Laminova Oil to Water Heat Exchanger

ME 271, Spring 2021: Computational Fluid Dynamics
San Jose State University

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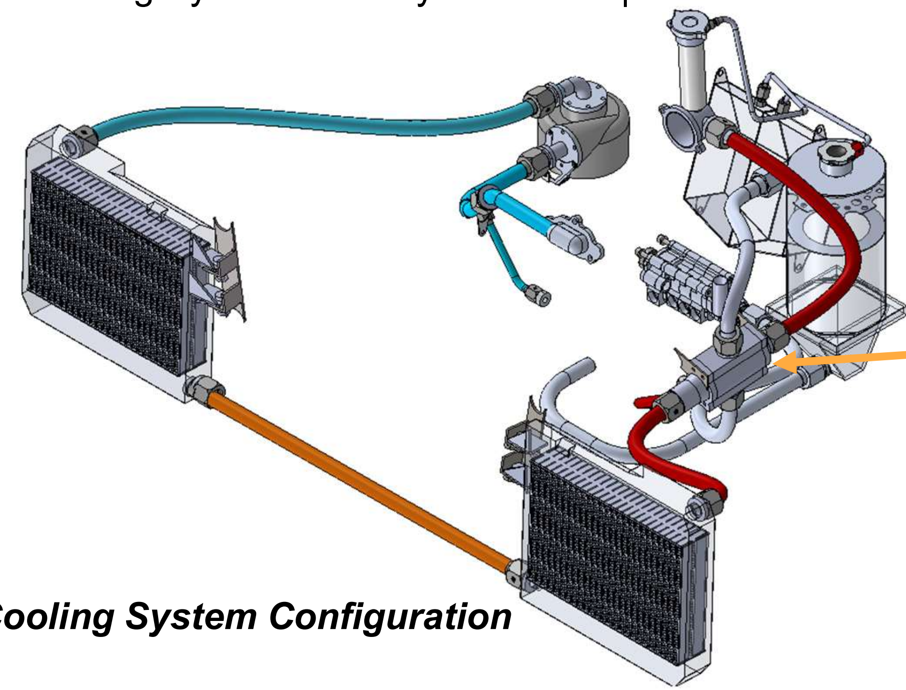
Background

