Journal of Cleaner Production 111 (2016) 76–84

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Efficient use of compressed air for dry ice blasting

Vítězslav Máša*, Pavel Kuba

Brno University of Technology, NETME Centre & Inst. of Process and Environmental Engineering – VUT ÚPEI, Technická 2896/2, 616 69 Brno, Czech Republic

ARTICLE INFO

Article history:
Received 23 December 2014
Received in revised form
9 July 2015
Accepted 10 July 2015
Available online 17 July 2015

Keywords:
Dry ice blasting
Compressed air
Specific energy consumption
Energy savings

ABSTRACT

Dry ice blasting is a highly efficient and environmentally-friendly method for cleaning of contaminated surfaces. The method is widely used in many industries, such as automotive, machinery and food industry. Dry ice blasting is a technology that requires large amounts of compressed air which is among the most expensive forms of energy currently employed in industries. Compressed air (air of high pressure and volume) accelerates particles of dry ice during the blasting. Our paper presents a comprehensive overview of saving measures which can greatly help decrease energy intensity of the blasting.

Technology of dry ice blasting comprises four key elements: a compressor (generator of compressed air), a blasting machine, transport of pellets, and a blasting nozzle. Our team successively analysed these four key aspects of the technology and designed relevant savings measures, which results in identification of minimum, theoretically attainable energy consumption. Experiments and operational tests proved that application of all available savings measures may decrease energy consumption by 87% compared to current industry standards.

It is possible to evaluate current technologies for dry ice blasting in terms of performance of the blasting machine and its functional properties. So far, there has been no method for evaluation of energy parameters of the technology. This paper presents a novel quantity which helps quantify and evaluate energy consumption of dry ice blasting. Main benefit of the quantity called "specific energy consumption of dry ice blasting" is the fact that it allows to compare energy consumptions of various blasting systems. For the purposes of this paper, the novel quantity is especially used to quantify the impact of recommended savings measures.

1. Introduction

Dry ice blasting is a cleaning process which accelerates particles of dry ice using compressed air; a stream of these particles is directed at a contaminated surface and cleans it. Major advantages of dry ice blasting include speed of the cleaning process and zero waste products (all the dry ice sublimes once it hits surface). Although carbon dioxide (CO_2) emissions are higher compared to other technologies (Millman and Giancaspro, 2012), the process is not a great burden for the environment. Carbon dioxide is standard by-product of chemical industry and its application in cleaning is basically a recycling method (Spur et al., 1999). Membrane separation for the post-combustion CO_2 capture was reviewed by Khalilpour et al. (2014). No new carbon dioxide is released into the atmosphere during dry ice production or use, so it does not increase CO_2 concentrations in the atmosphere.

Under atmospheric conditions, carbon dioxide is a colourless, chemically inert gas. It does not induce corrosion and does not adhere to solids. Dry ice is commonly transported liquefied in pressure vessels at 12–20 bar (1.2–2 MPa). Dry ice refers to solid state of the matter which is reached at temperatures lower than −78.5 °C. Snow-like dry ice is generated by expanding carbon dioxide through a nozzle. Generated "snow" may be directly used in a blasting machine but dry ice pellets are much more common. The pellets are little pins of pressed snow-like dry ice, with 3 mm diameter and 5–15 mm length (Fig. 1a) which are generated in the so called pelletizer machine. If we further press the dry ice, we obtain large-sized blocks which are more stable over time, can be easily transported, and may be further processed (Fig. 1b).

Dry ice blasting uses kinetic energy of accelerated dry ice particles hitting the surface. Dry ice produces thermal shock to the undercooled material and causes embrittlement of the contaminated layer. Dry ice further expands during sublimation of carbon dioxide (Uhlmann et al., 2009). Effects of dry ice blasting may be attributed to the compressed air which accelerates both the

* Corresponding author. Tel.: +420 541144916.
E-mail address: masa@fme.vutbr.cz (V. Máša).

http://dx.doi.org/10.1016/j.jclepro.2015.07.053

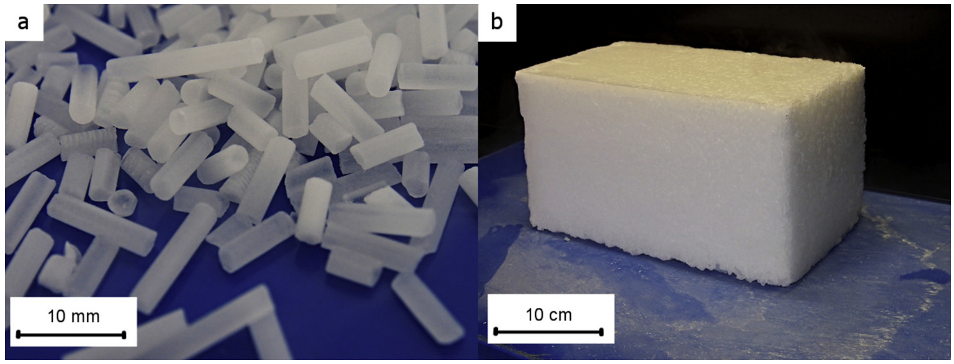

Fig. 1. Pellets (a) and block (b) of dry ice.

particles of dry ice and particles of the contaminated layer. Output rate of compressed air from an industrial blasting machine exceeds 150 m/s. Quality features of dry ice include purity (carbon dioxide concentrations), shape and age also have impact on efficiency of the cleaning.

