Effect of Coolant Choices for Liquid Cooled Engines

Presented at Rotary Roundup

Shady Bend, FL (flood)

Lake City, FL

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Outline of Topics Covered

- How much heat?
- Where does the heat go?
- How heat is transferred
  - Conduction
  - Convection
  - Radiation
- Fluid properties and considerations
- Water pump characteristics

Heat load proportional to horsepower

- 100 HP = 254,670 Btu/hr
- ~28% is useful work, rest is heat
- 255K /0.28 = 910K Btu/hr fuel input, to be rejected i you are making ~100 HP =655K Btu/hr
- Where it goes --
  - Exhaust (42%) 381K
  - Oil (7%) 63.7K
  - Coolant (17%) 155K
  - Other (6%) 55K

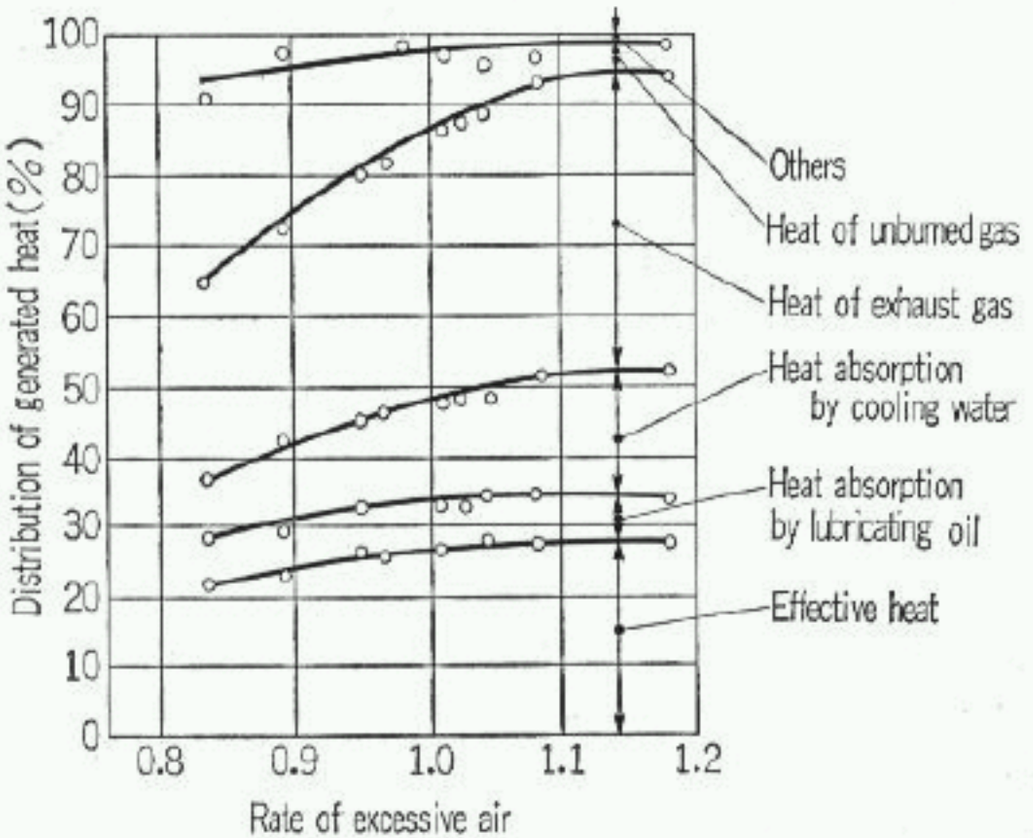
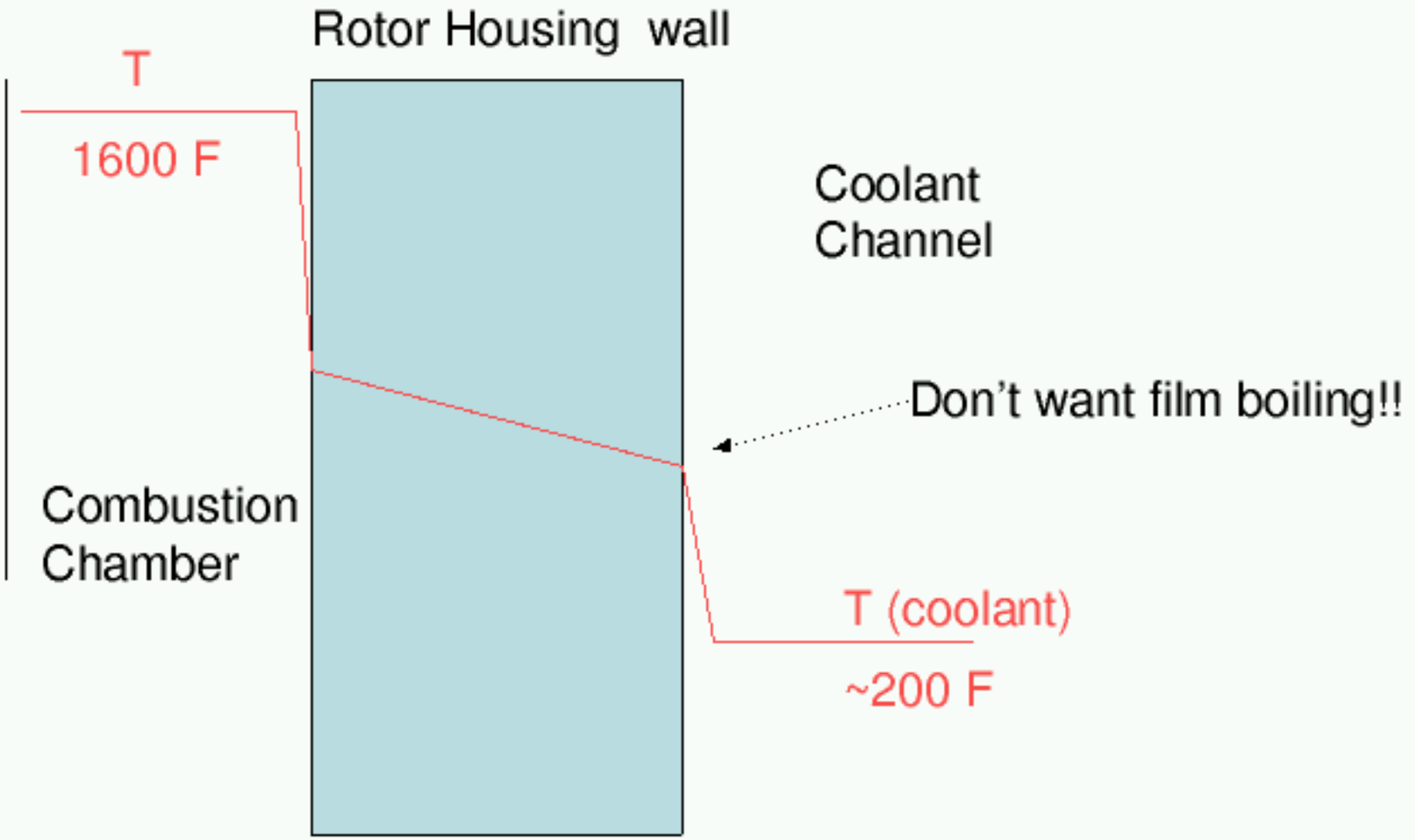