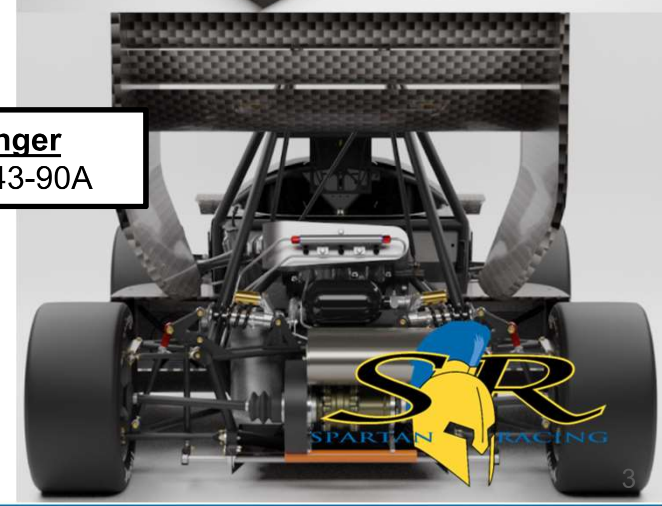
SJSU Formula Racing Team: SR12B

Oil Cooling System: Factory Oil Cooler | External Oil Cooler

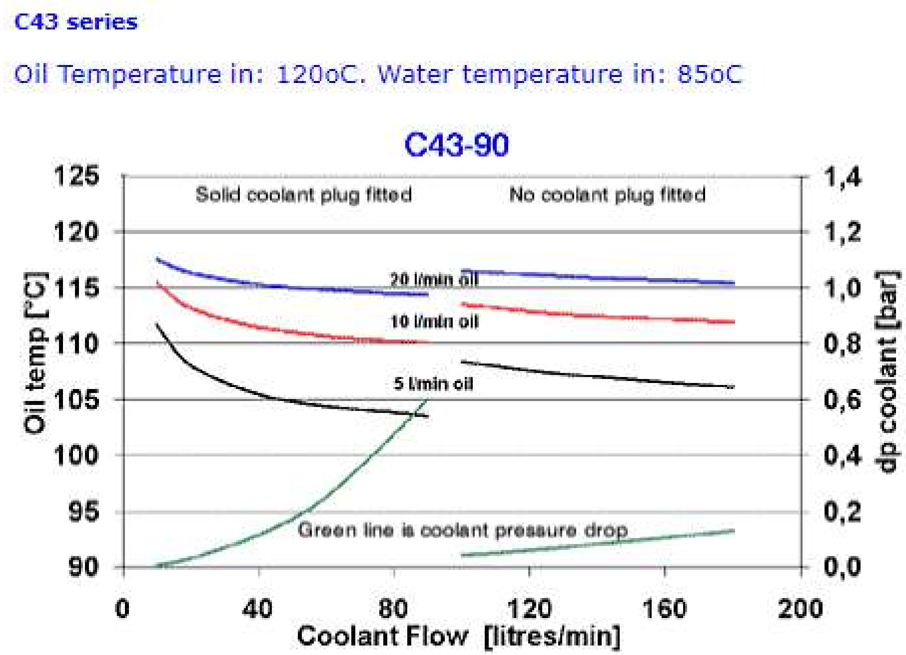


<u>Heat Exchanger</u>
Laminova C43-90A

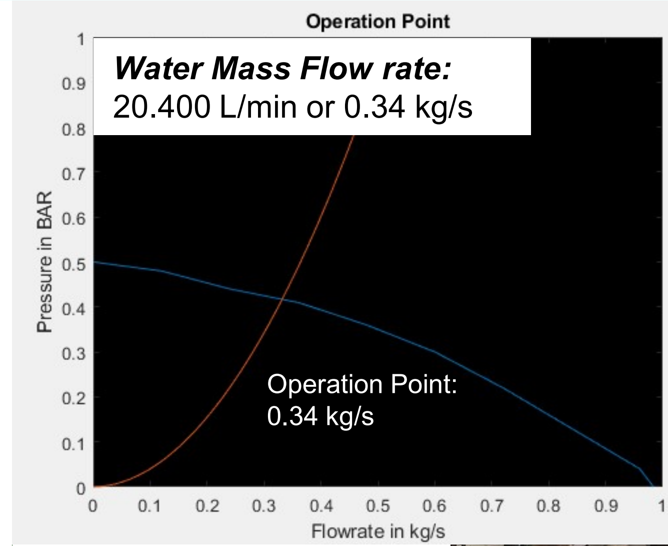
Cooling System Configuration



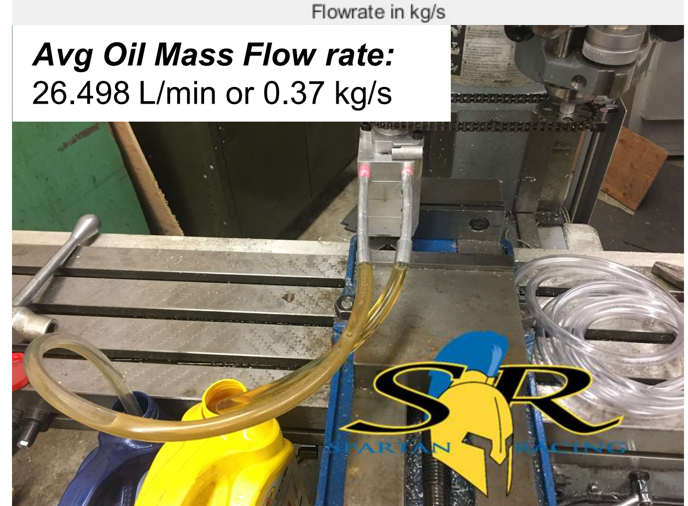
Background: Research



Oil Temp as a Function of Flowrate
Source: www.thinkauto.com/lamgraphs.htm.



Water Mass Flow rate:
20.400 L/min or 0.34 kg/s

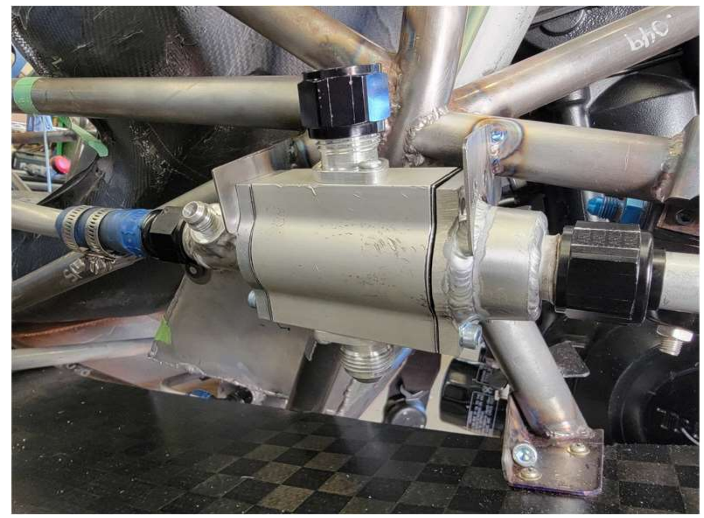


Avg Oil Mass Flow rate:
26.498 L/min or 0.37 kg/s

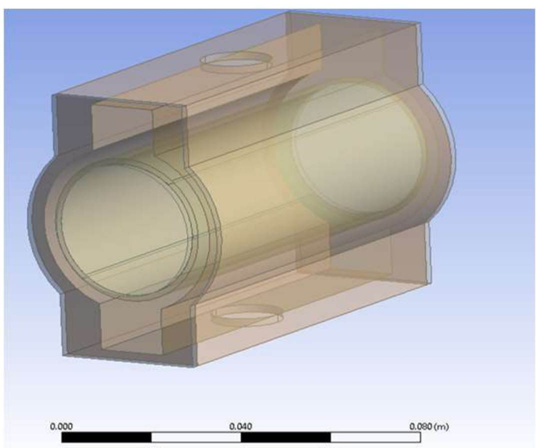
Objectives

Using a simplified model, the team would like to:

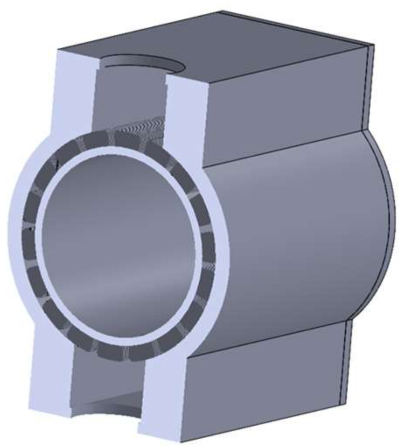
1. Observe velocity streamlines for oil
2. Analyze the temperature differences in the fluids
3. Determine heat rejected to the water



