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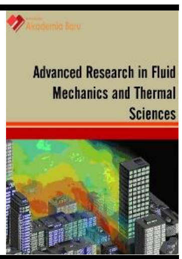

Effect of Refrigeration Assisted Intercooler Turbocharging on Engine's Horse Power

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ABSTRACT

The stringent regulations on fuel saving and emissions reduction in the transportation sector have become game-raisers in the development of present internal combustion engines for road applications, even if under-the-hood space constraints, downsizing and down-weighting prevent from adopting radical changes in the engine layout. In current research, objective is to find a viable and pragmatic solution to reduce the turbo-charged engine intake air temperature by a large value as compared to traditional air-to-air intercoolers to increase Engine Horsepower. In undergoing research, a refrigerated intercooler is designed on the basis of refrigeration cycle, which further decreases the intake air temperature of the engine, resulting in increased horsepower, and improved Formula 1 lap times. Additionally, Formula 1, 2014 (V6 Turbo-Charged) Engine is used. According to the results, horse power of 1209.74HP is obtained by using refrigeration assisted intercooler. However, 1061HP is obtained for air to air intercooler. So, performance gain of 15 to 20% over present intake air cooling system in Formula 1 engine cars is successfully achieved. Additionally, Research will be utilized to decrease lap time in formula 1 racing cars.

Keywords:
Turbo charging; refrigeration; intercooler; engine

1. Introduction

In current research, an intercooler IS designed, which reduces the Engine Inlet temperature by cooling the hot turbo air with the help of an A/C system. For the conceptual design, results are accomplished by adding a water cycle which takes away the heat from the intercooler and is cooled with the help of a radiator and refrigeration cycle. The historical backdrop of the turbocharged engine

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is practically as old as the development of the internal combustion engine itself. Gottlieb Daimler and Rudolf Diesel endeavored by pre-compression of the air provided to the motor the motor power increment and fuel utilization to be diminished [1,2]. In another patent results depicted are, in a reciprocating motor through the energy of the exhaust of the motor to expand the fuel-air blend stream and subsequently the execution can be increased [3]. Murray Willat experimented the very first super-charger was. Experimentations are performed on a 2 stroke engine. By using the turbo charger, the issue of aircraft performance reduction at high altitudes was also solved as superchargers increase the density of air [4]. The U.S. company General Electric installed a turbocharger on the aircraft biplane LUSAC-11 which was flown by Major Rudolf Schroeder Lepere. According to the results, the aircraft top ceiling record was broken on height of 28,500 [5]. Alfred Büchi successfully applied turbo charging through exhaust gases which gave a power boost of around 40%. After that, turbo-charging became common in aircrafts [6]. Dr. Werner Theodor von der Nuell who was the head of the laboratory for aviation (DVL) developed the VNT turbocharger first time [7]. Additionally, after the end of World War II, some former BMW employees started under the leadership of Dr. Müller in the WMF to design a VNT turbocharger [8]. An old automobile of the Chevrolet Company called the "Jetfire" was the first production car which came equipped with the exhaust turbocharger. As a result, it had a very high compression ratio of about 10.25:1, this resulted in easy engine self-ignition. The problem was later solved using water injection system to reduce the temperatures [9]. In early 70's turbo charging was introduced in Formula 1 and it gained huge popularity. As a result, the engine horse power got increased to 1500 hp which was almost 3 times [10]. At the same time in Europe production of turbocharged Gasoline cars was also started. BMW was the first car company, which bought turbo-charging into the market. High engine power, but high fuel consumption coupled with a low reliability brought this era of fast [11,12]. Today, almost every road car is turbocharged [13-15].So, if extra horse powers can obtained from new models than a lot of energy saving potential exists. In current research, the idea of using an air conditioner system integrated into the intercooler to further decrease the engine intake temperature and gain extra horse powers. Also, in current framework, the air conditioning system is utilized to help the turbo charging system in Formula 1 Cars. On tracks where the temperature is usually high for example "The Malaysian Grand Prix", the effectiveness of simple air-to-air intercooler is low because of high ram air temperature; the air conditioning system will be utilized to enhance its proficiency. Besides this it will also increase the charge density to a higher degree and will increase the oxygen accessibility in the chamber for ignition and combustion.

2. Methodology

In current research paper, after literature review, key step was theoretical design selection between air to air and water cooled intercoolers. So selection will be made carefully. On next stage designing of heat exchanger will took place followed by designing of radiator. For radiator design, water pump will also be designed. Designing of refrigeration system will be a key step in undergoing research. Two software's will be used in current research one is EES (Engineering equation solver) while other one will be compact heat exchanger V.2.1. Results will be examined carefully at last stage and after that conclusion will be drawn. Figure 1 shows complete methodology of the research.

