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Investigating Performance on Intercooler in Turbocharger Diesel Engine with ANN

*[1]Kemal Ermis, [2]Yasar Sen

*[1]Faculty of Technology, Department of Mechanical Engineering, Sakarya University, Turkey
[2]Faculty of Engineering, Department of Biomedical Engineering, Duzce University, Turkey

Abstract

Recently, application of turbocharged in internal combustion engines have increased. Most of the diesel engines have been covered by this application. Turbocharged can be defined as a supercharge functioning with exhaust gas. Turbocharged has two fans where one of them is on the exhaust side and the other is on suction side. In this study, performance of a turbocharged in diesel engine, made of Basak Tractors and Agricultural Machinery Industry and Trade Business in Turkey, is investigated by using the parameters. These parameters are calculated at 2500 rev/min and 370 K value of turbocharger by using Matlab programme. The good designed an intercooler with turbocharged is reduced specific fuel consumption by 3.8% and increased the effective power about 18 kW with increased rotation torque. According to these results, turbocharge with intercooler provide good performance for the engine. Also, artificial neural network analysis (ANN) is performed on effective power and specific fuel consumption on the engine by using a feed-forward back-propagation artificial neural network (ANN) algorithm. Results of ANN are good agreement with actual data.

Key words: Performance, turbocharger, thermal analysis, intercooler, artificial neural network

1. Introduction

Recently, application of turbocharged in internal combustion engines have increased. Nowadays, engines have turbocharged as is well known, a turbocharger system. This is one of the methods used to improve operational performance and efficiency. Most of the diesel engines have been covered by this application. In turbocharged engine has been observed that the improvement in fuel consumption and gas emissions to the environment. Turbocharged diesel engine produces 50% less NOx and CO_2 emissions compared to other engines [1]. Turbocharged can be defined as a supercharge functioning with exhaust gas. Turbocharged has two fans where one of them is on the exhaust side and the other is on suction side [2]. This way, with the pressure provided by the turbocharger the intercooler contributes to a power increase. The maximum engine power can be achieved with the help of coldest air entering the engine. Therefore, a larger size intercooler means more air molecules can take to send more cold air into the engine. Thus, increase of the air quantity obtained by cooling results in increased fuel economy and engine power and so, allows the improvement of durability and reduction of emissions. An intercooler, placed between the intake manifold and turbocharger, is a utility used to cool the heated air as a result of compression of the turbo in turbo-charged engine [3]. Using an intercooler allows more air to be heated as results of compression of the turbocharger and enters into the cylinder in the engine

*Corresponding author: Address: Faculty of Technology, Department of Mechanical Engineering Sakarya University, 54187, Sakarya TURKEY. E-mail address: ermisr@sakarya.edu.tr, Phone: +902642956528

block. In order to receive the output expected from the intercooler, the intercooler sizing, geometric shape and type of the fins must be well designed. Cooling and increasing gas intake manifold air molecules heats the air is taken in from here again and subjected to compression. The heated air expands. So it is the result of previous warming of the air going into the engine from the turbo pressure increases. To ensure the power rollers need to increase more air molecules is not enough just to increase the power of the engine pressure [4]. Motor revenues will be at the highest power that we can get the cold weather. This causes the intercooler to their large size always means that more air molecules can parse and send to colder air motor. Thus, by providing an increased amount of air and cooling;

- Improving fuel economy,
- 2-Increasing the engine power,
- Increasing the motor resistance,
- Reduction of good combustion engine gas emissions, in particular, is improved [5].

In this study, performance of a turbocharged in diesel engine, made of Basak Tractors and Agricultural Machinery Industry and Trade Business in Turkey, is investigated by using the parameters. The good designed an intercooler with turbocharged is reduced specific fuel consumption by 3.8% and increased the effective power about 18 kW with increased rotation torque. According to these results, turbocharge with intercooler provide good performance for the engine.

