www.rericjournal.ait.ac.th

Calculating Pollution Equivalent of Electric Heating with Heat Storage Technology Accommodating Wind Based on LCA

Weijun Wang*, Weisong Peng*[1], Yong Sun[+], and Wei Luo*

Abstract – *Electric heating with heat storage technology can effectively reduce the abandoned wind of wind farms located in north china during the winter, improving the consumptive capacity of wind power. Considering the poor economy and singleness of electric heating with heat storage technology, life cycle assessment method is applied to analyze each stage of electric heating boiler with heat storage technology, including production, transportation, construction, operation and dismantling scrap. Meanwhile, the pollution emissions of each stage are calculated and compared with the cogeneration of heat and power in order to analyze its superiority and expansibility. The research result shows that the electric heating with heat storage technology consuming abandoned wind will reach a obviously lower pollutant discharge level than cogeneration heating mode. Therefore, from the point of environmental protection, electric heating with heat storage technology has extensive popularization significance in north China where abandoned wind phenomenon is serious.*

Keywords – electric heating with heat storage, life cycle assessment, pollution discharge, wind power.

1. INTRODUCTION

According to the law of wind power generation, the night is the best stage of the wind power output in northern China, contrary to the power load. Considering the security and stability of power grid system, a large number of wind have to be abandoned, especially in the northeast of China during the period of winter heating [1]. On the basis of the wind power industry test statistics from National Energy Bureau, the rate of national abandoned wind was 8% in 2014, less than 7% of the next year, running up to 21% in the first half of 2016. The figures of 2015 indicated different rates of abandoned wind in different provinces, 39% in Gansu, 32% in Xinjiang, 32% in Jilin, 21% in Heilongjiang, 18% in Inner Mongolia, 13% in Ningxia, 10% in Hebei. In 2015, the approach of winter made the abandoned wind rate of wind power project up to 60%, including Gansu, Ningxia, Heilongjiang and so on, resulting in serious waste of energy and assets.

In order to improve the wind power utilization, the National Energy Bureau actively promoted the application of thermal energy storage technology to improve the output of wind power in limited conditions [2]. Wang did research on the economy of the wind power supply mode. According to the calculation principle, it can be known that there is a poor and single economic problem in the electric heating technology [3]. Currently, several domestic plants of electric heating with heat storage technology are enduring heavy financial losses, such as wind power clean heating pilot at Taonan Jilin. Therefore, it is necessary to analyze and evaluate the life cycle of electric heating with heat storage technology consuming abandoned wind, finding out the distinctions in environmental costs from thermoelectric unit, discussing the sustainability of electric heating by consumptive wind power from the view of environmental subsidy.

2. LCA PRINCIPLE AND CALCULATION MODEL

2.1 LCA Principle

The definition of life cycle assessment (LCA) is one of technologies and methods, compiling and evaluating the input, output and potential environmental impacts in the life cycle of a product system. It is applied to estimate the environmental effect of one product throughout the life cycle, including acquisition of raw materials, production, disposal after usage [4]. The LCA of electric heating with heat storage technology consuming abandoned wind and cogeneration heating mode, is defined to analyze and evaluate the resource consumption and environmental impact, depending on the basic data about resource consumption and pollutant emission from each stage of production chain. The LCA calculation model of electric heating with heat storage technology consuming abandoned wind is illustrated by Figure 1.

2.2 Environmental Cost Calculation Model Based on LCA List

Based on the pollution calculated by LCA inventory analysis, environmental cost may convert into economic cost in accordance with the disposal cost of unit equivalent pollution. Environmental costs of each process can be calculated and allocated to unit product,

*Department of Economic Management, North China Electric Power University, Hebei Baoding 071000, China.

[+] State Grid Jilin Electric Power Supply Company, Jilin Changchun 130000, China.

