Kuwait J. Sci. **47 (1)** pp. 72-78, 2020

Assessment of stack emissions during different phases of electric arc furnace steelmaking process

Zeeshan A Hameed[1,*], Azizur Rahman[2]

[1]*Dept. of Energy and Environment, Hamdard University, Karachi, Pakistan.*

[2]*Government Degree Boys College 5-L new Karachi, Karachi, Pakistan*

[*]*Corresponding author: z.chamist@gmail.com*

Abstract

Electric arc furnace (EAF) steelmaking is a fast-growing manufacturing process in which steel scrap is re-melted and desired quality of steel grades is produced. The process is known to generate high degree of harmful gases and hazardous metal dust. This research assesses the flue gases and their pollution impact during different technological process phases of EAF steelmaking. The flue gases are carbon oxide (CO_x) sulfur oxide (SO_x), carbon dioxide (CO_2), and nitrogen oxide (NO_x). Flue gas concentrations were analyzed using a portable combustion and stack emissions gas analyzer. The overall process was divided into two phases; melting and blowing. A comparison was made between both technological phases and their respective flue gas concentrations. In the melting phase, the minimum and maximum concentration of CO_x, SO_x, and NO_x were 75-836 mg/Nm^3, 4-33 mg/Nm^3 and 1-60 mg/Nm^3, respectively. During the blowing phase the minimum and maximum concentration of CO_x, SO_x and NO_x were 12-415 mg/Nm^3, 2-14 mg/Nm^3 and 1-42 mg/Nm^3, respectively. The results were compared with the standard concentration levels of gaseous emissions by the National Environmental Quality Standards (NEQS) of Pakistan. The study verifies that the melting phase has more of a negative impact on the environment than the blowing phase. Hence, it is necessary to mitigate the pollutant concentrations during this technological phase.A number of recommendations have been made to reduce pollutant gases so that the environmental impact can be minimized in the EAF process.

Keywords: Air Pollution; electric arc furnace; negative impact; stack emission gases; steel making.

1. Introduction

High air quality is very important for human life and all other living organisms on earth. Industrial pollutants adversely affect the quality of air. The steel sector is one of the biggest contributors of increasing pollutants in the modern industrial era (Wang *et al*., 2016). The high production of steel worldwide causes a proportional increase in air pollutant contaminates (Douchanov, 2002; Rynikiewicz, 2008; Mohamed and Sasi, 2013; Li, Lei and Pan, 2016). Stack emission is a major source of industrial gaseous emissions. Regulatory bodies have taken productive initiatives to monitor and control the environmental performance of steel industries (Teng and Huang, 1996; Liu *et al*., 2011; Cakir, Alp and Yetis, 2016)

The fast-growing steel industry is a big source of air pollution. Steel plant specific pollutants include solid hazardous waste (Poinescu *et al.*, 2010), carbon oxide (CO_x), carbon dioxide (CO_2), nitrogen oxides (NO_x), sulfur oxides (SOx), polychlorinated dibenzo-*p*-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) (Shih *et al.*, 2007). Among these pollutants, particulate matter and dust are major potential health problems for in-house staff, working in steel plants and for people living in nearby residential areas (Sekula, Wnek and Selinger, 2001; Hoshuyama *et al.*, 2006; Cantone *et al.*, 2011; Cappelletti *et al.*, 2016) Emission gases from steel plants (CO_x, SO_x and NO_x) are very critical to air quality. SO_2 has a negative impact on human beings and machinery (Tewari and Shukla, 1991). Despite emission gases, metal pollutants are also problematic and a major cause for bad air quality due to industrialization (Quraishi, Schauer and Zhang, 2009).

Electric arc furnaces (EAFs) are mostly used in the steel making process. They produce stainless and alloy steels by using scrap. The EAF steel making process belongs to the category of the industrial processes with a high degree of pollution from gases. They are transferred into the air and cause environmental problems. These EAF off-gases are utilized in energy conservation and ultimately to reduce CO_2. Most off-gases contain some greenhouse gases (GHG) (Thomson *et al.*, 2000). According to Varvara, the EAF process has negatively affects the environment (Dana-Adriana Iluţiu-Varvara, Elena-Maria Pica, 2011) The most common pollutants which are present in air are CO_x, SO_x, NO_x, volatile organic compounds (VOC), particulate matter, dioxins and furans (Iluţiu-Varvara *et al.*, 2015)