ANNs have been used in many engineering applications because of providing better and more reasonable solutions [6]. Therefore, the ANN is considered an efficient technique for estimation of performance of effective power in this type of the intercooler turbocharger. Aydogan et al. are presented performance of a turbocharged diesel engine using biodiesel produced from cotton and rapeseed oils through transesterification by using artificial neural network (ANN) [7]. They were observed that the ANN model can predict the engine performance quite well with correlation coefficient for the engine power, the engine torque, specific fuel consumption and exhaust gas temperature, respectively. Bolan et al. are presented a novel misfire detection model of a turbocharged diesel engine by using artificial neural network model [8]. They proposed neural network model has been implemented in Matlab/Neural Network Toolbox environment for misfire cases and found the mean square error of their model is satisfied. Tosun et al. are presented estimating the variation of several engine control parameters within the rotational speed-load map, using regression analysis and artificial neural network techniques [9]. They used a three-layer feed-forward structure and back-propagation algorithm was used for training the artificial neural network. They were showed that this technique is capable of predicting engine parameters with better accuracy than linear and non-linear regression techniques. Artificial neural network analysis (ANN) is performed on effective power on the engine by using a feed-forward back-propagation artificial neural network (ANN) algorithm. Results of ANN are good agreement with data.

2. Materials and Method

Specifications the diesel engine of tractor, made of Basak Tractors and Agricultural Machinery Industry and Trade Business in Turkey, are shown in Table 1.

Table 1. Characteristic of diesel engine

Cylinder diameter (D)	100 mm
Stroke (S)	100 mm
Number of cylinders (i)	4
Compression ratio (ε)	16.1
Number of rotation – Speed (n)	2500 d/d
Turbocharger pressure increase rate (ρ)=Pk/Po	1.8
Volumetric efficiency (η_v)	0.90
Air excess coefficient (λ)	1.7
Fuel diesel oil	50
Fuel lower heating value (Hu) kJ/kg	42437.4

2.1. Theory/calculation on intercooler in turbocharger

Calculations are made by using the diesel engine's value. These calculations are effective parameters and heat balance [10].

- ***Calculations of effective parameters***

Calculation of effective parameters in the diesel engine and related with equations are shown in Table 2.

Table 2. Effective parameters in the diesel engine calculations

Definitions	Equations	Value
Effective pressure (Pe), MPa	$Pe = Pi - Pm$	1.0413
Effective power (Ne), kW	$Ne = P_e.V_h i.n/30.Z$	68.1176
Effective efficiency (η_e)	$\eta_e = \eta_m \times \eta_i$	0.3939
Effective Specific Fuel Consumption (be), g/kWh	$be = 3600/(Hu.\eta_e)$	215.31
Fuel Consumption Per Hour (Gy), kg/h	$Gy = Ne.be.10^{-3}$	14.6667

Hu: Lower heating value, Pi: Indicated pressure, Pm: Mechanical pressure, Vh: Stoke volume, n: Revolutions per minute, Z: Stroke engine number, η_m: Mechanical efficiency, η_i: Indicated efficiency

- ***Calculations of heat balance***

Calculations of heat balances, burning energy, heat value for effective power, heat transfer to cooler and heat of exhaust gas are shown in Table 3.

Table 3. Calculations of heat balance

Definitions	Equations	Value
The total amount of heat that occurs with the burning of fuel (Qo), J/s	Qo = Hu.Gy/3.6	172893.5
The amount of heat that turns the effective work (Qe), J/s	Qe=1000 × Ne	68117.7
The amount of heat transferred to the cooler (Qc), J/s	Qc=C×í×B1+2m×nm×1/ λ	51583
The amount of heat from Exhaust gas to outside (Qr), J/s	$Qr = Gy/3.6[M2.mc_{to}^{tr}.tr\text{-}M1\ mc_{to}^{tk}.tk]$	50972.1
The amount of lost heat (Qd), J/s	Qd = Qo - (Qe + Qc + Qr)	2270.7

λ: Air excess coefficient, C: ratio of sides, M: Total product quantity, to: Normal atmospheric temperature, tr: Exhaust gas temperature, tk: Compressor output air temperature, mc: average molar specific heat of the fuel air mixture

3. Performance on Intercooler in Turbocharger

Intercooler sizing and analyzing geometric shapes when choosing the type of air-side louver fin surface, the gas side is flat finned surface types are selected [11]. Dimensions and size of the selected estimate is made considering the intercooler of the tractor engine. Geometric characteristics of the selected surface type are taken from reference [12].

