

THE FORM OF THE COOKING VESSEL AND THE ENERGETIC EFFICIENCY OF COOKING

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Abstract

The present paper examines the contribution of the form of the cooking vessel to the heat transfer efficiency of the stove/pot system. A rounded (convex) pot bottom increases the surface available for heat transfer and, hence, heat transfer efficiency. We suggest that combustion-efficient stoves combined with rounded-bottom vessels compare favourably to the same stoves in combination with flat-bottom stoves. Clay pots with a rounded bottom correspond to African traditions. Nowadays metal pots with rounded bottoms are locally produced in some areas. Implications of pot forms for the outcome of Water Boiling Tests are also discussed.

Keywords: Form of the cooking vessel, African tradition, Energy efficiency, Stove/pot system, Implications for testing.

1. Introduction

In Africa there are cooking vessels of two different types with regard to the form of the bottom: those with a rounded (convex) bottom (Figs. 1-4) and those with a plain (level, flat) bottom (Figs. 5-6). The first type corresponds to long standing African traditions. These pots are also more stable on a three-stone fire, because their centre of gravity is deeper. However, nowadays in many places flat-bottom vessels are used, which became common under European influence.

Abbreviations

IBK	Innocent Balagizi Karhagomba (co-author)
WBT	Water Boiling Test
WHO	World Health Organization

Explanation of technical terms

Hybridization	Here means mix-up of cultural traditions
Combustion efficiency	The degree to which latent energy of a fuel is set free as heat and to which carbon is oxidized to CO ₂
Heat transfer efficiency	The degree to which the energy released reaches the content of the pot

Efficiencies of stoves are commonly determined using the Water Boiling Test (WBT). Published data on the efficiency of the three-stone-fire show a large range of variation. Frequently efficiencies between 5% and 15% are mentioned [1].

Some authors report higher values, e.g. Anozie et al. [2], with 25% efficiency. This large variation suggests that there may be factors which have not been kept constant, or even simply neglected in the WBT protocols.

The traditional form of cooking vessels in Africa

In fact, the traditional African cooking vessel is a clay pot with rounded bottom. This is confirmed by anthropologists as well as by African observers. Innocent Balagizi Karhagomba (IBK), the co-author of this paper, who is involved in an Improved Stove Project in the Democratic Republic of Congo observed:

Marmite bombée (vessel with a rounded bottom) is the traditional pot made from clay and its technology was widespread in the whole of Africa. It is really adapted to the traditional "three stones stove". It had two advantages: food was enriched in minerals during cooking because of the mineral nature of the pot - the heat was capitalized. Then people were healthy. In West Africa people have maintained this cooking culture, in Congo people rejected it because only of their "unlikely modernity" as they have rejected traditional food. I remember up to 1970's our grandparents have been using these pots with rounded bottom. Just last week I was teaching about traditional technologies that are being overrun, including these pots made from clay and used to keep water, cook food. Really they have been using less wood compared to these aluminium-made saucepans. In fact, these ones are flat in their bottoms.

According to the "Association pour la Promotion des Femmes de Gaoua" (APFG, personal communication by the president Mrs Damien) in

Burkina Faso women in the countryside always use vessels with a round bottom, whereas in towns nowadays pots with a flat bottom are common, because they are more convenient on gas cookers. Henri Labouret [3], one of the first colonial administrators of the Gaoua area mentioned the “hemispheric vessels used for cooking millet, meat, fish, sauces, etc. An anthropologist specialized in the material culture of African peoples declared to be not aware of any flat-bottom cooking vessels in traditional African pottery. According to the Aprovecho Research Centre [4] this tradition should be capitalized: “Respecting that indigenous technologies are evolved from countless years of experimentation and have great worth changes the perspective of scientists who are trying to address the causes of human suffering.”

Flat bottom vessels made from metal seem to have been introduced by the Europeans. There has been some mix-up of traditions, however. Metal pots embracing the traditional rounded shape are nowadays produced locally by craftsmen from scrap corrugated iron and other materials (Fig. 7). Thus, they make use of the quicker heat transfer properties of metal compared to earthenware. However, clay pots may keep heat longer once the pot is taken off the fire. IBK observed that “The pot heats slowly but keeps the cooking heat, even after withdrawal from the fire for about two hours.”