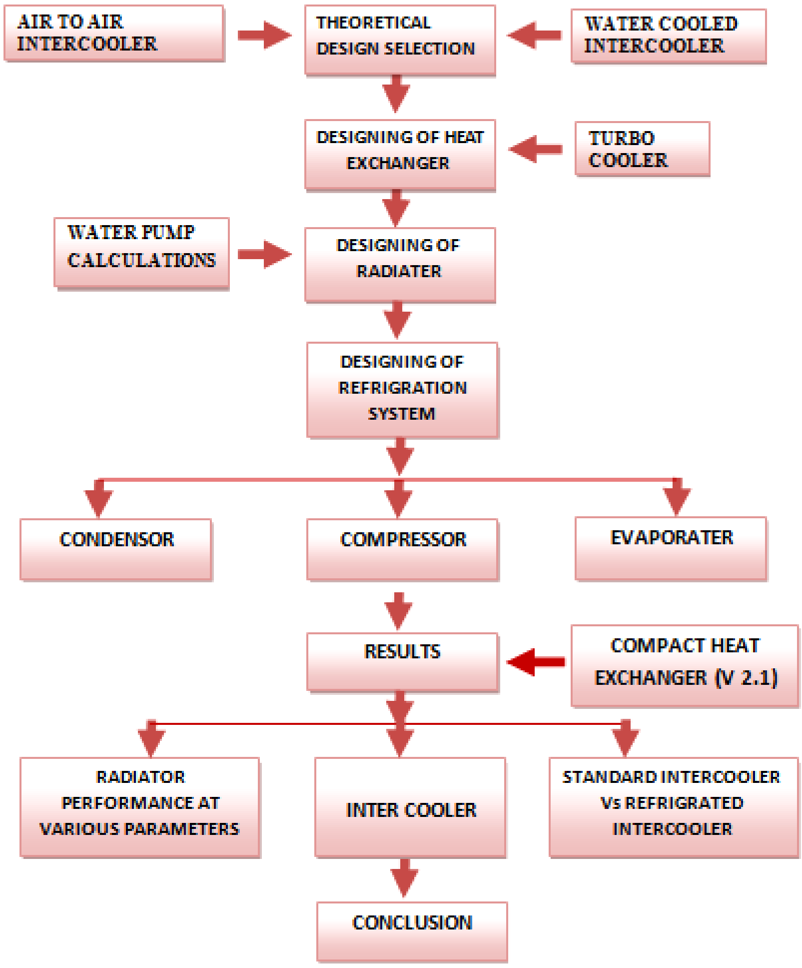

Fig. 1. Methodology of research

2.1 Theoretical Design Selection

2.1.1 Selection of intercooler

Selection of intercooler was important and difficult step. Basically, there are two main types

- Air-to-Air Intercooler
- Water cooled intercooler

2.1.1.1 Air-to-air intercooler

After carrying out several theoretical calculations it is found that this design failed to provide the required outcomes due to the reasons

i. As the speed of the vehicle increases the mass flow rate of the air entering the intercooler also increases, as a result the refrigeration system is unable to cool the incoming air to required temperature.
ii. The load on the refrigeration compressor increased as the mass flow rate of ram air increased, to an extent that the refrigeration system was rather an extra load on the engine.
iii. There is a very less difference between the Specific Heats (CP) of ram air and the hot turbo air, which does not provide efficient heat transfer.

iv. The Size of the Intercooler came out to be quiet large to achieve the required temperature drop. The evaporator fixed with the intercooler further increased its size.

2.1.1.2 Water cooled intercooler

Design of water cooled intercooler is successful due to the reasons

i. As water has a much higher specific heat capacity (CP), it is able to absorb much more heat than air.
ii. Intercooler design is much smaller as compared to air-to-air intercoolers.
iii. Due to increased effectiveness a large amount of temperature drop in the intercooler was achieved resulting increased engine horsepower as compared to standard air-to-air intercoolers
iv. The refrigeration system is perfectly synchronized hence the power required by the refrigeration compressor also reduces or increases depending not only on the engine RPM but the effectiveness of the radiator as well.
v. The use of radiator further increases the efficiency of the whole system, by not only helping to remove heat from water but also reducing the load on the refrigeration system
vi. The advantage gain of the engine performance was much higher than the weight of all components of the installed system.
vii. Water can also be replaced with a coolant to further increase the efficiency of the system.

2.2 Designing of Turbo Charger

EES is an equation-tackling program that can numerically comprehend a large number of coupled non-linear logarithmic and differential conditions. The program can likewise be utilized to provide a solution to differential and integral equations, perform quick optimization, give instability examinations, carryout linear and non-linear regression, and change over units, check unit consistency, and produce publication quality plots. So, the design calculations are carried out in EES software at 6800 RPM while the turbocharger efficiency is 75%. The turbocharger efficiency is obtained from the Compressor map. For the current research, the compressor map for the Formula one turbocharger was not available so Turbocharger efficiencies are assumed and given in Table 1

Table 1
RPM Vs turbo-compressor efficiency

RPM Range	Compressor Efficiency
7500-10000	77%
10500-13000	78%
13500-15000	68%

For the turbocharger efficiency Eq. (1) is used

$$T_{Turbo_{Out}} = \frac{\left(\left((T_{amb}+460)*\left(PR_{comp}\right)^{0.283}\right)-460\right)-T_{amb}}{\eta_{Turbo}} + T_{amb} \tag{1}$$

while

$\mathrm{Disp} = 97.638\ \mathrm{ft}^3, \mathrm{Rpm} = 6800, \eta_v = 1.00, \eta_{Turbo} = 0.77, P_{boost} = 50.7632\ \mathrm{psi\ abs}, T_{amb} = 68$
$P_{amb} = 14.7\ \mathrm{psi}$

Results obtained by EES software is given in Table 2

Table 2
Turbocharger EES Program Results

Engine RPM	$T_{Turbo,out}$	$\dot{m}$(kg/sec)	η_{Turbo}
15000	201.2	0.755	0.68
14500	201.2	0.73	0.68
14000	201.2	0.704	0.68
13500	201.2	0.679	0.68
13000	178	0.654	0.78
12500	178	0.6294	0.78
12000	178	0.604	0.78
11500	178	0.579	0.78
11000	178	0.553	0.78
10500	178	0.528	0.78
10000	184.277	0.503	0.77
9500	184.277	0.4783	0.77
9000	184.277	0.453	0.77
8500	184.277	0.42804	0.77
8000	184.277	0.402	0.77
7500	184.277	0.377	0.77