Selected this intercooler, Basak Tractor company's engine size and magnitude, are made by taking into account estimates as shown in Table 5.

Table 5. Intercooler size and values

	Intercooler Air-Side	**Intercooler Gas-Side**
Used surface	Louvered fin surface design, 3/8 - 6,06	Flat fin surface design, 14.77
Inlet temperature, K	293	370
Outlet temperature, K		303
Pressure, kPa	101.325	180.000
Material structure	Aluminum	Aluminum

In this study, the intended intake manifold filling gas temperature (303 K) to obtain the intended intercooler sizes, the size of the flaps used and sectional images is shown in the Figures 1 [4, 10].

The performance of the engine used for the calculations at high speed (2500 rev/min) while intercooler in charge air outlet temperature of 370 K from 303 K by comparison to reduced specific fuel consumption and consequently characteristic calculation was determined the effectiveness of inter-cooling method. Since turbocharger outlet gas temperature is high, the engine will be absorbed into the cylinder with turbocharger to affect the volume of the filler aircraft engines to reduce the temperature of the turbocharger, exhaust gas between the block, so to increase the volume of charge air intercooler is needed in the design.

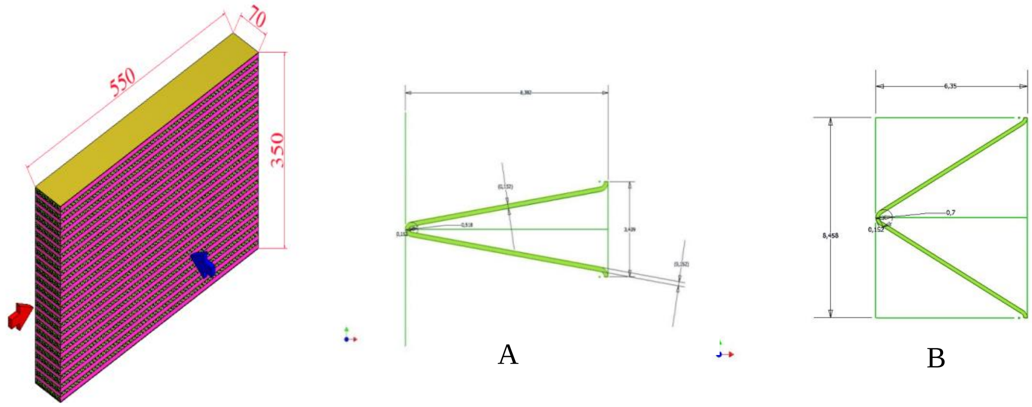

Figure 1. Designed intercooler with the fins on the air (A) and the gas (B) party appearance

Specific fuel consumption, engine power, engine torque, effective efficiency and Heat balance versus intercooler outlet temperature are shown in Figure 2.

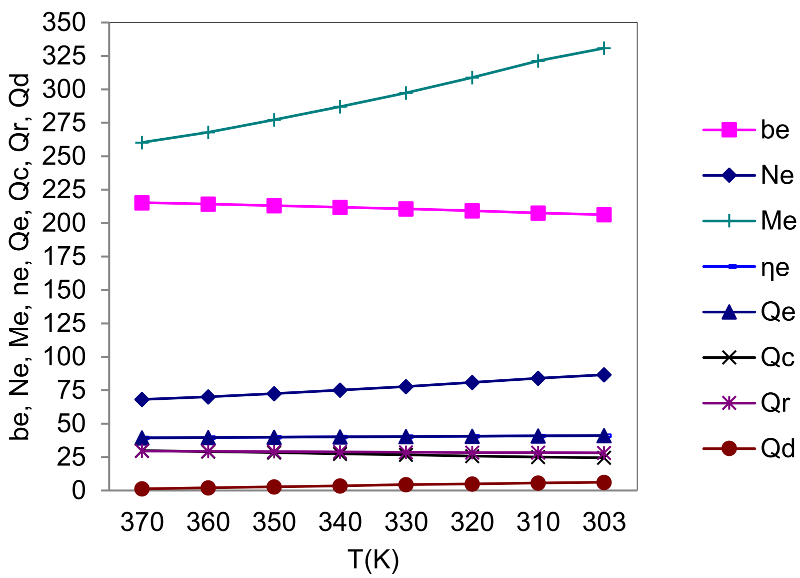

Figure 2. Specific fuel consumption, engine power, engine torque, effective efficiency and Heat balance versus intercooler outlet temperature