Assessing air pollution and its environmental effects during steelmaking is difficult to quantify because it depends on the charge's constituents. The most polluting technological phases are furnace charging, charge melting, refining, desulphurization, de-phosphorization, and alloying (Varvara, Brandusan and Pica, 2012). The process of steelmaking in EAFs pollutes the air with dust that is released with burned gases into the atmosphere. The composition and concentration of the burned gases are mainly variable by quality and purity of the furnace charge (Varvara D.A., Nagy E., Suciu C.R., Thalmaier G., 2005). This research assesses pollutant gas levels in both technological phases of EAF-based steelmaking, namely, melting and blowing. The goal is to measure the impact of pollutant gases on the environment and to know whether their concentration levels exceed the permissible exposure limits in either the melting or blowing phase. In addition, a way to reduce these risks is sought. The possibility of finding an optimal solution should be found that ensures an immediate treatment and follow-up in a periodical and coordinated system.

Electric arc furnaces have three apertures for the graphite electrode. A fourth aperture is designed for suction with the help of a de-dusting unit composed of a filter baggage and air blowers. The schematic diagram of an electric arc furnace is shown in Figure 1.

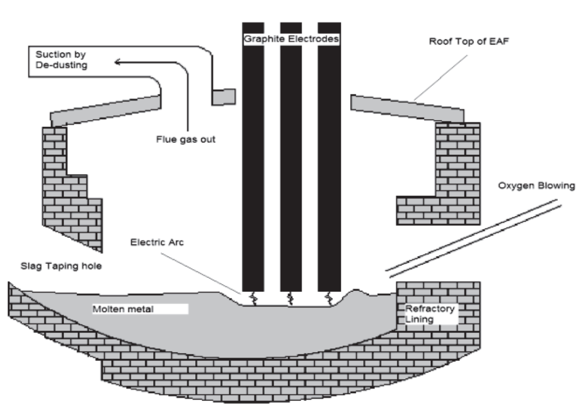

Fig. 1. Schematics of EAF.

Among most of the electric furnaces involved in steel making, EAFs are characterized by the exhaustion of a large amount of dust along with CO, CO_2, NO_x and SO_x with the process gases. When the furnace is blown with oxygen, its atmosphere contains gas bubbles (O_2, N_2 and CO, etc.) and metal is said to "boil" due to CO bubbles that are produced. The amount of process gases escaping from an EAF depends upon the composition of the charge, metal-slag reactions, and the amount of inspirited air during opening and closing of the EAF roof. The flue gases are sucked out from the fourth aperture with the help of the de-dusting plant, (Figure 1). The following reactions may take place in the EAF for the generation of flue gases (Huber *et al.*, 2005; Iluţiu-Varvara *et al.*, 2015):

$$C + O = CO_{(g)} \quad (1)$$

$$C + FeO = Fe + CO \quad (2)$$

$$MeS + 2O_2 = MeSO_4 \quad (3)$$

Where MeS is a metal sulfide:

$$2MeSO_4 = 2MeO + 2SO_2 + O_2 \quad (4)$$

$$S + O_2 = SO_2 \quad (5)$$

$$N + O = NO \quad (6)$$

2. Materials and methods

A detailed assessment of EAF gas emissions of CO, CO_2, NO, NO_x and SO_x was carried out. The process was divided in two phases. Both phases of the EAF process were extensively studied. The off-gas sampling was carried out from the stack and plotted against different parameters.

To assess the environmental air quality during steelmaking in electric arc furnaces, the concentrations of stack flue gas emission of the following pollutants were measured: CO, SO_x, NO and NO_x. The measurement of the flue gas concentrations from the stack was achieved with a stack flue gas analyzer (LAND III,UK). The flue gases were emitted from the EAF after passing the de-dusting unit which was then followed by the forced draft stack. The capacity of the EAF was 15 tons. The steel type made was carbon steel. The concentrations of gaseous pollutants at emissions were measured every 10 minutes, including after each important activity: charging scrap, lime and coke addition, oxygen blowing (lancing) and de-slaging.

3. Results and discussion

As stated, the stack emission studies were divided into melting and blowing phases. Results are discussed separately then comparison is made with National and International benchmarks.