The calculations are carried out in EES software using the Ideal turbocharged Otto cycle assuming standard air conditions where

$$V_{clearance} = \frac{V_{d_{cylinder}}}{r_c - 1} \tag{2}$$

State 1

$$v_1 = V_{d_{cylinder}} + V_{clearance} \tag{3}$$

$$m_m = \frac{P_1 * v_1}{R * T_1} \tag{4}$$

State 2

$$T_2 = T_1 * (r_c^{k-1}) \tag{5}$$

$$v_2 = \frac{m_m * R * T_2}{P_2} \tag{6}$$

$$m_a = \frac{A}{A+F} * m_m \tag{7}$$

State 3

$$Q_{in} = m_f * Q_{HV} * Eff_{combustion} \tag{8}$$

State 4

$$W_{pump} = (P_1 - P_{ex}) * V_{d_{cylinder}} \tag{9}$$

$$W_{net} = W_{gross} - W_{pump} \tag{10}$$

$$W_{gross} = W_3 - 4 + W_1 - 2 \tag{11}$$

$$W_{indicated} = \frac{W_{net} * \left(\frac{RPM}{60}\right) * 6}{2} \tag{12}$$

$$HP = 1.34102 * \ W_{indicated} \tag{13}$$

$$HP_{Actual} = HP * Eff_{mech} \tag{14}$$

$$APS = 2 * .053 * \frac{RPM}{60} \tag{15}$$

Results obtained in EES are given in Table 3

Table 3
Ideal turbocharger EES program results

A =13	AF =13	Crank height = 0.09 [m]
effciency =1	Tim = 0.7	HP = 1738
HPActush = 1217	k =1.35	mm=0.00106 [kg]
Powerindicated =1296	P1 =340 [KPa]	P4=1993 [kPe]
Pboost = 350 [kPa]	Pex = 101.3 [kPe]	R =0.287
RPM =13500	rc =13	T2 =792.7
T3 =4647	T4 =1894	Vclearance = 0.00002222 [m3)
Vd.cylinder =0.0002667	Vd total= -0.0016 [m3]	Wgross =1.984
Wnet =1.92	Wpump= 0.06365	W34 = 2.392
APS =23.85	Bore =0.08 [m]	W12= -0.4081
F =1	fuel intake limit=0.02778 [kg/sec]	V2 =0.00002222 [m3]
ma = 0.0009839 [kg]	mf=0.00007568 [kg]	V1=0.0002889 [m3]
P2 = 10847 [kPa]	P3=63588 [kPa]	T1=323 [K]
OHV=44300 [kJ/kg]	Oin = 3.353	Stroke=0.053 [m]

Above results are obtained at 13500 RPM when the mechanical efficiency of the engine is 70%. Similarly, the calculations at different RPMs with corresponding mechanical efficiencies are also carried out and given in Table 4

Table 4
Design calculations for turbo charger at different RPMs

RPM	Eff.Mech	HP	Actual HP	APS (m/s)
7000	0.9	901.4	811.2	12.37
7500	0.9	965.8	869.2	13.25
8000	0.9	1030	927.1	14.13
8500	0.9	1095	985.1	15.02
9000	0.9	1159	1043	15.9
9500	0.8778	1223	1074	16.78
10000	0.8556	1288	1102	17.67
10500	0.8333	1352	1127	18.55
11000	0.8111	1416	1149	19.43
11500	0.7889	1481	1168	20.32
12000	0.7667	1545	1185	21.2
12500	0.7444	1610	1198	22.08
13000	0.7222	1674	1209	22.97
13500	0.7	1738	1217	23.85
14000	0.6778	1803	1222	24.73
14500	0.6556	1867	1224	25.62
15000	0.6333	1932	1223	26.5

2.3 Designing of Heat Exchanger

Compact Heat Exchanger (v 2.1) is a classic DOS based software that uses DTO design and/or predict performance of heat exchangers using the data in Compact Heat Exchangers by Kays and London, Mc Graw-Hill 1984. Current design consists of four different heat exchangers as listed below

i. Turbo Intercooler
ii. Water Radiator
iii. Evaporator
iv. Condenser

2.3.1 Turbo intercooler

The Turbo Intercooler consists of two fluids

i. Hot air from Turbo
ii. Cold Water from the Refrigeration System

In current research, The Heat Exchanger is of unmixed cross flow type, with cold water passing inside the tubes and hot turbo air moving over the tubes. The heat exchanger is designed on Compact Heat Exchanger (V 2.1).It is important to note that the Heat Exchanger is designed for peak temperature of hot Turbo air, which is approximately 200 Degree Celsius and with the cold-water temperature of 5 Degree Celsius.

2.3.1.1 Design conditions for turbo intercooler

For designing of turbo intercooler, input parameters are

Engine RPM: 15000

- Hot Air from Turbo
  Mass flow rate: 0.755kg/sec, Temperature 200 °C, Pressure = 350 Kpa

- Cold Air to Engine
  Temperature = 50 Degree Celsius._Pressure = 346.5°C

- Cold Water In
  Temperature = 5°C, Pressure = 105.325 kPa, Mass Flow rate = 0.440 kg/sec.

Figure 2 shows all design parameters for turbo intercooler

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DATE IS 04-23-2017

CROSS FLOW HEAT EXCHANGER
      NTU =  2.12       EFFECTIVENESS = 0.77
Cmin/Cmax =  0.42         Cmin is on Side 1

PERCENT PRESSURE DROP, SIDE 1 (OUTSIDE TUBES)=  1.00
PERCENT PRESSURE DROP, SIDE 2 (INSIDE TUBES) =  1.00
SURFACE ---
    8.0-3/8T
   SCALE FACTOR = 0.20

TUBE WALL THICKNESS = 0.00050 m

VOLUME =    0.006cu m
   FLUID 1 (OUTSIDE) FLOW LENGTH =   0.134 m
   FLUID 2 (INSIDE)  FLOW LENGTH =   0.134 m
   NON-FLOW LENGTH               =   0.332 m

