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

Saba Arif1,2,3, Adil Qadeer4, Juntakan Taweekun5,*, Zamri Noranai3, Roman Kalvin6

1 Energy Technology Program, Faculty of Engineering, Prince of Songkla University Hat Yai, Songkla, Thailand
2 Department of Mechanical Engineering, Institute of aerospace and avionics, Air university, Islamabad, Pakistan
3 Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, Malaysia
4 Department of Mechanical Engineering, University of Lahore, Lahore, Pakistan
5 Department of Mechanical Engineering, Faculty of Engineering, Prince of Songkla University Hat Yai, Songkla, Thailand
6 Department of Mechanical Engineering, Wah Engineering College, University of Wah, Pakistan

ARTICLE INFO

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 is practically as old as the development of the internal combustion engine itself. Gottlieb Daimler and

* Corresponding author.
E-mail address: jantakan.t@psu.ac.th

https://doi.org/10.37934/arfmts.79.2.95111
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 quite 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.

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

For the turbocharger efficiency Eq. (1) is used

\[ T_{TurbO_{Out}} = \left( \frac{\left( T_{amb} + 460 \right) \cdot \left( P_{comp}^{0.283} \right) - 460}{\eta_{Turb}} \right) - T_{amb} + T_{amb} \]  

(1)

while
Disp = 97.638 ft³, Rpm = 6800, \( \eta_v = 1.00, \eta_{Turbo} = 0.77 \)

\( P_{boost} = 50.7632 \) psi abs, \( T_{amb} = 68 \)

\( P_{amb} = 14.7 \) psi

Results obtained by EES software is given in Table 2

| Engine RPM | \( T_{Turbo,out} \) | \( \dot{m} \) (kg/sec) | \( \eta_{Turbo} \) |
|------------|----------------------|------------------------|-----------------|
| 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

\[ V_{clearance} = \frac{V_{cylinder}}{r_c - 1} \]  

State 1

\[ v_1 = V_{cylinder} + V_{clearance} \]  

\[ m_m = \frac{P_1 \cdot v_1}{R \cdot T_1} \]  

State 2

\[ T_2 = T_1 \cdot (r_c)^{k-1} \]  

\[ v_2 = \frac{m_m \cdot R \cdot T_2}{P_2} \]  

\[ m_a = \frac{A}{A + F} \cdot m_m \]  

State 3

\[ Q_{in} = m_f \cdot Q_{HV} \cdot Eff_{combustion} \]
State 4

\[ W_{pump} = (P_1 - P_{ex}) \times V_{cylinder} \]  

(9)

\[ W_{net} = W_{gross} - W_{pump} \]  

(10)

\[ W_{gross} = W_3 - 4 + W_1 - 2 \]  

(11)

\[ W_{indicated} = \frac{W_{net} \times (\frac{RPM}{60})^6}{2} \]  

(12)

\[ HP = 1.34102 \times W_{indicated} \]  

(13)

\[ HP_{Actual} = HP \times E_{ff mech} \]  

(14)

\[ APS = 2 \times 0.053 \times \frac{RPM}{60} \]  

(15)

Results obtained in EES are given in Table 3

| Ideal turbocharger EES program results |  |
|--------------------------------------|--|
| A = 13                               | AF = 13                                      |
| Efficiency = 1                       | Tim = 0.7                                      |
| HPActush = 1217                      | mm = 0.00106 [kg]                              |
| Powerindicated = 1296                | P1 = 340 [kPa]                                 |
| Pboost = 350 [kPa]                   | Pex = 101.3 [kPa]                              |
| RPM = 13500                          | R = 0.287                                      |
| T3 = 4647                            | T2 = 792.7                                      |
| Vd. cylinder = -0.0002667            | Vclearance = 0.00002222 [m³]                  |
| Wnet = 1.92                          | W34 = 2.392                                    |
| APS = 23.85                          | W12 = -0.4081                                  |
| F = 1                                | fuel intake limit = 0.02778 [kg/sec]           |
| ma = 0.0009839 [kg]                  | V2 = 0.00002222 [m³]                          |
| P2 = 10847 [kPa]                     | P3 = 63588 [kPa]                               |
| OHV = 44300 [kJ/kg]                  | T1 = 323 [K]                                   |

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: 0.755 kg/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

![Figure 2. Design parameters for turbo intercooler](image)

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

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

Reynolds number

\[ Re = 8041.724 > 4000 \text{ Hence, Turbulent flow} \]

\[ f = 0.031 \text{ (from moody's chart)} \]

\[ \Delta P = f * l * \rho * \frac{k^2}{(2 \pi d)} \]  \hspace{2cm} (16)

\[ \Delta P = 1.4728 \text{ kPa} \sim 2 \text{ kPa} \]

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

![Fig. 3. Designed parameters for radiator](image)

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 |
|----------|-----------|
| $p_1 = 1.67 \text{ MPa}$ |
| $h_1 = 277.86 \text{kJ/kg}$ |
| $s_1 = 0.9078 \text{kJ/kgK}$ |
| $h_2 = 205 \text{kJ/kg}$ |
| $h_3 = 205 \text{kJ/kg}$ |
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) | m(kg/sec) | 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      | 6.45     | 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      | 11.5   | 57.73    | 0.72                 | 1209        |
| 12500      | 178    | 50      | 0.62       | 0.44      | 11.5   | 56.43    | 0.74                 | 1198        |
| 12000      | 178    | 50      | 0.6        | 0.44      | 11.5   | 54.21    | 0.76                 | 1185        |
| 11500      | 178    | 50      | 0.57       | 0.44      | 11.5   | 52.44    | 0.78                 | 1168        |
| 11000      | 178    | 50      | 0.55       | 0.44      | 11.5   | 50.61    | 0.81                 | 1149        |
| 10500      | 178    | 50      | 0.52       | 0.44      | 11.5   | 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    | 0.89                 | 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 be 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.

