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# Appendix A

## Uncertainty Analysis

Functional form of the various parameters are given by

$$m_c = f(V_c, \rho_c)$$

$$m_a = f(U_a, W_c, H_c, \rho_a)$$

$$h_c = f(m_c,\ c_{pc}, T_{ci}, T_{co}, T_w, d_{hc})$$

$$Re_c = f(V_c, \rho_c, d_{hc}, \mu_c)$$

$$h_a = f(m_a,\ c_{pa}, T_{ai}, T_{ao}, T_w, d_{ha})$$

Uncertainty Analysis for heat transfer rate Q

$$Q = f\,(Q_c, Q_a) = f\left(m_c,\ c_{pc}, T_{ci}, T_{co}, m_a,\ c_{pa}, T_{ai}, T_{ao}\right)$$

$$= f\,(V_c, \rho_c, c_{pc}, T_{ci}, T_{co}, W_c, H_c, U, \rho_a, c_{pa}, T_{ao}, T_{ai})$$

$$\frac{\Delta Q}{Q} = \sqrt{\left(\begin{array}{c}\left(\frac{\Delta V_c}{V_c}\right)^2 + \left(\frac{\Delta \rho_c}{\rho_c}\right)^2 + \left(\frac{\Delta c_{pc}}{c_{pc}}\right)^2 + \left(\frac{\Delta T_{ci}}{T_{ci}}\right)^2 + \left(\frac{\Delta T_{co}}{T_{co}}\right)^2 + \left(\frac{\Delta U}{U}\right)^2 + \\ \left(\frac{\Delta Wc}{W_c}\right)^2 + \left(\frac{\Delta H_c}{H_c}\right)^2 + \left(\frac{\Delta T_{ai}}{T_{ai}}\right)^2 + \left(\frac{\Delta T_{ao}}{T_{ao}}\right)^2\end{array}\right)}$$

$$\frac{\Delta Q}{Q} = \sqrt{\left(\begin{array}{c}(0.027)^2 + (0.02)^2 + (0.03)^2 + 4 * (0.014)^2 + \\ (0.021)^2 + (.003)^2 + (.003)^2\end{array}\right)}$$

$$\frac{\Delta Q}{Q} = \sqrt{(.002972)} = 5.42\ \%$$

# Appendix B

## (i) Experimental Analysis with wind tunnel based radiator set up with water, PG brine and hybrid nanofluids as coolants.

### (a) Experimental data for water

| CFR (l/min) | h(W/m$^2$K) | $T_{co}$ ($^o$C) | $T_{ao}$ ($^o$C) | Effectiveness |
|---|---|---|---|---|
| 5.4 | 180 | 64 | 41.5 | 0.54 |
| 7 | 245 | 67 | 42 | 0.5 |
| 9 | 365 | 66 | 42.5 | 0.44 |
| 10.8 | 440 | 68.2 | 43.5 | 0.42 |
| 12 | 530 | 73 | 44.5 | 0.40 |

### (b) Experimental data for PG brine

| CFR (l/min) | h (W/m$^2$K) | $T_{co}$($^o$C) | $T_{ao}$ ($^o$C) | Effectiveness |
|---|---|---|---|---|
| 5.4 | 200 | 67 | 42.5 | 0.55 |
| 7 | 280 | 68 | 43 | 0.51 |
| 9 | 370 | 67 | 43.8 | 0.47 |
| 10.8 | 450 | 68 | 45 | 0.44 |
| 12 | 480 | 70 | 45.7 | 0.41 |

### © Experimental data for PG brine at CFR 7l/min

| Air velocity (m/s) | Heat transfer rate (W) | Air side Pr.drop (Pa) |
|---|---|---|
| 1.1 | 1800 | 28 |
| 3.3 | 2700 | 37 |
| 4.5 | 3600 | 57 |

### ( d ) Experimental data for (0.5% $Al_2O_3$+0.5% CuO)/PG brine hybrid nanofluids

| CFR (l/min) | Q (W) | Tco($^o$C) | Efficitveness | Tao ($^o$C) |
|---|---|---|---|---|
| 6.1 | 3000 | 55 | 0.68 | 38 |
| 7 | 3200 | 58 | 0.64 | 40.5 |

| | | | | |
|---|---|---|---|---|
| 8.3 | 4800 | 58 | 0.58 | 41.8 |
| 9.7 | 5800 | 59 | 0.5 | 42.7 |
| 11 | 7100 | 60 | 0.41 | 43.8 |

**(e) Experimental data for (0.5% $Al_2O_3$+0.5% $TiO_2$)/PG brine hybrid nanofluids**

| CFR (l/min) | Q (W) | $T_{co}$ ($^oC$) | Effectiveness | $T_{ao}$ ($^oC$) |
|---|---|---|---|---|
| 6.1 | 2000 | 58 | 0.67 | 39 |
| 7 | 2500 | 60 | 0.62 | 39.2 |
| 8.3 | 3700 | 61 | 0.57 | 40.2 |
| 9.7 | 5400 | 62 | 0.48 | 41.3 |
| 11 | 6200 | 63 | 0.40 | 42.2 |