3.1 Emission concentrations during melting phase

The main objective of the EAF is melting the scrap metal and de-phosphorization. During this process, scrap metal, fluxing agents (lime and fluorspar), and a reducing agent (coke breeze) are usually added. The process normally takes 80-120 minutes. Flue gas concentrations are analyzed by the flue analyzer every 10 minutes. The results obtained are listed in Table 1.

Table 1. Concentration measurement during melting Phase (mg/Nm^3).

Time (min)	CO	SO_2	NO	CO_2	NO_x
10	75	4	38	0.63	60
20	198	6	0	0.49	1
30	278	13	20	0.68	32
40	103	4	0	1.06	1
50	836	33	9	0.76	15

The most concentrated gas found was CO, which is as low as 75 mg/Nm^3 at the start of the process, while at the end of the process, it reached 836 mg/Nm^3, exceeding the threshold limit of the national standards. On the other hand, the maximum and minimum concentrations of SO_x were 33 to 4 mg/Nm^3; respectively. NO_x in the melting phase was 1 to 60 mg/Nm^3. These values are comparable with the National Environmental Quality Standards (NEQS) of Pakistan (Gilani and Bhatti, 2015) shown in Table 2. It can be concluded that all gas emissions are within specified limits that do not exceed the standards maximum allowable limits, except CO, which randomly increased as the melting process proceeded.

Table 2. NEQS for industrial gaseous emissions.

Parameter	Source of Emission	Standard (mg/Nm^3)
CO	Any source	800
SOx	Others*	400
NOx	Other**	400

* Other than Sulphuric Acid Plants

** Other than Nitric Acid Plants

3.2 Emissions concentrations during blowing phase:

Results from this phase were different. When the bath was blown with oxygen, CO emissions were comparatively low, ranging from 12mg/Nm^3 to 415mg/Nm^3 maximum. The maximum and minimum concentration ranges of SO_x were also only 14-2 mg/Nm^3. NO_x varied from 0 to 42 mg/Nm^3. All recorded values of CO, SO_x and NO_x were within allowable limits set by NEQS in this phase. The recorded data are illustrated in Table 3.

Table 3. Measurement during the oxygen blowing (lancing) phase (mg/Nm^3).

Time (min)	CO	SO_2	NO	CO_2	NO_x
10	12	3	0	0.24	0
20	415	14	11	0.7	18
30	139	5	0	0.87	1
40	62	2	26	1.06	42
50	37	2	1	0.42	20

3.3 Comparison of gaseous emissions during process phases

The emission of CO is slightly higher in the melting phase and comparatively low in the blowing phase (Figure 2). At the end of the melting, the CO concentration was 836 mg/Nm^3 which exceeded the specified limit of industrial gaseous emissions of 800 mg/Nm^3. This is due to the fact that the rate of carbon oxidation increases with the increase in bath temperature. An increase of temperature also causes a more intensified course of FeO (Reaction 2). This indicates a potential hazard of having higher CO levels during the melting phase.

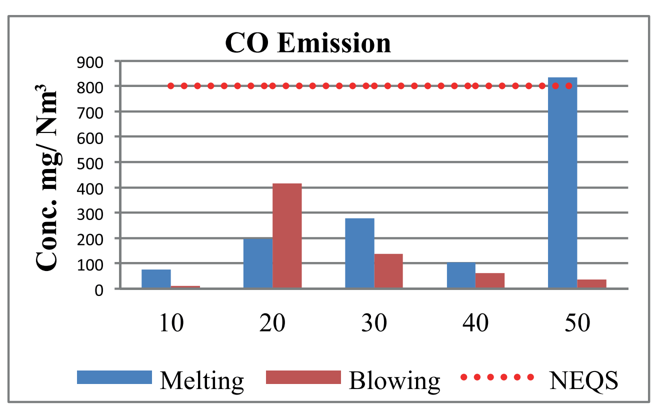

Fig. 2. Comparison of CO in melting and blowing after same process time duration.

Carbon monoxide has adverse impacts on the environment and of course on steel workers. It reacts with blood hemoglobin to yield carboxyhemoglobin because blood hemoglobin has the highest affinity for carbon monoxide. The formation of carboxyhemoglobin causes inflammatory diseases such as sepsis and pneumonia (Ilutiu-Varvara *et al.,* 2015).

SO_x and NO_x concentrations during the melting and blowing phase were within allowable NEQS limits as shown in Figure 3 and Figure 4 respectively.

