

# Analyzing and Increasing the Air Standard Efficiency of the Diesel Engine by Critically Conditioning the Inlet Air

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**ABSTRACT:** The objective of a turbocharger is to improve an engine's air standard efficiency by increasing the density of the intake gas (usually air, entering the intake manifold of the engine). When the pressure of the engine's intake air is increased, its temperature will also increase. Turbocharger units make use of an intercooler to cool down the intake air. Here, our purpose is to bring the temperature of intake air nearer to the ambient temperature. The intercooling of intake air is greatly increased by installing a specially designed intercooler in which air will run as hot fluid and refrigerant, of the air conditioning system coming from cooling coil fitted in the dashboard, will run as cold fluid. The intake air will be cooled down by the air flowing through the fins of the intercooler and the refrigerant coming from the evaporator. And hence the density of air is increased by increasing the temperature drop across the intercooler.

**KEYWORDS** - Air conditioner, intake manifold, intercooler, supercharger, turbocharger.

## I. INTRODUCTION

### 1.1 GENERAL

In case of a diesel engine the total heat loss is around 33-45%, of which 33% is due to exhaust gases and the rest is lost to the surroundings. Here, conditions in the engine are different from in a spark-ignition engine, because power is controlled by controlling the fuel supply directly, not by controlling the air supply. As a result, when the engine is running at low power, there is enough oxygen present to burn the fuel, and diesel engines only make significant amounts of carbon monoxide when running under load.

In thermal power stations, mechanical power is produced by a heat engine that transforms thermal energy, often from combustion of a fuel, into rotational energy. Most thermal power stations produce steam, and these are sometimes called steam power stations. Not all thermal energy can be transformed into mechanical power, according to the second law of thermodynamics. Therefore, there is always heat lost to the environment. If this loss is employed as useful heat, for industrial processes or district heating, the power plant is referred to as a cogeneration power plant or CHP (combined heat-and-power) plant.

1.2 Present methods to reduce exhaust gas temperature i)  
Turbocharging

ii) Exhaust gas recirculation (EGR)

### 1.3 TURBOCHARGING

A turbocharger, or turbo, is an air compressor used for forced-induction of an internal combustion engine. The purpose of a turbocharger is to increase the mass of air entering the engine to create more power. However, a turbocharger differs in that the compressor is powered by a turbine driven by the engine's own exhaust gases. The major parts of a turbocharger are turbine, wheel, turbine housing, turbo shaft, compressor, compressor housing and bearing housing. A turbo is a small radial fan pump driven by the energy of the exhaust flow of an engine. A turbocharger consists of a turbine and a compressor on a shared axle. The turbine inlet receives exhaust gases from the engine causing the turbine wheel to rotate. This rotation drives the compressor, compressing ambient air and delivering it to the air intake manifold of the engine at higher pressure, resulting in a greater mass of air entering each cylinder. In some instances, compressed air is routed through an intercooler before introduction to the intake manifold. The objective of a turbocharger is the same as a supercharger; to improve upon the size-to-output efficiency of an engine by solving one of its cardinal limitations. A naturally aspirated automobile engine uses only the downward stroke of a piston to create an area of low pressure in order to draw air into the cylinder through the intake valves. In the automotive world, boost refers to the increase in pressure that is generated by the turbocharger in the intake manifold that exceeds normal atmospheric pressure. Turbocharger parts are costly to add to naturally aspirated engines.

Heavily modifying OEM turbocharger systems also require extensive upgrades that in most cases requires most (if not all) of the original components to be replaced. Turbochargers require numerous additional systems if they are not to damage an engine.

### 1.4 EXHAUST GAS RECIRCULATION

The main objective of this method to reduce the amount NO<sub>x</sub> produced. EGR works by re-circulating a portion of an engine's exhaust gas back to the engine cylinders. Intermixing the incoming air with re-circulated exhaust gas dilutes the mix with inert gas, lowering the adiabatic flame temperature and (in diesel engines) reducing the amount of excess oxygen

EGR in Diesel Engines:- In modern diesel engines, the EGR gas is cooled through a heat exchanger to allow the introduction of a greater mass of re-circulated gas. Unlike SI engines, diesels are not limited by the need for a contiguous flame-front; furthermore, since diesels always operate with excess air, they benefit from EGR rates as high as 50% (at idle, where there is otherwise a very large amount of excess air) in controlling NO<sub>x</sub> emissions. Adding EGR to a diesel engine reduces the specific ratio of combustion gases in the power stroke. This reduces the amount of power that can be extracted by the piston. EGR tends to reduce the amount of fuel burned in the power stroke. This is evident by the increase in particulate emissions that corresponds to EGR.

