Evaluation of Solid Fuels for the Commercial Cooking Industry

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Oklahoma State University

Abstract

The National Fire Protection Association Standard for Ventilation Control and Fire Protection of Commercial Cooking Operations, or NFPA 96, provides strict design criteria on the requirements for commercial cooking equipment and the associated exhaust hoods. Within NFPA 96, there are additional restrictions should a commercial kitchen utilize solid fuels within their cooking process. These requirements include a separate exhaust hood for appliances that utilize solid fuels as the primary heat source. NFPA 96 defines solid cooking fuel as "any solid, organic, consumable, fuel such as briquettes, mesquite, hardwood, or charcoal." [(1)] Solid fuels present an added hazard, specifically when the creosote that results during the solid fuel burning process mixes with grease-laden vapors from other cooking appliances within the kitchen. However, NFPA 96 provides an exception for cooking appliances that are gas-powered and have a limited size tray for solid fuels solely intended for food flavoring. This gas-powered equipment, if the list of restrictions in NFPA 96 is met, will not be required to have a separate kitchen exhaust hood. However, there is minimal information provided as to why this exception is permitted. Given the restrictions, a better understanding of the various solid fuels, from manufacturing process to burning characteristics, is needed to validate the requirements for separate kitchen exhaust hoods or provide insight as to the limitations of the exception within NFPA 96 to not provide a separate exhaust hood. There are few regulations for the manufacturing of solid fuels because solid fuel cooking, historically, has occurred outdoors. With the rising popularity of smoked barbeque menu items and restaurants, solid fuel cooking within indoor commercial kitchens is increasing. The requirement of a separate exhaust hood specifically for solid fuel cooking appliances is costly to owners. Additionally, there have been recent innovations within the commercial cooking industry, specifically related to utilizing different solid fuels, such as wood pellets, as a part of the cooking process. Investigating the primary fuel sources for solid fuel cooking including wood pellets will provide the necessary data to determine what additional testing or criterion the commercial cooking appliances should undergo or potential changes or exceptions to NFPA 96 and the exhaust hood requirements for solid fuel cooking.

Introduction

Understanding codes, standards and regulations is an important aspect in the education of undergraduates in engineering technology. The National Fire Protection Association (NFPA) is a leading international organization in the development of consensus codes and standards that protect property, and eliminate injuries or deaths due to fire, electrical and related hazards. Jurisdictions worldwide adopt these codes and standards for incorporation into building and system design, operational best practices, or standards on equipment. Those that graduate with a degree in engineering technology need to understand the impacts of codes, standards and regulations within their particular industry. By having undergraduates participate in the research, application, and evaluation of these standards, undergraduates will be better prepared to enter the workforce and provide valuable insight to their employers. This project, utilizing an undergraduate researcher to provide an in depth analysis of these regulations, focuses on a specific standard and its impacts to the commercial cooking industry given the changes in the cooking industry towards the popular use of solid fuels. Additionally, this project is providing information for a real world application and problem that industry is facing.

The NFPA Standard for Ventilation Control and Fire Protection of Commercial Cooking Operations, or NFPA 96, provides strict design criteria on the requirements for commercial cooking equipment and the associated exhaust hoods. Within NFPA 96, there are additional restrictions should a commercial kitchen utilize solid fuels within their cooking process. These requirements include a separate exhaust hood for appliances that utilize solid fuels as the primary heat source. NFPA 96 defines solid cooking fuel as "any solid, organic, consumable, fuel such as briquettes, mesquite, hardwood, or charcoal." (1) Solid fuels present an added hazard, specifically when the creosote that results during the solid fuel burning process mixes with grease-laden vapors from other cooking appliances within the kitchen. Given the restrictions, a better understanding of the various solid fuels, from manufacturing process to burning characteristics, will validate the requirements for separate kitchen exhaust hoods or provide insight as to the limitations of the exception within NFPA 96 not requiring a separate exhaust hood. Investigating the primary fuel sources for solid fuel cooking, including wood pellet,s will provide the necessary data to determine what additional testing or criterion the commercial cooking appliances should undergo or potential changes or exceptions to NFPA 96 and the exhaust hood requirements for solid fuel cooking.

