OPTIMIZATION OF PERFORMANCE BY HEAT RECOVERY TECHNIQUE ON WDG4 LOCOMOTIVE

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ABSTRACT

A WDG4 (WIDE DIESEL GOODS-4000 HP) locomotive's efficiency is 30-35% and to increase the efficiency, various energy losses has to be analyzed at 8th notch (gear). The Diesel locomotive produces more heat mainly at the components like Compressor, Turbocharger, Exhaust pipe and various parts of an engine.The energy generated in an engine is equal to the heat value of fuel consumed. Some part of this energy is transformed into useful work and the rest of it is being wasted due to exhaust gas emissions letting freely into the atmosphere. A Turbo-Superchargeris introduced to use these exhaust gases for its working and sucks atmospheric air then compresses it, and pass to engine block. Another way of heat loss is due to the heat carried out by walls of exhaust pipe and it is recollected by using Thermoguard. The recollected heat is used to run the Turbocharger more efficiently. Thermoguard reduces the heat loss from the engine and Turbo-Supercharger reduces Compressor work. Due to this, efficiency of the engine may increase and specific fuel consumption rate will decrease which leads to optimization of performance.

Keywords: *Compressor, Locomotive, Supercharger, Thermoguard, Turbocharger, WDG4 engine*

1. INTRODUCTION

Energy supplied to an engine is the heat value of fuel consumed. As been repeatedly pointed out, only one part of this energy is transformed into useful work. The rest of energy iswasted and it can be utilized in special application like turbo compounding. The two main parts of the heat not utilized for work are heat carried away by the exhaust gases and the cooling medium.

1.1. ENGINE SPECIFICATIONS

Engine Model(s)	:	710G3B
Number of Cylinders	:	16
Engine Type	:	Two-Stroke, CI Engine
Cylinder Arrangement	:	45° “V”
Compression Ratio	:	16:1
Displacement per Cylinder	:	11,635 cc (710 Cu. In.)
Cylinder Bore	:	230.19 mm (9-1/16”)
Cylinder Stroke	:	279.4 mm (11”)
Rotation (Facing Flywheel End)	:	Counter-clockwise
Full Speed	:	910 RPM
Normal Idle Speed	:	269 RPM
Low Idle Speed	:	201 RPM

1.2. ENGINE WORKING

Locomotive engine is a diesel-electric combination mechanism on which a diesel engine gives its mechanical power to turbine that generates electric power to drive traction motors attached to wheel axles. Due to this hybrid mechanism equal power is given to all wheels according to the requirement. A 2-stroke diesel engine with air compressor is essential for power generation[1].

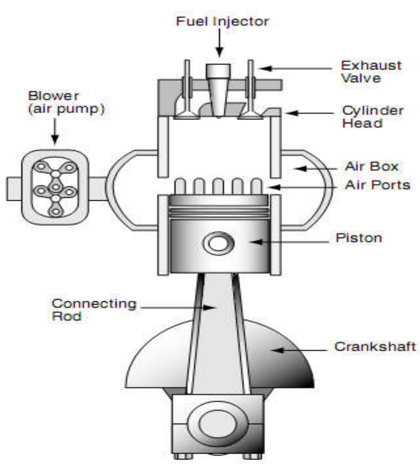

Fig. 1: 2-Stroke engine working

The diesel engine operates on a two-stroke cycle, with power applied on each downward stroke. At the bottom of each downward stroke, cylinders are aspirated through cylinder wall ports opening to a chamber (air box) that is supplied with pressurized air from the Supercharger impeller. The pressurized air scavenges spent gases from the cylinder through multiple exhaust valves in its cylinder head. As the piston moves upward, the ports are closed off and the exhaust valves close and air is compressed in the cylinder. At the top of the stroke, fuel is injected into the cylinder and ignited by the heat of compression to provide power to drive the piston downward until the cylinder wall ports and the exhaust valves again open. The exhaust gases from the cylinders pass through a manifold to exhaust silencer stack [2].

When starting, and at lower power levels, Supercharger is driven by battery power and at high power levels the engine drives the Supercharger through a gear train and an over-running clutch in the gear train disengages the mechanical drive from the engine. The air discharged under pressure from the Supercharger assembly is routed through after coolers to cool the air, before it enters the air box, thereby increasing its density for greater combustion efficiency [3].

Most of the exhaust gas power can be utilized for air compression and the heat energy of the exhaust gases improves performance of engine. Heat energy from coolant system has to be dissipated to avoid seize of engine. Pipes connecting engine and compressor have some heat energy which has to be taken care of and a heat balance sheet is required for calculation of performance [4].