![Engine RPM Vs mechanical efficiency](image1)

**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.

![Engine RPM Vs hot water exit temperature](image2)

**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](image)

As mostly the Formula 1 cars operate in the range between 10500 RPM to 13000 RPM 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                             | 0.756         | 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         |
| 13800| 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         |
| 18800| 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 (Km/Hr) | Mass flow rate of Ram air to radiator (Kg/Sec) | Effectiveness of radiator | T(H) to engine | Power input to compressor (HP) | HP by Engine | Net HP |
|-----------------------|-----------------------------------------------|---------------------------|----------------|-------------------------------|--------------|-------|
| Refrigerated system (@15000 Engine Rpm) |
| 180                   | 2.62                                          | 0.68                      | 50             | 14.37                         | 1223         | 1208  |
| 200                   | 2.91                                          | 0.70                      | 50             | 13.98                         | 1223         | 1209  |
| 220                   | 3.20                                          | 0.71                      | 50             | 13.59                         | 1223         | 1209  |
| 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 (@15000 Engine Rpm) |
| 180                   | 2.62                                          | 0.55                      | 100            | 1054                          |
| 200                   | 2.91                                          | 0.56                      | 99.2           | 1056                          |
| 220                   | 3.21                                          | 0.55                      | 98.3           | 1059                          |
| 240                   | 3.49                                          | 0.56                      | 97.58          | 1061                          |
| 260                   | 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.

![Fig. 11. Designed results for a refrigerated intercooler](image_url)

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.

References

[1] Brouillard, Eric, Brian Burns, Naeem Khan, and John Zalaket. "The design and manufacturing of an intercooler assembly with R-134a integration." Boston: Prestige Worldwide, Wentworth Institute of Technology (2011).
[2] STK Turbo Technik. "History of The Exhaust Driven Turbo Charger." 2016.
[3] Nguyen-Schäfer, Hung. Rotordynamics of automotive turbochargers. Springer International Publishing, 2015. https://doi.org/10.1007/978-3-319-17644-4
[4] Wu, Chih. Thermodynamic cycles: computer-aided design and optimization. CRC Press, 2003.
[5] Moran, Michael J., Howard N. Shapiro, Daisie D. Boettner, and Margaret B. Bailey. Fundamentals of engineering thermodynamics. John Wiley & Sons, 2010.
[6] Pulkrabek, Willard W. "Engineering fundamentals of the internal combustion engine." (2004): 198-198. https://doi.org/10.1115/1.1669459
[7] Cengel, Yunus A., and Afshin J. Ghajar. "Internal forced convection." YA Cengel, Heat Transfer, A Practical Approach 2nd Edition (McGraw-Hill) p 424 (2002).
[8] Bergman, Theodore L., Frank P. Incropera, David P. DeWitt, and Adrienne S. Lavine. Fundamentals of heat and mass transfer. John Wiley & Sons, 2011.
[9] Cengel, Yunus A., and Michael A. Boles. Thermodynamics: An Engineering Approach 6th Edition (SI Units). The McGraw-Hill Companies, Inc., New York, 2007.
[10] S. Klein, "EES Overview." *F-Chart Software* 2017.

[11] Gerhart, Philip M., Andrew L. Gerhart, and John I. Hochstein. *Munson, Young and Okiishi's Fundamentals of Fluid Mechanics*. John Wiley & Sons, 2016.

[12] Hammock, Gary L. "Cross-Flow, Staggered-Tube Heat Exchanger Analysis for High Enthalpy Flows." Masther thesis, *University of Tennessee Space Institute* (2011).

[13] Luigi, Teodosio, Attilio Roberto, and Nonatelli Fabio. "A 1D/3D Methodology for the Prediction and Calibration of a High Performance Motorcycle SI engine." *Energy Procedia* 82 (2015): 936-943. https://doi.org/10.1016/j.egypro.2015.11.842

[14] De Bellis, Vincenzo, Fabio Bozza, Daniela Siano, and Alfredo Gimelli. "Fuel consumption optimization and noise reduction in a spark-ignition turbocharged VVA engine." *SAE International Journal of Engines* 6, no. 2 (2013): 1262-1274. https://doi.org/10.4271/2013-01-1625

[15] De Bellis, Vincenzo, Elena Severi, Stefano Fontanesi, and Bozza Fabio. "Hierarchical 1D/3D approach for the development of a turbulent combustion model applied to a VVA turbocharged engine. Part II: combustion model." (2014): 1027-1036. https://doi.org/10.1016/j.egypro.2014.01.108