### 1.5.ECONOMISERS

Economisers, are mechanical devices intended to reduce energy consumption, or to perform another useful function like preheating a fluid. In case of coal fired power stations they are referred to as feedwater heaters and heat the condensate from turbines before it is pumped. Economizers are commonly used as part of a heat recovery steam generator in a combined cycle power plant. In an HRSG, water passes through an economizer, then a boiler and then a superheater. The economizer also prevents flooding of the boiler with liquid water that is too cold to be boiled given the flow rates and design of the boiler. A common application of economizers in steam powerplants is to capture the waste heat from boiler flue gas and transfer it to the boiler feedwater. This raises the temperature of the boiler feedwater thus lowering the needed energy input, in turn reducing the firing rates to accomplish the rated boiler output.

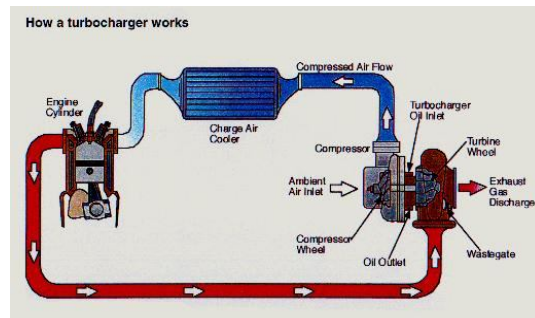


Figure 1: Layout of a turbocharger System

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### III. TURBOCHARGER WITH AFTERCOOLER (WATER)

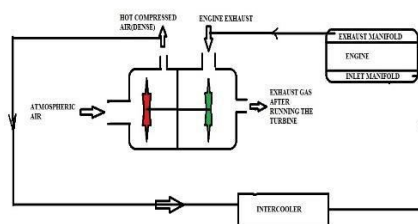


Figure 2: Working Principle of conventional turbocharger in Diesel Locoengine

A turbocharger consists of a turbine and a compressor connected by a shaft. The turbine section is mounted to the exhaust line from the engine. The compressor is connected to the turbine by a shaft and its outlet is routed to the engine air intake. Exhaust gas from the engine enters the turbine and expands, performing work on the turbine. The turbine spins the shaft connected to the compressor. The compressor draws in ambient air and compresses it. Figure 2 is a cross-section of a turbocharger. Turbocharger systems are measured by the amount of pressure the compressor can output above ambient. This pressure is commonly called boost pressure or boost.<sup>2</sup> The target boost pressure for the system analyzed in this project is 18 psi. A heat exchanger, or intercooler, is installed between the compressor and engine inlet to cool the charge air.<sup>2</sup> There are two different types of intercoolers, air-air and air-water. For this project, an air-water intercooler was chosen by the vehicle owner. In an air-water intercooler, air from the compressor is the external flow and the water is the internal cooling flow. The water cools the air exiting the compressor. A second cooling cycle is needed in the system to cool the water. The water is routed to a radiator, to be cooled by the moving air caused by the movement of the vehicle. The water flows through the radiator and into the water pump, which forces the water through the system. The pump adds a small amount of heat to the water, but not enough to affect the heat transfer in the intercooler.

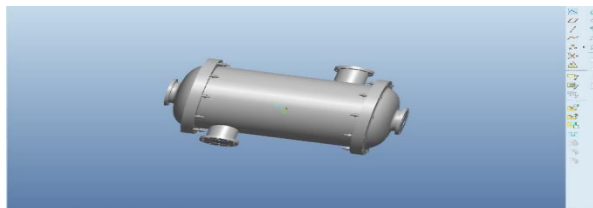


Figure 3: Modelling of after cooler in Pro-E

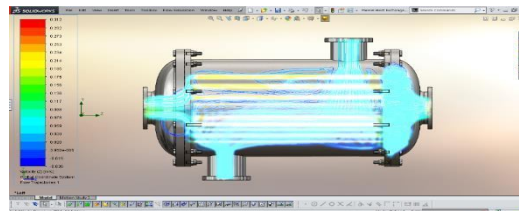


Figure 4: Flow pattern of after cooler (Solid works)