                                         SIDE 1         SIDE 2
HEAT TRANSFER COEFFICIENTS               431.5          2462.5     W/K-m2
FIN EFFECTIVENESS                          0.91
OVERALL HEAT TRANSFER COEFFICIENT, U1     93.5                     W/K-m2
MASS VELOCITIES                           31.782         259.827     kg/s-m2
REYNOLDS NUMBERS                        1008.5           279.4
RESISTANCE RATIO, SIDE1/SIDE2              0.31
WEIGHT                                     3.5  kg
```

Fig. 2. Design parameters for turbo intercooler

2.4 Designing of Water Pump

The pressure difference needed to provide the desired mass flow in current research; it is possible by using a pump, so

$$T = 35°C, \rho = 944\ \frac{kg}{m^3}, \mu\ =\ 0.000719\ \frac{Ns}{m^2}, v\ = 0.245\ \frac{m}{s}$$

Reynolds number

$$Re\ =\ 8041.724\ > 4000\ Hence\ , Turbulent\ flow$$

$$f\ = 0.031\ (from\ moody's\ chart)$$

$$\Delta P = f * l *\ \rho\ * \frac{\mu^2}{(2*D)} \tag{16}$$

$$\Delta P = 1.4728\ kPa \sim 2\ kPa$$

2.5 Designing of Radiator

Radiator is designed in the same way as the Intercooler, but with different input and output conditions. Using input parameters as: Engine RPM: 15000, Speed of Vehicle: 180 Km/hr (Average Speed at all tracks) and Ram Air Temperature is 20°C

- Hot water from intercooler
  Mass flow rate: 0.44 kg/sec, temperature: 67.499°c, pressure = 104.27175

- Cold water to refrigeration system
  Temperature = 35 °c, pressure = 103.277 kpa and mass flow rate = 0.440 kg/sec

- Cold ram air
  Temperature =20 °c, pressure = 101.325 and mass flow rate: 2.6208 kg/sec

Figure 3 shows all the designed parameters for radiator

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DATE IS 04-23-2017

CROSS FLOW HEAT EXCHANGER
      NTU =   1.98      EFFECTIVENESS = 0.68
Cmin/Cmax =   0.69         Cmin is on Side 2

PERCENT PRESSURE DROP, SIDE 1 (OUTSIDE TUBES)=  5.97
PERCENT PRESSURE DROP, SIDE 2 (INSIDE TUBES) =  1.00
SURFACE ---
    8.0-3/8T
   SCALE FACTOR = 0.22

TUBE WALL THICKNESS = 0.00050 m

VOLUME =    0.015cu m
   FLUID 1 (OUTSIDE) FLOW LENGTH =    0.096 m
   FLUID 2 (INSIDE)  FLOW LENGTH =    0.364 m
   NON-FLOW LENGTH               =    0.433 m
                                        SIDE 1          SIDE 2
HEAT TRANSFER COEFFICIENTS              387.0           2231.3     W/K-m2
FIN EFFECTIVENESS                         0.91
OVERALL HEAT TRANSFER COEFFICIENT, U1    90.1                      W/K-m2
MASS VELOCITIES                          31.503          233.637     kg/s-m2
REYNOLDS NUMBERS                       1265.4            512.2
RESISTANCE RATIO, SIDE1/SIDE2             0.34
WEIGHT                                    8.4   kg
```

Fig. 3. Designed parameters for radiator

2.6 Evaporator, Condenser & Compressor (Refrigeration System)

For current research, market available compressor is selected. Cars with 1300 to 1800 cc Engines used Denso Compressors.

With the help of calculated high side and low side pressures of the compressor, enthalpies in the refrigeration cycle, amount of cooling needed to reduce the temperature of water, heat absorption from refrigeration space and most importantly the power input to the compressor is calculated.

Low Side	High side
$p_1 = 1.67\ MPa$	$P_2 = 3.53 Mpa,$
$h_1 = 277.86 kJ/kg$	$h_f = 205 kJ/kg$
$s_1 = 0.9078 kJ/kgK$	$h_4 = h_3 = 205 kJ/kg$

3. Results and Discussion

3.1 Intercooler

Now it can be clearly seen in Table 5 that everything is dependent on the RPMs of the engine. As the engine, RPMs increase the mass flow rate of air going into the engine (Max: 0.755 @ 15000RPM & Min: 0.377 @7500RPM) also increases because the turbo turbine spins more and subsequently the compressor sucks in more air to be taken into the engine (Figure 4).

Table 5
Intercooler results

Engine RPM	T(H) in	T(H) out	m (kg/sec) (Engine)	m(kg/sec) (Water)	T(c) in	T (c) out	Mechanical Efficiency	Horse Power
15000	201	50	0.75	0.44	5	6.45	0.63	1223
14500	201	50	0.73	0.44	5	65.43	0.65	1224
14000	201	50	0.7	0.44	5	63.28	0.67	1222
13500	201	50	0.67	0.44	5	61.21	0.7	1217
13000	178	50	0.65	0.44	11.59	57.73	0.72	1209
12500	178	50	0.62	0.44	11.59	56.43	0.74	1198
12000	178	50	0.6	0.44	11.59	54.21	0.76	1185
11500	178	50	0.57	0.44	11.59	52.44	0.78	1168
11000	178	50	0.55	0.44	11.59	50.61	0.81	1149
10500	178	50	0.52	0.44	11.59	48.84	0.83	1127
10000	184	50	0.5	0.44	9.71	46.94	0.85	1102
9500	184	50	0.43	0.44	9.71	45.11	0.87	1074
9000	184	50	0.45	0.44	9.71	43.24	0.9	1043
8500	184	50	0.42	0.44	9.71	41.39	0.9	985
8000	184	50	0.4	0.44	9.71	39.47	0.9	927
7500	184	50	0.37	0.44	9.71	37.61	0.9	869