The characteristics were compared to data presented diesel engine intercooler taken on the basis of the parametric values of the most commonly used size available on the market as a result of geometric design of the fins kept constant effective survey data. 0.07-0.55-0.35 m is the size of the intercooler designed to achieve the intended temperatures have been identified. Fin design, derived from literature for research to airside louvered fin intercooler 3/8 to 6.06 as the selected surface design, has been preferred for the gas side. These results were compared with 9.03; 11.1; 14.77; 15.08; 19.86 in shown Table 6. Fin surface design structure was presented in the tables on comparisons of the results obtained by the calculations. When the 14.77 type of side surface design is used, the cylinder air temperature in the intake manifold of the engine is dropped from 370 K from to a value of 302.24 K [4, 10].

Table 6. The comparison of the calculated results table

		Air Side Plate-fin surfaces, louvered fins	**Gas side Plate-fin surfaces, Plain fins**				
Surfaces Code		**3/8-6,06**	**14.77**	**9.03**	**11.1**	**15.08**	**19.86**
Calculated Fluid specification	c_p, J/kgK	1019	1021.1	1021.1	1021.1	1021.1	1021.1
	Pe, Pa	$9.93x10^4$	$1.764x10^5$	$1.764x10^5$	$1.764x10^5$	$1.764x10^5$	$1.764x10^5$
Reynolds number Re		1899	680.545				
		3428,1		839,3			
		1638,3			877.6		
		2194,5				613,8	
		1638,2					574,44
St.Pr$^{2/3}$		$9.155x10^{-3}$	$7.395x10^{-3}$				
		$3,10x10^{-3}$		$6,69x10^{-3}$			
		$9,506x10^{-3}$			$5,664x10^{-3}$		
		$2,253x10^{-3}$				$8,04x10^{-3}$	
		$9,50x10^{-3}$					$8,66x10^{-3}$
Heat transfer coefficient, W/m^{2}K		101,2	51,10				
		59,69		31,83			
		87,7			37,81		
		22,06				38,5	
		87,7					69,75
Fin factor		0.982	0.984	0,995	0,996	0,991	0,992
Surface factor		0.989	0.986	0,993	0,989	0,992	0,991
Total heat transfer coefficient, W/m^{2}K			50.463	37,03	30,95	18.1	31.56
Exit temperature		360.76 K	302.24 K				
		337,6 K		325,3 K			
		349,2 K			313,7K		
		337,6 K				325,4 K	
		345 K					317K

4. Artificial neural network (ANN) approach

The back-propagation algorithm that is the focus of recent studies on modeling is the most suitable method for training multi-layer feed-forward networks. The algorithm for training a back-propagation network was developed based on different literatures by Ermis [13, 14]. In this study, an ANN model for the prediction of performance of intercooler in turbocharged is performed. A feed-forward back-propagation ANN approach is used for the training and learning processes. A computer code in the C++ programming language is developed to solve the ANN model algorithm [13, 14].

A three-layer feed-forward back-propagation neural network for effective specific fuel consumption (be), and effective power (Ne) as shown Figure 3. The four input parameters for the network were the amount of heat transferred to the cooler (Qc), the amount of heat from Exhaust gas to outside (Qr), the amount of heat that turns the effective work (Qe) and intercooler in charge air outlet temperature (T). The two output terms were effective specific fuel consumption (be), and effective power (Ne). The weights, biases and hidden node numbers are altered to minimize the error between the output values and the current data. In order to obtain the least error convergence, the configurations of the ANN are set by selecting the number of hidden layers and nodes, and the learning rate and the momentum coefficient. 35 cases were formed out of data and further grouped into two data sets, such that the first group consists of 7 sets which were used to train of the network (80% of all data) and the second group consists of 8 cases which were used to verify the ANN model. Comparison of the absolute mean relative error (AMRE) and absolute fraction of variance (R^2) and standard deviation (STD) for effective specific fuel consumption (be), and effective power (Ne) are shown in Table 7.