Fig. 4.5 Heat balance of rotary engine

The heat must be rejected to the air – (duh!)

- With air-cooled aircraft engine, path is direct – Cylinder wall to air
- Water cooled engine path is longer – cylinder to water, water to heat exchanger surface, surface to air
- Available Temperature driving force is less for water cooled engine

Inside the engine heat transfer



Coolant Properties make a difference

- NACA report #853
- Measured head and wall temperatures
- Varied flow rate and coolant composition
- Desired properties
  - High **k** (thermal cond)
  - High **Cp** (heat capacity
  - Low μ (Viscosity)

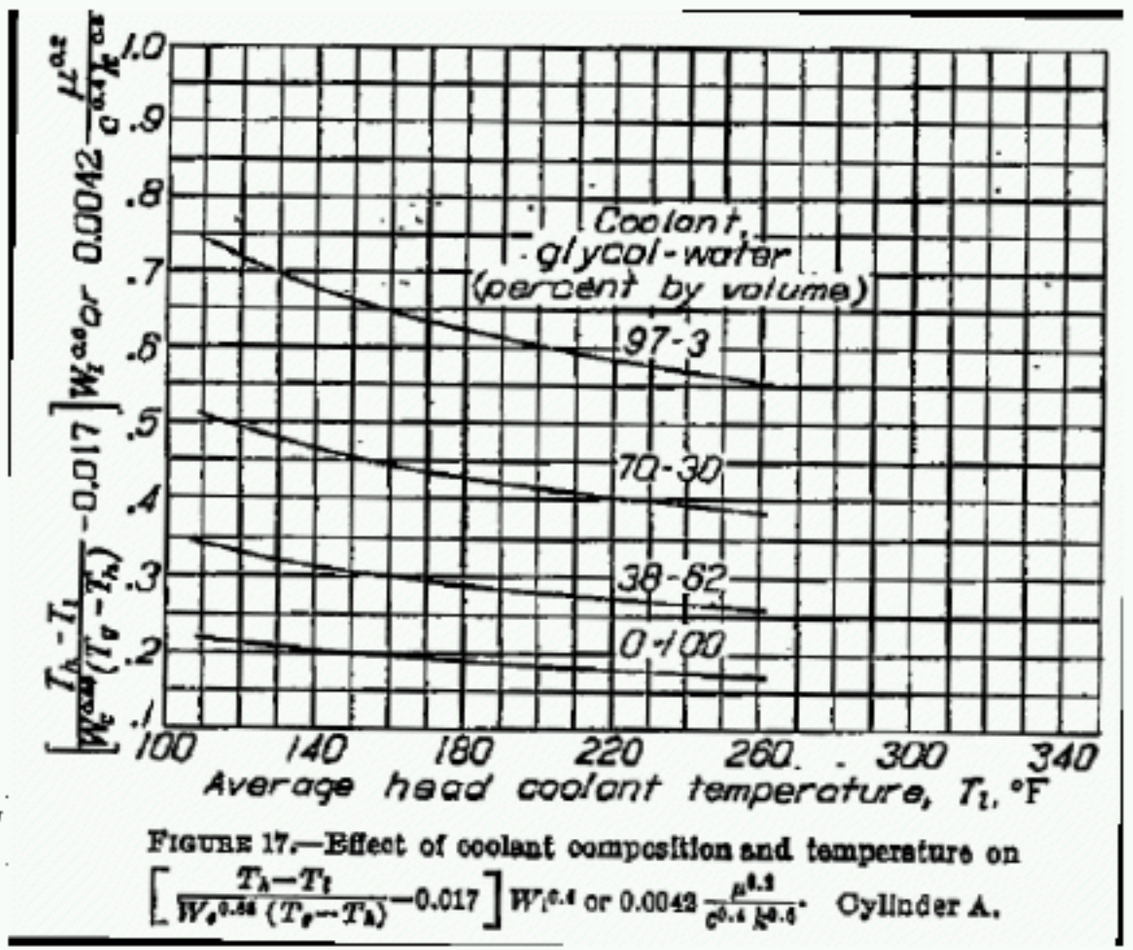


FIGURE 17.—Effect of coolant composition and temperature on $\left[\frac{T_h-T_1}{W_e^{0.8}(T_e-T_h)}-0.017\right]W_t^{0.8}$ or $0.0042\frac{\mu^{0.8}}{c^{0.4}k^{0.6}}$. Cylinder A.

