the lubricant flows back through various drain lines to the lube reservoir.

LUBE OIL TANK AND PIPING

The lube oil tank in the accessory end of the turbine base also supports and contains several lubrication system components. Mounted on or supported from the tank top are the ac and dc motor driven lube pumps, and various control and protective devices. Extending into the tank from the side of the lube reservoir are the lube fluid heat exchangers and filters. Access to the tank interior is through an opening in the top. An oil tank fill connection is provided in the side of the tank as are two oil drains near the tank bottom. The tank also has connections for a centrifuge.

Lube piping consists mainly of welded fabrications of seamless steel pipe with gaskets used to prevent leakage at bolted flanges. Whenever possible, the lube oil feed piping is contained within the oil tank or drain headers. A vent to atmosphere is installed at a flanged opening in a junction box in the external oil drain. All drain points are shown on the Purchaser's Connection Outline and the notes contained in the Reference Drawing section of this manual. Visual oil flow checks can be made using the flow sights provided in the drains. This flow should be checked when the lube oil pumps are started prior to every turbine startup.

A lube level gauge and alarm device is part of the tank level indicator which is operated by a float-arm. The device is mounted to the side of the lube oil tank above the maximum expected level of the lube supply. The float mechanism operates a dial gauge and two device switches, 71QH-1 and 71QL-1. The switches are connected into the alarm circuit of the turbine control panel to initiate an alarm display message on the turbine panel scope and sound an audible alarm if the liquic level rises above, or falls below, the levels shown on the Schematic Piping Diagram The oil level gauge will indicate "F" (full) or "E" (empty) before the alarm is given.

There is also a sight glass mounted on the oil tank which provides for visual monitoring of the oil level.

Temperature readings of the lube oil feed header are taken from the thermometer installed in the header. A diaphragm-operated regulating valve VPR2 is installed in the pump discharge line. I regulates pressure by sensing the pressure downstream of the main lube oil filters Capacity of the system including tank piping and system components is approxi mately 3500 gallons.

STANDBY HEATERS

During standby periods, the lubricatin fluid is maintained at a viscosity proper fo turbine startup and operation by tw immersion heaters, 23QT-1 and 23QT-2 installed in the lube reservoir. Temperatur switches 26QL-1 and 26QN-1 sens reservoir fluid temperature, and control th heaters to maintain fluid temperature t achieve allowable viscosity. Also switc 26QN-1 will not permit the turbine to b started if the fluid temperature drops belo that required for startup.

The ac motor-driven auxiliary lube o pump operates during standby heatin periods to circulate the oil in the system.

LUBRICATING OIL PUMPS

The lubrication system uses three lub pumps:

a. The main lube supply pump is positive displacement type pum mounted in and driven by th accessory gear.

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b. The auxiliary (cooldown) lube supply pump driven by a vertical ac motor.

c. The emergency lube supply pump driven by a vertical dc motor.

Both the auxiliary and emergency pumps are mounted on the oil tank cover. Output of each of the pumps at rated speed together with motor ratings are included in the Device Summary of this manual. Functional information concerning the pumps is included in the paragraphs that follow.

Main Lube Pump

The main lube pump is built into the inboard wall of the lower half casing of the accessory gear. It is driven by a splined quill shaft from the lower drive gear. The output pressure to the lubrication system is limited by back-pressure valve VR1 to maintain system pressure.

Auxiliary And Emergency Lube Supply Pumps

The auxiliary and the emergency lube supply pumps are both . submerged, centrifugal-type pumps that provide lubricant pressure during startup and shutdown of the gas turbine. These pumps operate as follows:

a. Auxiliary Lube Pump Operation - When ac power is available during the turbine starting and stopping sequences, system lube pressure is supplied by the auxiliary supply pump driven by ac motor 88QA during the time that the main shaft-driven pump is at a speed insufficient to develop operating pressure. At turbine startup, the ac pump starts automatically when the master control switch on the turbine control panel is turned to the START position. It continues to operate until the turbine reaches

a. (Continued)

approximately 95 percent of operational speed. At this point, the pump shuts down and system pressure is supplied by the shaft-driven, main lube pump.

On turbine shutdown, the ac motor-driven auxiliary pump starts after the 14HSX relay contact drops out. This occurs when turbine speed drops to 95 percent of operational speed. The pump continues to operate throughout the shutdown and cooldown period and runs until the operator takes the unit off of cooldown.