Laminova C43-90A



Geometry: Simplified Model

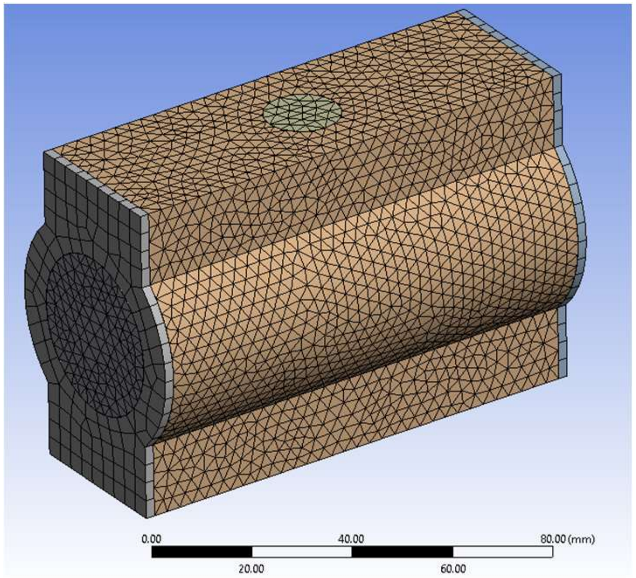


CAD: Finned Core

Pre-Processing: Mesh Quality

Mesh-Metric			
Metric	Min	Max	Avg
Aspect Ratio	1.1583	10.083	1.8745
Orthogonality	0.12976	0.99999	0.76809
Skewness	1.3057e-10	0.87024	0.2324

Mesh
Nodes: 20,312 Elements: 77,129 Element Size: 4 mm Geometry: Triangular



Mesh Refinement:
Body Meshing, Sphere of influence

Pre-Processing: Mesh y+

- y+ value of 63.9 determined for the water, which lies between 30 and 300
- y+ value not determined for the oil due to difficulties in determine the skin friction around a cylinder

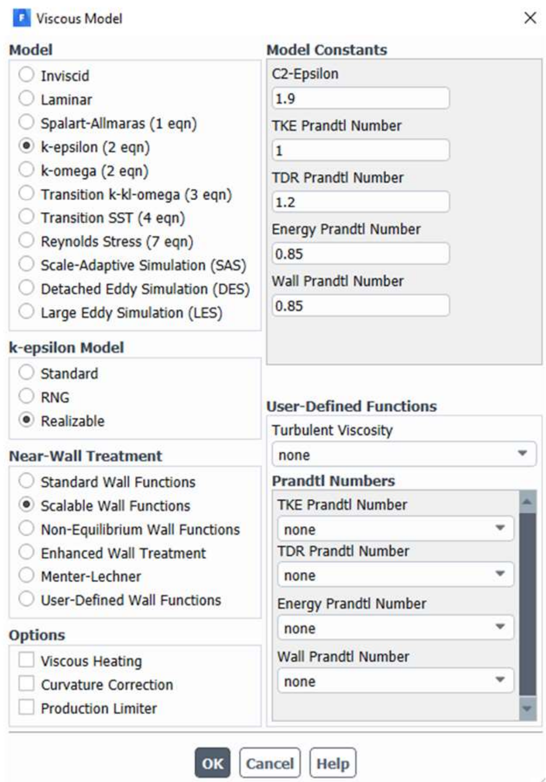
rho_oil	859	kg/m^3	D_i	0.034798	m		
rho_water	988.2	kg/m^3	D_o	0.034798	m		
y	0.004	m	kinematic viscosity, water	3.255E-07	m^2/s		
m_w	0.34	kg/s	v_w	0.3617726	m/s		
m_o	0.37	kg/s					
ReD	38675.76						
Cf	0.000414						
tau_wall	0.026753						
u_tau	0.005203						
y+	63.93964						

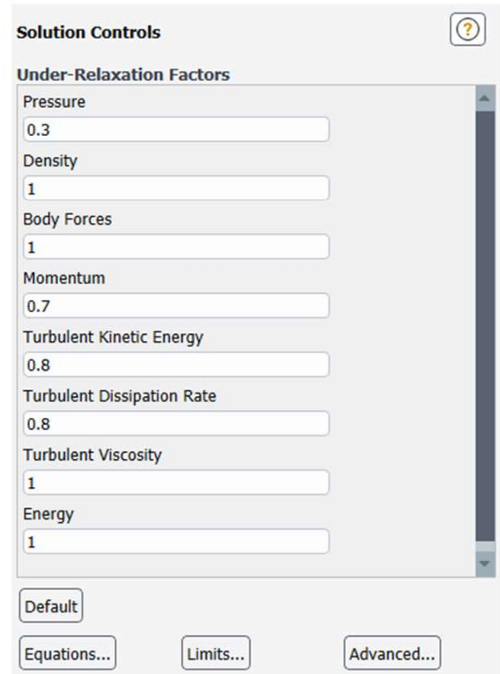
- For fully developed pipe flow $C_f = \frac{16}{Re_D} = 0.16$

Solving: Settings and Initializations

Named Selections	
Inlet	Oil-Inlet Water-Inlet
Outlet	Oil-Outlet Water-Outlet
Internal	Interior-Oil Interior-Water
Wall	Oil-Shell Water Tube