Flow velocity makes a difference

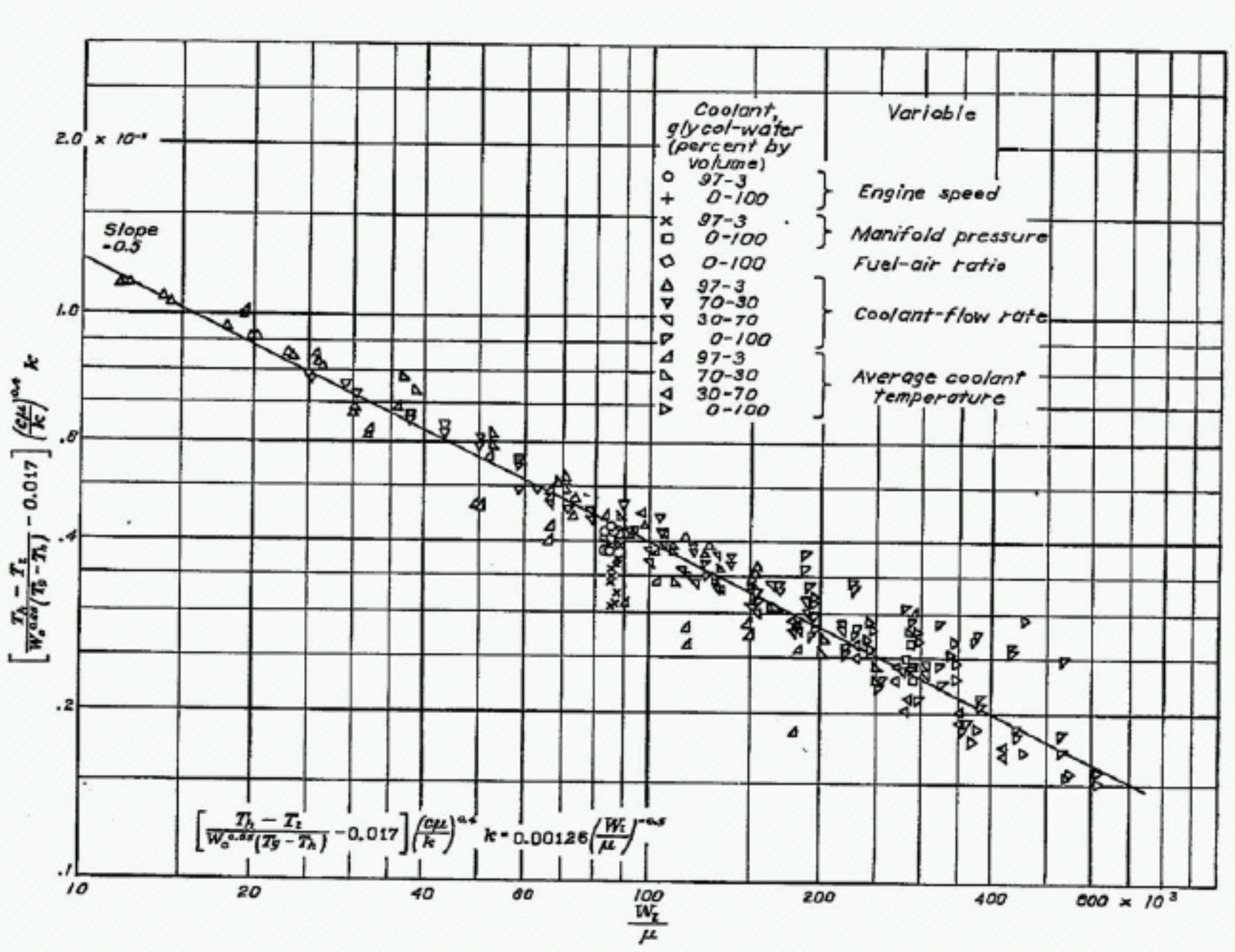
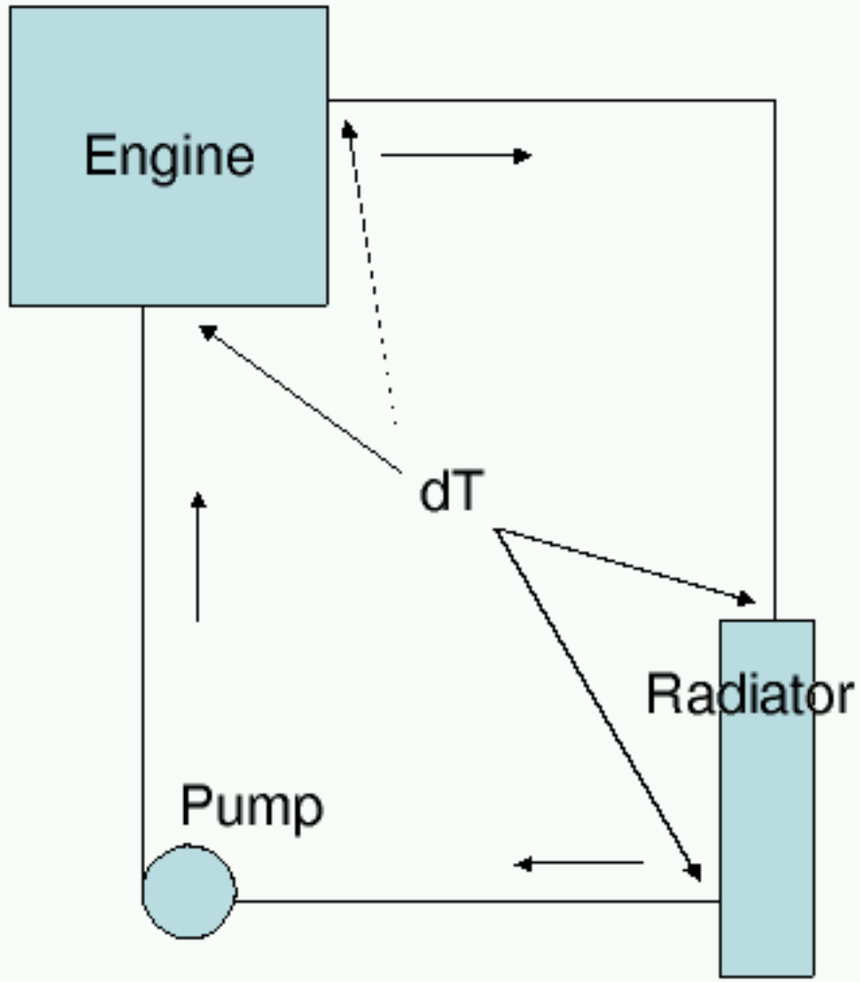