On gas turbines equipped with optional immersion heaters, the actuated auxiliary pump starts automatically whenever the heaters are on, to circulate the system lubricating fluid. For this function, the ac pump is controlled by the immersion heater contact which, in turn, is controlled by two temperature switches. The pump and heaters are actuated by the lubricating fluid temperature switch, 26QL-1.

b. Auxiliary Lube Supply Operation Testing - A test valve, mounted on the gauge cabinet, provides the means of checking the automatic startup of the auxiliary lube oil pump with signals generated by the low lube oil alarm/pump start pressure switch 63QA-2 while the unit is operating normally on the main lube oil pump. As the test valve is opened, lube oil pressure falls to the setting of the pressure switch and the auxiliary lube oil pump should start. The condition of "Auxiliary Lube Oil Pump Running" should be displayed on the turbine panel CRT. When the test valve is closed, the pump will continue to run (through the contacts of the

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b. (Continued)

complete sequence check relay) until it is shut down manually at the motor control center. After this test has been completed the alarm should be reset.

c. Emergency Lube Pump Operation -If ac power is not available during the turbine starting and stopping sequences, system lube fluid pressure is supplied by the emergency lube supply pump driven by a dc motor (88QE) energized by a pressure switch, 63QL. The pump operates until the turbine reaches approximately 50 percent speed. It will continue to operate after 40 percent speed is reached if the system pressure has not reached the pressure setting of switch 63QL.

The emergency lube pump functions to supply lube fluid to the main bearing header during an emergency shutdown in the event that the auxiliary pump has been forced out of service, or is unable to maintain adequate lube pressure.

d. Emergency Lube Supply Operations Testing - A test valve and pressure switches are installed aft of an orifice in the pressure switch piping connected to the bearing lube header. The test valve is normally closed, and maintains lubricating system pressure on the switches. When a test is being performed, the test valve should be opened gradually to lower lubricating system pressure in the switch piping. This pressure is indicated on a gauge connected into the pressure line. The gauge provides a means of checking the pressure points at which the switches operate to indicate a condition of low lubricating fluid pressure on the alarm display and to start the emergency lube supply pump. If the pressure is indicated on setting of

d. (Continued)

switch 63QA-2, a condition of low lubricant pressure is indicated on the alarm display. Further opening of the test valve will reduce pressure in the test line to the pressure setting of switch 63QL which starts the emergency lube pump. An alarm indicates either a low pressure condition or that the emergency lube supply pump is running. A low lubricating fluid pressure indication should occur before the pump begins operating.

When the test valve is closed and the lube pressure is returned to normal, the emergency lube supply pump should stop as a result of restoration of pressure on switch 63QL.

A check valve is placed in the discharge piping of the auxiliary and emergency lube pumps to prevent fluid from being circulated to the oil tank through these centrifugal pumps when the main pump is operating.

NOTE

When tests are completed, the alarm display should be reset.

HEAT EXCHANGERS (LUBE OIL COOLERS)

Extended tank-type heat exchangers/coolers, with exposed fixed-tubesheet and bundle construction (straight-tube), are used to dissipate heat absorbed by the lubricating oil. Two (dual) heat exchangers are used and are installed horizontally through the side of the lube oil tank. Water is supplied to the heat exchangers for cooling.

Dual heat exchangers, arranged horizontally side by side, are installed in the tank and connected into the pump discharge header through a manual transfer valve.

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Only one heat exchanger will be in service at a time, thus cleaning, inspection, and maintenance of the second one can be performed without interrupting oil flow or shutting the gas turbine down. By means of the manually-operated, worm-driven transfer valve, one heat exchanger can be put into service as the second is taken out; without interrupting the oil flow to the main lube oil header. The transfer of operation from one heat exchanger to the other should be accomplished as follows:

1. Open the filler valve and fill the standby heat exchanger until a solid oil flow can be seen in the flow sight in the cooler vent pipe. This will indicate a "filled" condition.

2. Operate the transfer valve with a wrench to bring the standby heat exchanger into service.

3. Close the filler valve.

Water flow through the heat exchanger is regulated by a temperature actuated valve VTR1 which has a sensor installed in the lube oil header downstream from the heat exchangers.

OIL FILTERS

Main Oil Filters

Filtration of all lube oil is accomplished by a 5 micron, pleated paper filter cartridges installed in the lube system just after the lube oil heat exchanger. A dual filter arrangement is used with a transfer valve installed between the filters to direct oil flow through either filter and into the lube oil header.