Solutions Settings
Steady State Energy (on) Hybrid Initialization





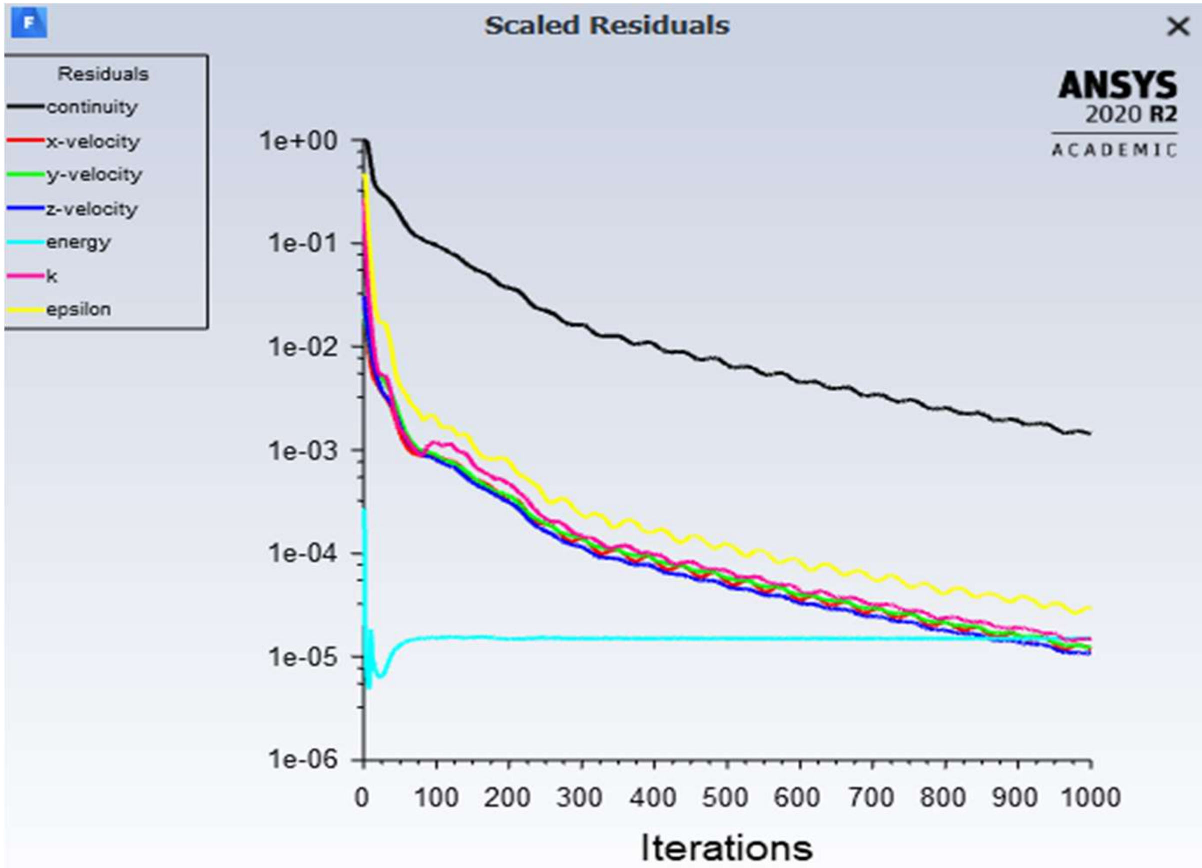
Relaxation

Solving: BCs and Fluid Properties

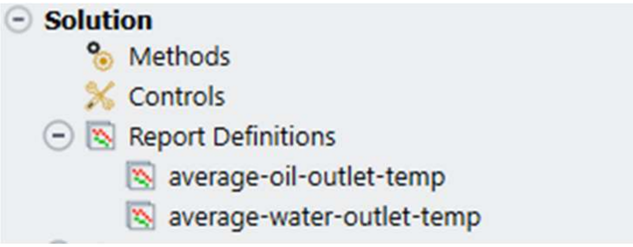
Boundary Conditions	
Water Inlet	Mass flow rate: 0.34 kg/s Inlet temperature: 90C
Oil Inlet	Mass flow rate: 0.37 kg/s Inlet temperature: 132.22C
Water/Oil Outlet	Pressure
Wall Oil Shell End Plates	Heat flux = 0
Wall Inner Water Tube	Convection: Output Parameter Freestream Temperature: 363.15K Material: Aluminum
Wall Outer Water Tube	Convection: Output Parameter Freestream Temperature: 405.37K Material: Aluminum

Fluid Properties	
Oil	Density: 859 kg/m^3 Cp = 3315 J/kgC
Water	Density: 988.2 kg/m^3 Cp = 4182 J/kgC