[1] Corresponding author;
Tel: +15032296502.
E-mail: 250540493@qq.com

making comparison among pollution costs of each product where CE denotes the environmental cost of heat storage electric heating boiler, CEEj denotes the environmental cost of the j pollutant in the material exploitation list of electric heating boiler with heat storage, CEFj denotes the environmental cost of the j pollutant in the list of manufacturing equipment for electric heating boiler with heat storage, CETj denotes the environmental cost of the j pollutant in transportation list of electric heating boiler with heat storage, CEIj denotes the environmental cost of the j pollutant in installation list of electric heating boiler with heat storage, CEOj denotes the environmental cost of the j pollutant in function list of electric heating boiler with heat storage, CEDj denotes the environmental cost of the j pollutant in dismantlement list of electric heating boiler with heat storage.

$$C_E = \sum_{j=1}^{n} C_{EE_j} + \sum_{j=1}^{n} C_{EF_j} + \sum_{j=1}^{n} {}_{ET_j} + \sum_{j=1}^{n} {}_{EI_j} + \sum_{j=1}^{n} {}_{EO_j} + \sum_{j=1}^{n} C_{ED_j} \qquad (1)$$

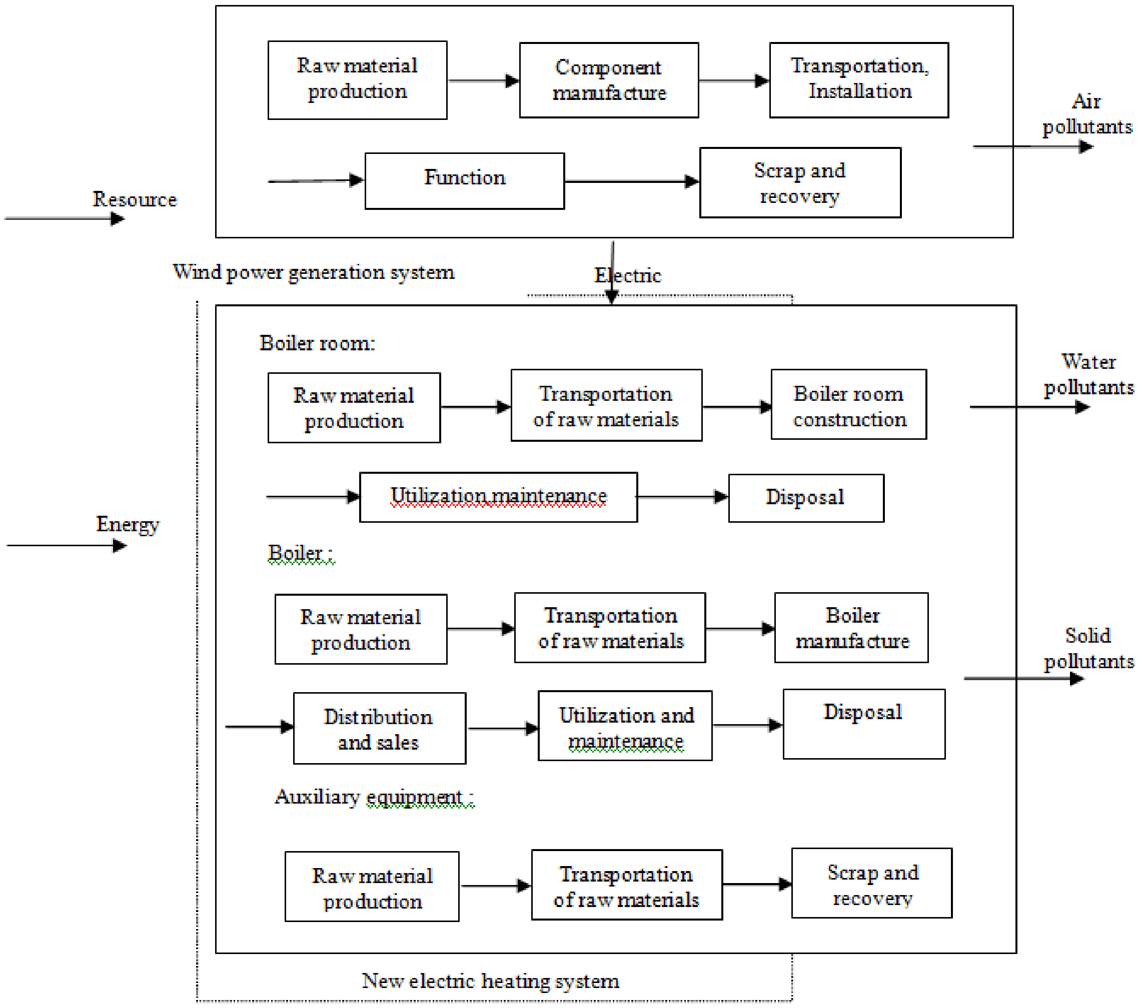

Fig.1. The LCA model of electric heating with heat storage technology consuming abandoned wind.