To give sufficient data for the preparation of heat balance sheet, a test should be conducted including the method of determining the friction power, measurement of speed, load, fuel consumption, air consumption, exhaust temperature, rate of flow of cooling water and lubricating oil, and also its temperature rise while flowing through the water jackets. Besides the small losses, such as radiation and incomplete combustion, the above enumerated data makes it possible to account for the supplied energy and indicate its distribution.

2. HEAT RECOVERY TECHNIQUE (HRT)

Every internal combustion engine does not produce 100% efficiency; there may be losses atdifferentpartsofanengine. The following are the stages were energy loss occur in the locomotive,

- Work utilized for running air compressor
- Heat carried away by lube oil
- Heat carried by exhaust gasses
- Unaccountable losses

Energy loss by exhaust gasses can be controlled or recovered by using some methods like Turbo charger, Supercharger, multi stage Turbo-Supercharger, Thermoguard. The application of both Turbo-Supercharger and Thermoguard is referred to be a Heat Recovery Technique (HRT).

2.1. TURBO-SUPERCHARGER

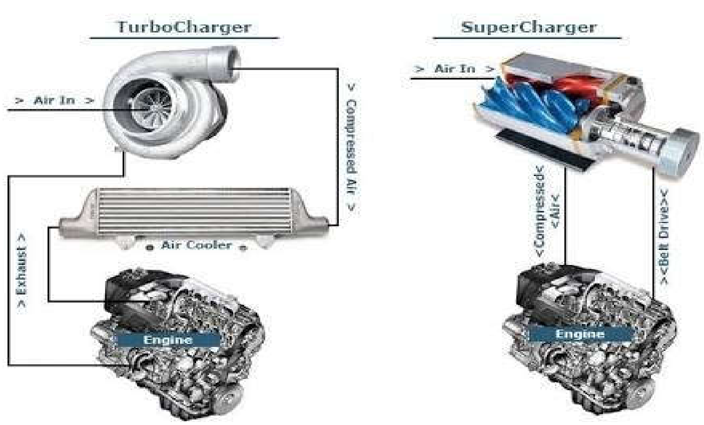

Fig. 2: Working of Turbocharger and Supercharger

The diesel engine produces mechanical energy by converting heat energy derived from burning of fuel inside the cylinder. For efficient burning of fuel, availability of sufficient air in proper ratio is a pre-requisite. An improvement in the naturally aspirated engines is the super-charged or pressure charged engines [5]. During the suction stroke, pressurized stroke of high density is being charged into the cylinder through the open suction valve for efficient combustion. Supercharger is mechanically driven by the engine or battery whereas Turbocharger is driven by exhaust gases for air compression. Some of the energy of engine is utilized for rotating impeller of a Supercharger and energy loss occurs here. A Turbocharger uses exhaust gases which has to be dissipated into atmosphere for impeller rotation and compresses air for combustion. Air of higher density containing more oxygen will make it possible to inject more fuel into the same size of cylinders and produce more power, by effectively burning it[6].