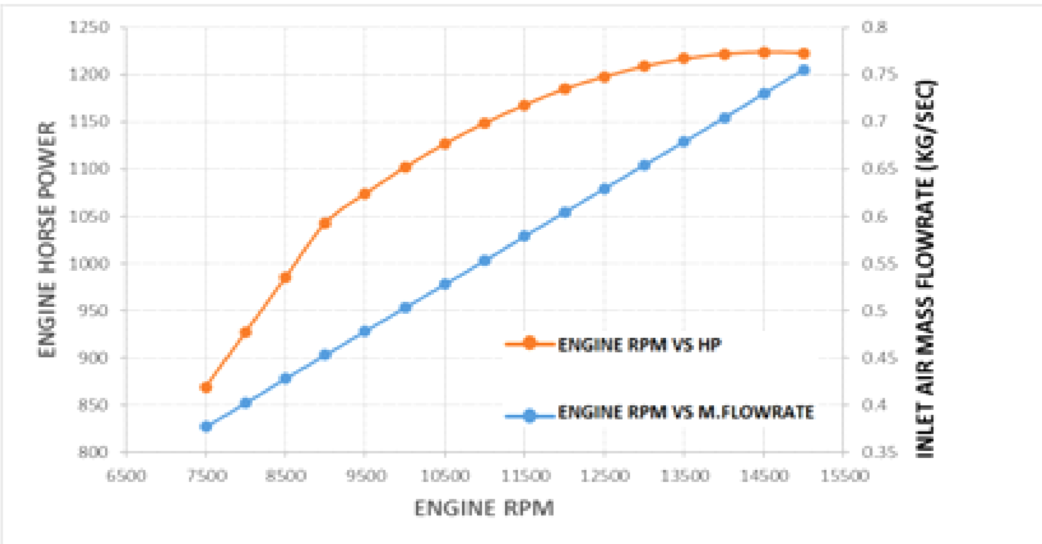

Fig. 4. Engine RPM Vs HP and engine RPM Vs M. flow rate

It can also seen in Figure 4 that the relationship of Engine Horse Power and RPM is not linear due to the drastic decrease in mechanical efficiency of the engine at high RPMs or "Piston Speed" shown in Table 5. Figure 5 clearly depicts the inverse relationship between the Engine RPM and the mechanical efficiency of the engine.

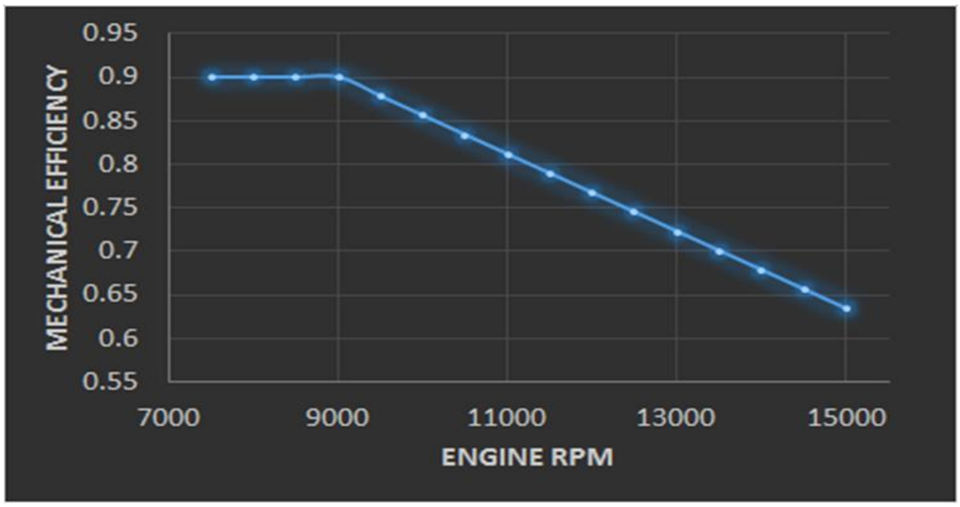

Fig. 5. Engine RPM Vs mechanical efficiency

The minimum horsepower is 869.2 (@ 7500 RPM) and maximum 1223 (@15000 RPM). However, the temperature of intake (intercooled) air going into the engine will always be at 50°C and the effectiveness of the Intercooler will remain same i.e. 0.76923 or 76.923 %.With the help of refrigeration system, intercooler is able to maintain its effectiveness.

At the same time, according to the results, as the RPMs decrease the temperature of water going out from the intercooler also decreases (Figure 6). Minimum temperature is 37.61°C (@ 7500 RPM) and maximum 67.499°C (@ 15000 RPM). This will subsequently put fewer loads on the refrigeration system. The reason being the mass flow rate of hot compressed air entering the intercooler is decreasing as well. Additionally, mass flow rate of water throughout the cycle is 0.44kg/sec.

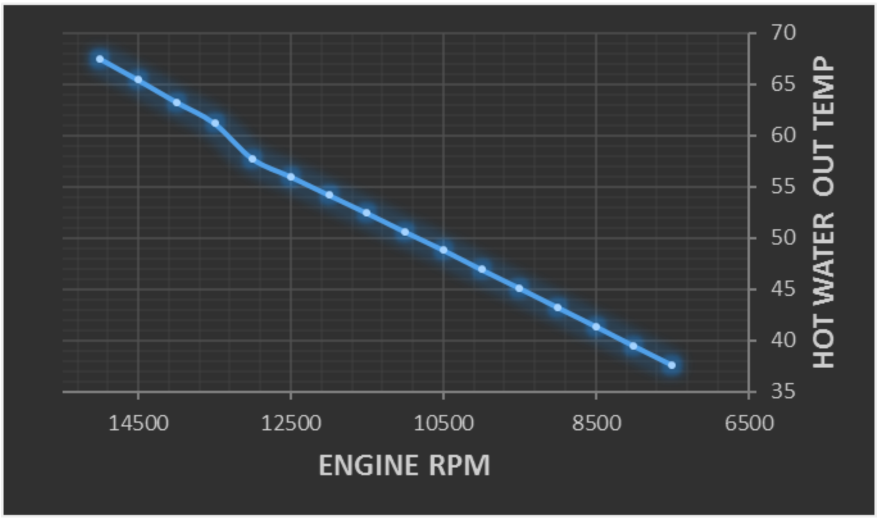

Fig. 6. Engine RPM Vs hot water exit temperature

Depending on the efficiency charts of a turbo compressor, different temperatures are obtained at various RPMs as shown in Figure 7.