3. DATA LIST AND ANALYSIS OF ELECTRIC HEATING MODE WITH HEAT STORAGE TECHNOLOGY CONSUMING ABANDONED WIND

3.1 LCA Calculation and Analysis of the New Electric Heating System

The full life cycle of electric heating boiler with heat storage function is consist of many links, including construction, operation, maintenance, removal and so on. A electric heating boiler with heat storage function in China is chosen to be the objective for study, which contains two sets of 1440 kW automatic high temperature electric heating boilers with 98% conversion efficiency.

3.1.1 Inventory Analysis of Electric Heating Boiler Room

The list of boiler room mainly consists of three sections: production list of building materials for electric boiler room construction, transportation list and building list of electric heating boiler room. The following analysis is aiming at the three parts.

©2018. Published by RERIC in International Energy Journal (IEJ), Selection and/or peer-reviewed under the responsibility of the Organizers of the **"International Conference on Energy Engineering and Environmental Engineering 2017 (ICEEEE 2017)"** and the Guest Editors: Dr. Guazhong Zheng, Dr. Tielu Jiang (North China Electric Power University, Baoding, China) and Prof. Dr. Muhammad Aqeel Ashraf (China University of Geosciences, Wuhan, China).
www.rericjournal.ait.ac.th

A. Inventory analysis of materials production for electric boiler room construction

According to the data of boiler room construction process, the type and quantity of building materials mainly consumed by the construction of boiler room are 6880kg steel, 33440kg cement and 67840kg brick [5]-[7]. Referring to the list of data in CLCD, calculation results of production list of building materials for electric boiler room construction are shown in Table 1.

B. Inventory analysis of building materials transportation for electric heating boiler room

The total weight of building materials is 1.2 times the weight of the main building materials, totally 129792kg. The average transportation mileage is 25 kilometers by the medium-sized gasoline trucks. After circulation of LCA data., transportation list of building materials for electric heating boiler room is shown in Table 2.

C. Inventory analysis of building the electric heating boiler room

The pollution from the construction of electric heating boiler room are mainly consist of waste residue, waste water, and exhaust gas. After these measures, the quantity of pollution contains 25600kg waste water, 1600kg rubbish, and 629.6kg dust.

Table 1. Production list of building materials for electric boiler room construction.

List items		Steel	Cement	Brick
Environmental emissions, (kg)	CO	207.00	8.03	2.62
	CO_2	14610.37	3945.92	867.27
	SO_2	37.63	1.98	1.25
	NO_x	31.68	8.83	8.12
	COD	41.42	0.24	2.98
	Slag	3716.58	67926.67	/

Table 2. Transportation list of building materials for electric heating boiler room.

List items	Environmental emissions (kg)				
	CO	CO_2	SO_2	NO_x	COD
Amount	2390.00	10981.00	28.74	161.42	53.29

3.1.2 Inventory Analysis of Electric Heating Boiler

A. Inventory analysis of materials production for electric heating boiler

Steel is the main material of electric heating boiler equipment, weighing 7700kg. Inventory analysis of materials production for electric heating boiler is shown in Table 3.

B. Inventory analysis of manufacturing electric heating boiler

In the boiler factory, firstly, the raw materials are cut by cutting machine or sheared by shearing machine. Then they need to be rolled, bent and stamped. Finally, they can be welded. After the completion of assembling boiler, there is flaw detection text to check cracks or defects. The products through inspection need take water pressure test to check whether they meets the technical requirement standard. Ultimately, they need take a series of treatment measures, including removing rust, painting, packaging and so on.

Other main materials in the manufacture process of electric heating boiler:

- The electrode: according to the principle that the quantities of electrodes consumed per ton steel is 25 kg, total electrodes are 0.19 tons;
- Paint: the amount of paint consumed in manufacturing electric heating boiler is about 45 kg.

The environmental pollution in the manufacturing process of electric heating boiler mainly contains welding pollution and paint pollution [9]. The quantity of electrodes and paint respectively are 190kg, 45kg. The calculation results are shown in Table 4

C. Inventory analysis of transportation of electric heating boiler

The transportation mileage of electric heating boiler take an average of 25 kilometers. And medium - sized gasoline trucks' LCA data is selected for calculation. Transportation list of electric heating boiler is shown in Table5.