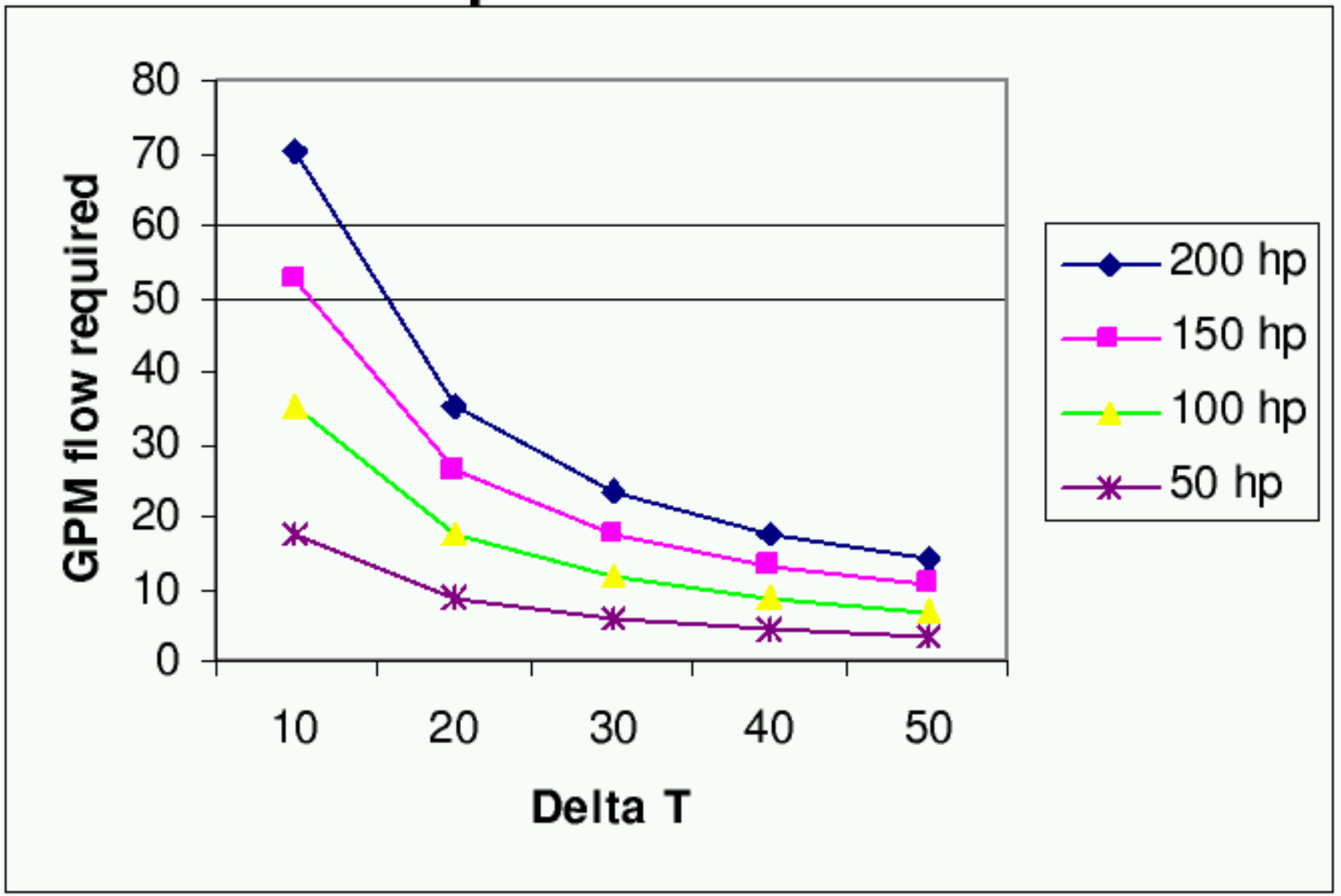
FIGURE 14.—Final correlation of average gas-side head temperatures for cylinder B.

Heat transfer - engine to radiator

- Want to transport the heat from core to radiator
- Done by coolant flow
- Q = m(Cp)dT
  - m is mass flow #/hr
  - Cp is heat capacity
  - dT is temperature rise
- dT(rad) = dT(engine)



