Reduce, Refuel, Refire: The Thermodynamic Process of a Smokeless Campfire Pit

Jack Burke and John Paul Jochum

ABSTRACT

With the evidence of the first use of fire by homo sapiens occurring nearly 400,000 years ago, it is safe to say the campfire has lived alongside the human race for the majority of our existence. As the human mind developed throughout the ages, so did fire-centered technologies. A recent breakthrough is the development of above-ground smokeless campfire pits (SCP). These campfires utilize modern thermodynamic understanding of heat and mass transfer to provide optimal flame and minimal smoke output, perfect for both recreational and culinary purposes.

This project explores the history and development of the smokeless firepit and our design and manufacturing of one, as well as an analysis of the thermodynamic process behind the effective performance of this device.

OBJECTIVES

- Conduct research into the history and development of smokeless fire pits
- Design and manufacture a prototype fire pit and smokeless fire pit for testing and comparison
- Analyze the thermodynamic process of our design and why its performance is so effective
- Provide feedback from testing phase and whether or not our design works

MATERIALS

The raw materials chosen for the prototypes include: (2) Recycled Steel Barrels, 6' Slotted 7/8" Strut, (6) ¼" Screws, 0.035" Flux Core Welding Wire, and (3) General Purpose All Ferrous Metal Cutting Wheels.

This project required the operation of many tools and machines, comprising a list: Milwaukee Band Saw, Milwaukee Sawzall, Milwaukee ¼" 18V Impact Driver, Hobart Handler 120 MIG Welder, ½" Corded power drill with 3/8" Steel Cutting Bit, and both a 4 ½" Angle Grinder and a 7 ½" Angle Grinder.

Other materials consists of: Firewood, Blow Torch, and Atmospheric Air

Safety materials incorporated encompass safety glasses, face shield, gloves, hearing protection, welding mask, leather boots, heavy denim jeans, flame-retardant sleeves and coverings, and a heavy cotton, long sleeved shirt.

HISTORY

The first known smokeless firepit was developed sometime within the 1600s, during America's colonial era by the Dakota people when hunting Bison herds. This design, shown in Figure 1 below, utilizes two holes dug into the ground. One hole holds the fuel (firewood), while the other allows for a passage of air. The wood is burned from the top down. It also conveys a constant stream of air through both holes, which provides a steady source of oxygen, allowing the fire to reach a nearly complete combustion. A fire with complete combustion burns efficiently, burns brightly, and produces no smoke. Because the Dakota fire hole is easier to light under strong wind conditions and gives off a low light signature, the United States military often utilizes it.