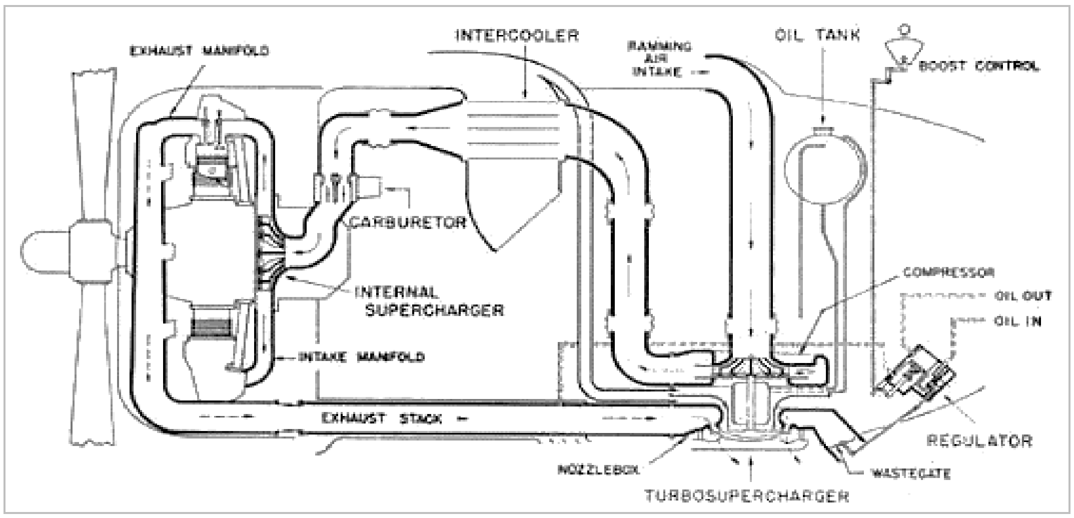

Fig. 3: Working of Turbo-Supercharger

A Turbo-Supercharger is a combination of both Turbo and Super chargers. The main function of Turbo-Supercharger is to suck air from atmosphere by using exhaust gasses and compresses it then pass this air to Super charger through air cooler for additional compression which increases the density of air and then passes compressed air to engine block [7]. The Turbo-Supercharger assembly is primarily used to increase engine horsepower and provide better fueleconomythroughtheutilizationofexhaustgases.

2.2. THERMOGUARD

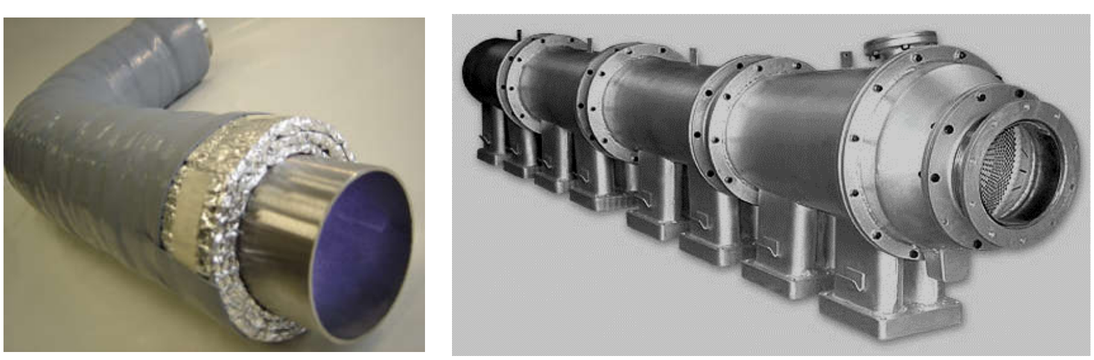

Fig. 4& 5: Application of Thermo guard on connecting pipes and exhaust system

The Thermo guard is used for insulation purpose nexhaustpipesotha the heat cannot dissipatetoatmospheresothatmoreamountofheatisutilizedforrunningTurbo- Supercharger which improves thermal efficiency. Exhaust Wrap is an innovative way to create more horsepower and reduce under-hood temperatures. The heat loss by cooling water is useful because the engine should cool otherwise it may lead to seize of engine and so this lossshoul doccurin the engine. Most of the engines are equipped with water cooling system and lube oil cooling system.

3.OBSERVATIONS AND CALCULATIONS

To calculate the losses, various temperatures are required at full load conditions i.e., at 8^{th}notch. The required temperatures are taken by using laser gun and the amount of loss is calculated at various stages.

Table 1: Various observations of locomotive engine before and after applying Heat Recovery Technique (HRT):

S. No.	REQUIRED PARAMETERS	NOTATIONS	BEFORE HRT	AFTER HRT
1.	Inlet of air compressor	T_{A1}	72˚C	72˚C
2.	Outlet of air compressor	T_{A2}	78˚C	78˚C
3.	Water at inlet of engine block	T_{W1}	75˚C	80˚C
4.	Water at outlet of engine block	T_{W2}	118˚C	125˚C
5.	Lube oil at inlet of engine	T_{L1}	70˚C	90˚C
6.	Lube oil at outlet of engine	T_{L2}	77˚C	96˚C
7.	Air at inlet of engine	T_{E1}	73˚C	59˚C
8.	Air at outlet of engine	T_{E2}	388˚C	412˚C
9.	Exhaust gas at inlet of Turbocharger	T_{T1}	322˚C	396˚C
10.	Exhaust gas at outlet of Turbocharger	T_{T2}	152˚C	168˚C
11.	Indicated Power	**IP**	4000 hp	4000 hp
12.	Frictional Power	**FP**	67 hp	67 hp
13.	Work done by Air Compressor	W_{AC}	54 hp	50 hp

These are the numerical formulas to be calculated for finding efficiency of locomotive.