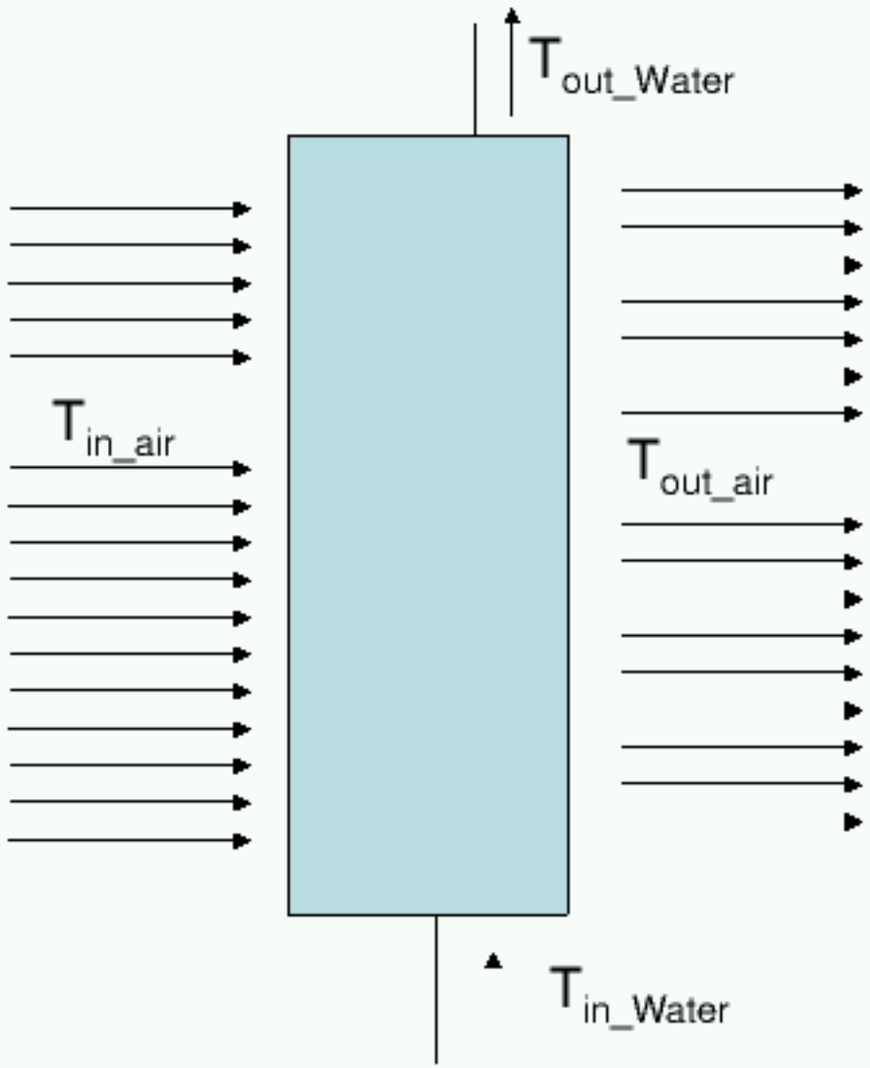
Sample calculation



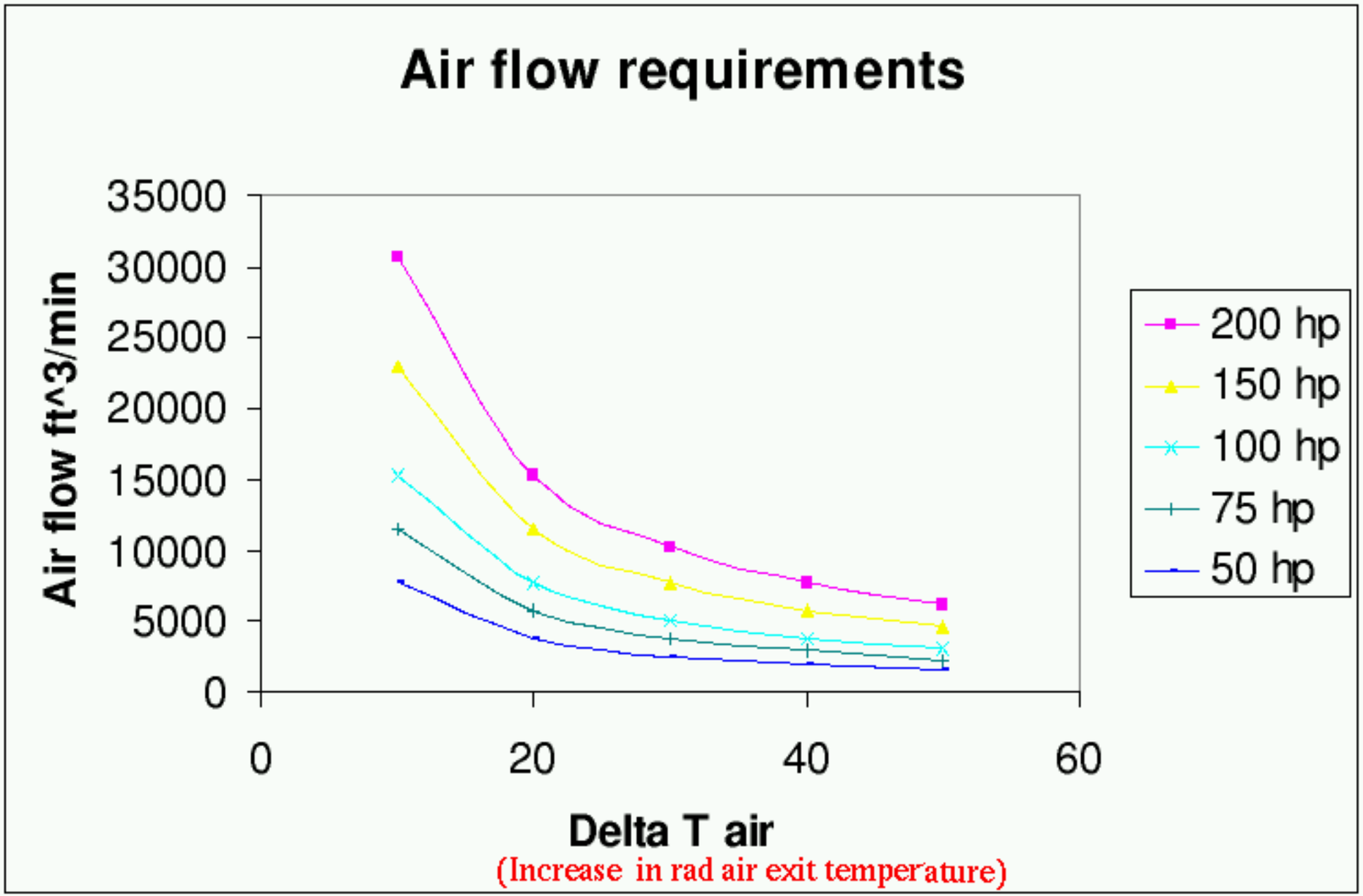
50% glycol, Cp = 0.87, density = 8.47#/gal

Heat transfer – radiator to air

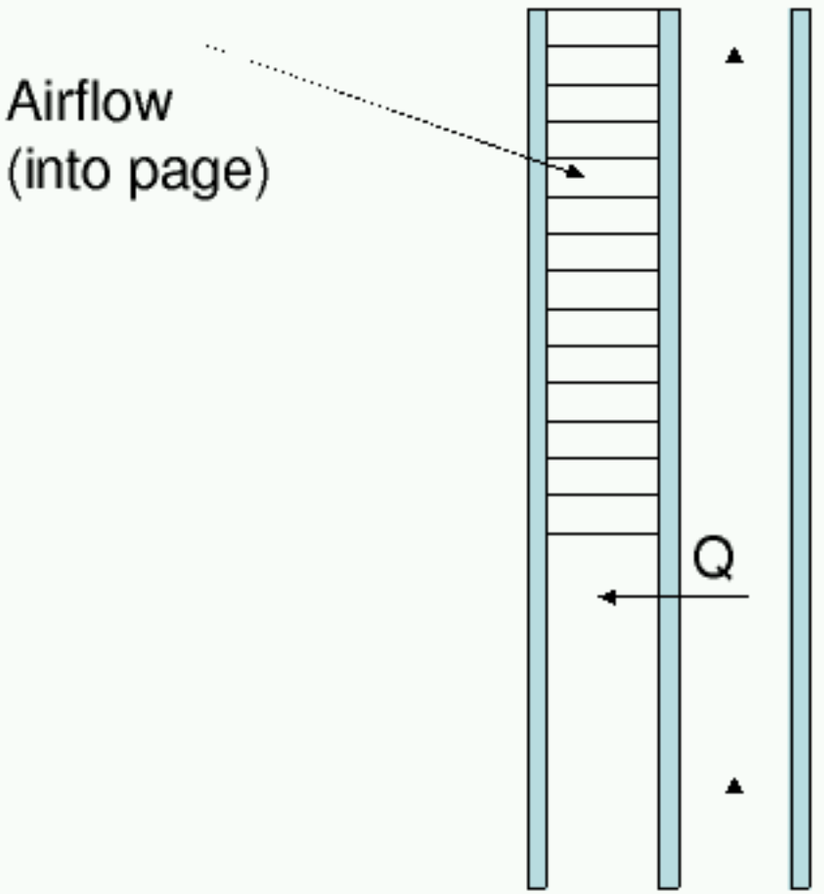
- Heat lost by water = heat picked up by air
- $Q_{water} = Q_{air}$
- $Q_{water} = m_w * Cp_w * dT_w$
- $Q_{air} = m_a * Cp_a * dT_a$
- $T_{out_air} < T_{in_water}$
- $T_{out_water} > T_{in_air}$
- $Cp_w >> Cp_a$
- Therefore, $m_a > m_w$



How much air?