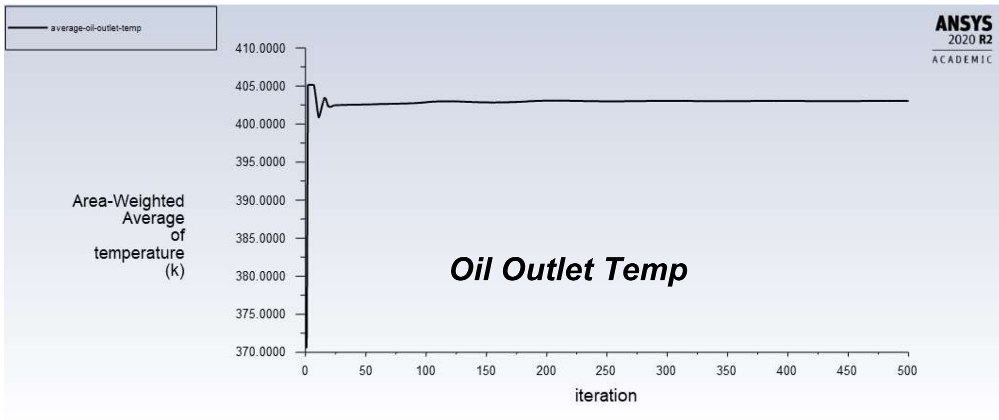
Solving: Residuals

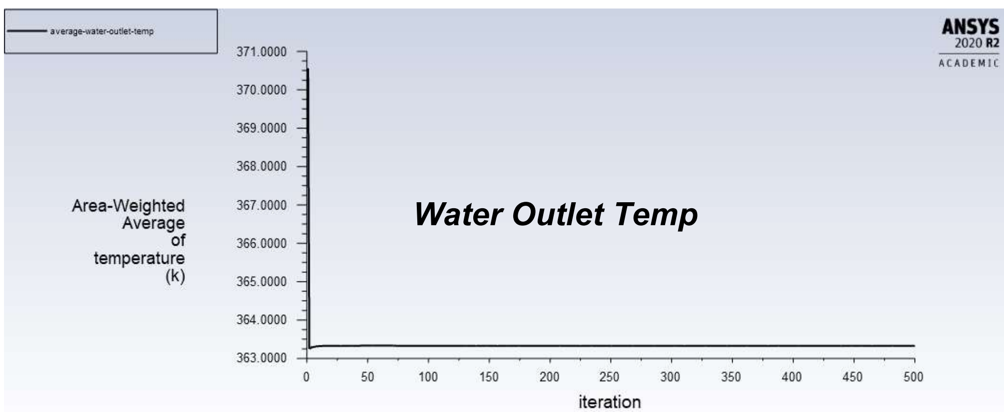


Report Definition:



Solving: Residuals, Outlet Temperatures






```
           Mass-Weighted Average                   (k)
-------------------------------- --------------------
                       oiloutlet            403.02945

           Mass-Weighted Average                   (k)
-------------------------------- --------------------
                     wateroutlet            363.32956
```

Average Temperatures at Outlet

Solving: Residuals – Heat Transfer Coeff.

Additional Report Definitions

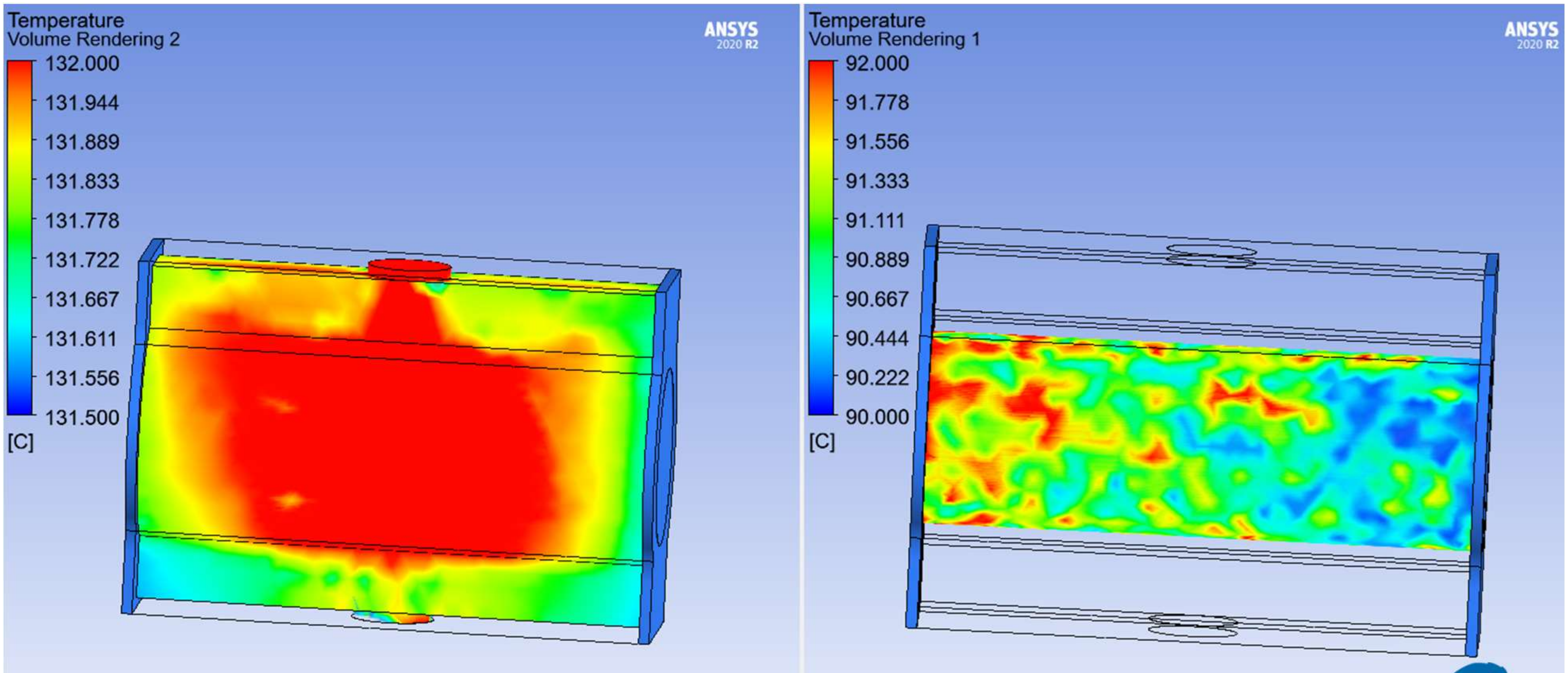
```
Calculation complete.

          Area-Weighted Average              (w/m2-k)
-------------------------------- -------------------
           contact_region_9-trg            250.71757

          Area-Weighted Average              (w/m2-k)
-------------------------------- -------------------
          contact_region_10-trg           -168.25412
```

