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Diacetyl and 2,3-pentanedione in breathing zone and area air during large-scale commercial coffee roasting, blending and grinding processes

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ABSTRACT

Recently described scientific literature has identified the airborne presence of 2,3-butanedione (diacetyl) and 2,3-pentanedione at concentrations approaching or potentially exceeding the current American Conference of Industrial Hygienists' (ACGIH) Threshold Limit Values (TLVs) at commercial coffee roasting and production facilities. Newly established National Institutes of Occupational Safety and Health (NIOSH) Recommended Exposure Limits for diacetyl and 2,3-pentanedione are even more conservative. Chronic exposure to these alpha-diketones at elevated airborne concentrations has been associated with lung damage, specifically bronchiolitis obliterans, most notably in industrial food processing facilities.

Workers at a large commercial coffee roaster were monitored for both eight-hour and task-based, short-term, 15-min sample durations for airborne concentrations of these alpha-diketones during specific work processes, including the coffee bean roasting, blending and grinding processes, during two separate 8-h work periods. Additionally, the authors performed real-time Fourier transform infrared spectroscopy (FTIR) analysis of the workers' breathing zone as well as the area workplace air for the presence of organic compounds to determine the sources, as well as quantitate and identify various organic compounds proximal to the roasting and grinding processes. Real-time FTIR measurements provided both the identification and quantitation of diacetyl and 2,3-pentanedione, as well as other organic compounds generated during coffee bean roasting and grinding operations.

Airborne concentrations of diacetyl in the workers' breathing zone, as eight-hour time-weighted averages were less than the ACGIH TLVs for diacetyl, while concentrations of 2,3-pentanedione were below the limit of detection in all samples. Short-term breathing zone samples revealed airborne concentrations for diacetyl that exceeded the ACGIH short-term exposure limit of 0.02 parts per million (ppm) in two samples collected on a grinder operator. FTIR analysis of air samples collected from both the workers' breathing zone and area air samples revealed low concentrations of various organics with diacetyl and 2,3-pentanedione at concentrations less than the limit of detection for the FTIR methods. Neither the breathing zone nor area air samples measured using the FTIR reflected airborne concentrations of organic compounds that, when detected, approached the ACGIH TLVs or regulatory standards, when available. FTIR analysis of headspace of ground coffee beans revealed ppm concentrations of expected alpha diketones, carbon monoxide and other volatile organic compounds (VOCs).

Coffee roasting and grinding, with adequate building ventilation and typical roasted bean handling and grinding, appears to generate very low, if any, concentrations of diacetyl and 2,3-pentanedione in the workers' breathing zones. This study also confirmed via FTIR that roasted

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coffee beans naturally generate alpha-diketones and other organic compounds as naturally occurring compounds resultant of the roasting and then released during the grinding process.

1. Introduction

Coffee roasting and brewing have been occurring for millennia. Specialty coffee roasting has increased dramatically during the last two decades, with the growth of specialty roasters expanding throughout the United States. The authors performed a study to collect airborne samples at a commercial coffee roaster and compare the results to regulatory and consensus standards as well as to the scientific literature (Study). This Study was conducted at the request of a specialty coffee roaster and café operator located in Wisconsin. Following its employees' concerns regarding recent reports of alleged worker exposures to 2,3-butanedione (diacetyl) and 2,3-pentanedione at coffee roasting facilities, as reported by the *Milwaukee Journal Sentinel* in winter 2015 [1]. Specifically, the concerns were due to the reports that concentrations of diacetyl and 2,3-pentanedione had been measured in other industrial food processing facilities, including coffee roasting and flavoring operations, and worker exposures to these compounds have been associated with lung disease [2].