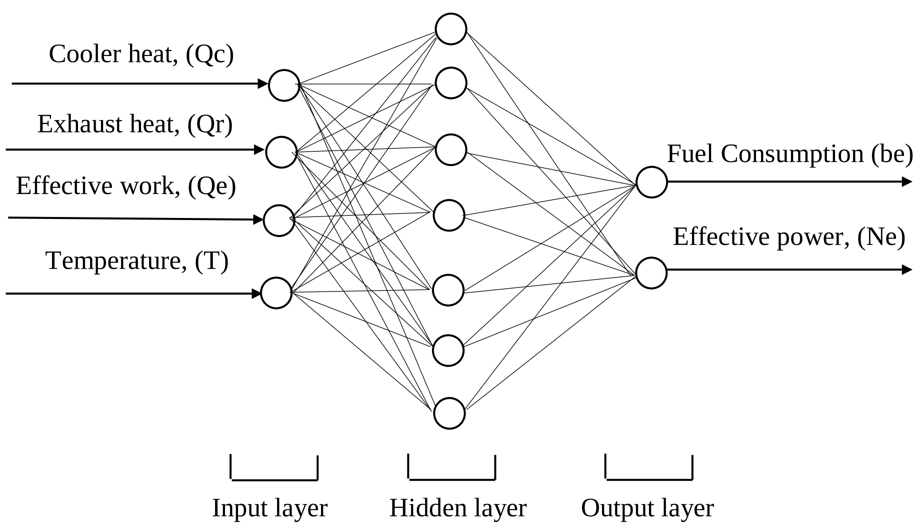

Figure 3. A three-layer feed-forward back-propagation neural network for Effective Specific Fuel Consumption (be), and Effective power (Ne),

Result of comparison is shown that ANN model results are very close to actual data for effective specific fuel consumption; AMRE is 0.39, average R^2 is 1.000 and average STD is 1.16453 and for effective power; AMRE is 0.83, average R^2 is 0.9999 and average STD is 1.39027. ANN results are compared with actual data for effective specific fuel consumption (be), and effective power (Ne) as shown in Figure 4.

Table 7. Comparison of AMRE, R^2 and (STD) for effective specific fuel consumption (be), and effective power (Ne).