Fig. 1. A Pot with Convex Rounded Bottom, here on a Papillon Solar Cooker (not visible) in Chad. (Photo: Jochen Dessel)



Fig. 2. The Traditional Earthenware Pot Locally Known as Kanoga (in the Mashi Dialect) is Still Used in Some Remote Areas Like Walungu in Kivu, Democratic Republic of Congo. (Photo: IBK, co-author)



Fig. 3. Earthenware (Clay) Pots (with a Round Convex Bottom) on a Market in Bobo-Dioulasso 1960, Burkina Faso. (Photo: Jean Dutertre. Source: <http://pagesperso-orange.fr/jdtr/>)



Fig. 4. If it is Raining or Storming, Cooking is Done inside the House. The Gray haze is due to Smoke Particles. Again Clay Pots with a Rounded Bottom are Used. Village near Gaoua around 2000, Burkina Faso. (Photo: Paul Krämer, corresponding author)



Fig. 5. Metallic Flat-Bottom Pot on an Open Fire in Kivu, The Democratic Republic of Congo. (Photo: Heinz Rothenpieler)



Fig. 6. Flat-Bottom Vessel on a Metallic Stand, Kaduna, Nigeria 2007. (Photo Yahaya Ahmed)

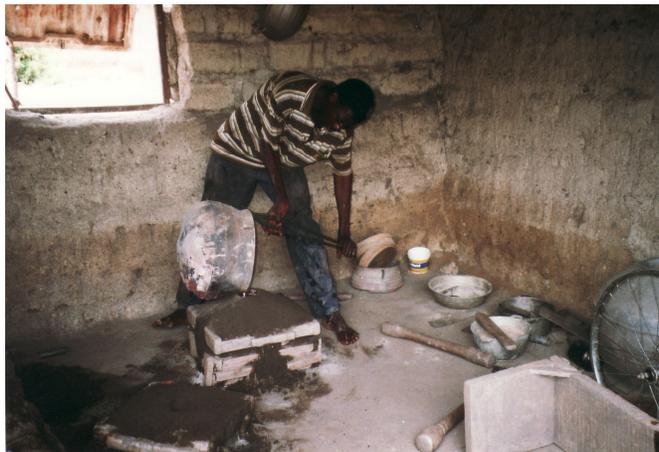


Fig. 7. Local Handicraft Production of Cooking Vessels (Foundry Work) from Scrap Metal, Gaoua, around 2000. (Photo Paul Krämer)

2. Theory

Heat transfer efficiency

Efficiency is a compound notion. WHO [5] defines it like this: “Efficiency is a product of combustion efficiency and heat transfer efficiency”. The geometry of the pot bottom could be an important factor in heat transfer efficiency. Usually authors writing about the efficiency of stoves do not mention the form of the cooking vessels, and the impression is that a flat pot bottom is considered as “normal”. A notable exception is Susan Amrose et al. [6] who specifically refer to the round-bottomed traditional vessels of Darfurian refugees. Another exception is Samuel F. Baldwin [7], who made further distinctions in his book “*Biomass Stoves: Engineering Design, Development and Dissemination*”:

- “Combustion Efficiency: so that as much of the energy stored in the combustible as possible is released as heat.
- Heat Transfer Efficiency: so that as much of the heat generated as possible is actually transferred to the contents of the pot. This includes conductive, convective, and radiative heat transfer processes.
- Control Efficiency: so that only as much heat as is needed to cook the food is generated.
- Pot Efficiency: so that as much of the heat that reaches the contents of the pot as possible remains there to cook the food.
- Cooking Process Efficiency: so that as little energy as possible is used to cause the physico-chemical changes occurring in cooking food.”

While Baldwin [7] mentions pot efficiency, he does not specifically refer to the geometry of the pot and the relation between pot design and heat transfer efficiency. In fact, when assessing the efficiency of a new system both elements – the stove and the pot – have to be considered.