The dual filters, arranged horizontally side by side, are installed on the tank and connected into the pump discharge header through a manual transfer valve. Only one filter will be in service at a time; thus cleaning, inspection, and maintenance of the second one can be performed without interrupting oil flow or shutting the gas turbine down. By means of the manually-operated, worm-driven transfer valve, one filter can be put into service as the second is taken out, without interrupting the oil flow to the main lube oil header. The same procedure should be used in filter transfer as given above for heat exchange transfer.

Filter elements should be changed when the differential pressure gauge indicates a differential pressure of 15 psi. An alarm switch 63QQ-1 signals when the differential pressure exceeds 15 psi. Refer to the Maintenance section of this manual for inspection schedules.

PRESSURE REGULATION

Two regulating valves are used to control lubrication system pressure. A back-pressure relief valve, VR1, limits the positive displacement main pump discharge header pressure and relieves excess fluid to the lube reservoir. The lube pressure in the bearing header is maintained at approximately 25 psig by the diaphragm-operated regulating valve, VPR2. The diaphragm valve is operated by sensing fluid pressure in the bearing header. This valve throttles flow to give 25 psig in the bearing header.

PRESSURE AND TEMPERATURE PROTECTIVE DEVICES

Low lubricating fluid pressure is detected by pressure switches 63QA-2, 63QT-2A and 2B which open after a decrease of line pressure to a specified value and trips the unit. Pressure switch 63QA-2, installed in the lubricant feed piping, signals an alarm and starts the auxiliary pump if the lubricant pressure drops below its predetermined setting.

Temperature switches 26QA-1 and 26QT-1A and -1B are installed in the lubricating fluid header piping to cause an alarm to sound and to trip the unit should the temperature of the lubricant to the bearings exceed the preset limit. Switch settings are such that an alarm is actuated

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Appendix (B)

Figure 1 Lube oil heaters

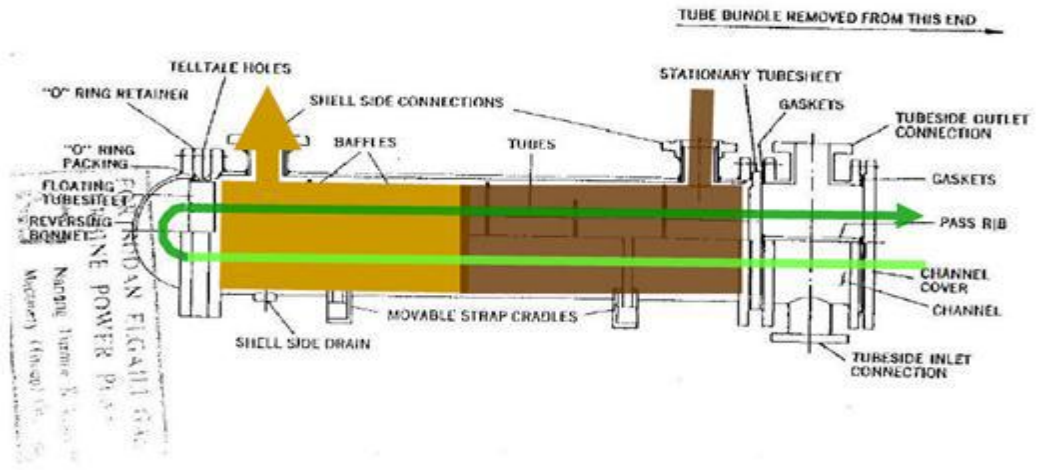

Figure 2 lube oil cooler pipe cooling

TABLE 13–1

Representative values of the overall heat transfer coefficients in heat exchangers

Type of heat exchanger	U, W/m^2 · °C*
Water-to-water	850–1700
Water-to-oil	100–350
Water-to-gasoline or kerosene	300–1000
Feedwater heaters	1000–8500
Steam-to-light fuel oil	200–400
Steam-to-heavy fuel oil	50–200
Steam condenser	1000–6000
Freon condenser (water cooled)	300–1000
Ammonia condenser (water cooled)	800–1400
Alcohol condensers (water cooled)	250–700
Gas-to-gas	10–40
Water-to-air in finned tubes (water in tubes)	30–60†
	400–850†
Steam-to-air in finned tubes (steam in tubes)	30–300†
	400–4000‡

Figure 3: Representative values of the overall heat transfer coefficients in heat exchangers.