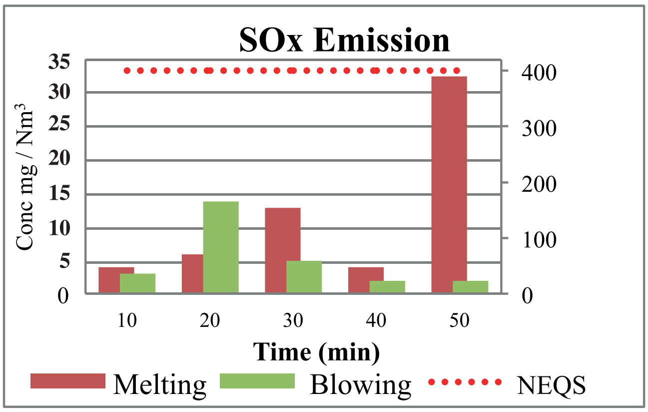

Fig. 3. Comparison of SOx in melting and blowing.

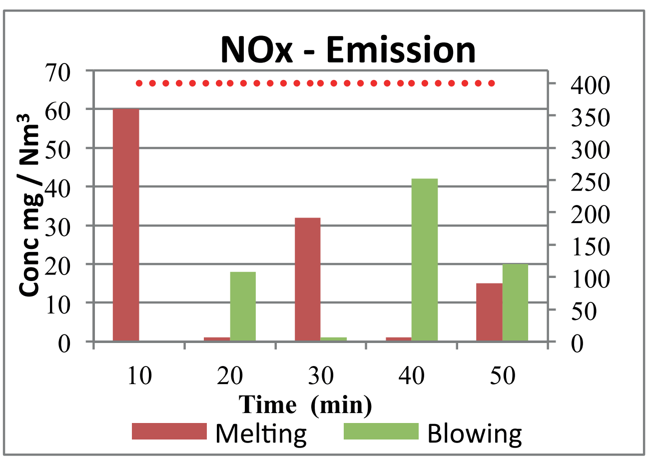

Fig. 4. Comparison of NOx during melting and blowing.

However, the concentration levels of these gases in the melting phase were much higher than those in the blowing phase.

4. Conclusion

The average emissions from stack gas are much higher during the melting phase than the blowing phase of EAF steel production. This is attributed to the composition and concentration of burned gases which are highly variable and mainly depend upon the degree of purity of the charge and absolute thermodynamics conditions of the EAF. The average concentration of CO in the melting phases was within the allowable limits, but it exceeded the alert threshold (800mg/Nm^3) by 105%. This occurred near the completion of melting and exceeded the NEQS allowable limits. The CO emissions during the blowing phase were within the NEQS permissible limits. The average concentrations of SO_x and NO_x were within allowable limits of emissions during the melting and blowing phases.

The high concentrations of CO are detrimental to the environment and indicate a waste of chemical energy. This gas may be utilized in the process optimization of EAF.

5. Recommendations

The following measures are recommended by the present authors for the short-term and long-term planning. It can be adopted to minimize air pollution generated from the EAF steelmaking process. The recommendations are:

1. Installing a chemical energy package at EAFs to properly utilize the chemical energy of the system caused by carbon monoxide. Hence, CO emissions into the environment could be minimized.
2. Applying CO post-combustion technology during scrap melting. This is a process of utilizing the chemical energy of CO and hydrogen evolving from the steel bath. It is suggested by the Sector Policies and Programs Division, US EPA (US EPA, 2012).
3. Providing personal protecting equipment (PPE) to employees such as certified dust masks and safety glasses.
4. Increasing stack height: This will mitigate inhalation, as the concentration of pollutants at ground level is directly proportional to the speed of escaping pollutants from the stack and inversely proportional to the effective stack height.
5. Protecting skin from flue gases and metal dust by providing protective clothing to workers.
6. Periodical monitoring of stack gas emissions. It is a quick preventive and corrective measures that would limit human and environmental exposure to CO gas.
7. Monitoring the furnace gas flow rate and consumption in order to control post-combustion of the off-gases online. This would reduce natural gas, oxygen and carbon consumption (USEPA, 2012).

References

Cakir, N., Alp, E. and Yetis, U. (2016). 'Evaluation of Environmental Performance Based on Proximity to Bat Associated Resource Utilization and Emission Values: A Case Study in a Steel-Making Industry', *Waste and Biomass Valorization*. Springer Netherlands, **7**(4), pp. 975–993. doi: 10.1007/s12649-016-9493-5.