D. Inventory analysis of operation of electric heating boiler

Energy consumption of electric heating boiler is electricity. According to the boiler 's rated power and the heating time in the whole life cycle, the power consumption in the whole life cycle can be calculated. Heating time take an average of 122 days per year. Considering the efficiency of heating, the total electricity consumed by the electric heating boiler during the whole life cycle is 110GWh.

Table 3. Production list of boiler equipment materials.

List items	Environmental emissions (kg)					
	CO	CO_2	SO_2	NO_x	COD	Slag
Amount	231.77	16351.72	42.11	35.46	46.36	4159.54

Table 4. Pollution list of boiler manufacturing processes.

List items	Environmental emission (kg)			
	CO	CO_2	SO_2	NO_x
welding	8.17	3752.50	695.40	30.40
spray lacquer	0.23	34.62	5.16	0.98

Table 5. Transportation list of boiler.

List items	Environmental emissions (kg)				
	CO	CO_2	SO_2	NO_x	COD
Amount	141.76	651.43	1.71	9.58	3.16

Table 6. The steel consumption of main auxiliary equipment in electric boiler room and the boiler room pipe system.

Serial number	Name	Unit	Weight
	Main auxiliary equipment for electric heating boiler room		
1	Plate heat exchanger	kg	3300
2	High temperature storage tank (heat preservation / anti corrosion / color steel plate)	kg	6700
3	Automatic water softener	kg	1700
4	Soft water tank	kg	800
	Subtotal	kg	11000
	Pipe system of electric heating boiler room		
5	Steel pipe	kg	8912
6	Elbow	kg	631
7	Flange	kg	308
8	Valve	kg	902
9	Steel plate	kg	12147
	Subtotal	kg	22900
	Total	kg	33900

Table 7. Production list of auxiliary equipment materials in electric heating system.

List items	Environmental emissions (kg)				
	CO	CO_2	SO_2	NO_x	COD
Amount	1020.40	71990.00	185.42	156.00	204.09

Table 8. Transportation list of auxiliary equipment material in electric heating system.

List items	Environmental emissions (kg)				
	CO	CO_2	SO_2	NO_x	COD
Amount	624.13	2867.97	7.51	42.16	13.92

3.1.3 Inventory Analysis of Auxiliary Equipment's Material Production of Electric Heating System

The auxiliary equipment list of electric heating system includes two parts: auxiliary equipment material production list and auxiliary equipment material transportation list. The inventory analysis of these two parts is as follows.

A. Inventory analysis of auxiliary equipment's material production for electric heating system

The total consumption of auxiliary equipment for electric heating boiler room is the sum of auxiliary equipment's consumption and pipe system's consumption. The main auxiliary equipment and steel consumption of electric heating boiler is shown in Table

6. The list of auxiliary equipment's material production is shown in Table 7.

B. Inventory analysis of auxiliary equipment material transportation in electric heating system

The transportation mileage of electric heating boiler take an average of 25 kilometers. Medium - sized gasoline trucks' LCA data is selected for calculation. Transportation list of auxiliary equipment material in electric heating system is shown in Table 8.

3.1.4 The Quantity List of Unit Heating in Electric Heating Mode

According to the above analysis of the electric heating boiler room, electric heating boiler and auxiliary equipment of electric heating system, the quantity list of unit heating in electric heating mode is shown in Table 9.

3.2 Analysis of Wind Power List

Several people including Xiao Shao take an onshore wind machine as an example, domestic vents V90.3MW, calculating the environmental benefits of wind generator in the whole life cycle [10]; Weiguang Zhu take the wind power plant called HaiWang temple, located at Faku County, ShenYang, for research to conduct the study. The results show that wind power can reduce the emission of 9.923 tons of carbon dioxide , 0.050 tons of NOx and 0.079 tons of S02 into atmosphere every 10MW·h electricity, compared with coal-fired power generation; Tremeac B utilize LCA to make comparison between the two systems, 4.5MW and 250W wind turbine, to evaluate their impact on environment [9]-[11]. Based on the above research results and proportion of domestic wind power type, pollutant discharge of unit power generation of wind power generating is shown in Table 10.

3.3 LCA List of Electric Heating Mode with Heat Storage Technology Consuming Abandoned Wind

Through summarizing the electric heating boiler room list, electric heating boiler list, auxiliary equipment list and wind power list, LCA list of electric heating model with heat storage technology consuming abandoned wind is shown in Table 11.