Appendix (C)

TABLE 2-353 Saturated Liquid Water—Miscellaneous Properties

Temperature, °C	$10^4\beta$	$10^4 k_T$/bar	$10^4 k_s$/bar	v_s, m/s	μ_f, 10^{-6} Pa·s	c_p, kJ/kg·K	k, W/m·K	Pr, bar	σ, N/m
0	−0.681	0.50885	0.50855	1402.4	1.793	4.2176	0.567	13.32	0.07565
1	−0.501	0.50509	0.50493	1407.4	1.732	4.2140	0.569	12.83	0.07551
2	−0.327	0.50151	0.50143	1412.2	1.675	4.2107	0.570	12.37	0.07537
3	−0.160	0.49808	0.49806	1417.0	1.621	4.2077	0.572	11.93	0.07522
4	0.003	0.49481	0.49481	1421.6	1.569	4.2048	0.573	11.51	0.07508
5	0.160	0.49169	0.49167	1426.2	1.520	4.2022	0.575	11.11	0.07494
6	0.312	0.48871	0.48865	1430.6	1.474	4.1999	0.577	10.73	0.07480
7	0.460	0.48587	0.48573	1434.9	1.429	4.1977	0.578	10.38	0.07465
8	0.604	0.48315	0.48291	1439.1	1.387	4.1956	0.580	10.04	0.07451
9	0.744	0.48056	0.48019	1443.3	1.346	4.1938	0.581	9.72	0.07436
10	0.880	0.47809	0.47757	1447.3	1.308	4.1921	0.5828	9.41	0.07422
11	1.012	0.47573	0.47504	1451.2	1.271	4.1906	0.5844	9.11	0.07407
12	1.141	0.47347	0.47260	1455.0	1.236	4.1892	0.5859	8.84	0.07393
13	1.267	0.47133	0.47024	1458.7	1.202	4.1879	0.5875	8.57	0.07378
14	1.389	0.46928	0.46797	1462.4	1.170	4.1867	0.5891	8.32	0.07364
15	1.509	0.46733	0.46578	1465.9	1.139	4.1856	0.5906	8.07	0.07349
16	1.626	0.46548	0.46366	1469.4	1.110	4.1847	0.5922	7.84	0.07334
17	1.740	0.46371	0.46162	1472.7	1.081	4.1838	0.5937	7.62	0.07319
18	1.852	0.46203	0.45966	1476.0	1.054	4.1830	0.5953	7.41	0.07304
19	1.961	0.46043	0.45776	1479.2	1.028	4.1823	0.5968	7.20	0.07289
20	2.068	0.45892	0.45593	1482.3	1.003	4.1817	0.5983	7.01	0.07274
21	2.173	0.45748	0.45417	1485.3	0.979	4.1812	0.5999	6.82	0.07259
22	2.275	0.45612	0.45248	1488.3	0.955	4.1807	0.6014	6.64	0.07244
23	2.376	0.45484	0.45084	1491.2	0.933	4.1802	0.6029	6.47	0.07228
24	2.475	0.45362	0.44927	1493.9	0.911	4.1798	0.6044	6.30	0.07213
25	2.572	0.45247	0.44776	1496.7	0.891	4.1795	0.6059	6.15	0.07198
26	2.667	0.45139	0.44630	1499.3	0.871	4.1792	0.6074	5.99	0.07182
27	2.761	0.45038	0.44490	1501.9	0.852	4.1790	0.6089	5.85	0.07167
28	2.852	0.44943	0.44355	1504.3	0.833	4.1788	0.6104	5.70	0.07151
30	3.032	0.44771	0.44102	1509.1	0.798	4.1785	0.6133	5.44	0.07120
32	3.206	0.44622	0.43869	1513.6	0.765	4.1783	0.6162	5.19	0.07089
34	3.375	0.44496	0.43655	1517.8	0.734	4.1782	0.6190	4.95	0.07058
36	3.539	0.44390	0.43459	1521.7	0.705	4.1783	0.6218	4.74	0.07025
38	3.698	0.44305	0.43280	1525.4	0.679	4.1784	0.6246	4.54	0.06992
40	3.853	0.44239	0.43118	1528.9	0.653	4.1786	0.6273	4.35	0.06960
42	4.004	0.44192	0.42972	1532.1	0.629	4.1789	0.6299	4.17	0.06927
44	4.152	0.44162	0.42842	1535.0	0.607	4.1792	0.6315	4.02	0.06894
46	4.296	0.44149	0.42726	1537.7	0.586	4.1797	0.6351	3.86	0.06861
48	4.438	0.44153	0.42624	1540.3	0.566	4.1801	0.6375	3.71	0.06828
50	4.576	0.44173	0.42535	1542.6	0.547	4.1807	0.6400	3.57	0.06795
55	4.910	0.44290	0.42370	1547.4	0.5043	4.1824	0.6457	3.267	0.06710
60	5.231	0.44496	0.42281	1551.0	0.4668	4.1844	0.6511	3.000	0.06624
65	5.539	0.44788	0.42262	1553.4	0.4338	4.1869	0.6561	2.768	0.06537
70	5.837	0.45162	0.42309	1554.8	0.4045	4.1897	0.6607	2.565	0.06449
75	6.128	0.45614	0.42418	1555.1	0.3784	4.1929	0.6649	2.386	0.06359
80	6.411	0.46143	0.42587	1554.4	0.3550	4.1965	0.6686	2.228	0.06268
85	6.689	0.46748	0.42812	1552.9	0.3340	4.2005	0.6721	2.088	0.06176
90	6.962	0.47429	0.43093	1550.5	0.3150	4.2050	0.6753	1.962	0.06083
95	7.233	0.48185	0.43429	1547.2	0.2979	4.2102	0.6779	1.850	0.05988
100	7.501	0.49019	0.43819	1543.1	0.2823	4.2164	0.6800	1.756	0.05892