Intercooler in charge air outlet temperature (T)	Specific fuel consumption (be)	Effective power (Ne),)	Specific Fuel Consumption (be ANN Model				Effective power (Ne),) ANN Model			
			Results	AMRE (%)	STD (%)	R^2	Results	AMRE (%)	STD (%)	R^2
370	215.31	68.12	216.9654	0.77	1.37465	0.9999	68.325	0.30	1.23958	1.0000
368	215.11	68.52	214.1007	0.47	1.01726	1.0000	68.6704	0.22	1.21607	1.0000
366	214.92	68.92	213.7715	0.53	0.99844	1.0000	69.2209	0.44	1.27874	1.0000
364	214.72	69.32	215.5022	0.36	1.25786	1.0000	69.7713	0.65	1.34064	1.0000
362	214.53	69.72	215.2330	0.33	1.24730	1.0000	70.3218	0.86	1.40188	0.9999
360	214.33	70.12	213.9637	0.17	1.10337	1.0000	70.8722	1.07	1.46237	0.9999
358	214.08	70.61	212.3945	0.79	0.92542	0.9999	71.4227	1.15	1.48496	0.9999
356	213.83	71.09	213.4252	0.19	1.09805	1.0000	71.9731	1.24	1.51130	0.9998
354	213.59	71.58	214.1560	0.26	1.22920	1.0000	72.5236	1.32	1.53325	0.9998
352	213.34	72.06	212.8867	0.21	1.09137	1.0000	73.0740	1.41	1.55891	0.9998
350	213.09	72.55	214.2175	0.53	1.30545	1.0000	73.6245	1.48	1.58024	0.9998
348	212.84	73.06	213.8482	0.47	1.28944	1.0000	74.1749	1.53	1.59322	0.9998
346	212.59	73.58	212.0790	0.24	1.08331	1.0000	74.7254	0.20	1.20975	1.0000
344	212.33	74.09	211.0970	0.58	0.98507	1.0000	75.2758	0.25	1.22509	1.0000
342	212.08	74.61	212.5404	0.22	1.21537	1.0000	75.8263	0.69	1.35246	1.0000
340	211.83	75.12	212.1120	0.13	1.19113	1.0000	76.3767	0.34	1.25135	1.0000
338	211.60	75.67	212.7019	0.52	1.30303	1.0000	76.9272	0.34	1.25082	1.0000
336	211.36	76.21	211.7327	0.18	1.20361	1.0000	77.4776	1.27	1.51922	0.9998
334	211.13	76.75	211.4634	0.16	1.19829	1.0000	78.0281	0.36	1.25730	1.0000
332	210.89	77.29	210.1942	0.33	1.05746	1.0000	78.5785	2.18	1.78335	0.9995
330	210.66	77.83	209.6249	0.49	1.01086	1.0000	79.1290	0.64	1.33778	1.0000
328	210.36	78.43	209.2557	0.52	1.00116	1.0000	79.6794	0.96	1.42853	0.9999
326	210.06	79.03	209.3864	0.32	1.06013	1.0000	80.2299	1.27	1.51794	0.9998
324	209.75	79.64	209.1172	0.30	1.06561	1.0000	80.7803	0.80	1.38479	0.9999
322	209.45	80.24	209.9479	0.24	1.22133	1.0000	81.3307	0.99	1.43717	0.9999
320	209.15	80.84	208.5787	0.27	1.07385	1.0000	81.8812	1.29	1.52451	0.9998
318	208.84	81.49	209.3094	0.22	1.21759	1.0000	82.4316	1.16	1.48626	0.9999
316	208.53	82.13	209.5401	0.48	1.29253	1.0000	82.9821	1.04	1.45220	0.9999
314	208.22	82.78	208.7709	0.26	1.22908	1.0000	83.5325	0.91	1.41512	0.9999
312	207.91	83.43	208.5016	0.28	1.23484	1.0000	84.0830	0.78	1.37865	0.9999
310	207.60	84.07	206.2324	0.66	0.96253	1.0000	84.6334	0.03	1.34616	1.0000
309	207.41	84.43	208.0978	0.33	1.24843	1.0000	84.9087	0.91	1.31637	0.9999
307	207.04	85.14	208.8285	0.86	1.40207	0.9999	85.4591	0.83	1.26090	0.9999
305	206.66	85.85	207.5593	0.44	1.27832	1.0000	86.0096	1.40	1.20637	0.9998
303	206.29	86.56	207.2478	0.46	1.28673	1.0000	86.4510	0.87	1.11635	0.9999
Average				0.39	1.16458	1.0000		0.83	1.39027	0.9999