Diacetyl is naturally present in numerous foods, including butter, wine and coffee, and is added as an artificial flavor to baked goods and oils. The Centers for Disease Control and Prevention (CDC), National Institute for Occupational Safety and Health (NIOSH) recently identified limited exposure to diacetyl and 2,3-pentanedione during work with flavoring agents in the food industry [3]. Curwin et al. evaluated 105 area samples and 74 personal samples from 10 sites encompassing several food manufacturing facilities. The majority of the samples collected for acids and ketones (including diacetyl) were non-detectable with aldehydes and respirable dust primarily detected [3]. Airborne diacetyl and other ketones, including 2,3-pentanedione, were identified in personal breathing zones and area samples almost exclusively in association with flavoring use. The research of Kreiss et al., Akpinar-Elci et al., Parmet and Von Essen, and Kullman et al. have demonstrated the potential association between airborne diacetyl and other organic compound exposure from flavoring ingredients with the suspected development of bronchiolitis obliterans in microwave popcorn workers [4–7]. Kullman et al. identified diacetyl at concentrations from below the analytical detection limits to 98 parts per million (ppm), with the geometric mean concentrations of 0.71 ppm measured at microwave popcorn manufacturing plants [12]. Alternatively, Ronk et al. [8] opined that exposures to flavoring chemicals in the workplace did not produce an increased risk of abnormal lung function, while Egilman et al. [9] suggested that very low, 1 ppb as an eight-hour time weighted average (TWA), occupational exposure limits (OELs) should be adapted for diacetyl. Clark and Winter authored a document providing a comprehensive review of naturally occurring diacetyl in foods and a review of the safety and sensory characteristics of diacetyl [10]. These authors, amongst others, illustrate the conflicting evidence as to the role of diacetyl and other alpha-diketones play in chronic lung disorders, namely bronchiolitis obliterans, which have been observed in selected cohorts of food industry employees exposed to varying concentrations of diacetyl and other organic compounds [10].

There is limited published information regarding occupational exposure to naturally occurring diacetyl and 2,3-pentanedione in workers employed in the coffee roasting industry. A manuscript currently in press identified that mean estimated eight-hour TWA diacetyl exposures for the barista grinding of roasted coffee beans and pouring of the coffee ranged from 0.007 to 0.013 ppm [11]. The study was conducted in a small residential kitchen. Also, Gaffney et al. recently measured naturally occurring diacetyl, 2,3-pentanedione and respirable dust at a facility that roasts and grinds coffee beans [17]. Diacetyl, 2,3-pentanedione and respirable dust concentrations measured during roasting ranged from less than the limit of detection (<LOD) to 0.0039 ppm, <LOD to 0.018 ppm and <LOD to 0.31 milligrams per cubic meter (mg/m^3), respectively [12]. During grinding, diacetyl, 2,3-pentanedione and respirable dust concentrations ranged from 0.018 to 0.39 ppm, 0.0089–0.21 ppm and <LOD to 1.7 mg/m^3, respectively [12]. These authors noted that "[f]or any given bean/roast combination and sample location, diketone concentrations during grinding were higher than those measured during roasting. During grinding, concentrations decreased with increased distance from the source."[12] Gaffney et al.'s study was performed at a commercial roasting and grinding facility with a of volume 1133 m^3 with approximately 40,000 square feet (ft^2) of the floor surface and with 2.1 air exchanges per hour [12]. The authors reported a total of 1250 pounds of coffee roasted per week at this facility [12]. In 2016, Duling et al. reported workers in the grinding/packing area of unflavored coffee had the highest mean diacetyl exposures, with mean personal breathing zone concentrations of 93 ppb and mean personal breathing zone 2,3-pentanedione concentrations of 53 ppb [13]. It is important to note that local exhaust systems operating proximal to the coffee processes may substantially reduce the airborne concentrations detected in the employee's personal breathing zone and in area sampling.

Previously, it has been well described that roasted coffee beans contain a wide variety of volatile organic compounds (VOCs) and semi-VOCs (SVOCs). Hertz-Schünemann et al. identified that roasted coffee contains 0.1% VOCs and SVOCs per dry weight, respectively, while containing 850 identified compounds [14]. Akiyama et al. identified 47 organic compounds released during the coffee bean grinding process, including: diacetyl; 2,3-pentanedione; 2,3-hexanedione; and 3,4-hexanedione [15]. It has been reported that the roasting temperature and duration in which the coffee beans are roasted can alter the concentrations of organic compounds contained within the roasted beans. Additionally, different varieties of freshly brewed coffees have differing profiles of released organic compounds in their aroma [16,17]. Therefore, the organic compounds emitted during coffee processing are dependent on the coffee bean variety, temperature and duration of the roasting, and the grinding processes. Wang and Lim utilized Fourier transform infrared spectroscopy (FTIR) and physicochemical analysis to characterize roasted coffee beans to evaluate the roasting temperature and duration effects on the profiles of organic compounds [18]. Wang and Lim identified that the low temperature, long-duration roasting process resulted in the released of organic compounds with a greater infrared absorbance for aldehyde, ketones, aliphatic acids, aromatic bands and caffeine carbonyl bands on the FTIR spectra [18].

The United States Department of Labor, Occupational Safety and Health Administration (OSHA) has established regulatory standards as an eight-hour TWA Permissible Exposure Limit (PEL) and Short-term Exposure Limit (STEL) to be protective of worker health.