Values mostly from Aleksandrov, A. A. and M. S. Trakhtenhertz, *Thermophysical Properties of Water at Atmospheric Pressure*, Standartov, Moscow, 1977 (99 pp.).

Figure 1: Thermo physical Properties of water at atmospheric pressure.

Appendix (D)

TABLE 2-28 Density (kg/m³) of Water from 0 to 100°C*

	ρ, kg/m³									
t, °C	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	999.839	999.846	999.852	999.859	999.865	999.871	999.877	999.882	999.888	999.893
1	999.898	999.903	999.908	999.913	999.917	999.921	999.925	999.929	999.933	999.936
2	999.940	999.943	999.946	999.949	999.952	999.954	999.956	999.959	999.961	999.962
3	999.964	999.966	999.967	999.968	999.969	999.970	999.971	999.971	999.972	999.972
4	999.972	999.972	999.972	999.971	999.971	999.970	999.969	999.968	999.967	999.965
5	999.964	999.962	999.960	999.958	999.956	999.954	999.951	999.949	999.946	999.943
6	999.940	999.937	999.934	999.930	999.926	999.923	999.919	999.915	999.910	999.906
7	999.901	999.897	999.892	999.887	999.882	999.877	999.871	999.866	999.860	999.854
8	999.848	999.842	999.836	999.829	999.823	999.816	999.809	999.802	999.795	999.788
9	999.781	999.773	999.765	999.758	999.750	999.742	999.734	999.725	999.717	999.708
10	999.699	999.691	999.682	999.672	999.663	999.654	999.644	999.635	999.625	999.615
11	999.605	999.595	999.584	999.574	999.563	999.553	999.542	999.531	999.520	999.509
12	999.497	999.486	999.474	999.462	999.451	999.439	999.426	999.414	999.402	999.389
13	999.377	999.364	999.351	999.338	999.325	999.312	999.299	999.285	999.272	999.258
14	999.244	999.230	999.216	999.202	999.188	999.173	999.159	999.144	999.129	999.114
15	999.099	999.084	999.069	999.054	999.038	999.022	999.007	998.991	998.975	998.958
16	998.943	998.926	998.910	998.894	998.877	998.860	998.843	998.826	998.809	998.792
17	998.775	998.757	998.740	998.722	998.704	998.686	998.668	998.650	998.632	998.614
18	998.595	998.577	998.558	998.539	998.520	998.502	998.482	998.463	998.444	998.425
19	998.405	998.385	998.366	998.346	998.326	998.306	998.286	998.265	998.245	998.224
20	998.204	998.183	998.162	998.141	998.120	998.099	998.078	998.057	998.035	998.014
21	997.992	997.971	997.949	997.927	997.905	997.883	997.860	997.838	997.816	997.793
22	997.770	997.747	997.725	997.702	997.679	997.656	997.632	997.609	997.585	997.562
23	997.538	997.515	997.491	997.467	997.443	997.419	997.394	997.370	997.345	997.321
24	997.296	997.272	997.247	997.222	997.197	997.172	997.146	997.121	997.096	997.070
25	997.045	997.019	996.993	996.967	996.941	996.915	996.889	996.863	996.836	996.810
26	996.783	996.757	996.730	996.703	996.676	996.649	996.622	996.595	996.568	996.540
27	996.513	996.485	996.458	996.430	996.402	996.374	996.346	996.318	996.290	996.262
28	996.233	996.205	996.176	996.148	996.119	996.090	996.061	996.032	996.003	995.974
29	995.945	995.915	995.886	995.856	995.827	995.797	995.767	995.737	995.707	995.677
30	995.647	995.617	995.586	995.556	995.526	995.495	995.464	995.433	995.403	995.372
31	995.341	995.310	995.278	995.247	995.216	995.184	995.153	995.121	995.090	995.058
32	995.026	994.997	994.962	994.930	994.898	994.865	994.833	994.801	994.768	994.735
33	994.703	994.670	994.637	994.604	994.571	994.538	994.505	994.472	994.438	994.405
34	994.371	994.338	994.304	994.270	994.236	994.202	994.168	994.134	994.100	994.066
35	994.032	993.997	993.963	993.928	993.893	993.859	993.824	993.789	993.754	993.719
36	993.684	993.648	993.613	993.578	993.543	993.507	993.471	993.436	993.400	993.364
37	993.328	993.292	993.256	993.220	993.184	993.148	993.111	993.075	993.038	993.002
38	992.965	992.928	992.891	992.855	992.818	992.780	992.743	992.706	992.669	992.631
39	992.594	992.557	992.519	992.481	992.444	992.406	992.368	992.330	992.292	992.254
40	992.215	992.177	992.139	992.100	992.062	992.023	991.985	991.946	991.907	992.868
41	991.830	991.791	991.751	991.712	992.673	991.634	991.594	991.555	991.515	991.476
42	991.436	991.396	991.357	991.317	991.277	991.237	991.197	991.157	991.116	991.076
43	991.036	990.995	990.955	990.914	990.873	990.833	990.792	990.751	990.710	990.669
44	990.628	990.587	990.546	990.504	990.463	990.421	990.380	990.338	990.297	990.255
45	990.213	990.171	990.129	990.087	990.045	990.003	989.961	989.919	989.876	989.834
46	989.792	989.749	989.706	989.664	989.621	989.578	989.535	989.492	989.449	989.406
47	989.363	989.320	989.276	989.233	989.190	989.146	989.103	989.059	989.015	988.971
48	988.928	988.884	988.840	988.796	988.752	988.707	988.663	988.619	988.574	988.530
49	988.485	988.441	988.396	988.352	988.307	988.262	988.217	988.172	988.127	988.082