**(f) Experimental data for heat transfer (0.5% $Al_2O_3$+0.5% $TiO_2$) hybrid nanofluids**

| Air velocity (m/s) | Q (W) (0.5% $Al_2O_3$+ 0.5% CuO) hybrid nanofluid | Q(W) (0.5% $Al_2O_3$+ 0.5% $TiO_2$) hybrid nanofluid |
|---|---|---|
| 1.5 | 3000 | 2900 |
| 3.4 | 3800 | 3500 |
| 4.5 | 4100 | 3800 |

## (ii) Experimental Analysis of radiator with engine assembly for various coolants.

**(a) Experimental data for Engine performance at different load.**

| Load (kg) | $m_f$ (kg/hr) | BP (W) | IP (W) | BSFC (Kg/ kW-h) | $\eta_m$ |
|---|---|---|---|---|---|
| 0 | 0.42 | 0 | 2125 | 0 | 0 |
| 3 | 0.82 | 1526 | 3651 | 0.5316 | 0.418 |
| 4.5 | 1.04 | 2214 | 4464 | 0.6912 | 0.4956 |
| 6 | 1.2 | 3052 | 5177 | 0.7674 | 0.5895 |

**(b) Experimental data for radiator heat transfer rate for various coolants at different loads**

| Coolants | No load | ½ load | 3/4load | Full load |
|---|---|---|---|---|
| Water | 800 | 2200 | 2700 | 4500 |
| PG brine | 764 | 2100 | 2534 | 4400 |
| EG brine | 500 | 1100 | 2208 | 3605 |
| EG brine+ $Al_2O_3$ nf | 2000 | 2200 | 2600 | 2904 |
| PG brine+ $Al_2O_3$ nf | 2500 | 2900 | 330 | 4302 |
| PG brine+ $Al_2O_3$ +$TiO_2$) hnf | 3000 | 3200 | 3600 | 4604 |

**(c)Experimental data for radiator air side heat transfer rate for various coolants at different loads**

| Coolants | No load | ½ load | 3/4load | Full load |
|---|---|---|---|---|
| Water | 650 | 1000 | 1500 | 2100 |
| PG brine | 680 | 1200 | 1600 | 2200 |
| EG brine | 600 | 800 | 1480 | 1500 |
| EG brine+ $Al_2O_3$ nf | 743 | 1045 | 1570 | 2034 |
| PG brine+ $Al_2O_3$ nf | 789 | 1306 | 1705 | 2356 |
| PG brine+ $Al_2O_3$ +$TiO_2$) hnf | 770 | 1405 | 1880 | 2612 |

**(d)Experimental data for radiator coolat side heat transfer rate for various coolants at different loads**

| Coolants | No load | ½ load | 3/4load | Full load |
|---|---|---|---|---|
| Water | 1300 | 1400 | 2000 | 2600 |
| PG brine | 1250 | 1645 | 2212 | 2745 |
| EG brine | 1023 | 1221 | 1623 | 2278 |
| EG brine+ $Al_2O_3$ nf | 1345 | 2167 | 2734 | 3234 |
| PG brine+ $Al_2O_3$ nf | 1074 | 1567 | 1732 | 2532 |
| PG brine+ $Al_2O_3$ +$TiO_2$) hnf | 1121 | 1823 | 2245 | 3023 |

# Appendix C

## User Defined Function (UDF) of nanofluid for Numerical Simulation

```
#include "udf.h"
#define rho_bf 997
#define rho_p 10500
#define k_bf 0.28
#define k_p 429
#define mu 0.00076
#define cp_bf 3958
#define cp_p 235
#define vol_fr 0.02

DEFINE_PROPERTY(cell_density,c,t)
{
 real rho_nano;
 rho_nano = (1-vol_fr)*rho_bf + vol_fr*rho_p;
 return rho_nano;
}

DEFINE_PROPERTY(cell_th_conductivity,c,t)
{
 real k_nano;
 real temp = C_T(c,t);
 k_nano    =    (k_p+2*k_bf-2*vol_fr*(k_bf-k_p))*k_bf    /
(k_p+2*k_bf+vol_fr*(k_bf-k_p))+0.00078*((-
134.63+1722.3*vol_fr)+(0.4705-6.04*vol_fr)*temp)*sqrt(temp);
 return k_nano;
}

DEFINE_PROPERTY(cell_viscosity,c,t)
{
 real mu_nano;
 mu_nano=(1+2.5*vol_fr)*mu;
 return mu_nano;
}

DEFINE_PROPERTY(cell_specific heat,c,t)
{
 real cp_nano;
 cp_nano=((1-vol_fr)rho_bf*cp_bf+vol_fr*rho_p* cp_p)/rho_p)
 return cp_nano;
}
```