Cantone, L. *et al.* (2011). 'Inhalable metal-rich air particles and histone H3K4 dimethylation and H3K9 Acetylation in a Cross-sectional Study of Steel Workers', *Environmental Health Perspectives*, **119**(7), pp. 964–969. doi: 10.1289/ehp.1002955.

Cappelletti, R. *et al.* (2016). 'Health status of male steel workers at an electric arc furnace (EAF) in Trentino, Italy.', *Journal of occupational medicine and toxicology (London, England)*. Journal of Occupational Medicine and Toxicology, 11, p. 7. doi: 10.1186/s12995-016-0095-8.

Dana-Adriana Iluţiu-Varvara, Elena-Maria Pica, L.B. (2011). 'Assessment of Air Environmental Factor Pollution to the Steelmaking (Pădureni Area)', *Bulletin of the Polytechnic Institute of Jassy - CONSTRUCTIONS. ARCHITECTURE Section*, LIV(LVIII) (Issue 3), pp. 113–118.

Douchanov, D. (Union of C. in B. (2002). 'σελ92-100.pdf', *Journal of Environmnetal Protection and Ecology*, **3**(1), pp. 92–100.

Gilani, S.R. and Bhatti, K.P. (2015). 'Polluted Air Quality Component Analysis from Stack Emission and its Hazardous Consequences on Human Health .', **12**(23).

Hoshuyama, T. *et al.* (2006). 'Mortality of Iron-Steel Workers in Anshanl China: A Retrospective Cohort Study', *International Journal of Occupational and Environmental Health*. Taylor & Francis, **12**(3), pp. 193–202. doi: 10.1179/oeh.2006.12.3.193.

Huber, J. *et al.* (2005). 'Dust formation in Electric Arc Furnace : Birth of the particles', 157, pp. 2–11. doi: 10.1016/j.powtec.2005.05.006.

Iluţiu-Varvara, D.A. *et al.* (2015). 'The Assessment and Reduction of Carbon Oxides Emissions at Electric Arc Furnaces – Essential Factors for Sustainable Development', *Procedia Technology*, 19, pp. 402–409. doi: 10.1016/j.protcy.2015.02.057.

Li, L., Lei, Y. and Pan, D. (2016). 'Study of CO_2 emissions in China's iron and steel industry based on economic input-output life cycle assessment', Natural Hazards, **81**(2), pp. 957–970. doi: 10.1007/s11069-015-2114-y

Liu, Z.G. *et al.* (2011). 'Empirical analysis on environmental disclosure and environmental performance level of listed steel companies', *Energy Procedia*, 5, pp. 2211–2218. doi: 10.1016/j.egypro.2011.03.382.

Mohamed, J. and Sasi, B. (2013). 'Air Pollution Caused by Iron and Steel Plants', **1**(3), pp. 1–4.

Poinescu, A.A. *et al.* (2010). 'Monitoring Environmental Pollution with Heavy Metals from Settable and Suspended Powders Resulted from Electric Arc Furnaces - Case Study', *Recent Advances in Energy and Environment*, pp. 292–295.

Quraishi, T.A., Schauer, J.J. and Zhang, Y. (2009). 'Understanding sources of airborne water soluble metals in Lahore, Pakistan', *Kuwait Journal of Science and Engineering*, **36**(1 A), pp. 43–62.

Rynikiewicz, C. (2008). 'The climate change challenge and transitions for radical changes in the European steel industry', *Journal of Cleaner Production*, **16**(7), pp. 781–789. doi: 10.1016/j.jclepro.2007.03.001.

Sekula, R., Wnek, M. and Selinger, A. (2001). 'Electric arc furnace dust treatment : investigation on mechanical and magnetic separation methods', (Zunkel 1997), pp. 271–275.

Shih, S.I. *et al.* (2007). 'Emission characteristics of polychlorinated dibenzo- p -dioxins and dibenzofurans in the stack flue gases of electric arc furnaces', p. 2007.

Teng, H. and Huang, T.S. (1996). 'Control of NOχemissions through combustion modifications for reheating furnaces in steel plants', *Fuel*, **75**(2), pp. 149–156. doi: 10.1016/0016-2361(95)00231-6.