Figure 1: Density of water from 0°C to 100 °C

TABLE 2-28 Density (kg/m³) of Water from 0 to 100°C (*Concluded*)

	ρ, kg/m³									
t, °C	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
50	988.037	987.992	987.946	987.901	987.844	987.810	987.764	987.719	987.673	987.627
51	987.581	987.536	987.490	987.444	987.398	987.351	987.305	987.259	987.213	987.166
52	987.120	987.073	987.027	986.980	986.933	986.886	986.840	986.793	986.746	986.699
53	986.652	986.604	986.557	986.510	986.463	986.415	986.368	986.320	986.272	986.225
54	986.177	986.129	986.081	986.033	985.985	985.937	985.889	985.841	985.793	985.745
55	985.696	985.648	985.599	985.551	985.502	985.454	985.405	985.356	985.307	985.258
56	985.219	985.160	985.111	985.062	985.013	984.963	984.914	984.865	984.815	984.766
57	984.716	984.666	984.617	984.567	984.517	984.467	984.417	984.367	984.317	984.267
58	984.217	984.167	984.116	984.066	984.016	983.965	983.914	983.864	983.813	983.762
59	983.712	983.661	983.610	983.559	983.508	983.457	983.406	983.354	983.303	983.252
60	983.200	983.149	983.097	983.046	982.994	982.943	982.891	982.839	982.787	982.735
61	982.683	982.631	982.579	982.527	982.475	982.422	982.370	982.318	982.265	982.213
62	982.160	982.108	982.055	982.002	981.949	981.897	981.844	981.791	981.738	981.685
63	981.631	981.578	981.525	981.472	981.418	981.365	981.311	981.258	981.204	981.151
64	981.097	981.043	980.989	980.935	980.881	980.827	980.773	980.719	980.665	980.611
65	980.557	980.502	980.443	980.393	980.339	980.284	980.230	980.175	980.120	980.065
66	980.011	979.956	979.901	979.846	979.791	979.736	979.680	979.625	979.570	979.515
67	979.459	979.403	979.348	979.293	979.237	979.181	979.126	979.070	979.014	978.958
68	978.902	978.846	978.790	978.734	978.678	978.621	978.565	978.509	978.452	978.396
69	978.339	978.283	978.226	978.170	978.113	978.056	977.999	977.942	977.885	977.828
70	977.771	977.714	977.657	977.600	977.543	977.485	977.428	977.370	977.313	977.255
71	977.198	977.140	977.082	977.025	976.967	976.909	976.851	976.793	976.735	976.677
72	976.619	976.561	976.503	976.444	976.386	976.327	976.269	976.211	976.152	976.093
73	976.035	975.976	975.917	975.858	975.800	975.741	975.682	975.623	975.564	975.504
74	975.445	975.386	975.327	975.267	975.208	975.148	975.089	975.029	974.970	974.910
75	974.850	974.791	974.731	974.671	974.611	974.551	974.491	974.431	974.371	974.311
76	974.250	974.190	974.130	974.069	974.009	973.948	973.888	973.827	973.767	973.706
77	973.645	973.584	973.524	973.463	973.402	973.341	973.280	973.218	973.157	973.096
78	973.025	972.974	972.912	972.851	972.789	972.728	972.666	972.605	972.543	972.481
79	972.419	972.358	972.296	972.234	972.172	972.110	972.048	971.986	971.923	971.861
80	971.799	971.737	971.674	971.612	971.549	971.487	971.424	971.361	971.299	971.236
