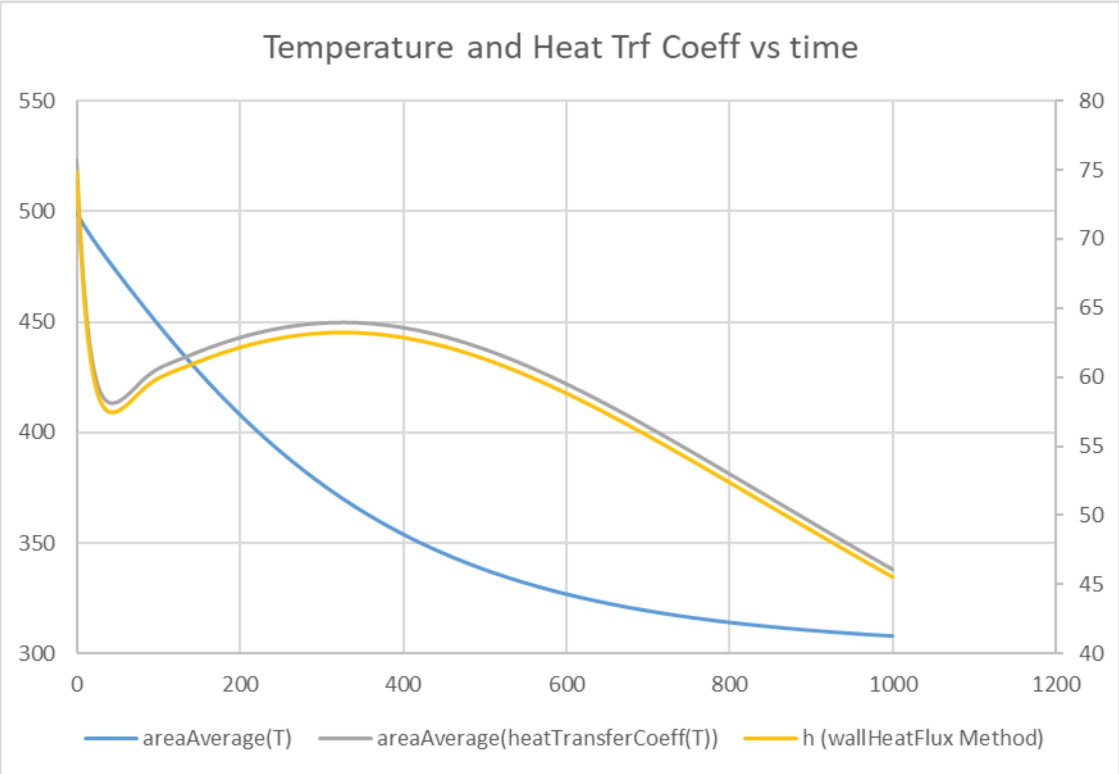
Hot Sphere in Oil Coarse Mesh Case

$$\int q \, dA = hA(T_f - T_s)$$

$$h = \frac{\int q dA}{A(T_f - T_s)}$$



Nusselt Number (Tf=300K)

$$Nu = \frac{hD}{k}$$

$$k_{fluid} = 0.1856 - 0.0002 * 300 = 0.1376 \frac{W}{m \cdot K}$$

$$D_{sphere} = \frac{3}{100} m$$

Prandtl Number (Tf=300K)

$$\Pr = \frac{\mu c_p}{k}$$

$$k_{fluid} = 0.1856 - 0.0002 * 300 = 0.1376 \frac{W}{m \cdot K}$$

Dynamic viscosity (300K)