#### IV. TURBOCHARGING SYSTEM WITH AIR CONDITIONER ASSISTED INTERCOOLER

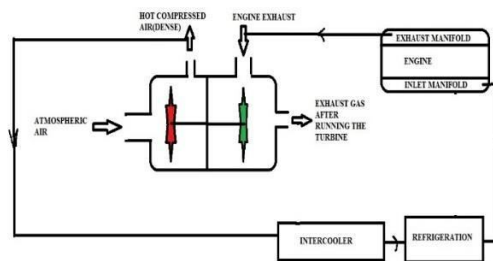


Figure 5: Aftercooler with refrigerator assisted

In this system the air conditioning system is used to assist the turbocharging system. In summers, when the efficiency of the intercooler is low due to high ambient temperature, the air conditioning system will be used to improve its efficiency because in summers, normally the AC is always switched on while we drive and on the other hand, we don't need this system in winters because the ambient temperature is sufficiently cool to improve the efficiency of the intercooler. So the design of the intercooler is such that it will work properly with and without the air conditioning system (i.e. in summers and winters both). Besides this it will also increase the charge density to high extent. This will increase the oxygen availability in the cylinder for combustion.

Circulating refrigerant enters the compressor in the thermodynamic state known as a saturated vapor and is compressed to a higher pressure, resulting in a higher temperature as well. The hot, compressed vapor is then in the thermodynamic state known as a superheated vapor and it is at a temperature and pressure at which it can be condensed in the condenser. That hot vapor is routed through a condenser where it is cooled and condensed into a liquid by flowing through a coil or tubes of the condenser. This is where the circulating refrigerant rejects heat from the system and the rejected heat is carried away by the air. The condensed liquid refrigerant, in the thermodynamic state known as a saturated liquid, is next routed through an expansion valve where it undergoes an abrupt reduction in pressure. That pressure reduction results in the adiabatic flash evaporation of a part of the liquid refrigerant. Then this mixture of vapor and liquid refrigerant is passed through the intercooler of the turbocharger as the cold fluid where it is completely

evaporated by absorbing the required latent heat. This cools the hot compressed air flowing in the tubes of intercooler coming from the turbocharger compressor.

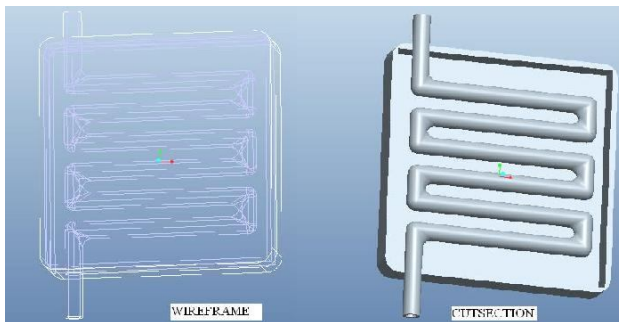


Figure 6: Modelling of refrigerator cooler

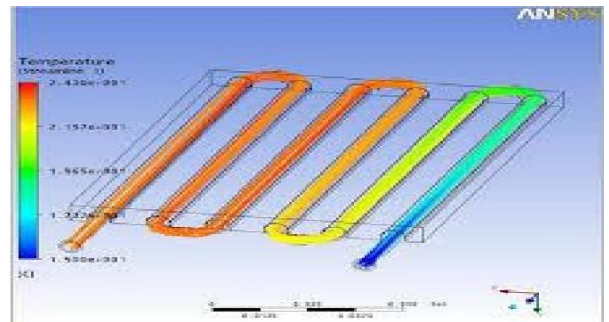


Figure 7: Analysis of refrigerator cooler

## V. ANALYSIS OF OXYGEN CONTENT IN INLET AIR

In the intercooler there is constant pressure intercooling. Here our main purpose is the measurement of drop in the temperature of the air to be cooled between the inlet and the outlet of the intercooler. Calculation of amount of heat being exchanged between the hot and cold fluid is not required.