- Brake Power (BP) = Indicated Power (IP) - (Frictional Power (FP) + Air Compressor Work (W_{AC}))

- Specific Fuel Consumption of a locomotive is,

$$\text{SFC in kg/hr/BP} = \frac{\text{Weight of fuel consumed per hour}}{\text{Indicated Power (IP)}}$$

Weight of fuel consumed per hour is given as,

W = (Consumed fuel in cubic meter) * (Weight density of fuel)

Fuel consumed per hour in cubic meters = $(X_1 - X_2) * \frac{60}{1000*8}\ m^3/hr$

Initial reading of the fuel in fuel supply tank (X_1)

Final reading of the fuel in fuel supply tank (X_2)

- Heat supplied into the engine is given as, $H_s = M_f * Cv$

  Where,

  M_f = Mass flow rate

  Cv= Calorific value of the fuel

- Percentage of heat utilized in developing work is given as,

$$P_{\text{Developing Work}} = \frac{\text{Work output by the engine (BP)}}{\text{Heat supplied to the engine (Hs)}} * 100$$

- Percentage of heat lost due to friction is given as

$$P_{\text{friction}} = \frac{\text{Frictional power loss (FP)}}{\text{Heat supplied to the engine (Hs)}} * 100$$

- Percentage of heat carried away by the lube oil is given as,

$$P_{\text{lube oil}} = \frac{\text{Heat carried by the lube oil}}{\text{Heat supplied to the engine (Hs)}} * 100$$

Heat carried by the lube oil is given as, $Q_{\text{lube oil}} = M_L * C_{PL} * (T_{L2} - T_{L1})$

Where,

M_L = Mass of lube oil

C_{PL}= Specific heat of lube oil

- Percentage of Heat carried away by the cooling water is given as,

$$P_{\text{Cooling water}} = \frac{\text{Heat carried away by the cooling water}}{\text{Heat supplied to the engine (Hs)}} * 100$$

Heat carried by cooling water is given as, $Q_{\text{Cooling water}} = M_W * C_{PW} * (T_{W2} - T_{W1})$

Where,

M_W = Mass of cooling water

C_{PW}= Specific heat of cooling water

- Percentage loss of Heat carried away by exhaust gases is given as

$$P_{Exhaust\ gases} = \frac{\text{Heat carried away by the exhaust gases}}{\text{Heat supplied to the engine (Hs)}} * 100$$

Heat carried by exhaust gases is given as, $Q_{Exhaust\ gases} = M_E * C_{PG} * (T_{E2} - T_{E1})$

Where,

M_E = Mass of exhaust gases

C_{PG}= Specific heat of exhaust gases

- Percentage loss of heat carried away by Turbocharger is given as

$$P_{Turbo\ charger} = \frac{\text{Heat lost by the turbo charger}}{\text{Heat supplied to the engine (Hs)}} * 100$$

Heat loss by the Turbocharger is given as, $Q_{Turbo\ charger} = M_E * C_{PG} * (T_{T2} - T_{T1})$

Where,

M_E = Mass of exhaust gases

C_{PG}= Specific heat of exhaust gases

- Overall heat lost at exhaust gases, $Q_{Overall} = Q_{Exhaust\ gases} - Q_{Turbo\ charger}$
- Overall heat percentage loss due to exhaust gases, $P_{Overall} = P_{Exhaust\ gases} - P_{Turbo\ charger}$
- Unaccountable losses = (Total Heat supplied – Heat taken by the engine components)

$$U_L = P_{Total} - (P_{Work} + P_{Friction} + P_{Lube\ oil} + P_{Cooling\ water} + P_{Overall})$$

- Efficiency of the locomotive = $\frac{\text{Energy Output}}{\text{Energy Input}}$

4. RESULTS AND DISCUSSION

Table 2: Comparison of various heat energy values of locomotive engine before and after applying Heat Recovery Technique (HRT):

S.No.	Heat Parameters	Heat Input (kW)		Heat Expenditure (kW)		Percentage of heat gained (%)	
		Before HRT	After HRT	Before HRT	After HRT	Before HRT	After HRT
1.	Air compressor	8338.11	7533.19	2892.57	2895.55	34.69	38.437
2.	Friction	8338.11	7533.19	49.96	49.96	0.599	0.663
3.	Lube oil	8338.11	7533.19	264.568	266.773	3.1729	3.541
4.	Cooling water	8338.11	7533.19	2858.89	2991.87	34.288	39.715

5.	Overall exhaust gases	8338.11	7533.19	590.62	507.057	7.084	6.736
6.	Un accountable heat	8338.11	7533.19	1681.49	821.981	20.1661	10.914