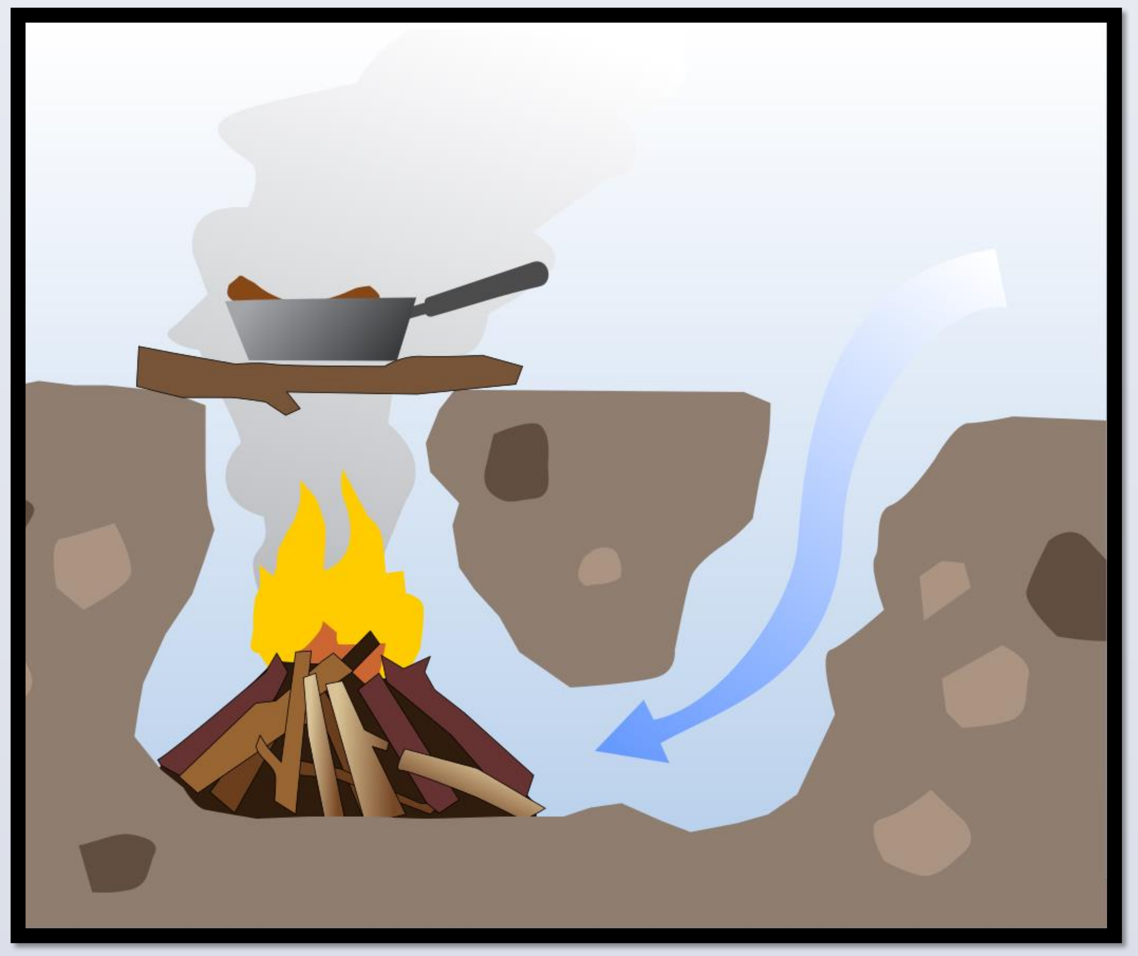

Figure 1: Illustration of a Dakota Fire Pit

MODERN DESIGNS

Modern smokeless campfire pits take the benefits of the Dakota fire hole and both optimizes and mobilizes it. The majority of modern designs utilize a design similar to the concept shown in Figure 2 below.