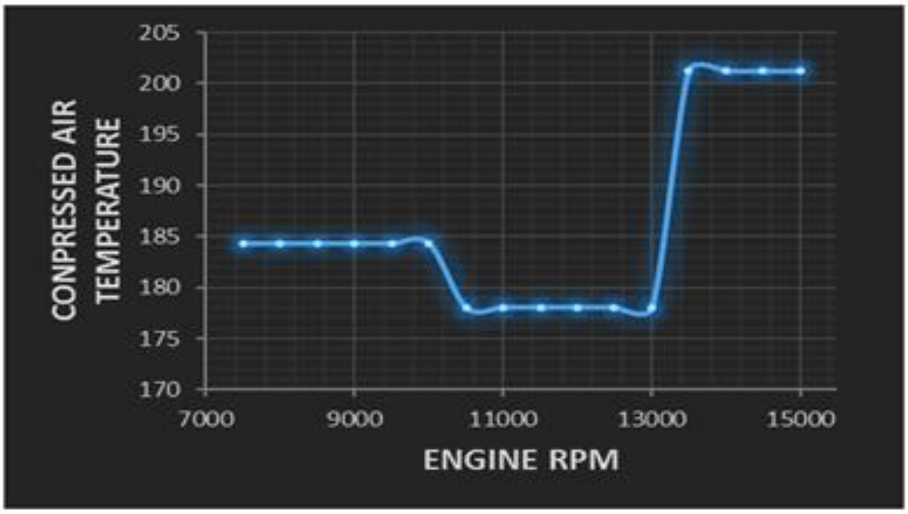

Fig. 7. Engine RPM vs compressed air temperature

As mostly the Formula 1 cars operate in the range between 10500 RPM to 13000RPM so the compressor gives the maximum efficiency and lowest compressed air temperature at this range which is 178 Degrees. On the other hand, it gives the lowest efficiency and the maximum compressed air temperature of around 200°C. While the Pressure ratio remains constant.

3.2 Radiator

With reference to Table 6 and 7, for every RPM of the engine i.e;(10000, 13000 & 15000), the race car travels at different speeds. For example, at 15000 RMP it may be on 3rd Gear or 6th Gear, and its speed is around 180 Km/Hr. or 280 Km/Hr. So for different RPMs the mass flow rate of ram air flowing into the radiator will also vary. For every RPM, speed varies from 160 Km/Hr. to 300 Km/Hr. However; the radiator is designed for an average speed of 180 Km/Hr. (Mass Flow rate 2.62 Kg/Sec).

In Figure 8, the speed of the vehicle increases (with increase in mass flow rate of ram air @ 20°C) the effectiveness also increases. The most important point is, graph is not linear. The main reason is, with increase in speed of ram air the heat transfer increases while decreasing the temperature difference of water. However, temperature difference itself is a function of heat transfer so with decrease in temperature difference the heat transfer also decreases giving the graph a bit of a curve.

In Figure 9, at every RPM with increase in velocity of RAM air, the temperature of water decreases. It is simple to note that at lower RPMs the temperature of water temperature is lower and at higher RPMs, it will be higher (Max temperature: 36.3056 @ 15000 RPM & Lowest temperature: 26.411 @ 10000 RPM)

As for the compressor work, at higher Engine RPMs the water temperature is also high so the refrigeration compressor has to work harder. In Figure 10, maximum Horsepower that the refrigeration compressor is consuming is around 15 HP @ 15000 Engine RPM & the lowest is 7.99 HP @ 10000 RPM. So, with decreasing HP of the refrigeration compressor the mass flow rate of refrigerant also decreases. However, refrigeration compressor is based on variable speed drive so it changes its RPMs based on the load (Its Pressure Ratio remains constant).

Table 6
Results obtained for radiator

RPM	Vehicle speed (km/hr)	Mass flow rate of Ram Air(kg/sec)	Effectiveness	T(H) in water	T(H) out water
15800	150	2.32	0.65	67.49	5.3
15888	180	2.62	0.68	67.49	3.5
15880	200	2.91	0.7	67.49	34.17
15888	220	3.2	0.71	67.49	33.39
15880	240	3.49	0.73	67.49	33.65
15808	250	3.78	0.74	67.49	33.19
15800	280	4.06	0756	67.49	31.56
15880	300	4.36	0.77	67.49	30.9
13800	150	2.32	0.65	57.73	33.45
13000	180	2.62	0.68	57.73	31.94
13000	200	2.91	0.7	57.73	31 32
13000	220	3.2	0.71	57.73	30.67
13000	240	3.49	0.73	57.73	30.11
13000	260	3.78	0.74	57.73	29.65
13800	280	4.06	0.75	57.73	29.32
13000	300	4.36	0.76	57.73	28.79
16800	150	2.32	0.65	46.94	29.32
18800	180	2.62	0.68	46.94	28.52
16800	200	2.91	0.69	46.94	28.13
18800	220	3.2	0.71	46.94	27.67
18800	240	3.49	0.72	46.94	23.22
16800	250	3.78	0.7	46.94	26.95
	280	4.06	0.75	46.94	25.68
18800	300	4.36	0.76	46.94	25.41