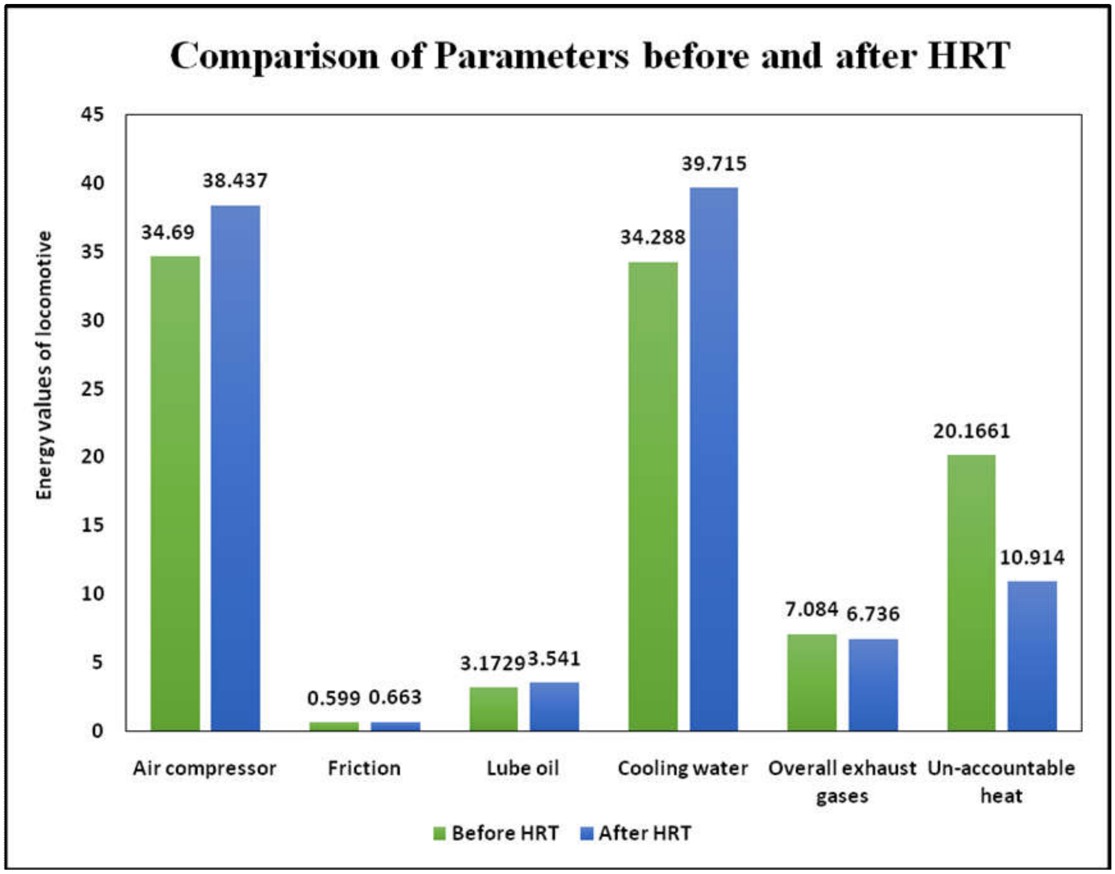

Fig. 6: Comparison of various heat energy values in alocomotive

Figure 5 shows various heat values in a locomotive. The abscises are presents the various heat parameters and ordinate represents the heat values in the locomotive. When a Thermo guard is applied on the connecting pipes of air compressor and engine, losses are reduced which results in energy gain of 4%. Dissipation of temperatures of cooling water and lube oil are reduced as insulation is provided. Before insulation, exhaust gases temperature at the outlet of engine is 388^{o}C which reaches the Turbocharger at a temperature of 322^{o}C whereas after insulation, the temperature of gases at engine outlet is 412^{o}C and the temperature at Turbocharger inlet is 396^{o}C, which shows that the insulation with Thermo guard provides resistance to dissipation of heat. Unaccountable heat is the remaining heat value obtained after calculating energy losses by work, friction, lube oil, cooling water and exhaust gases.