Output Heat Transfer Coefficients

Water

Oil

Post Processing: Volume Rendering



Temperature Distributions, LHS: Oil and RHS: Water

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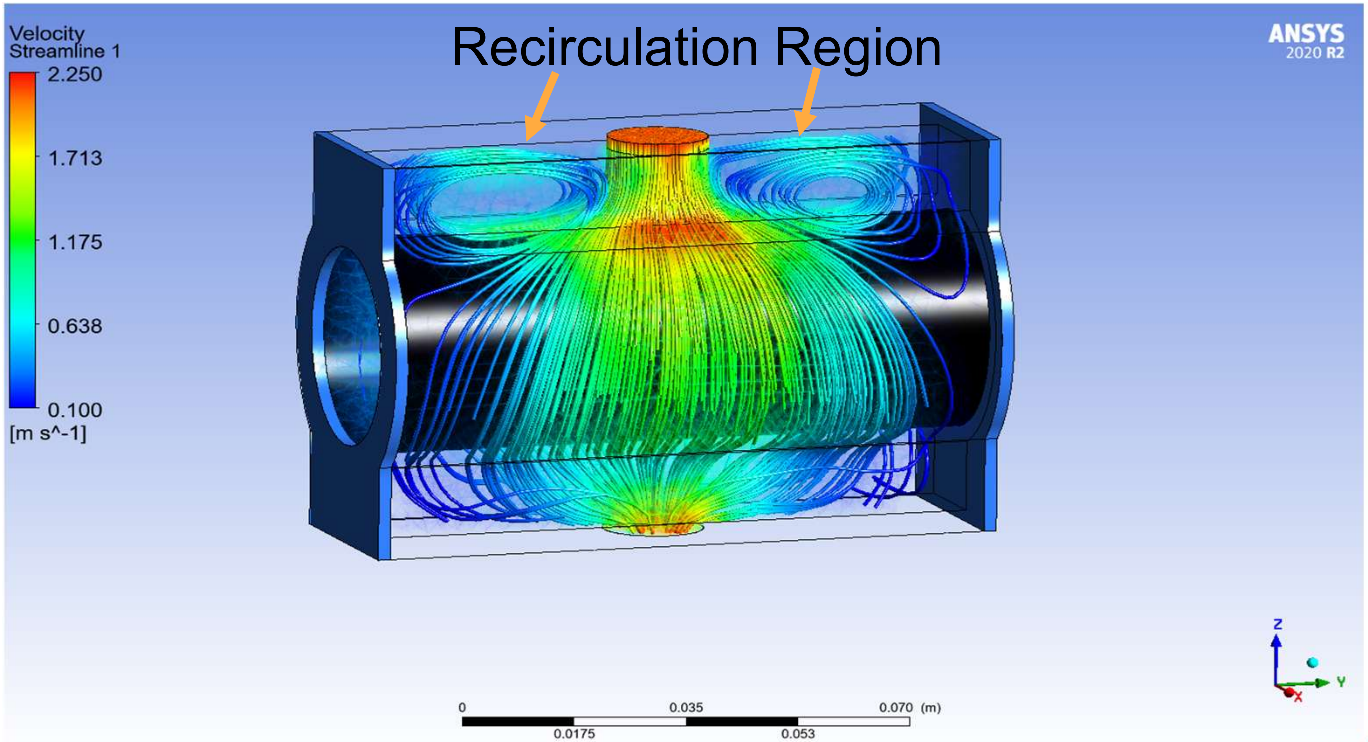
Post Processing: Velocity Streamlines



Velocity Streamlines of the Oil

Theoretical Calculations

D_o	0.037084	m	L	0.09779	m						
D_i	0.034798	m	A_s	0.011041663	m^2						
T_o,i	132.22	C	c_p,o	3315	J/kgK	m_o	0.37	kg/s	h_o	168.2541	W/m^2K
T_w,i	90	C	c_p,w	4182	J/kgK	m_w	0.34	kg/s	h_w	250.7176	W/m^2K