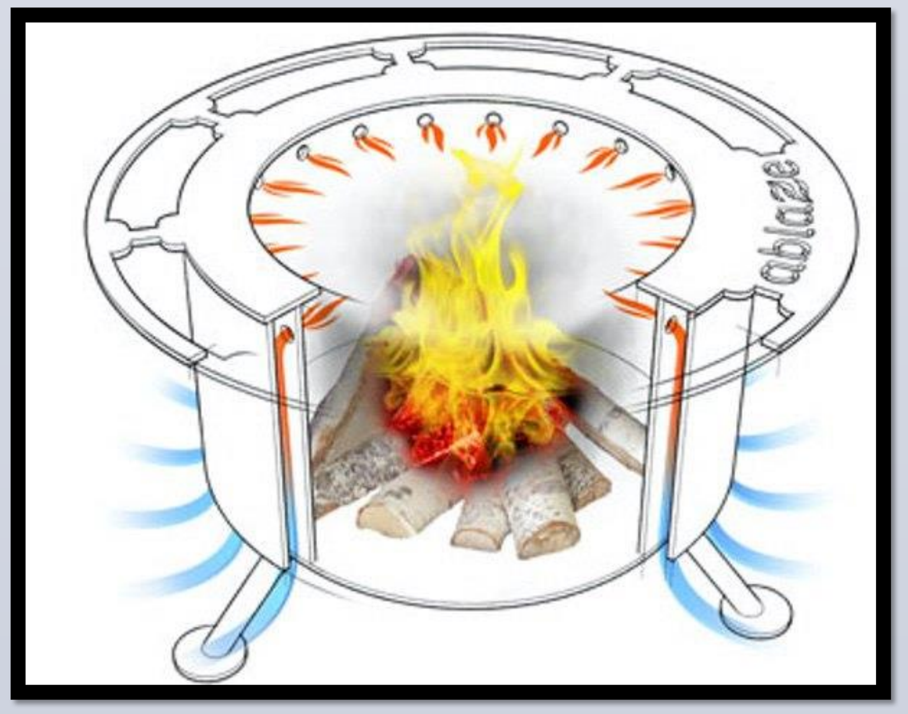

Figure 2: Inner-Workings of a Modern SCP

DESIGN AND DEVELOPMENT

Every campfire pit without a secondary air source (such as a normal campfire ring) under normal weather conditions produces smoke. This is because the air from the primary source doesn't have enough oxygen to completely combust the fuel. You've probably seen this before whenever someone 'smothers' the fire with too much wood or a bundle of leaves. Only a small amount of oxygen can reach the flame, and the flame, in turn, produces a large amount of smoke.

$$C_xH_y + O_2 \longrightarrow CO_2 + H_2O + \Delta H$$

Figure 3: Equation of Combustion for a Campfire

The chemical equation for the combustion of a campfire is shown in Figure 3 above. The CxHy signifies the wood; O2 – air; CO2 – Carbon Dioxide; H2O – Water; and ΔH – Hydrocarbons, otherwise called smoke. In a complete combustion, no hydrocarbons are present. Therefore, in an incomplete combustion, when not enough reactants are provided, smoke is produced. In order to produce a complete combustion with enough reactants, either a greater air supply is needed originally (since there is always enough wood) or oxygen must mix with the hydrocarbons leaving the original reaction and react or burn again.

This is why the double ringed chamber works so well and is also why we decided to proceed with a design that follows it. The primary air source for the first reaction enters the main chamber through bottom holes, colored blue in Figure 2. A secondary air source, colored orange in Figure 2, enters the main chamber through holes in the top of the inner ring, mixes with the hydrocarbons (smoke) remaining, and re-reacts, producing a near complete combustion.

The secondary air source never 'runs out' either for one reason: the fire in the main chamber heats the inner ring, which in turn heats the air inside the outer chamber via convection. This hot air 'shoots out' of the upper holes and creates a low-pressure environment near the top of the outer chamber, essentially sucking up more air from the bottom.

FINAL DESIGN AND RESULTS

Our final design was built using a recycled steel drum and slotted 7/8" strut. We first cut apart the three sections of the barrel and trimmed one's circumference by about half a foot to use as the inner ring. The bottom section was flipped over and used as the SCP's outer ring. We then welded the bottom of the inner ring to the top plate of the outer ring and cut along the newly welded perimeter. This not only provided us with the outer chamber's ceiling, but also the bottom of the main chamber. (At this stage, the pit acted as a normal campfire ring, and can be seen in the left image of Figure 4). Finally, we drilled 3/8" holes along the bottom and top of the SCP to create the Primary and Secondary air sources.

Figure 4: Normal Campfire Pit (left) and SCP (right)

Even with the difficulties of capturing a photo with smoke on a cloudy day, Figure 4 shows clearly the workings of both a normal campfire pit and an SCP. The image on the left shows the normal fire ring with a hazy distortion easily identifiable as smoke. The image on the right ,which is our Smokeless Campfire Pit design, shows no visible smoke above it. You can also see the secondary combustion working in the air directly above the fire pit. What looks as if there are floating flames is the smoke re-combusting with the secondary air source. Our design not only worked, but worked efficiently and effectively.

If videos of the normal campfire pit and the smokeless campfire pit working are requested, please email Jack Burke via: burk9594@ravens.benedictine.edu