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A Review of Cooking Systems and Energy Efficiencies

Hesborn Rasugu Ayub[1, 2, *], Willis Jakanyango Ambusso[1], Franklin Muriuki Manene[2], Daudi Mongeri Nyaanga[2]

[1]Department of Energy Engineering, Kenyatta University, Nairobi, Kenya

[2]Department of Industrial and Energy Engineering, Egerton University, Nakuru, Kenya

Email address:

hesborn.rasugu@egerton.ac.ke (H. R. Ayub), manenef@egerton.ac.ke (F. M. Manene), ambusso.willis@ku.ac.ke (W. J. Ambusso),
dmnyaanga@egerton.ac.ke (D. M. Nyaanga)

[*]Corresponding author

Abstract: Accessing affordable and reliable energy services for cooking is important in most developing countries. Improving access to affordable energy reduces effects on human health and environmental influences caused by burning of various biomasses. This review examines the energy resources available in the world and their use in cooking. It also looks at challenges and the ways these energy resources are used as well as possible solutions to such challenges. The major challenges facing the use of available fuels are low efficiencies, high cost, un-sustainability and indoor house pollution that affect many people. The paper has identified that the use of combustion-less cooking, the use of solar for cooking, hydrogen and electrical systems that improve cooking activities and therefore overcome indoor and environmental pollution. Research findings indicate that the pressure-cooking concept improves energy efficiencies in boiling operations. Other energy efficiency improvement techniques in cooking are insulation, containment of escaping steam while cooking and automating the cooking vessel with micro-controllers. The overall efficiencies for electrical induction heating, natural gas, traditional cooking stoves, fuel wood stoves and electrical resistive heating was found to be 90%, 45-60%, 10%, 23-40% and 75% respectively. Induction cooking is both faster and more efficient than gas cooking, while electrical energy systems as a whole were found to be the cleanest, offering ease of control and versatility. The combination of a micro-controller automated insulated pressure cooker and induction cooker can highly improve the cooking efficiency. This is done by cutting a power supply using a relay controlling an induction cooker and therefore preventing the exit of steam. It is therefore identified that zero emission release during cooking will reduce both indoor and environmental pollution significantly.

Keywords: Clean Cooking, Cooking Efficiency, Indoor Pollution, Induction Cooker, Pressure Cooker

1. Introduction

Thermal energy is essential for human life. Cooking is vital for feeding humankind, and boiled water is needed to fight infections [1]. Energy requirement is directly related to the development rate and the growth of population of any country in the world. Energy sources are classified into renewable and non-renewable sources. Biomass is among the kind of most abundant renewable energy resource in developing countries [2]. It is well known that improving access to cheap, clean and reliable modern forms of energy is important, particularly for developing countries, to reduce poverty and promote economic development [1]. Household cooking consumes more energy than any other activity in rural and urban areas of developing countries [3]. Energy required for cooking accounts for approximately 90% of all the domestic energy needs in many countries, and this is about 40% of Kenya's total energy consumption. Biomass sources, such as agricultural wastes and trees from forests, account for 80% of cooking energy in sub-Saharan Africa [4]. Other cooking energy sources are LPG, natural gas, electricity and kerosene. The choice of energy resource for cooking depends on its availability, affordability, ease of control and level of cleanliness. The scope of this paper is thus to evaluate and analyse the energy resources available and their use in cooking. Challenges and the ways energy resources are used as well as solutions to these challenges are also discussed.
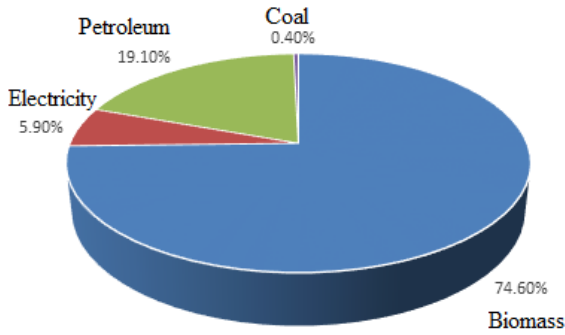
Figure 1. Energy Supply in Kenya [5].

Kenya, like many other African countries, relies heavily on biomass energy (firewood, charcoal and farm residues) mainly for domestic cooking, heating and for operating small‐scale rural industries. Biomass fuels, mainly firewood and charcoal, have remained the main source of energy in Kenya. The energy balance of Kenya shows that biomass use accounts for over 74.6% of energy consumption. Petroleum and electricity accounts for about 19.1% and 5.9% respectively of Kenya's energy consumed while coal accounts for 0.4%. This heavy dependence of biomass as the main energy source contributes to deforestation, while the importation of oil has forced the Nation to spend between 25% and 35% of her foreign earnings [5]. Although it is mainly used in domestic applications, biomass is the most abundant energy resource in Kenya as shown in Figure 1.