Suppose,

$T_1$  = temperature of air entering the intercooler

$T_2$  = temperature of air leaving intercooler when the intercooler is normal

$T_3$  = temperature of air leaving intercooler when the intercooler is refrigerated

$v_1$  = specific volume of air entering the intercooler

$v_2$  = specific volume of air leaving the intercooler when the intercooler is normal

$v_3$  = specific volume of air leaving the intercooler when the intercooler is refrigerated

$P_1$  = Pressure of air entering the intercooler

$P_2$  = Pressure of air leaving the intercooler when the intercooler is normal

$P_3$  = Pressure of air leaving the intercooler when the intercooler is refrigerated

We know that the general gas equation is as follows:

$$\frac{P_1 v_1}{T_1} = \frac{P_2 v_2}{T_2}$$

But,

$$P_1 = P_2 = P_3$$

(Constant pressure intercooling)

So,

$$\frac{v_1}{T_1} = \frac{v_2}{T_2}$$

Therefore,

$$\frac{T_1}{T_2} = \frac{v_1}{v_2}$$

And

$$v_2 = \frac{T_2}{T_1} \cdot v_1 \text{ ---- (1) (for normal intercooler)}$$

Similarly

$$v_3 = \frac{T_3}{T_1} \cdot v_1 \text{ ---- (2) (for refrigerated intercooler)}$$

If  $v_1$ ,  $v_2$  and  $v_3$  are the specific volumes of air in  $m^3/kg$  entering and leaving the intercooler then the density of air at inlet and the outlet will be  $\frac{1}{v_1}$ ,  $\frac{1}{v_2}$  and  $\frac{1}{v_3}$  (reciprocals of the specific volumes) in  $kg/m^3$ .

If the air directly enters the engine cylinder (without intercooling) having swept volume  $v$   $m^3$ , then the mass of oxygen entering the cylinder will be



$$\begin{aligned}
 &= \text{swept volume} \times \text{density} \times \text{percentage of oxygen in air} \\
 &= v \cdot \frac{1}{v_1} \times 0.21 \\
 &= \frac{0.21v}{v_1}
 \end{aligned}$$

**Case 1-** When the air enters the engine cylinder after normal intercooling.

Then the mass of oxygen entering the cylinder will be

$$\begin{aligned}
 &= \text{swept volume} \times \text{density} \times \text{percentage of oxygen in air} \\
 &= v \cdot \frac{1}{v_2} \times 0.21 \\
 &= \frac{0.21v}{v_2}
 \end{aligned}$$

Then increase in mass of oxygen entering the engine cylinder will be as follows,

$$\begin{aligned}
 &= \frac{0.21v}{v_2} - \frac{0.21v}{v_1} \\
 &= \frac{0.21v(v_1 - v_2)}{v_1 v_2}
 \end{aligned}$$

Percentage increase in the mass of oxygen entering the engine cylinder,

$$\begin{aligned}
 &= \frac{\frac{0.21v(v_1 - v_2)}{v_1 v_2}}{\frac{0.21v}{v_1}} \times 100 \\
 &= \frac{100(v_1 - v_2)}{v_2} \\
 &= \frac{100(v_1 - \frac{T_2}{T_1} v_1)}{\frac{T_2 v_1}{T_1}} \quad \text{(From eq. 1 } v_2 = \frac{T_2}{T_1} v_1) \\
 &= \frac{100(1 - \frac{T_2}{T_1})}{\frac{T_2}{T_1}} \quad \text{----- (3)}
 \end{aligned}$$

**Case 2-** When the air enters the engine cylinder after refrigerated intercooling,  
Similarly percentage increase in the mass of oxygen entering the engine cylinder,

## VI. COMPARISON OF OXYGEN CONTENT

6.1 Calculations for the percentage increase in the mass of oxygen entering into intake manifold of the engine.

When the air enters into intake manifold of the engine through normal air cooled intercooler. Taking average of all readings of temperature of air at the inlet and outlet of the intercooler, we have T<sub>1</sub>=110 °C and T<sub>2</sub>=82.22 °C

Now from equation 3, we have

$$\begin{aligned}
 \text{Percentage increase in the mass of oxygen} &= 100(1 - T_2/T_1)/(T_2/T_1) \\
 &= 100(1 - 82.22/110)/(82.22/110) = 33.7793\%
 \end{aligned}$$

6.2 Calculations for the percentage increase in the mass of oxygen entering into intake manifold of the engine.

When the air enters into intake manifold of the engine through specially designed refrigerated and air cooled intercooler. Taking average of all readings of temperature of air at the inlet and outlet of the intercooler, we have T<sub>1</sub>=100.83 °C and T<sub>2</sub>=39.16 °C