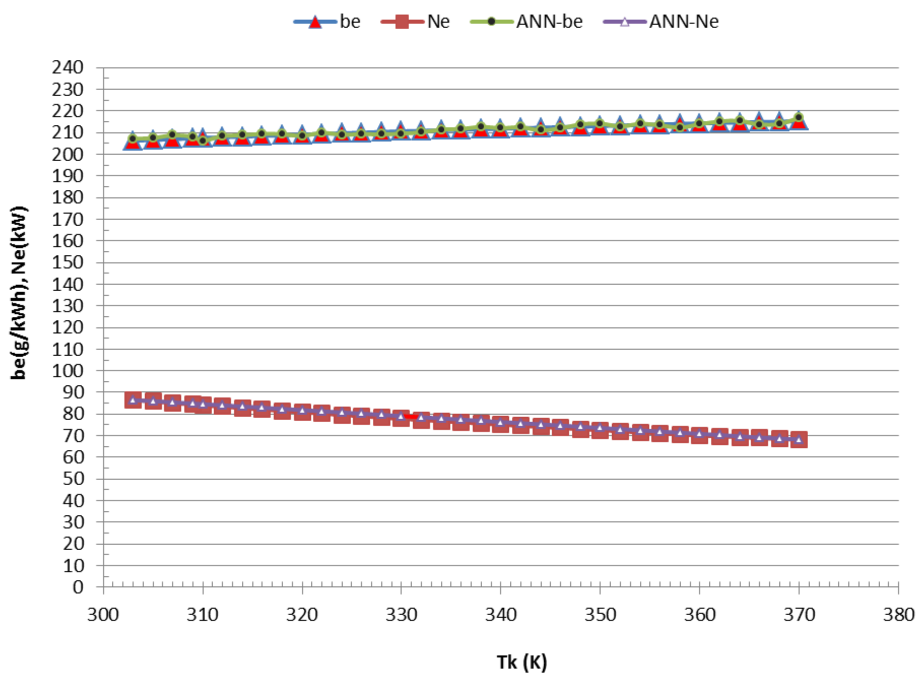

Figure 4. Comparison of the results of the ANN model with real data for specific fuel consumption (be) and effective power (Ne).

4. Discussion

In this study, investigating performance on intercooler in turbocharger diesel engine is presented. A cooler size, 0.07-0.55-0.35m, is found best size that is designed to achieve the intended temperatures of 302.24 K for dimension. When the cylinder air filling temperature in the engine's intake manifold reduced from 370 K to 302.24 K value at engine speed of 2500 rpm, obtained results are shown some benefits; these are specific fuel consumption decreased by 3.8%, the effective power is increased by 18 kW, rotation torque increases by 68 Nm, the heat rises 1.5% that is equivalent to the effective work, the heat expended for cooling a 5% decrease, the heat discharged from the exhaust has fallen 1%, the temperature 168 K decreased at end of the burning and 1% of the combustion pressure increases at end of the burning. An ANN developed model for the prediction of performance of intercooler in turbocharged is performed. Result of comparison is shown that ANN model results are very close to actual data for effective specific fuel consumption (be), and effective power (Ne). According to all results, turbocharge with intercooler provide good performance for the engine.

References

[1] Luders H, Stommel P, Geckler S. Diesel exhaust treatment–new approaches to ultra-low emission diesel vehicles, SAE paper; 1999;01-0108.

[2] Leet JA, Matheaus A, Dickey D. Egr system ıntegration on a pump line-nozzle engine, SAE Paper, 1998; 980181.
[3] Lundqvıst U, Smedler G, Stalhammar P. A comparison between different egr systems for hd diesel engines and their effect on performance, fuel consumption and emissions, SAE Paper, 2000;01-0226.
[4] Sen Y, Ermis K. The Parametric study on intercooler in turbocharger diesel engine. First International Conference on Engineering and Natural Sciences, Macedonia, 2015;71-80.
[5] Mack Technical Bulletin, Econdyne Fuel Efficiency – Mack's New Chassis Mounted Charge – Air Cooling, 1996; 3 – 7.
[6] Lin TY, Tseng CH. Optimum design for artificial neural networks: an example in a bicycle derailleur system, Engineering Applications of Artificial Intelligence, 2000;13:3–14.
[7] Aydogan H, Altun, AA, Ozcelik AE. Performance analysis of a turbocharged diesel engine using biodiesel with back propagation artificial neural network. Energy education science and technology part a-energy science and research, 2011;28-1:459-468.
[8] Bolan L, Changlu Z, Fujun Z, Tao C, Jianyun S. Numbers and letters correspond to the affiliation list. Click to expose these in author workspace. Applied Thermal Engineering, 2013;55-1:26-32.
[9] Tosun E, Aydin K, Merola SS, Irimescu A. Estimation of operational parameters for a direct injection turbocharged spark ignition engine by using regression analysis and artificial neural network, Thermal Science, 2017;21-1B:401-412.
[10] Sen Y, Ermis K. Thermal analysis of turbocharger and intercooler in diesel engine, 3rd International Symposium on Innovative Technologies in Engineering and Science(ISITES2015), Spain, 2015;2012-2021.
[11] Kale intercooler – radiator book, Istanbul, 1996.
[12] Kays WM, London AL. Compact heat exchangers, 3rd Ed. New York; McGraw-Hill, 1984.
[13] Ermis K. ANN modeling of compact heat exchangers. International Journal of Energy Research, 2008;32(6): 581-594.
[14] Ermis K, Erek A, Dincer İ. 2007). Heat transfer analysis of phase change process in a finned tube thermal energy storage system using artificial neural network. International Journal of Heat and Mass Transfer, 2007; 50:(15-16).