Table 9. Electric heating mode heating unit heating quantity list of heating meter.

List items	Unit environmental emissions (kg/MJ)				
	CO	CO_2	SO_2	NO_x	COD
Amount	4.60×10^{-6}	1.95×10^{-4}	5.02×10^{-7}	5.36×10^{-7}	5.70×10^{-7}

Table 10. Pollutant discharge meter of unit power generation of wind power generating.

List items	Environmental emissions (kg/MWh)			
	CO	CO_2	SO_2	NO_x
Amount	0.101	22.910	0.457	0.253

Note: the average loss rate of wind power transmission is 5.4%.

Table 11. LCA-list of heating unit by electric heating boiler with heat storage technology consuming abandoned wind.

List items	Environmental emissions (kg/MJ)				
	CO	CO_2	SO_2	NO_x	COD
Amount	3.32×10^{-5}	6.68×10^{-3}	1.29×10^{-4}	7.22×10^{-5}	5.70×10^{-7}

4. COMPARISON OF ENVIRONMENTAL COST BETWEEN ELECTRIC HEATING WITH HEAT STORAGE TECHNOLOGY AND COGENERATION HEATING MODE

4.1 Comparison of Pollutant Emissions of Two Heating Modes

The data list and analysis of Cogeneration heating mode mainly include three sections: inventory analysis of boiler room, inventory analysis of boiler, inventory analysis of auxiliary equipment. According to the research results conducted by Junxiang Zhang, the LCA list of unit heating by cogeneration heating mode can be obtained [12]-[13]. The pollution discharge of per heat from electric heating with heat storage technology and cogeneration heating model is respectively shown in Table 12.

4.2 Comparison of Environment Cost between Two Heating Modes

According to the relevant provisions of "regulation for the collection of sewage charges" (the State Planning Commission, Treasury Department, the State Environmental Protection Administration, Economic and Trade Commission , the thirty-first orders in 2003) and "notice of the adjustment of the sewage fee collection standards and other related issues" (NDRC price [2014] NO. 2008), the equivalent values of statistical pollutant including CO, CO2, SO2, NOx, and COD are 16.7kg, 1kg, 0.95kg, 1kg, corresponding to the prices: \$0.09, \$0.006, \$0.18, \$0.18 and \$0.21. Pollution

©2018. Published by RERIC in International Energy Journal (IEJ), Selection and/or peer-reviewed under the responsibility of the Organizers of the **"International Conference on Energy Engineering and Environmental Engineering 2017 (ICEEEE 2017)"** and the Guest Editors: Dr. Guazhong Zheng, Dr. Tielu Jiang (North China Electric Power University, Baoding, China) and Prof. Dr. Muhammad Aqeel Ashraf (China University of Geosciences, Wuhan, China).
www.rericjournal.ait.ac.th

equivalent value and environment cost of unit heating by two heating modes are shown in table 3-2 [15], [16].

In addition, according to the average rate of coal ash 26% (coal power plant in accordance with the average 4000kcal/kg) and ash utilization rate of 70%, the yield of fly ash per heat is about 12.8kg/GJ. With the sewage charges 30 Yuan / ton, the pollution cost of coal ash per heat from cogeneration heating mode was $0.058/GJ.

From the data in Table 13, it is obvious that the environment cost of unit heat by electric heating mode with heat storage technology consuming abandoned wind is significantly lower than that of cogeneration heating mode. Currently, the heating price in north China is generally around $4.22/GJ. Table data displays that environmental cost of cogeneration heating mode is about $1.03/GJ, but environmental cost of electric heating mode with heat storage technology consuming abandoned wind is only $0.66/GJ. Therefore, from the point of environmental cost, electric heating with heat storage technology consuming abandoned wind mode has obvious advantages in the economy and significant promotion worth].

Table 12. The contrast in unit pollutant emissions between two heating modes.

List items		pollutant emissions per heat (kg/GJ)	
		electric heating with heat storage technology consuming abandoned wind	cogeneration heating mode
Environmental emission	CO	3.48×10^{-2}	3.69×10^{-2}
	CO_2	7.06	17.00
	SO_2	0.137	0.703
	NO_x	7.63×10^{-2}	0.143
	COD	5.70×10^{-4}	3.33

Table 13. The comparison of equivalent value and environment cost of unit heating between two kinds of heating modes.