Now from equation 3, we have

$$\begin{aligned}
 \text{Percentage increase in the mass of oxygen} &= 100(1 - T_2/T_1)/(T_2/T_1) \\
 &= 100(1 - 39.16/100.83)/(39.16/100.83) \\
 &= 161.7823\%
 \end{aligned}$$

Table 1: Aftercooler (Water)

S.No	Rpm of the engine	Ambient temperature °C	Temperature of the air at the inlet of the intercooler (T1) °c	Temperature of the air at the outlet of the intercooler (T2) °c	Temperature drop across the intercooler °C	Percentage increase in oxygen content (%)
1.	2800	20	89	45	44	97.78
2.	3200	20	93	55	38	69.09
3.	3600	20	99	68	31	45.59
4.	4000	20	105	77	28	36.36
5.	4400	20	111	86	25	29.07
6.	4800	20	118	99	19	19.19

Regression Equation:

$$\text{Intercooler output (T2)} = (18.248 * \text{Speed}) + (0.024 * \text{ambient temp}) - (2.804 * \text{Inlet temp of intercooler}) + 0.182$$

Table 2: Air Conditioner Assisted Intercooler

S.No	Rpm of the engine	Ambient temperature °C	Temperature of the air at the inlet of the intercooler (T1) °c	Temperature of the air at the outlet of the intercooler (T2) °c	Temperature drop across the intercooler °C	Percentage increase in oxygen content (%)
1.	2800	19	87	22	65	295.46
2.	3200	19	92	28	64	228.58
3.	3600	19	96	34	62	182.35
4.	4000	19	101	38	63	165.79
5.	4400	19	110	51	59	115.68
6.	4800	19	119	62	57	91.94

Regression Equation:

$$\text{Intercooler output (T2)} = (-170.246 * \text{Speed}) - (0.002 * \text{ambient temp}) + (4.1 * \text{Inlet temp of intercooler}) + 1.387$$

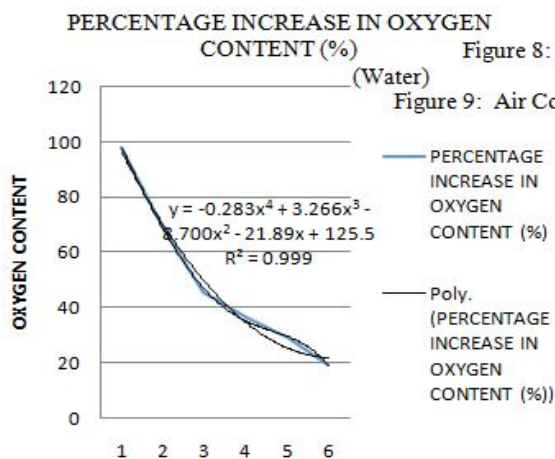


Figure 8: Aftercooler (Water)

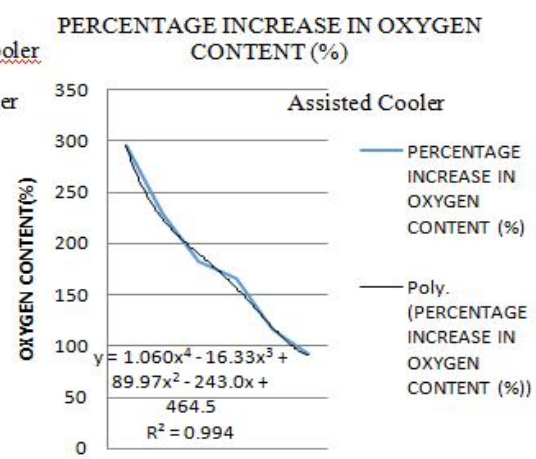


Figure 9: Air Conditioner Assisted Cooler



## VII. CONCLUSION

From the above collected data and calculations, it is being concluded that when normal air cooled intercooler is used to cool down the hot air before entering into the engine cylinder, the mass of oxygen being fed to the engine becomes 1.43 times but when refrigerated intercooler is used, it becomes 2.618 times. Increasing the oxygen content with the air leads to faster burn rates and the ability to control exhaust emissions. Added oxygen in the combustion air offers more potential for burning diesel. In future work, we are going to create an Artificial Neural Network for the above results that are generated from analysis report.

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