Standards and regulations requirements

NFPA 96 sets the minimum preventative and operative requirements to design, install, operate, inspect, and maintain all public and private cooking operations. The purpose of NFPA 96 is to reduce the potential fire hazards of cooking operations regardless of the type of cooking equipment used. NFPA 96 outlines the minimum fire safety requirements for all devices and components that are involved in capturing, containing, and controlling grease-laden cooking vapors and residue deposits such as creosote made by solid fuels. Cooking equipment that produces grease-laden vapors shall be equipped with an exhaust system that meets the performance standards and requirements set in NFPA 96. The standard also outlines clearance distances, integrity of the system, construction material, design, and construction of the exhaust system and appurtenances. (1)

Requirements for solid fuel cooking

NFPA 96 classifies solid fuel cooking equipment as any equipment that derives all or part of its heat source from the burning of solid fuels. NFPA 96 sets stringent requirements for solid fuel commercial cooking to account for the associated hazards of grease-laden vapors and creosote deposits. Examples of solid fuel cooking equipment are broilers, rotisseries, ovens, grills, barbeque pits, and tandoori charcoal pots. NFPA 96 requires that gas powered equipment using solid fuels for flavoring shall not require a separate exhaust system if they meet all 11 stipulations listed in the standard. In newer equipment, the combustion of the solid fuel powers the cooking equipment and is not gas powered. An example of solid fuel cooking equipment versus commercial cooking equipment used in everyday life is a charcoal grill and a conventional home kitchen oven. The solid fuel, such as charcoal briquettes, supplies the heat source for the grill while a kitchen oven produces heat with the use of natural gas or electricity.

Challenges with meeting requirements

The problem with meeting the requirements in NFPA 96 for solid fuel commercial cooking is requiring a separate exhaust system for solid fuels. Installing a separate exhaust system with listed components, fire suppression systems, grease filters, spark arrestors, along with maintenance and upkeep, exponentially adds cost that are not feasbile to the end-user. In some buildings, it may not be possible to add a secondary exhaust system due to the amount of the space the business possesses or space the exhaust duct system must travel through to meet requirements. The exhaust ducts are further limited in that exhaust ducts can not pass through fire walls, shall lead directly to the outside of the building, and not be connected to any other type of ventilation or exhaust system. [(1)] Buildings requiring renovations to install the exhaust or ventilation system will not find it financially beneficial to install the system and will be put at a disadvantage because they can not use solid fuel appliances and solid fuels for cooking and flavoring.

Exhaust systems are used to capture the grease-laden vapors,smoke, and byproducts that are produced during solid fuel commercial cooking. These contaminants are captured near where they are produced and are exhausted through the system ducts to the outside environment. The exhaust system consists of five main components which are: the hood, duct system, air cleaner, fan or air mover, and stack. [(2)] Having an effective exhaust system to capture, filter and exhaust grease-laden vapors and contaminants, are fundamental in controlling the hazards of solid fuel cooking. Designing the system with accurate air flow velocities and equipement is critical in keeping the contaminants flowing through the system properly.

Statistics in eating and drinking establishments

The prominent threat to eating and drinking establishments is cooking fires. Fires can be extremely costly, threaten the lives of employees and people not intimate with the initial fire development, and cause significant down time for repairing the damage. Examining the fire statistics in eating and drinking establishments between the years 2000-2010 with data published by the U.S. Fire Administration's (USFA's) National Fire Incident Reporting System (NFIRS) and NFPA's annual fire department experience survey, shows that no significant advances in lowering the amount of causalities and property damage annually has occurred. In 2000-2004, the United States fire departments responded to 8,520 structure fires. In 2006-2010, the amount of fires declined to 7,640 structure fires in eating and drinking establishments. However, from 2000-2004, these fires caused an annual loss of three civilians, 113 civilian injuries, and $190 million in direct property damage while the statistics stayed comparable in the years 2006-2010, which caused an annual loss of two civilians, 115 civilian injuries, and $246 million in direct property damage. Extrapolating the fire and injury data from these years, it shows that no significant changes in reducing the amount of fires and injuries in those ten years. This should prompt the need for more attention to commercial cooking operations in eating and drinking establishments. When considering a broader time-span from the year 1980 and 2010, structure fires in eating and drinking establishments have had a major decrease from 23,000 fires in the 1980 to 6,800 fires reported in the 2000s given 30 years of advancement in technology. [3] [4]