List items		pollution equivalent of unit heat (Equivalent value /GJ)		environment cost every ten thousand GJ($)	
		electric heating with heat storage technology consuming abandoned wind	Cogeneration heating mode	electric heating with heat storage technology consuming abandoned wind	Cogeneration heating mode
Environmental emission	CO	2.09×10^{-3}	2.21×10^{-3}	1.88	2.00
	CO_2	7.43	17.9	446.69	1076.86
	SO_2	0.145	0.74	261.70	1335.55
	NO_x	8.04×10^{-2}	0.151	144.99	272.22
	COD	5.70×10^{-4}	3.33	1.20	7011.65
Total		-	-	855.78	9699.30

Note: the pollution equivalent value of a pollutant = The pollutant emission (kg)/ Pollution equivalent of the pollutant (kg).

5. CONCLUSION

Compared with the cogeneration heating mode, electric heating mode with heat storage technology consuming abandoned wind has obvious advantages, with low environment cost per heat. From the perspective of environmental protection, electric heating mode with heat storage technology consuming abandoned wind deserves to be widely promoted, especially in north areas where the phenomenon of abandoned wind is serious, which can consume wind power efficiently. What's more, environment pollution caused by electric heating mode with heat storage technology consuming abandoned wind is low.

ACKNOWLEDGEMENTS

This research was financially supported by the national science and technology support project, consuming wind power heat-electric joint optimal planning and operational control technology (2015BAA01B01) and Hebei province social science fund project, the research of rural winter heating pollution and emission reduction countermeasures in Hebei province (HB16GL063).

REFERENCES

[1] Liu Q.C, Zhang Q.Y. And Xu X., 2012. Heat storing electric boiler application for energy storage and peak shaving to increase utilization rate of wind power capacity. *Huadian Technology* 34(9):75-82.

[2] Pei Z.Y. and G.F. Fan. 2014. Research on wind power operation and accommodation problems in China. *Electric Power* 47(4):1-4.

[3] Wang C.X., Li Q.H. and Xie G., 2014. Pricing mechanism and economic analysis of heating supply by wind power. *Electric Power* 47(10): 156-160.

[4] Frischknecht R., Jungbluth N. and Althaush., 2007. Implementation of life cycle impact assessment methods, Swiss Centre for Life Cycle Inventories.

[5] Yang J.X. and B.J. Liu. 2002. Life cycle inventory of steel products in China. *Environmental Science Journal* 22(4): 519-522.

[6] Michaeleb., 2010. Identifying improvement potentials in cement production with life cycle assessment. *Environmental Science and Technology* (44): 9143-9149.

[7] Burgess A. and D.J. Brennan. 2001. Application of life cycle assessment to chemical processes. *Chemical Engineering Science* (2): 589-604.

[8] Shao X., Ju M.T. and Shao C.F., 2012. Environmental load of wind turbine in China based on life cycle assessment. *Ecological Economy* 145-148.

[9] Tremeac B. and F. Meunier. 2009. Life cycle analysis of 4.5MW and 250W wind turbines. *Renewable and Sustainable Energy Reviews* 8 (13): 2104-2110.

[10] Crawford R.H., 2009. Life cycle energy and green house emissions analysis of wind turbines and the effect of size on energy yield. *Renewable and Sustainable Energy Reviews* 8(13):2653- 2660.

[11] Martnez E., Sanz F. and Pellegrini S., 2009. Life cycle assessment of a multi-megawatt wind turbine. *Renewable Energy* 34:667- 673.

[12] Zhang J.X. and G.F. Zhu. 2014. Comparative study on life cycle assessment of photovoltaic and coal-fired power generation. *Environmental Science and Management* 39 (10): 86-90.

[13] Su X., Zhang X., and Yuan Y., 2010. Environmental performance of power generation system in China based on LCA[C]. AIP Conference Proceedings, 260-263.

[14] Agarwal G., Agarwal K.K., and Roy S., 2014. Investigations on physical and mechanical properties of short jute fiber reinforced epoxy composites. *Journal of Mechanical Engineering Research & Developments* 37(2): 1-10.

[15] Dorraj S., Mojtaba M.B., and Vafaie-Sefti A.A., 2014. Compressive, flexural and abrasive performance of steel fiber-reinforced concrete. *Journal of Mechanical Engineering Research & Developments* 37(1): 1-10.