Q_max	51784.94	W
U	100.6852	W/m^2K
NTU	0.000906	
c	0.862626	
ε	0.000904	
Q_dot	46.83055	W
T_o,o	132.1818	C
T_w,o	90.03294	C
Simulation Results:		
Tw_o,sim	90.17967	
Q_dot	255.4692	W

$$\dot{Q}_{max} = C_{min} \Delta T_{max}$$

If $A_i \cong A_o$, $\dfrac{1}{U} = \dfrac{1}{h_i} + \dfrac{1}{h_o}$

$$\text{NTU} = \frac{UA_s}{C_{\min}} = \frac{UA_s}{(\dot{m}c_p)_{\min}}$$

$$c = \frac{C_{\min}}{C_{\max}}$$

3 *Cross-flow* (*single-pass*) Both fluids unmixed $\quad \varepsilon = 1 - \exp\left\{\frac{\text{NTU}^{0.22}}{c}\left[\exp\left(-c\text{NTU}^{0.78}\right) - 1\right]\right\}$

$$\dot{Q} = \epsilon \dot{Q}_{max}$$

$$\dot{Q} = C_c (T_{c,o} - T_{c,i})$$

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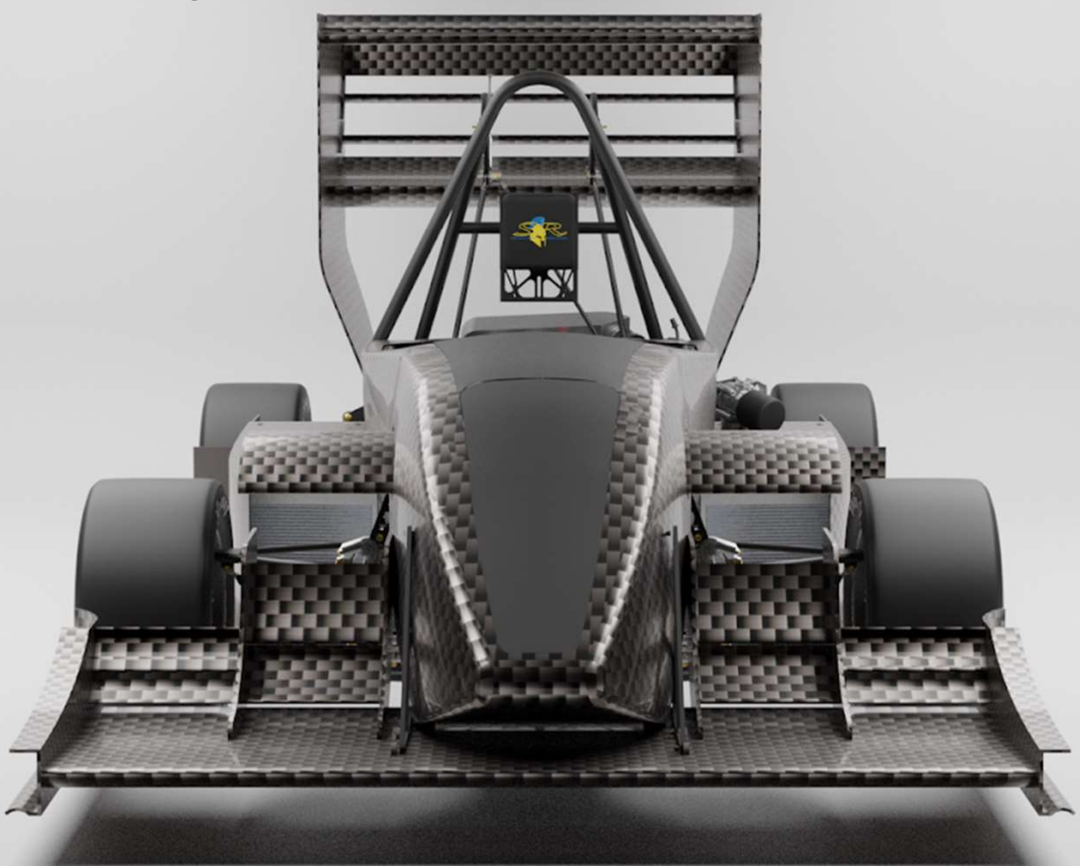
Conclusion and Future Works

Findings	
Low pressure region near the top	
Heat Transfer Rate Across Water Simulated: 255.4692 W Theoretical: 46.83 W	***Temperature Differences*** Oil: -2.34C Water: 0.17C

Improvements:
Account for system resistance in average oil mass flow rate
Run simulation with finned core
Verify convective heat transfer coefficients through on-car testing

Thank you for your time!



References

Çengel Yunus A., & Ghajar, A. J. (2015). *Heat and Mass Transfer: Fundamentals & Applications* (6th Edition). McGraw-Hill Education.

Dimensions of C43 range of coolers. (n.d.). www.thinkauto.com/lamgraphs.htm.

Powertrain. (2020). In *Formula SAE Rules 2021* (pp. 62-63). Warrendale, PA: SAE International.

Appendix A: MATLAB Pump Calcs (1 of 3)

```
clc;clear;
format compact

%Input Variables (mm, mm,mm ,m)
d_i = 19.05; e = 0.0013; z = 110.744; L = 5.08;
%Water Properties (m/s, kg/m^3 , N.s/m^2)
v_water = linspace(0,1.8,50); rho = 965.3; mu = 0.315*10^-3;
%Minor Losses (Unitless)
inlet = 7; outlet = 7; deg90_smooth = 0; deg90_miter = 2;
deg45_elbow = 4; deg180_return = 0;
%Static Outputs (m^2, unitless)
Area_pipe = pi()/4 * (19.05*10^-3)^2; e_d = e/d_i;
m_dot = rho * v_water * Area_pipe; %Dynamics- kg/s
%hardline
hardline_length = 150/39.37;
hardline_Dh = d_i*10^-3;
Reynolds_hardline = rho * v_water * hardline_Dh / mu;
ff = (-1.8*log(6.9./Reynolds_hardline + (e_d / 3.7)^1.11)).^(-1/2);
Minor_head_hardline = (2*0.8 + 2*1.05)*(v_water.^2/(2*9.81));
Major_head_hardline = ff.*(hardline_length/hardline_Dh).*v_water.^2/(2*9.81)
Total_hardline_pressure = Major_head_hardline + Minor_head_hardline
%Laminova
laminova_Dh = 0.038; laminova_length = 0.2608;
Reynolds_laminova = rho*v_water*laminova_Dh/mu;
e_d2 = e/laminova_Dh;
ff2 = (-1.8*log(6.9./Reynolds_laminova + (e_d2 / 3.7)^1.11)).^(-1/2);
Major_head_laminova = ff2.*(laminova_length/laminova_Dh).*v_water.^2/(2*9.81);
Minor_head_laminova = (0.8 + 1.05)*(v_water.^2/(2*9.81));
Total_laminova_pressure = Major_head_laminova + Minor_head_laminova
```