The major leading causes of fires from 2000-2004 and 2006-2010 were cooking equipment, which accounts for 48% of fires and 57% of fires respectively. The top five major causes of fires in eating and drinking establishments have remained the same from 2000-2010, which are cooking equipment, heating equipment, electrical, smoking material, and intentional. [3] [4]

Fire risk from solid fuel commercial cooking

Solid, organic, or consumable fuel such as briquettes, mesquite, hardwood, and charcoal generate large quantities of combustion particles. These particles congest grease filters and emit the grittiest type of cooking emissions. Solid fuel cooking appliances produce a large amount of creosote, grease, ash, and smoke during combustion. The buildup of creosote, grease, ash, and smoke on the filters and exhaust system increases the fire risk, because it is highly unstable and increases the temperature of the fire substantially.[5] The creosote and grease-laden vapors can coat fire suppression systems and heat detectors that will cause a delay or cause failure of the system to initiate.

Creosote and grease-laden vapors

The main concerns in utilizing solid fuels in commercial cooking are the hazards associated with the buildup of creosote deposits and grease-laden vapors. Solid fuel commercial cooking has a distinct hazard that creates a highly combustible tar-like substance when burned. Creosote is composed of unburned wood particles and condensed flue gases produced by incomplete combustion of wood.

Grease-laden vapors are a secondary concern for solid fuel commercial cooking appliances. According to NFPA 96, grease is any rendered animal fat, vegetable shortening, and other such oily matter used for the purposes of and resulting from cooking and/or preparing foods. [1] The development of grease-laden vapors occurs when the temperature exceeds the vaporization point of the grease. The vapors rise and enter into the exhaust system. When the vapors cool, the grease will condense and settle inside the exhaust ducts.

The primary hazard with creosote is the low flash point and auto-ignition temperature characteristics. According to the Agency for Toxic Substances and Disease Registry, they have determined the flash point of wood creosote to be 74 degrees Celsius or 165 degree Fahrenheit (6). With such a low flash point, any type of spark or flame that reaches the exhaust hood, filters, or duct could ignite the creosote leading to a fire. During solid fuel cooking, flames and embers are always present, so ignition of a buildup of creosote can occur at any time. The auto-ignition temperature of creosote is the same as paper, 451 degrees Fahrenheit, due to both being made of wood. With the addition of grease, the fire can be easier to ignite and burn at a higher temperature increasing the severity of the fire. The combination of grease and creosote increases the severity of the fire and lead to dangerous fire conditions when ignited. [7]

Several conditions increase the amount of creosote that builds up. An air supply that does not provide adequate flow to extract the creosote and a large temperature difference in the exhaust system increases the amount of buildup of creosote. Having an insufficient air supply due to improper maintenance and cleaning allows the creosote to accumulate in the ducts. A large temperature difference causes the particles to cool, mix with water vapors, and forms deposits on the inside of the exhaust ducts. [(7)]

Creosote and grease-laden vapors in solid fuel commercial cooking is a continually evolving matter. In order to mitigate these hazards in commercial cooking exhaust systems, a combination of proper design, installation, and maintenance of the exhaust systems coupled with routine inspections, and preventative maintenance, ensures the exhaust system is operating at efficiently.

Chapter 14 of NFPA 96 is devoted solely to solid fuel cooking operations and the requirements to reduce the hazards associated with Solid Fuel Cooking. Chapter 14 requirements include venting applications, location of appliances, hoods for solid fuel cooking, exhaust for solid fuel cooking, grease removal devices for solid fuels, air movement for solid fuel cooking, fire-extinguishing equipment for solid fuel cooking, procedures for inspection, cleaning, and maintenance for solid fuel cooking, and minimum safety requirements. [(1)]

Types of solid fuels

Given the broad definition of solid fuels provided in NFPA 14, this study focused primarily on wood pellets, mesquite wood, and charcoal. The solid fuels manufacturing process is different for each of the chosen fuels; therefore, studying these three fuels will provide a broad range of information.