Table 7
Results obtained for refrigeration cycle

RPM	Temperature Drop In Refrigerator Required	Cooling Needed (KW)	Mass Flow rate OF Refrigerant (kg/sec)	Input To compressor (HP)	Heat Rejection to Environment
15000	31.31	57.64	0.79	15.00	68.83
15000	30.65	55.24	0.18	14.38	55.96
15000	29.17	53.77	0.17	13.98	64.14
15000	28.36	57.25	0.78	13.59	62.37
15000	27.65	50.92	0.78	13.25	60.90
15000	27.10	49.79	0.68	12.96	59.43
15000	26.56	18.91	0.67	12.73	58.41
15000	25.90	47.69	0.67	12.44	56.95
13000	21.42	39.43	0.54	10.26	56.95
13000	20.34	37.46	0.51	9.75	44.74
13000	19.72	36.32	0.50	9.45	43.37
13000	19.08	35.14	0.48	9.15	41.99
13000	18.51	34.10	0.46	8.87	40.72
13000	18.06	34.10	0.45	1.66	39.72
13000	17.72	32.64	0.44	8.50	38.97
13000	17.19	31.66	0.44	8.24	37.81
10000	19.61	36.05	0.49	9.38	43.05
10000	18.80	34.58	0.47	9.00	41.29
10000	18.42	33.87	0.47	8.86	40.45
10000	17.96	33.94	0.45	8.60	39.44
10000	17.58	32.34	0.44	8.41	38.61
10000	17.23	31.70	0.44	8.24	37.84
10000	16.96	31.20	0.42	8.12	37.25
10000	16.70	30.70	0.42	7.99	36.66

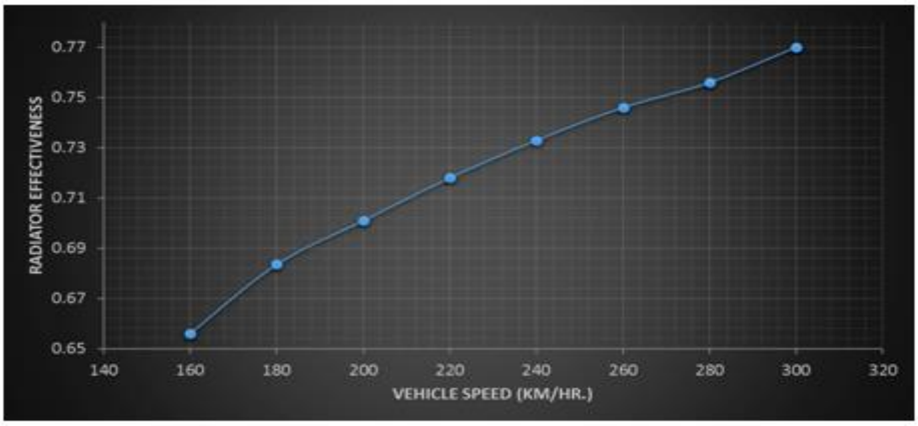

Fig. 8. Radiator effectiveness VS. vehicle speed

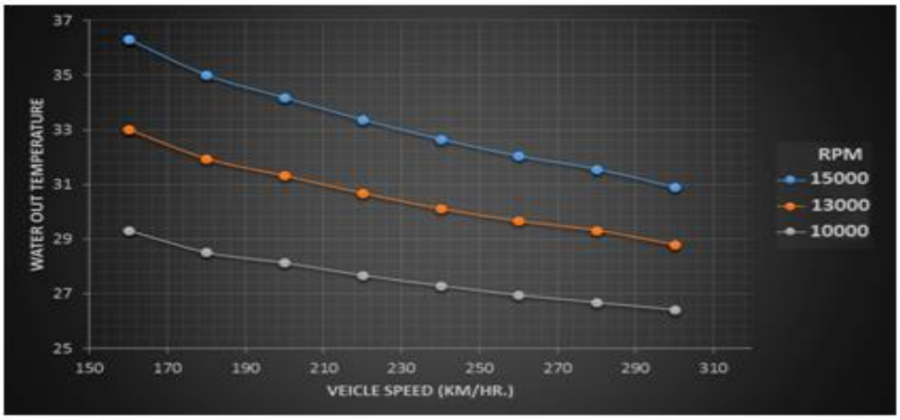

Fig. 9. Water exit temperature VS. vehicle speed

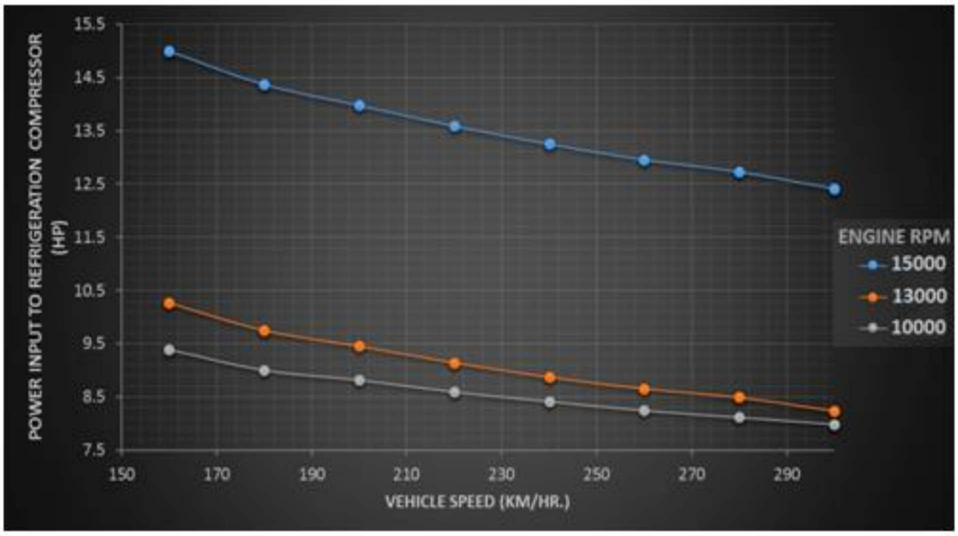

Fig. 10. Vehicle speed Vs power input to refrigeration compressor (HP)

3.3 Standard Inter. Vs Refrigerated Intercooler

In undergoing research, an air-to-air intercooler is also designed so that a comparison could be made to see how much horse power advantage a refrigerated intercooler will gives (Table 8).