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Appendix A: MATLAB Pump Calcs (2 of 3)

```
%Radiator
rad_tube_height = 10/39.37; s_rad = 0.0024; l_rad = 0.0174;
rad_tube_Ac = s_rad*l_rad;
velocity_tubes = (m_dot/78) / (rho*s_rad*l_rad)
rad_tube_Perimeter = s_rad + l_rad;
rad_Dh = 4*rad_tube_Ac / rad_tube_Perimeter
Reynolds_rad = rho*velocity_tubes*rad_Dh/mu;
e_d3 = e/rad_Dh
ff3 = (-1.8*log(6.9./Reynolds_rad + (e_d3 / 3.7)^1.11)).^(-1/2);
Major_head_rad = ff3.*(rad_tube_height/rad_Dh).*velocity_tubes.^2/(2*9.81);

outlet_rad_tube = 78; inlet_rad_tube = 78;
Minor_head_rad_tube = (outlet_rad_tube*0.8 + inlet_rad_tube*1.05)*(velocity_tubes.^2/(2*9.81));

tank_height = 2.31 / 39.37;
tank_length = 10/39.37;
tank_depth = 1.57/39.37;
Dh_tank = 4*tank_length*tank_depth / (tank_length+tank_depth);
velocity_tank = m_dot / (rho*tank_length*tank_depth)
Reynolds_tank = rho*velocity_tank*Dh_tank/mu;
e_d4 = e/Dh_tank
ff4 = (-1.8*log(6.9./Reynolds_tank + (e_d4 / 3.7)^1.11)).^(-1/2);
Major_head_rad_tank = ff4.*(tank_height/Dh_tank).*velocity_tank.^2/(2*9.81);

outlet_rad_tank = 1; inlet_rad_tank = 1;
Minor_head_rad_tank = (outlet_rad_tank*0.8 + inlet_rad_tank*1.05)*(velocity_tank.^2/(2*9.81));

Total_rad_pressure = 2*(Major_head_rad + Minor_head_rad_tube + Minor_head_rad_tank + Major_head_rad_tank)
```

Appendix A: MATLAB Pump Calcs (3 of 3)

```
%Output
Net_head = (Total_hardline_pressure + Total_laminova_pressure +
Total_rad_pressure)*rho*9.81

%Converted values for Sys Resistance Curve
Net_head_Bar = Net_head * 10^-5
%m_dot_LitersPerMin = m_dot * 81.15

%EWP Pump Curve
pump_x = [0,10,20,30,40,50,60,70,80,82];
pump_x_kgs = pump_x * 0.012 %L/min to kg/s
pump_y = [0.50,0.48,0.44,0.41,0.36,0.30,0.22,0.13,0.04,0];

%Plots
plot(pump_x_kgs,pump_y)
hold on
plot (m_dot,Net_head_Bar)
hold off

xlabel('Flowrate in kg/s')
ylabel('Pressure in BAR')
title('Operation Point')
set(gca,'color',[0 0 0])
```

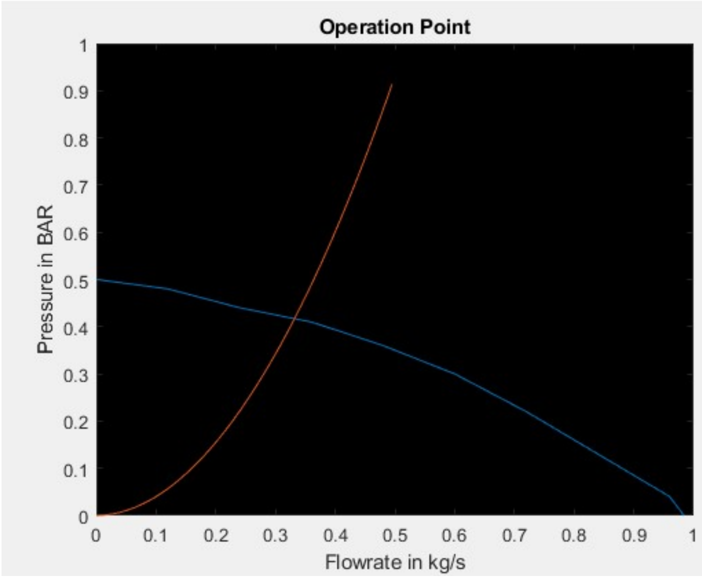

Figure 1: System resistance curve is in orange produced from the corresponding equations above. Blue curve is the pump performance curve of the selected pump. The operation point was determined to be 0.34 kg/s at the point of intersection