Wood Pellets

The pellet industry has been around since the 1930s. In the wake of the energy crisis in 1970, the pellet industry grew substantially. In the last fifteen years, the North America pellet sector spurted from 1.1 million metric tons in 2003, to 4.2 million in 2008 and expected to increase well over 6 million metric tons by 2009. The use of wood pellets for energy is relatively new in North America but with the increasing cost of fossil fuels and policies aiming to reduce carbon dioxide emissions, wood pellets could thrive in the future. [(8)]

Wood pellets are a clean burning, cost stable, and renewable fuel source. Pellets are a biomass fuel consisting mainly of recycled wood paste. Pellet fuel diverts millions of tons of waste that would end up landfills to energy. Pellet manufactures use wood by-products such as sawdust or wood shavings, cornstalks, residual forest waste, straw, and refine them into small cylindrical pieces that are uniform in density, shape, size, moisture, and energy content. Biomass fuel consistency and burn efficiency emits a fraction of emissions when compared to the particulate emissions of raw biomass. When comparing all solid fuel cooking appliances, pellet burners emit the lowest particulates emissions. United States and Canada manufacturing facilities supply wood pellets to North America. [(9)]

Wood pellets production starts with a hammer milling process that takes all the wood content and shreds or crushes the aggregate material into smaller chunks. The material moisture content must be 12% to 17% to ensure the product can burn efficiently. The size of the particles are set to the manufactures specifications and can be treated with steam conditioning to soften the lignin to facilitate shape consolidation during the extrusion process thereafter. Lignin is a polymer that acts as a binder, which aids in achieving the desired shape of the pellets. Additional binding agents can minimize breakage and improve characteristics of the wood pellets. An extruding process adds dyes and cuts the material to size as the strands emerge from the process. (8)

The Pellet Fuel Institute sets standards for the fuel grade of wood pellets. Standards allow the industry to have guidelines to ensure they are clean burning, and meet manufacturing requirements of the Pellet Fuel Institute. Wood pellets have four fuel grade divisions based on density, diameter, durability, inorganic ash, moisture percentage, and chloride emissions.

Wood pellet cookers and grills are trending in the cooking industry according to Hearth, Patio, and Barbecue Association. Pellet fuels are clean burning, generate minimal wood smoke, and have the lowest emissions of solid fuels. This makes them popular among areas with air quality issues. (10) Wood pellets are versatile and allows chefs to barbecue, roast, grill, and smoke meets. Pellets come in a variety of flavors, which allows you to get the perfect flavor for your meat. Popular flavors consist of mesquite, hickory, maple, bourbon, pecan and other varieties. Grillers can add smoke bricks for additional flavor in their pellet grills. (11)

Pellet grills work as a convection oven, which allows you to load the cook chamber with pellets and step away without fear of uneven cooking. The indirect heat cooks larger cuts of meats at lower temperatures to produce better flavors and moisture content of the meat. New technology in grills allows users to regulate the temperature with pinpoint accuracy. A thermostat in the chamber sends signals to the controller, which regulates the pellet delivery and the amount of oxygen to the area of combustion. (12)

Mesquite

Mesquite wood is a natural flavor enhancer when it comes to solid fuel commercial cooking. Mesquite wood adds a sweet, earthy, and smoky flavor to the meat. The wood is in chip and chunk form for even burning. Mesquite wood contributes its popularity due to good marketing practices, smells good, looks good, and does not rub off on one’s hand. (13) In the United States, mesquite wood is mainly grows in areas of Texas and other small areas in the south. Mesquite wood must be have moisture content of 14% to 20% to ensure the odor and flavor is ideal for cooking meats. (13)

Charcoal and briquettes

Charcoal is the solid carbon material residue remaining after the burning of raw carbon materials. It is a complex combination of hydrocarbons and carbon with formations depending on the temperature used during the burning process. Raw carbon material can be made up of animal, mineral, or vergetable source, but medium and dense hardwoods are the main commerical raw material. Medium and dense hardwoods consist of birch, beech, maple, oak, and hickory. Other raw materials are softwoods (slash pine and long leaf), coal, nutshells, fruit pits and papermmill residue. (14)