	Dynamic Viscosity		T(K)
	Coefficient	T^n	300
first term	4.57E-17	7.29E+14	
second term	-1.42E-13	2.43E+12	
third term	1.83E-10	8100000000	
fourth term	-1.24E-07	27000000	
fifth term	4.71E-05	90000	
sixth term	-9.47E-03	300	
seventh term	7.89E-01	1	
dynamic viscosity	0.003756412		

$$\mu(300K) = 0.003756\ Pa\ s$$

Cp (300K)

	cp		T(K)
	Coefficient	T^n	300
first term	3.22E-08	8100000000	
second term	-5.51E-05	27000000	
third term	3.44E-02	90000	
fourth term	-6.49E+00	300	
fifth term	1.67E+03	1	
Cp (J/kgK)	1591.1103		

$$C_p = 1591.1103 \frac{J}{kg \cdot k}$$

Grasshof Number

$$Gr = \frac{g\beta(T_s - T_f)D^3}{\nu^2} = \frac{g\beta(T_s - T_f)D^3\rho^2}{\mu^2}$$

$$g = 9.81 \frac{m}{s^2}$$

$$\beta = -\frac{1}{\rho}\left(\frac{\partial\rho}{\partial T}\right)_p$$

$$D = \frac{3}{100} m$$

Density Data (300K)

	density		T(K)
	Coefficient	T^n	300
T^6	0.00E+00	7.29E+14	
T^5	0.00E+00	2.43E+12	
T^4	0.00E+00	8100000000	
T^3	-1.74E-06	27000000	
T^2	1.73E-03	90000	
T	-1.39E+00	300	
constant	1.36E+03	1	
density	1054.258887		

$$\rho = 1054.2588$$

	d(rho)/dT		T(K)
	Coefficient	T^n	300
T^6	0.00E+00	7.29E+14	
T^5	0.00E+00	2.43E+12	
T^4	0.00E+00	8100000000	
T^3	0.00E+00	27000000	
T^2	-5.22E-06	90000	
T	3.47E-03	300	
constant	-1.39E+00	1	
d(rho)/dT	-0.82281423		
beta	0.000780467		

$$\left(\frac{\partial \rho}{\partial T}\right)_p = -0.8228$$

$$\beta = -\frac{1}{\rho}\left(\frac{\partial \rho}{\partial T}\right)_p = 0.000780467$$

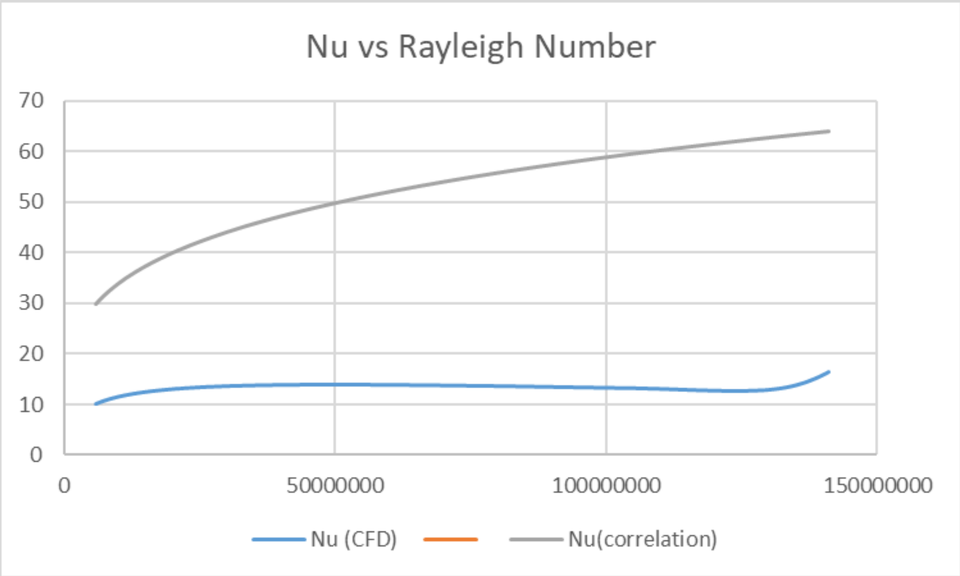
Largest Rayleigh Number

Ra=Gr*Pr=1.411E+08

This is below our threshold (3e8) for liquids!

Laminar simulation is correct!