Air flow requirements
Air flow ft^3/min
35000
30000
25000
20000
15000
10000
5000
0
0
20
40
60
Delta T air
(Increase in rad air exit temperature)
200 hp
150 hp
100 hp
75 hp
50 hp

Heat transfer – radiator to air



- Film coefficient from water to metal
  $h_w = Nu^*k/(4r_h)$
- Conduction through metal and metal fins
  k = metal property, fin effectiveness
- Film coefficient on air side
  $h_a = St^*G^*C_p$
- Overall heat transfer resistance
  $1/U = 1/h_a + x/k + 1/h_w$
- Overall heat transfer coefficient
  $U = 1/(1/h_a + x/k + 1/h_w)$
  U [Btu/hr*ft^2]
- $Q = U^*A^*(T_h - T_c)$

So for best performance you want

- High k
  - Aluminum or copper for walls and fins
  - High k for the fluid also
- High Cp (water > glycol mix > glycol)
- Low Viscosity
- Lots of surface area on air side
- Max temperature difference between water and air

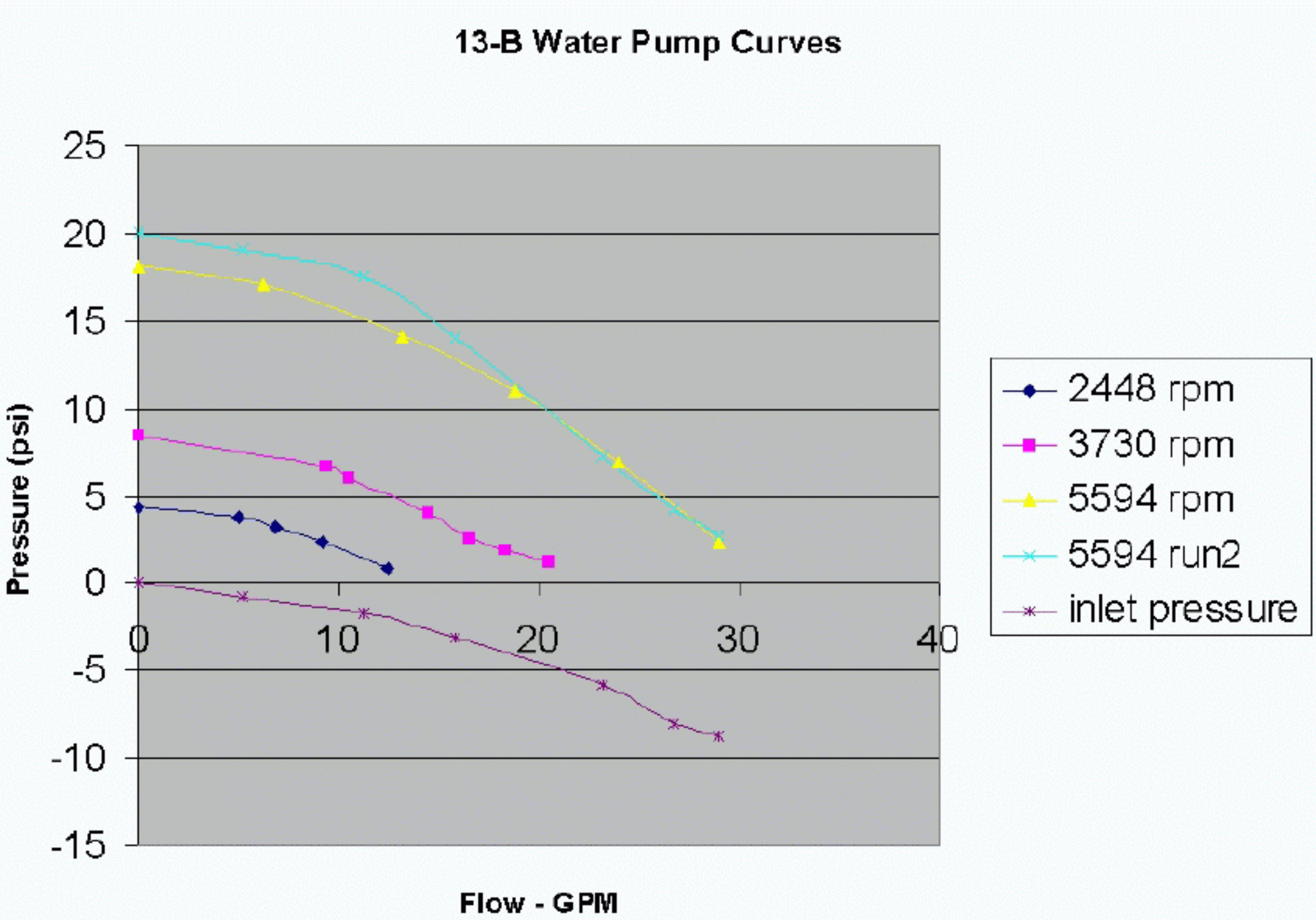
What about other fluids

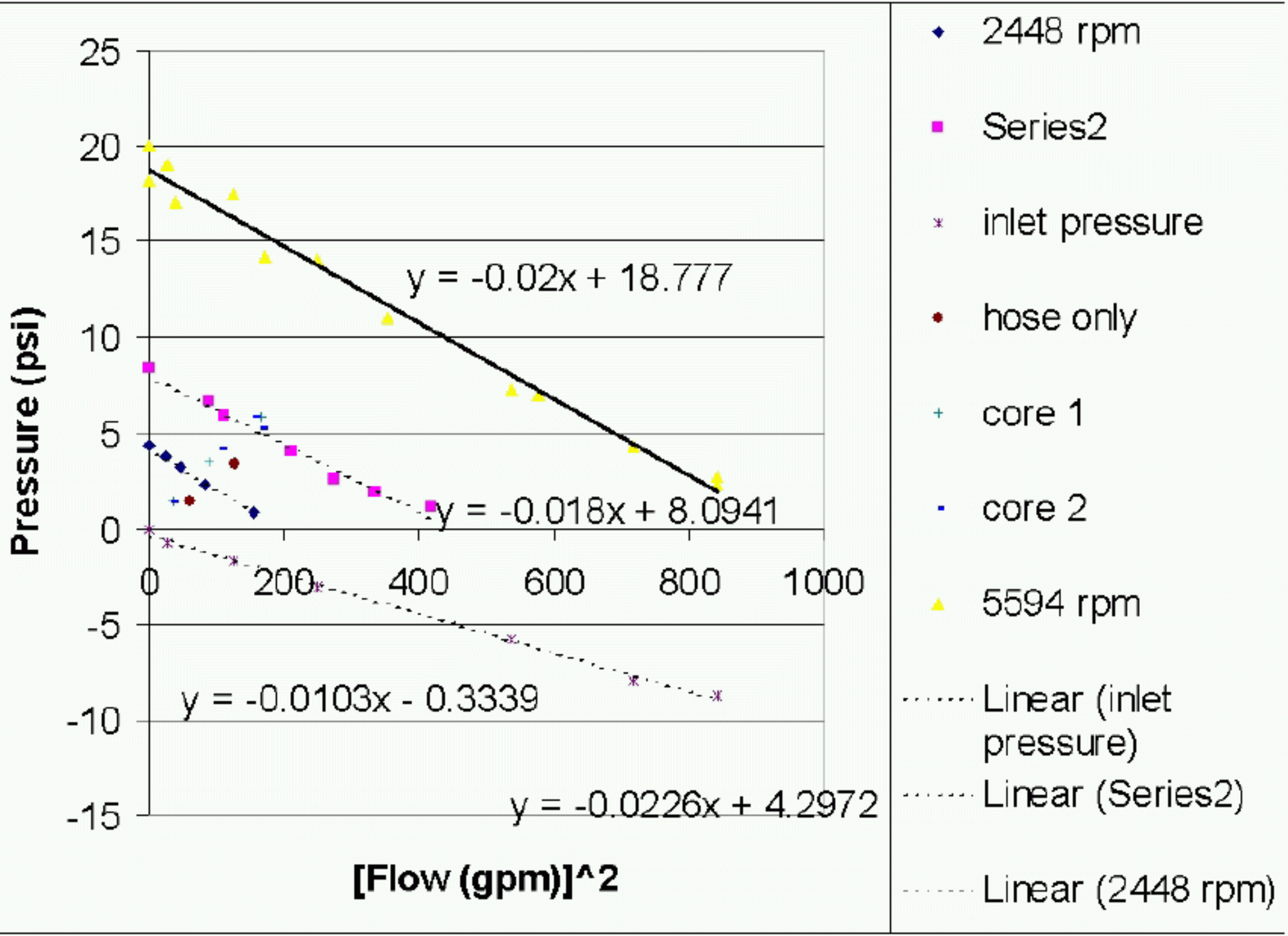
- Oil
  - Generally has higher viscosity, lower C_p, lower k
  - Mazda oil cooler has 'turbulence enhancers' to improve performance
- Evans Coolant (Propylene Glycol)
  - Generally has higher viscosity, lower Cp, lower k
  - Has *some* advantages IF you can run hotter (we can't)