Producing charcoal by the batch is done either one stage at a time or continuously. Furnances or kilns heat the raw materials and limit the amount of oxygen available to produce the amount of carbon specified. Charcoal manufacturing in the batch process uses pits or kilns that are covered to limit the oxygen concentration in the pit. In the beginning of the process, a large amount of air enters the pits or kilns to ensure the heat level is sufficient to produce the rapid combustion for pyrolysis. Maintaining the burning zone is imperative to achieve the correct burning conditions to produce enough carbonization for the process. Continuous charcoal production uses mutiple hearth furnaces stacked on top of one another in which the material drops through the hearths holes as it burns until it reaches the floor. Water sprays cool the charcoal as they exit the furnance. (14)

Briquettes are a compact fuel source consisting of coal dust, charcoal, or combustible biomass for use in commercial cooking and industrial applications. (15) The protection of foresty resouces are international concern because forests are major absorbers of CO_2. With the increase in consumption of wood fuels, controlling and reducing deforestation is a great concern. Briquettes can help with conserving forests by substituting charcoal for firewood. (16)

Manufacturing of coal briquettes start from hammer milling charcoal to the size of approximately three millimeters to pass through a screen aperture to ensure size**.** To strengthen the charcoal, a binder that is 10% by weight mixes and forms a 70% charcoal mixture. The addition of other materials can ensure faster burning or higher temperature if specified. The briquettes enter a press and into an oven to obtain a 5% moisture content. (14)

Testing methodology

As a part of the undergraduate researchers in depth look at the solid fuel industry and the related manufacturing regulations, the literature review brought forth the idea of testing the solid fuels to gain a better understanding of the fuels burning in controlled conditions. By understanding the solid fuels in specific parameters, further analysis to the standard requirements could potentially be provided. Therefore, providing a further understanding to the code, standard, and regulations.

The preliminary testing of the solid fuels utilized a cone calorimeter. A cone calorimeter can provide real fire properties of materials under particular preset conditions. The test specimens are 100mm x 100mm and subjected to a selected heat flux. At the start of each test, the cone calorimeter collects a minimum of 60 seconds of pre-data, prior to inserting the test specimen. After the pre-data is collected, the research team inserts the test specimen into the cone. Once inserted, the specimen is subjected to a heat flux and an ignition source, a spark ignitor. The researcher monitors the specimen and notes in the system when ignition occurs and a flame is present. The test then runs until the flame goes out on its own. After flameout, the specimen remains in the cone calorimeter for an additional 120 seconds for posttest data.

EVALUATION OF SOLID FUELS

For this particular testing, three different solid fuels were tested, wood chips, food grade wood pellets, and charcoal briquettes. It was determined that this would give the spectrum of solid fuels used in the commercial cooking industry. The research included testing each fuel three separate times to provide preliminary data on the burn characteristics of the fuel. Additionally, this data would be essential in determining what future testing and research needs, whether the individual fuels or in conjunction with commercial cooking equipment. All the test specimens were subject to a 50 KW/m^2 heat flux. The cone calorimeter provides one second time step data that monitors temperatures, oxygen, carbon monoxide, and carbon dioxide levels, and specimen mass.

Results

During the course of the testing, it was determined the best data to review would be the comparison between the mass loss during burning over the test time (g/s). The research compared the starting specimen mass to the specimen mass at the time of flameout. Additional comparisons were made of the additional mass loss after flameout and the end of the test (time at flameout plus 120 seconds).

As shown in Tables 1 and 2, there is a difference in the mass loss rate during flaming combustion between the wood chips and wood pellets. The wood chips averaged a loss rate of 86.5 mg/s while the wood pellets averaged 135.6 mg/s. Given the manufacturing process being different between the two types of specimens (wood chips are raw and unprocessed, while wood pellets are processed with additives to create the pellets), this could be a result of the process itself adding to the mass loss rate. However, it may also have to do with the overall mass subject to the test itself. Wood pellets are heavier then wood chips. Furthermore, the surface area characteristics of each type of fuel are also different.