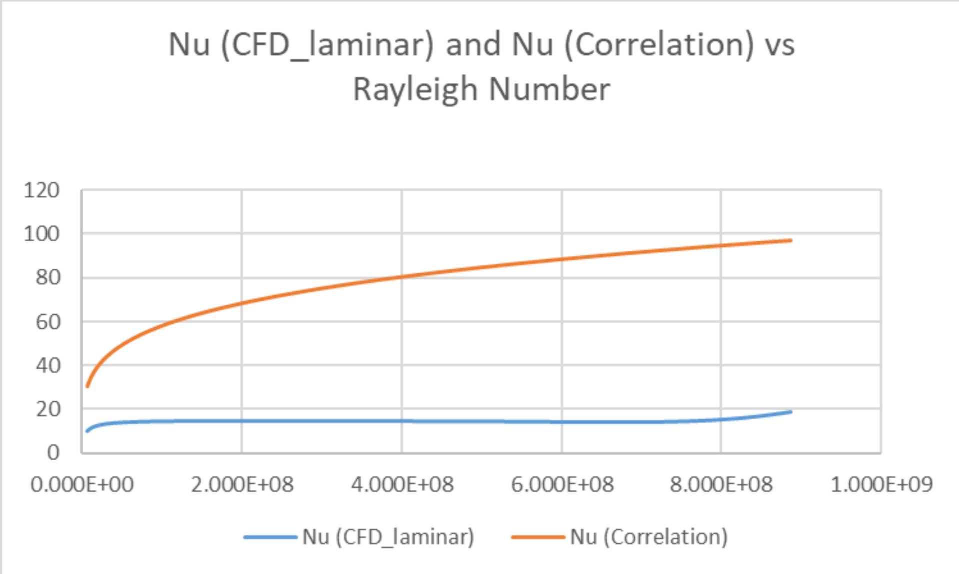
Comparison vs correlation



Round one doesn't seem convincing!

Why the mismatch?

- Mesh is too coarse (we found out this can contribute, but it's not the only problem)
- The correlation developed is for steady state and the experiment was transient (not really, because some experimental data found online with transient conjugate heat trf matched the spherical Nusselt Number Correlation)
    - http://courses.washington.edu/mengr331/lab/ME331_Transient_Lab_Sample_Report.pdf
- β changes with temperature??, don't use bulk fluid temperatures for β (natural convection)
    - [redacted]'s input: film temperature instead of bulk temperature
    - Yes we shld always use film temperature $\frac{T_S+T_\infty}{2}$ for Thermodynamic property calculation
    - http://courses.washington.edu/mengr331/lab/ME331_Transient_Lab_Sample_Report.pdf
- After we include temperature variation using film temperature, the discrepancy grows (for turbulent) and remains for laminar.