81	971.173	971.110	971.048	970.985	970.922	970.859	970.796	970.732	970.669	970.606
82	970.543	970.479	970.416	970.353	970.289	970.226	970.162	970.098	970.035	969.971
83	969.907	969.843	969.772	969.715	969.652	969.587	969.523	969.459	969.395	969.331
84	969.267	969.202	969.138	969.073	969.009	968.944	968.880	968.815	968.751	968.686
85	968.621	968.556	968.491	968.427	968.362	968.297	969.232	968.166	968.101	968.036
86	967.971	967.906	967.840	967.775	967.709	967.641	967.578	967.513	967.447	967.381
87	967.316	967.250	967.184	967.118	967.052	966.986	966.920	966.854	966.788	966.722
88	966.656	966.589	966.523	966.457	966.390	966.324	966.257	966.191	966.124	966.057
89	965.991	965.924	965.857	965.790	965.723	965.656	965.589	965.522	965.455	965.388
90	965.321	965.254	965.187	965.119	965.052	964.984	964.917	964.849	964.782	964.714
91	964.647	954.579	964.511	964.443	964.376	964.308	964.240	964.172	964.104	964.036
92	963.967	963.899	963.831	963.763	963.694	963.626	963.558	963.489	963.421	963.352
93	963.284	963.215	963.146	963.077	963.009	962.940	962.871	962.802	962.733	962.664
94	962.595	962.526	962.457	962.387	962.318	962.249	962.180	962.110	962.041	961.971
95	961.902	961.832	961.762	961.693	961.693	961.553	961.483	961.414	961.344	961.274
96	961.204	961.134	961.064	960.993	960.923	960.853	960.783	960.712	960.642	960.572
97	960.501	960.431	960.360	960.289	960.219	960.148	960.077	960.006	959.936	959.865
98	959.794	959.723	959.652	959.581	959.510	959.438	959.367	959.296	959.225	959.153
99	959.082	959.010	958.939	958.867	958.796	958.724	958.653	958.581	958.509	958.431
100	958.365									

Figure 2: Density of water from 0°C to 100 °C

Appendix (E)

TABLE 4.5 Summary of useful empirical equations for calculating friction factors and heat transfer coefficients in flow over flat or slightly curved surfaces at zero angle of attack[a]

Coefficient	Equation	Conditions
	Laminar Flow	
Local friction coefficient	$C_{fx} = 0.664Re_x^{-0.5}$	$Re_x < 5 \times 10^5$
Local Nusselt number at distance x from leading edge	$Nu_x = 0.332Re_x^{0.5}Pr^{0.33}$	$Pr > 0.5$, $Re_x < 5 \times 10^5$
	$Nu_x = 0.565(Re_xPr)^{0.5}$	$Pr < 0.1$, $Re_x < 5 \times 10^5$
Average friction coefficient	$\bar{C}_f = 1.33Re_L^{-0.5}$	$Re_L < 5 \times 10^5$
Average Nusselt number between $x = 0$ and $x = L$	$\overline{Nu}_L = 0.664Re_L^{0.5}Pr^{0.33}$	$Pr > 0.5$, $Re_L < 5 \times 10^5$
	Turbulent Flow	
Local friction coefficient	$C_{fx} = 0.0576Re_x^{-0.2}$	$Re_x > 5 \times 10^5$, $Pr > 0.5$
Local Nusselt number at distance x from leading edge	$Nu_x = 0.0288Re_x^{0.8}Pr^{0.33}$	
Average friction coefficient	$\bar{C}_f = 0.072[Re_L^{-0.2} - 0.0464(x_c/L)]$	$Re_L > 5 \times 10^5$, $Pr > 0.5$
Average Nusselt number between $x = 0$ and $x = L$ with transition at $Re_{x,c} = 5 \times 10^5$	$\overline{Nu}_L = 0.036Pr^{0.33}[Re_L^{0.8} - 23{,}200]$	