Another interesting comparison between the wood chips and wood pellets is that the mass loss rates of the fuels smoldering only (occurred during the last 120 seconds of the test) were similar. Wood chips were at a rate of 8.4 mg/s and the wood pellets were at a rate of 9.7 mg/s. Given that the primary make up of both fuels is hard wood, this similarity in mass loss rate during smoldering seems appropriate.

Table 1: Wood Chip Testing

Wood Chip Specimen	Starting Mass (g)	Mass Flameout (g)	Final Mass (g)	Mass loss Flaming (g)	Total Mass loss (g)	Mass loss to Smoldering only (g)	Time ignition (s)	Time flameout (s)	Time flaming (s)	Time total (s)	Mass loss rate flaming (g/s)	Mass loss rate smoldering only (g/s)	Mass loss rate total (g/s)
1	21.2	4.78	3.98	16.42	17.22	0.80	43	335	292	412	0.056233	0.006667	0.041796
2	17.2	2.70	1.39	14.50	15.81	1.31	25	152	127	247	0.114173	0.010917	0.064008
3	19.1	4.03	3.10	15.07	16.00	0.93	19	188	169	289	0.089172	0.007750	0.055363
									AVERAGES:		0.086526	0.008444	0.053723

Table 2: Wood Pellet Testing

Wood Pellet Specimen	Starting Mass (g)	Mass Flameout (g)	Final Mass (g)	Mass loss Flaming (g)	Total Mass loss (g)	Mass loss to Smoldering only (g)	Time ignition (s)	Time flameout (s)	Time flaming (s)	Time total (s)	Mass loss rate flaming (g/s)	Mass loss rate smoldering only (g/s)	Mass loss rate total (g/s)
1	47.7	7.80	6.61	39.90	41.09	1.19	47	528	481	601	0.082952	0.009917	0.068369
2	43.8	8.61	7.50	35.19	36.30	1.11	39	256	217	337	0.162166	0.009250	0.107715
3	45.9	9.01	7.80	36.89	38.10	1.21	46	274	228	348	0.161798	0.010083	0.109483
									AVERAGES:		0.135639	0.009750	0.095189

The charcoal briquettes provided interesting test data, which is to say, almost none at all. During the three different test runs, only one time did the charcoal briquettes ignite and provide a flame to monitor. However, during that one test, it only had flaming combustion for 21 seconds. The other two tests, the charcoal briquettes never had a flaming ignition. During each of the charcoal tests, pyrolysis did occur, but no flaming ignition. Additionally, all three tests of the charcoal briquettes saw no recordable loss in mass by the cone calorimeter during the test. Therefore, a comparison of the mass loss rate to the other solid fuels could not be completed.

Discussion

Engineering technology students go on to work in a variety of industry. However, there is one common element that many of these undergraduates will apply in their daily lives, which is codes, standards, and regulations. Using these standards in the classroom, as well as part of undergraduate research projects, provide further experience for students to have a deep understanding of how these codes, standards, and regulations can be applied or interpreted. After completing the literature review of the solid fuel requirements for solid fuel cooking, it has come to light the limited knowledge of both the commercial cooking and regulation industry have on solid fuels and their impacts to the protection of life and fire.

Solid fuels increase the risk for potential fire hazards through the production of creosote and grease-laden vapors. However, there is an increase in popularity in commercial kitchens to utilize appliances that have solid fuels. NFPA 96 provides the requirements for kitchen exhaust hoods, including those kitchens that utilize appliances in which the primary heat source is a solid fuel.

NFPA 96 defines solid cooking fuel as "any solid, organic, consumable, fuel such as briquettes, mesquite, hardwood, or charcoal." (1) This definition does not take into account the different manufacturing processes that several of these fuels utilize to obtain their final product. As shown in the testing conducted here, there is a difference in the mass loss rate between two of the fuels, wood chips and wood pellets. Additionally, the third fuel tested could not sustain flaming combustion. Given these preliminary results, further testing on mass loss rates should be conducted as well as the soot production of each of the fuels. The soot production of the fuels will be key in understanding the creosote production that is a part of solid fuel cooking. Full scale testing in conjunction with the small-scale cone calorimeter can provide the data needed for the requirements in NFPA 96, whether that be additional or less restrictions for solid fuel commercial cooking.

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