The technology is widely used in all types of industries, such as automotive and foundry industries, mostly for cleaning of functional surfaces and removing undesired materials (such as dust, rust, resins and all sorts of grease). One of the specific features of dry ice blasting is a combination of the above mentioned effects of dry ice and its low hardness which allows to efficiently remove the contaminants without damaging the surface. Technology is very successful in cleaning various types of molds and devices operating in high-temperatures. High temperature difference has a positive impact on the cleaning process. In contrast to common cleaning with water, the equipment to be cleaned does not have to be turned off and cooled. Certain applications in food industry use the same effect of the technology to remove residues of dough from baking molds, forms and pans. Millar (2001) argues that dry ice blasting further has a positive impact on elimination of certain types of bacteria. Promising areas of utilization include cleaning of air units, treatment of materials before coating (painting and varnishing), and special direct application on bearings surface. Besides blasting, dry ice cools foods in food industry, and even substitutes ammonia in leather industry (Sathish et al., 2013).

Compared to other cleaning methods (water blasting, sand blasting, and blasting using a sand-like material), dry ice blasting can be a less energy-intensive and time consuming technology (Millman and Giancaspro, 2012). As to the efficiency of the cleaning, noise levels and operators' skills, dry ice blasting scores similar to the other cleaning methods above. Still, dependency of the technology on compressed air supplies adversely affects its potential. Compressed air transports and accelerates dry ice pellets, and helps corrupt the contaminants on the treated surface. However, compressed air is an expensive medium due to a low efficiency of compressors (Dindorf, 2012). Systems working with compressed air usually waste up to 80–93% of supplied energy in the form of heat and/or losses caused by leakages (SEI, 2007), Fig. 2. Volumetric flow rate of 6 bar (0.6 MPa) compressed air is commonly about 5 N m^3/min (300 N m^3/h). In order to achieve these parameters, it is necessary to use powerful industrial compressors. Although consumption of compressed air decreases worldwide, its generation still requires lots of energy. In Europe, generation of compressed air is responsible for more than 10% of electrical energy consumption in all industries (Radgen, 2005).

Efforts to decrease compressed air consumption in dry ice blasting processes are in line with current worldwide trends of energy savings in industry. Tonn et al. (2014) thoroughly discuss various approaches to energy savings. Jovanovic et al. (2014) examine a topic closely related to dry ice blasting, that is production and distribution systems for compressed air with special focus on its application and reliability in large-scale facilities. Although dry ice blasting technology has a great potential for industrial cleaning, there are only few researchers who analyse and study this topic. Liu et al. (2012) analyse cleaning mechanisms of dry ice blasting, Uhlmann et al. (2009) introduce new fields of application and Foster (2012) discusses cleaning rate and costs of the dry-ice blasting. However, our team has not found any papers dealing with the energy savings measures in the area of dry ice blasting.

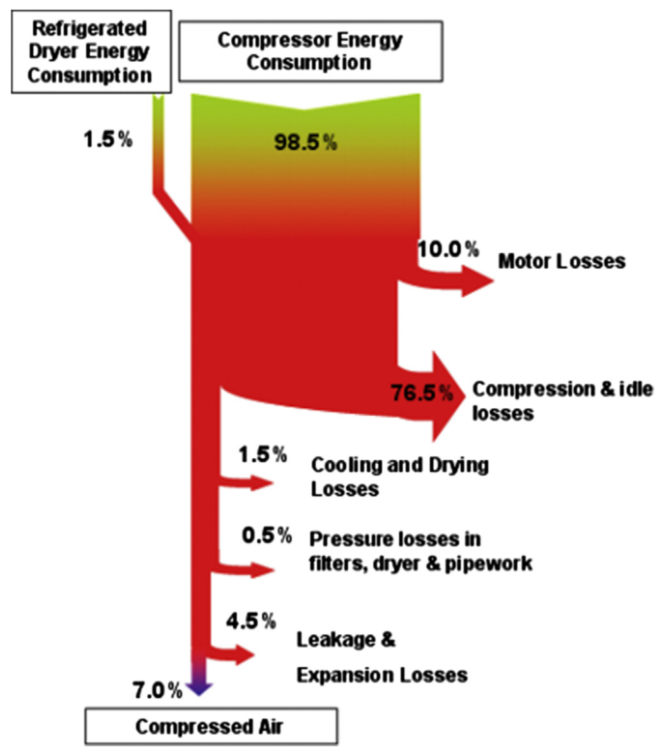

Fig. 2. Losses in systems using compressed air (SEI, 2007).

Essential benefit of our research is an introduction of a quantitative analysis of blasting systems' energy intensity. So far, there has been no method to compare energy consumption of various dry ice blasting machines and systems. Thanks to a newly introduced quantity called “specific energy consumption of dry ice blasting”