Table 8
Comparison between air-to-air intercooler to refrigerated intercooler

	Vehicle speed	Mass flow rate of Ram air to radiator	Effectiveness of radiator	T(H) to engine	Power input to compressor	HP by Engine	Net HP
	180	2.62	0.68	50	14.37	1223	1208
Refrigerated system	200	2.91	0.70	50	13.98	1223	1209
(@15000 Engine	220	3.20	0.71	50	13.59	1223	1209
Rpm)	240	3.49	0.73	50	13.25	1223	1210
	260	3.78	0.74	50	12.95	1223	1210
	280	4.06	0.75	50	12.73	1223	1210
	300	4.36	0.77	50	12.41	1223	1210
Air to Air Intercooler							
	180	2.62	0.55	100			1054
Air to Air	200	2.91	0.56	99.2			1056
Intercooler	220	3.21	0.55	98.3			1059
(@15000 Engine	240	3.49	0.56	97.58			1061
Rpm)	280	3.78	0.57	96.86			1063
	280	4.06	0.57	96.32			1066
	300	4.36	0.58	95.92			1066

Designed results for a refrigerated intercooler are shown in Figure 11.

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DATE IS 04-27-2017

CROSS-FLOW HEAT EXCHANGER
      NTU =  0.90      EFFECTIVENESS = 0.56
Cmin/Cmax =  0.25        Cmin is on Side 2

PERCENT PRESSURE DROP, SIDE 1 (OUTSIDE TUBES)=  9.97
PERCENT PRESSURE DROP, SIDE 2 (INSIDE TUBES) =  3.00
SURFACE ---
    8.0-3/8T
   SCALE FACTOR = 0.40

TUBE-WALL THICKNESS = 0.00050 m

VOLUME =    0.012cu m
   FLUID 1 (OUTSIDE) FLOW LENGTH =   0.127 m
   FLUID 2 (INSIDE)  FLOW LENGTH =   0.221 m
   NON-FLOW LENGTH               =   0.423 m

                                        SIDE 1          SIDE 2
HEAT TRANSFER COEFFICIENTS              398.2           521.0       W/K-m2
FIN EFFECTIVENESS                         0.85
OVERALL HEAT TRANSFER COEFFICIENT, U1    34.6                       W/K-m2
MASS VELOCITIES                          52.540          145.636      kg/s-m2
REYNOLDS NUMBERS                       4050.7          18638.5
RESISTANCE RATIO, SIDE1/SIDE2             0.11
WEIGHT                                    4.9  kg
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Fig. 11. Designed results for a refrigerated intercooler

In current research, air-to-air intercooler is designed for an average vehicle having speed of 180 Km/Hr. and Mass Flow rate of 2.62 Kg/Sec, at which it gives an Effectiveness of around 0.55 (Effectiveness of air-to-air intercoolers is usually very less than air to water based intercoolers). So, air-to-air Intercoolers are not as effective as air to water intercoolers is. Figure 12 Show how the effectiveness of an air to air intercooler is increased with the speed of the vehicle; however the temperature of compressed air to engine is approximately 100°C, which is approximately 50% more than the refrigerated system.

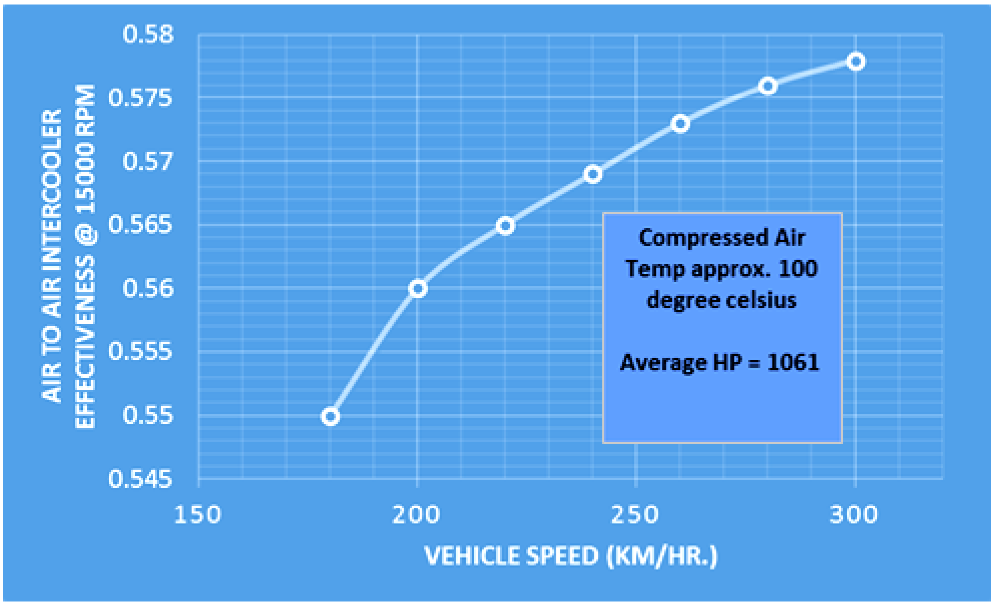

Fig. 12. Vehicle speed VS. air to air intercooler effectiveness @ 15000 RPM

4. Conclusion

A comprehensive analysis of a turbocharged refrigeration assisted intercooler engine for formula 1 racing cars was performed, through a detailed virtual modeling activity with the help of EES and compact heat exchanger (v.2.1), to assess the effectiveness of an additional refrigerated intercooling on engine's horse power. According to the results 1209.747HP is obtained with refrigerated intercooler and 1061HP for air-to-air intercooler. Moreover, approximate increase in engines horsepower by using refrigeration assisted intercooler is 150HP. Additionally, by taking ERS (energy recovery system) and providing 150HP for about 30 to 60 seconds it will decrease the lap time to approximately 1.5 to 2 seconds in a F1 car.

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