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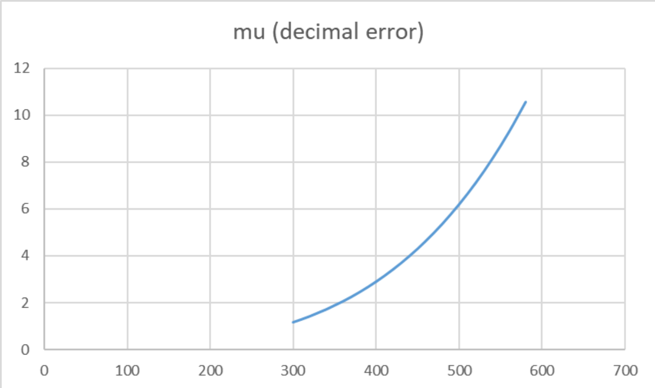
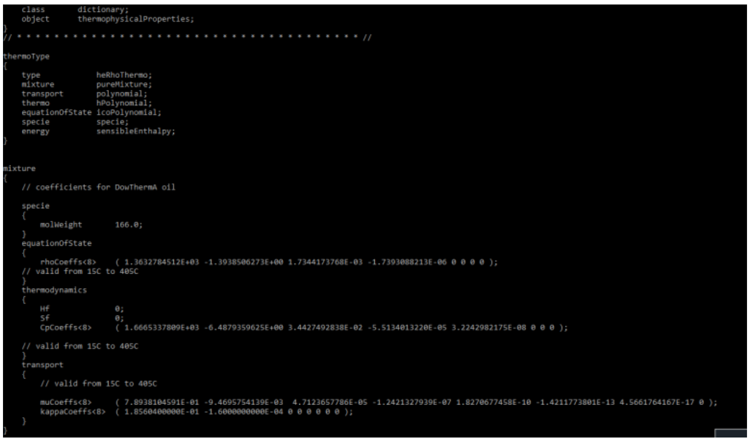
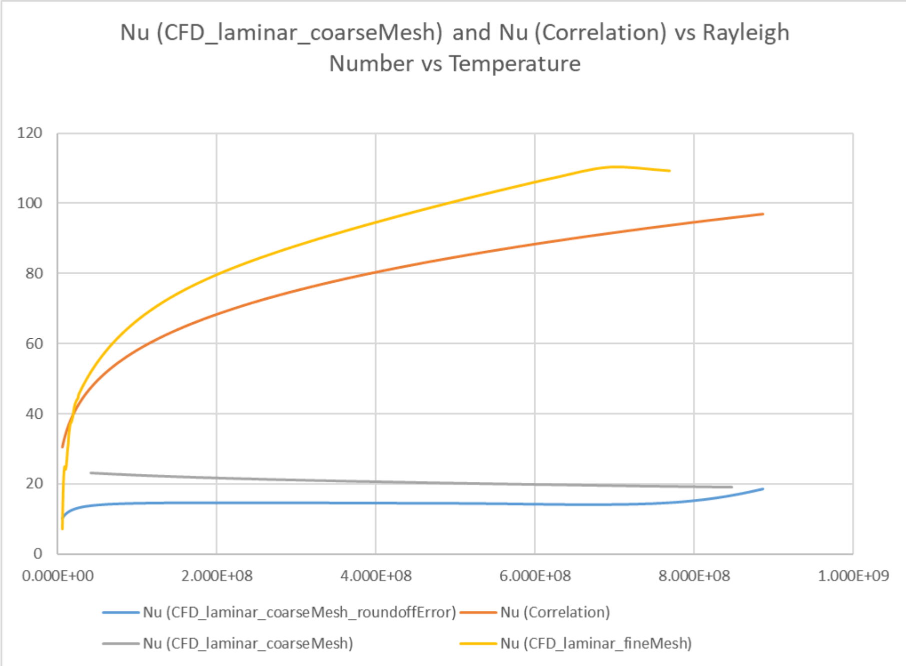
- Actual additional reason post debugging: thermophysical property round off error.
  - 

  - I rounded off the polynomial not using enough significant figures for OpenFOAM input, this resulted in μ being several orders of magnitude bigger, and also it increases viscosity with temperature (not physical for liquids)
    - 

```
    class       dictionary;
    object      thermophysicalProperties;
}
// * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * //

thermoType
{
    type            heRhoThermo;
    mixture         pureMixture;
    transport       polynomial;
    thermo          hPolynomial;
    equationOfState icoPolynomial;
    specie          specie;
    energy          sensibleEnthalpy;
}


mixture
{
    // coefficients for DowThermA oil

    specie
    {
        molWeight       166.0;
    }
    equationOfState
    {
        rhoCoeffs<8>    ( 1.3632784512E+03 -1.3938506273E+00 1.7344173768E-03 -1.7393088213E-06 0 0 0 0 );
    // valid from 15C to 405C
    }
    thermodynamics
    {
        Hf              0;
        Sf              0;
        CpCoeffs<8>     ( 1.6665337809E+03 -6.4879359625E+00 3.4427492838E-02 -5.5134013220E-05 3.2242982175E-08 0 0 0 );

    // valid from 15C to 405C
    }
    transport
    {
        // valid from 15C to 405C

        muCoeffs<8>     ( 7.8938104591E-01 -9.4695754139E-03  4.7123657786E-05 -1.2421327939E-07 1.8270677458E-10 -1.4211773801E-13 4.5661764167E-17 0 );
        kappaCoeffs<8>  ( 1.8560400000E-01 -1.6000000000E-04 0 0 0 0 0 0 );
    }
}
```

    - Using 10 decimal places helps!
  - So we can see effect of having corrected thermophysical properties:

- 

- Without which, we get close to zero Nu for convection with fineMesh
- We can see that even with correct thermophysical properties, the fineMesh outperforms the coarse Mesh, fineMesh laminar flow matches well with correlation
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