Table3:Comparisonresultsofa locomotive engine before and after applying Heat Recovery Technique (HRT):

S.No.	Specification	Compressor work (hp)	Efficiency of locomotive (%)	Specific Fuel Consumption (gm/hr/BP)
1.	Before HRT	54	34.69	154
2.	After HRT	50	38.437	139

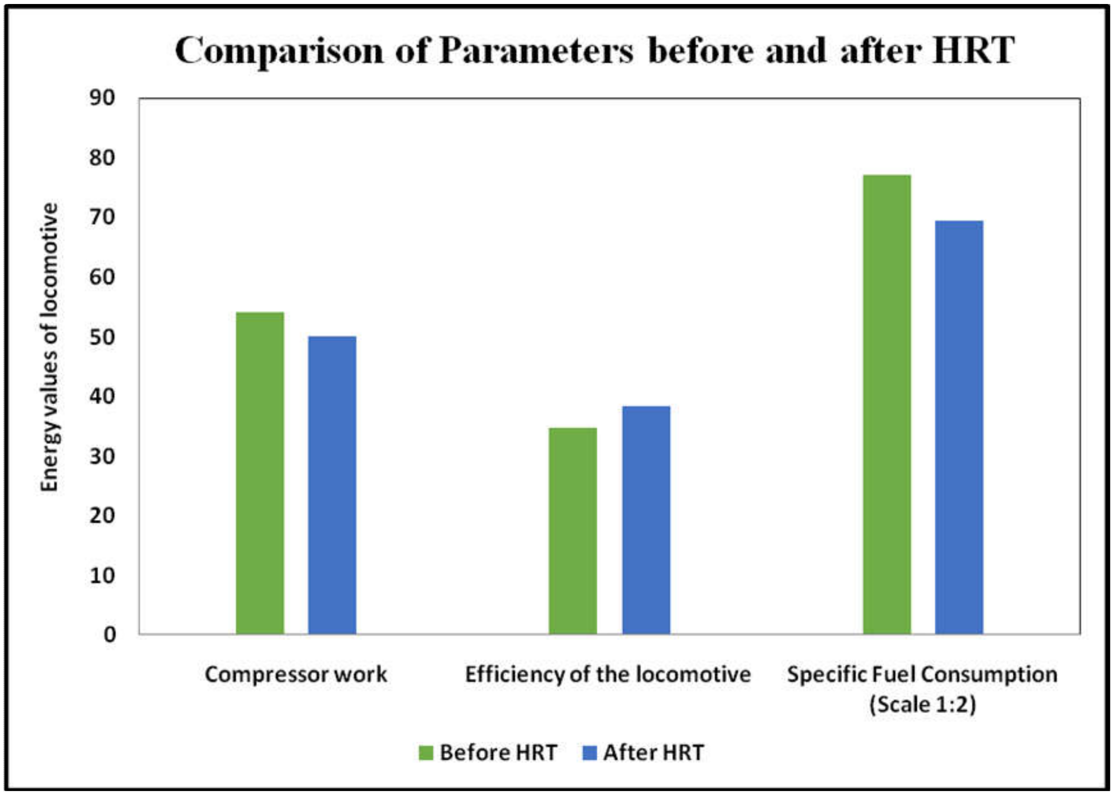

Fig. 7: Comparisons of heat parameters in a locomotive

Figure 6 shows heat parameters in a locomotive. The abscissa represents the heat parameters and ordinate represents the heat parameter value in the locomotive. By using Turbo-Supercharger, the air compresses without any external work and also the air is supplied to air compressor that directs to engine. Compression is already done once and so the air compressor work is reduced and also the combustion gives extra energy, which increases the performance of locomotive. Efficiency of the locomotive can be drastically increased as the compressor work reduced, external work not required, power generation is achieved faster. Specific fuel consumption is ratio of weight of fuel consumed to the indicated power. The fuel consumption reduces as the density of air increases which in-turn reduces Specific fuel consumption rate.

5. CONCLUSION

The Heat Recovery Technique (HRT) process increases theefficiency of engine and decreases the Specific fuel consumption by using Turbo-Supercharger and Thermoguard which leads to optimization of performance. From the numerical calculations, the Compressor work is reduced by 4 % and Specific fuel consumption reduces from 154 gm/hr/BP to 139 gm/hr/BP. Due to reduction in fuel consumption rate it causes the reduction in air pollution. Thus the efficiency of the locomotive increases from 34.69 % to 38.437 %. By insulating the pipes with Thermoguard, heat dissipation to atmosphere reduces which increases the life of components near the engine. Combination of a Turbocharger and a Supercharger results in double stage compression of air and increases the combustion efficiency. The torpedo shaped Turbocharger works efficiently but maintenance is more crucial as thickness of engine exhausts which are sticked to wall increases and can lead to blockage of holes.

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