3. Geometric Considerations

Now let us suppose that the form of the vessel is cylindrical and that heat transfer happens mainly via the bottom, and let us consider two cases:

- I. The bottom of the vessel is a plain circle. In this case a surface of πr^2 is available for heat transfer, where r is the radius of the bottom.
- II. The bottom is hemispherical; the convex surface of a hemisphere is $2\pi r^2$.

In the latter case the contact surface between the hot gases and the pot is twice as large as in the first case. Of course, the pot bottom is seldom exactly hemispherical; often it approaches an ellipsoid. If an ellipse is rotated it describes a rotational ellipsoid. If one axis is shorter than the two others, the result may be conceived of as a flattened sphere, and the surface is between that of a circle and that of a hemisphere ($\pi r^2 < \text{bottom} < 2\pi r^2$). If one axis is larger than the two others, the convex surface of the ellipsoid is more than two times larger than a flat circle with the same

radius. This form is approximated by the ancient Greek and Roman storage vessels known as amphoras.

Discussion

These considerations lead to the hypothesis that a greater contact surface between the hot combustion gases and the pot allows a more effective use of fuel wood energy. If two stoves are compared for efficiency using the WBT, the use of different pot types (flat bottom and round bottom) may increase the variability of outcomes of the WBT.

If the sides of the pot – not only the bottom – act as heat exchanger, the heat transfer efficiency is further increased, because “The surface of the heat exchanger should be as large as possible” [4]. Accordingly, the authors recommend pots with a large diameter; however, they do not mention pots with a rounded bottom, and the drawings in their paper show flat-bottom pots only. Likewise, in the instruction for the WBT written by R. Bailis [8] and others there is no mention of the form of the pot bottom, but annex 4 on page 33 shows a drawing depicting a pot with plain bottom. Apparently it is generally assumed that pots with a plain bottom are “normal” and should be used in the WBT. A maximum of heat transfer efficiency may be obtained if a round-bottom vessel is sunk deeply into the casing of the stove up to the upper rim, thus exposing also the pot sides to the scratch of hot gases. Under windy conditions, a further advantage of this design is that it decreases heat losses without requiring a wind shield. Such a design is realized according to Crispin Pemberton-Pigott [9], “in some institutional stoves with pots sunk completely into an all-enclosing insulated body. In such a stove, decreasing the excess air can show a constant or even a decreasing exit temperature and a substantial increase in efficiency”. This supposes that stove and pot are adapted to each other. If stoves and pots are designed, made and marketed together in a set, there should be no problem.

Most authors who publish on the efficiency of new stove designs generally do not distinguish between combustion efficiency and heat transfer efficiency, and omit the contribution of the pot to the latter. This may be one reason for the large variation of published data on the efficiency of stoves.

4. Implications for the Water Boiling Test WBT

What kind of efficiency are we going to measure? Combustion efficiency or heat transfer efficiency, or both? We suggest that heat transfer efficiency depends more on the pot characteristics than on the “stove design” taken in isolation. In fact, stove and pot should be seen as one system, the overall efficiency of which has to be determined. If the components of the system are well adapted to each other, the efficiency of the system as a whole is increased. If only the efficiency of a new stove design is going to be compared to the old one using a Water Boiling Test,

pots of equal heat transfer characteristics should be used in both cases, i.e. either with a flat or a round bottom.

If however the efficiency of the new system taken as a whole – the stove and the pot that comes with it – is going to be tested, the new system should be compared to the old one using the standard procedure; this implies the use of a flat bottom vessel on the side of the old system that is going to be replaced.

5. Conclusion

A number of lessons regarding stove/pot design and test procedures can be drawn from these observations. Round-bottomed cooking vessels have probably higher heat transfer efficiencies if other factors are equal. This should be confirmed by testing. Neglect of the influence of pot form may lead to larger variations in the outcome of the WBT. Round-bottomed vessels correspond to long-standing African traditions. “Hybridization” with science-based stove and pot designs is possible. Maximum energy efficiency presupposes that stoves and pots are adapted to each other. They have to be considered as components of one system. Ideally they should be designed, produced and marketed in combination, at least if industrial production is envisaged. The form of the pot is an important element in efficiency testing using the Water Boiling Test and should always be noted.

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