[a]Applicable to low-speed flow (Mach number <0.5) of gases and liquids with all physical properties evaluated at the mean film temperature, $T_f = (T_s + T_\infty)/2$.

Figure 1: Equations for flow over flat plate

TABLE 1–1

The thermal conductivities of some materials at room temperature

Material	k, W/m · °C*
Diamond	2300
Silver	429
Copper	401
Gold	317
Aluminum	237
Iron	80.2
Mercury (l)	8.54
Glass	0.78
Brick	0.72
Water (l)	0.613
Human skin	0.37
Wood (oak)	0.17
Helium (g)	0.152
Soft rubber	0.13
Glass fiber	0.043
Air (g)	0.026
Urethane, rigid foam	0.026

*Multiply by 0.5778 to convert to Btu/h · ft · °F.

Figure 2: The Thermal Conductivities of Some materials

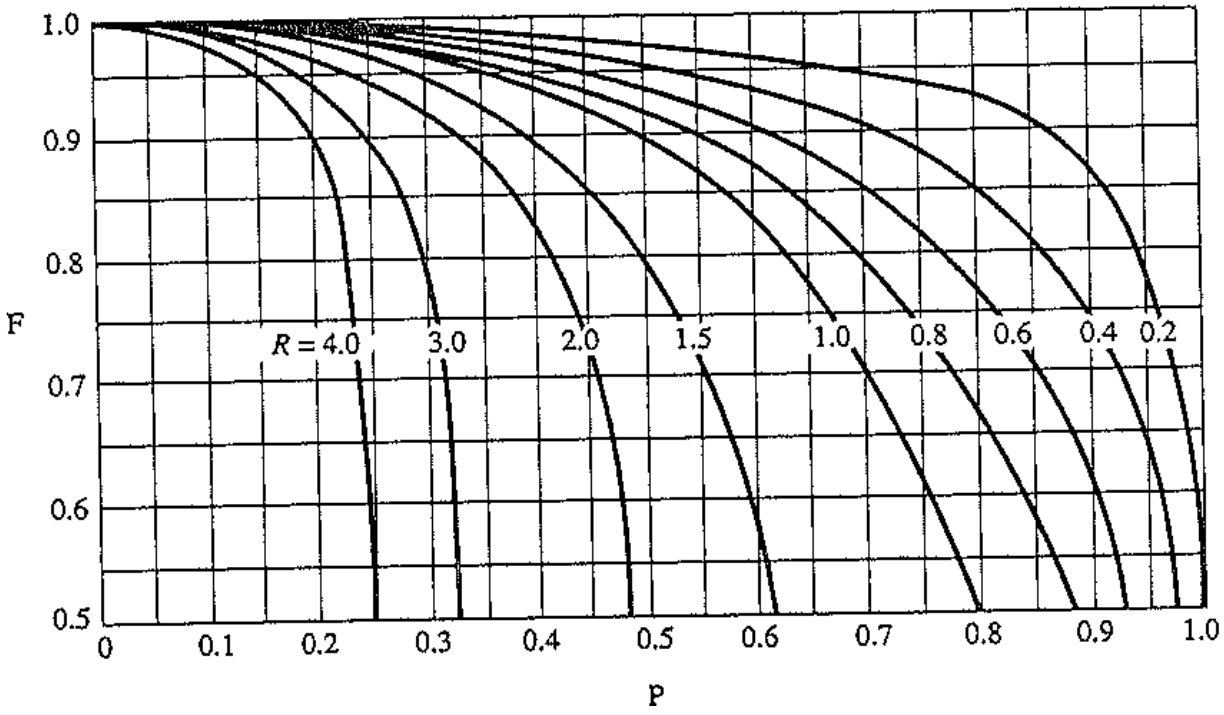

Figure 3: corrections factors plot for single pass cross flow exchanger both fluids unmixed.