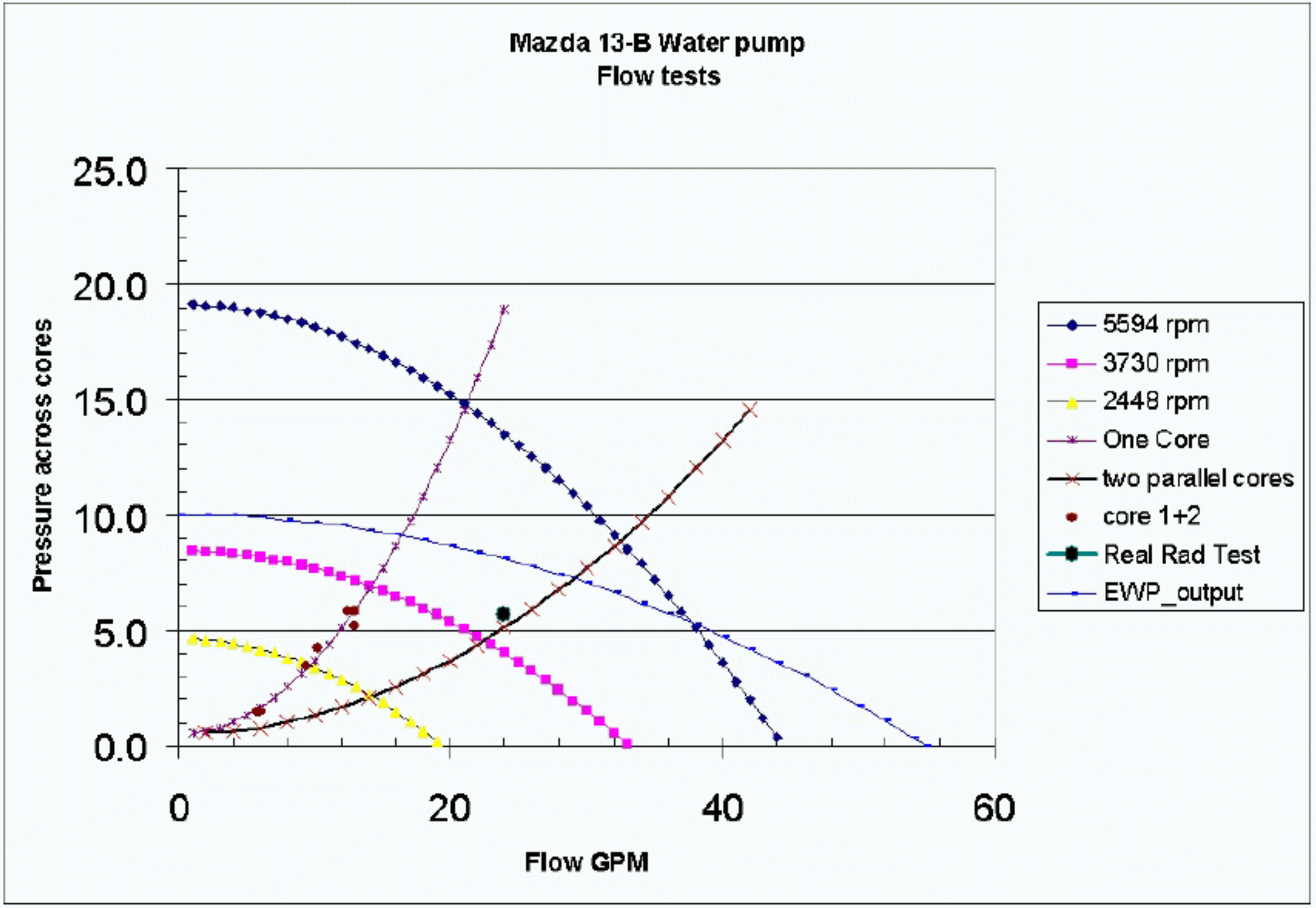
Some fluid properties

Table 2-4. Candidate Fluids

Fluid	°F Use Range	Pour Freeze °F	Boil °F	Flash °F	Fire °F	Auto IGN °F	Min. Pump Temp 300 CP	Cp BTU/lb°F 200°F	Cp BTU/lb°F 400°F	Viscosity ft²/HR 200°F	Viscosity ft²/HR 400°F	Density 16/ft³ 200°F	Density 16/ft³ 400°F	Thermal Cond. BTU ft/HR ft² °F 200°F	Thermal Cond. BTU ft/HR ft² °F 400°F	Part. Press. 400°F PSIA	1977 Sell Price
Dowtherm A	+ 55 - 750	54 F	495	255	275	1150		.426	.500	.0428	.0159	62.46	56. 7	.0765	.0685	≈ 6.0	
Dowtherm C	+ 12 - 650	- 18 P	575	305	315	>1030		.420	.478	.1076	.0277	65.24	59.62	.0742	.0720	≈ 1.7	
Dowtherm HP	+ 15 - 550	15°P / 0 F	695	420	460	880		.520	.640	1.156	.256	51.77	46.78	.0755	.0705	≈ .3	
Dowtherm J	-100 - 575	-100 F	358	145	155	806	-100	.494	.595	.098	.045	50.12	44.36	.0730	.0656	≈32.0	
Therminol 44	- 60 - 425	- 80 P	640	405	438	705	- 20										
55	0 - 600	- 40 P	- est	355	410	675	+ 25	.520	.620	.1067	.0455	52.36	47.87	.0753	.0692		8.20
60	- 60 - 600	- 90 P	600	310	320	835	- 35	.445	.543	.0677	.0238	59.1	54.6	.0731	.0681	1.26	2.80
66	0°- 650	- 18 P	675	355	382	705	40	.430	.530	.1712	.0350	59.30	53.70	.0685	.0657		7.50
Sun Vis 701		- 20 P		400				.53	.64	.186	.049	50.8	46.5	.0750	.0705		7.50
Humble Therm 500	- 5 - 600	+ 15 F	720 / 950	425	475			.625	.533	.2441	.0564	50.79	46.42	.0750	.0705		1.25
Caloria HT43	+ 15 - 600	+ 15 P		400				.461	.542	.2712	.0577	58.84	52.86	.0561	.0648	≈.77	1.25
Mobiltherm 600	- 5 - 600	0 P	650	350	390			.438	.532	.2710	.0543	56.27	52.16	.0675	.0631		
Sun 21	0 - 600	0 P		415				.535	.650	.282	.053	51.46	47.40	.0733	.0683		1.25
SF-81(50)		-120 P	None	>600	>640	815		.456	.478	.0241	.0103	54.71	48.16	.0645	.048		12.00
SF-96(100)		- 67 P	None	>600	>640	850		.394	.430	.0384	.0144	55.69	49.27	.0645	.048		≈18.00
UCON 500	0 - 500	- 35 P		500	750	750		.52	.56	.446	.132	60.87	56.69	.089	.081		
Therminol 88	293 - 800	293 F	700 est	375	460	>1000											
Water		32°F	212	None	None	None	32°	1.00	1.08	.0123	.0061	60.00	53.65	.392	.382	250	
50% Water Glycol		- 34 F	225	None	None	903	-34	.87	≈ .94	.0287	.0081	63.43	≈56.89	.260	≈.260		
100% Glycol		- 8 F	326	270		856	- 8	.64	≈ .83	.0860	.0223	66.17	59.75	.135	≈.090		3.50
UCON XHTF-2		- 55 F						.49	.55	.066							
UCON XHTF-4		- 20 P						.49	.55	.164							
DURO S-150		- 25 P	715	400	450			.52	.63	.233	.054	51.46	42.47	.068	.0595		1.25
DURO S-105		- 20 P		370	420					.167	.043						1.25
Ideal Plusoil		+ 10 P															1.00
Sun Vis 916		- 20 P						.53	.64	.225	.052	50.83	46.47	.0750	.0700		1.25
Sun Vis 700		- 20 P		395				.53	.64	.213	.048	50.8	46.5	.0745	.0700		1.25


13-B Water Pump Curves
25
20
15
10
5
0
-5
-10
-15
Pressure (psi)
0
10
20
30
40
Flow - GPM
2448 rpm
3730 rpm
5594 rpm
5594 run2
inlet pressure


25
20
15
10
5
0
-5
-10
-15
0
200
400
600
800
1000
Pressure (psi)
[Flow (gpm)]^2
y = -0.02x + 18.777
y = -0.018x + 8.0941
y = -0.0103x - 0.3339
y = -0.0226x + 4.2972
2448 rpm
Series2
inlet pressure
hose only
core 1
core 2
5594 rpm
Linear (inlet pressure)
Linear (Series2)
Linear (2448 rpm)


Mazda 13-B Water pump
Flow tests
Pressure across cores
25.0
20.0
15.0
10.0
5.0
0.0
0
20
40
60
Flow GPM
5594 rpm
3730 rpm
2448 rpm
One Core
two parallel cores
core 1+2
Real Rad Test
EWP_output