Tewari, A. and Shukla, N.P. (1991). 'Air pollution--adverse effects of sulfur dioxide', *Rev Environ Health*, 9(1), pp. 39–46. Available at: http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=1957049.

Thomson, M.J. *et al.* (2000). 'Control of greenhouse gas emissions from electric arc furnace steelmaking: evaluation methodology with case studies', *Ironmaking & Steelmaking*, **27**(4), pp. 273–279. doi: 10.1179/030192300677552.

US EPA (2012). *Available and Emerging Technologies for Reducing Greenhouse Gas Emissions From the Iron and Steel Industry*. Available at: http://www.epa.gov/nsr/

ghgdocs/ironsteel.pdf.

Varvara, D.A.I., Brandusan, L. and Pica, E.M. (2012). 'Assessment of Recycling Potential of Solid Wastes from Steelmaking in the Electric Arc Furnaces', 57(71), pp. 15–18.

Varvara D.A., Nagy E., Suciu C.R., Thalmaier G., T.G. (2005). 'The Specificity of Air Pollution to the Steelmaking.', *Şt. şi Ing., Edit. AGIR, Bucureşti*, 8, 341–344.

Wang, K. *et al.* (2016). 'A comprehensive emission inventory of multiple air pollutants from iron and steel industry in China: Temporal trends and spatial variation characteristics', *Science of the Total Environment*. Elsevier B.V., 559(19), pp. 7–14. doi: 10.1016/j.scitotenv.2016.03.125.

Submitted : 30/07/2017

Revised : 22/06/2018

Accepted : 27/06/2018

تقييم انبعاثات المداخن خلال المراحل المختلفة لعملية صناعة الصلب في فرن القوس الكهربائي

[1]زيشان عبد الحميد، [2]عزيز الرحمن
[1]قسم الطاقة والبيئة، جامعة هامارد، كراتشي، باكستان
[2]كلية الحكومة للبنين، كراتشي، باكستان

الملخص

تُعتبر عملية صناعة الصلب في فرن القوس الكهربائي (EAF) من عمليات التصنيع سريعة النمو حيث يتم فيها إعادة صهر خردة الصلب وإنتاجه بالجودة المطلوبة. ومن المعروف أن هذه العملية تُولد الغازات الضارة والغبار المعدني الخطير بدرجة عالية. والهدف من هذا البحث هو تقييم غازات المداخن وتأثيرها على التلوث البيئي أثناء عملية صناعة الصلب في المراحل المختلفة للعملية التكنولوجية EAF. الغازات المنبعثة هي CO_x (أكسيد الكربون)، SO_x (أكسيد الكبريت)، CO_2 (ثاني أكسيد الكربون) وNO_x (أكسيد النيتروجين). تم تحليل تركيز الغازات المنبعثة بواسطة محلل متنقل لغازات الاحتراق والمداخن. وانقسمت العملية إلى مرحلتين؛ الإنصهار والنفخ. تم إجراء مقارنة بين المرحلتين التكنولوجيتين وتركيزات غازات المداخن الخاصة بكل منهما. في مرحلة الانصهار، كان الحد الأدنى والحد الأقصى لتركيز أكسيد الكربون وأكسيد الكبريت وأكسيد النيتروجين 75 – 836 مجم / Nm^3، 4 - 33 مجم / Nm^3 و1 - 60 مجم / Nm^3 على التوالي، بينما أثناء مرحلة النفخ، كان تركيز الحد الأدنى والحد الأقصى لأكسيد الكربون وأكسيد الكبريت وأكسيد النيتروجين 12 – 415 ملغ / Nm^3 ، 2 – 14 ملغ / Nm^3 و1 - 42 ملغ / Nm^3 على التوالي. تم تفسير النتائج ومقارنتها مع مستويات التركيز القياسية للانبعاثات الغازية في معايير الجودة البيئية الوطنية (NEQS) في باكستان. وأظهرت هذه الدراسة أن مرحلة الانصهار لها تأثير سلبي على البيئة أكثر من مرحلة النفخ، وبالتالي فمن الضروري تخفيف تركيز الملوثات خلال هذه المرحلة التكنولوجية. وتم اقتراح عدد من التوصيات لتقليل الغازات الملوثة، بحيث تقل الأضرار على البيئة ويزيد العائد من العملية إلى الحد الأقصى.