In Kenya, less than 10% of rural and urban households use alternative sources of energy other than biomass. About 70% of the people in Kenya reside in rural areas, and it is only about 63.8% of them that have access to electricity, whereby 15% are connected to grid [6]. Due to improved standard of living, many people in the household level attempt to move up the energy ladder to start using safer, more accessible and cleaner sources of energy such as electricity and Liquefied Petroleum Gas (LPG). Kerosene has been used and is still used in rural areas for lighting purposes and its demand increases. Common cooking devices in the rural areas include the traditional three-stone fire, metal charcoal stoves, improved charcoal stoves and kerosene stoves. While fuels for cooking are relatively diverse (firewood, charcoal, kerosene, electricity, cow dung, crop residues, wood processing residues), wood-based biomass fuels stand out as the most important. However, in most rural areas of Kenya, the cooking process is done on three stones arranged triangularly to accommodate the pot, on traditional metal charcoal stoves and on the kerosene stoves as shown in Figure 2.

Figure 2. Three stone cooking, different traditional metal charcoal stoves and a kerosene stove [7, 8].

The use of kerosene is mainly limited to lighting, and quick cooking purposes for approximately one-third of low income houses. Kerosene is commonly used for cooking in urban areas as it facilitates quick cooking. As kerosene is widely used in Kenya for cooking, food sometimes takes the odor of its exhausts, and the smoke discourages many potential users. However, the most significant constraint against the wider use of kerosene is its cost, and the expenditure for special equipment such as kerosene stoves. At present, one litre of kerosene costs about 94 Kenyan shillings and therefore calls for alternative sources of energy (wood, crop residues and cow dung) [9]. The use of Liquid Petroleum Gas (LPG) by low income households is almost negligible. LPG's low uptake is due to the difficulty of accessing gas stations in rural surroundings and the high cost of buying LPG and its expensive accessories. The constant use of biomass in poorly ventilated households has led to indoor pollution and respiratory diseases. Access to safe, clean and reliable energy is a key driver to development for people in Kenya. This has led to newer and improved forms of renewable energy use, especially biomass gasification and biogas production.
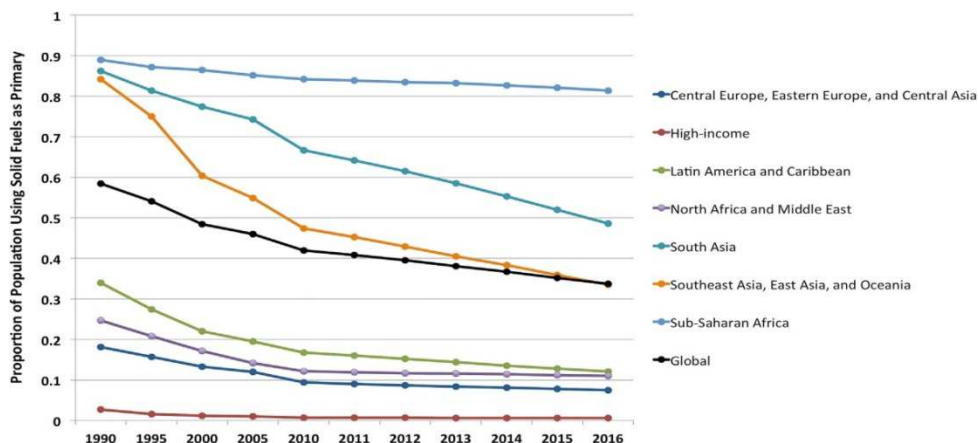

Figure 3. Global and Regional Trends use of Solid fuels as Primary Fuel [11].

As shown in Figure 3, the global solid fuel use is declining with time which is likely caused by indoor pollution, improvement of economic position of people and the Technology advancement. Despite this, world energy demand grows by 8.1% annually as the world population grows. This emphasizes the need to make available energy resources more sustainable [10].

2. Cooking Energy

Figure 4 shows the various ways of defining household cooking energy types. Basing on the typical level of development, cooking energy can be categorized as traditional energy type which comprise of animal dung, agricultural residue and firewood, Intermediate energy types are such as wood pellets, charcoal, briquettes, lignite, coal and kerosene. Modern types of energy are solar, LPG, biogas, natural gas, electricity, gel fuel and plant fuels. On the other hand, primary and secondary energy base on how they are extracted. The energy types obtained from natural resources like firewood, agricultural waste, animal dung, coal, solar and natural gas are known as primary energy source. Secondary energy types are obtained after transformation of primary energy types and example here is when kerosene and LPG are extracted from petroleum crude oil, ethanol are produces from sugar cane, wood pellets and charcoal are obtained from fuel wood, from animal dung and agricultural wastes. Electricity is produced from combustion of fossil fuels and from renewables such as solar, hydro and wind. For the level of consumption, the cooking energy also are categorized into urban and income, where there are rural and urban as well as high and low-income households. Various cookstoves are used by households and are associated with specific energy types. Traditional three stoves, clay pot types and simple ceramic liners, charcoal, gasifier stoves which use solid fuels are more used in rural areas.

Biomass and fossil fuel are used in their raw forms for combustion-based cooking. The other most sources are converted into electricity first, for it to be used for combustion-less cooking. Renewable energy resources are used either directly to cook or indirectly to generate electricity. Solar parabolic cookers like the one shown in Figure 5 are the example of the direct application of solar energy. The sun is the major source of renewable energy since it powers wind, hydro power, biomass, tidal waves and Ocean Thermal Energy Technology (OTEC). Solar cookers include parabolic cookers, box cookers and Scheffler cookers [7].
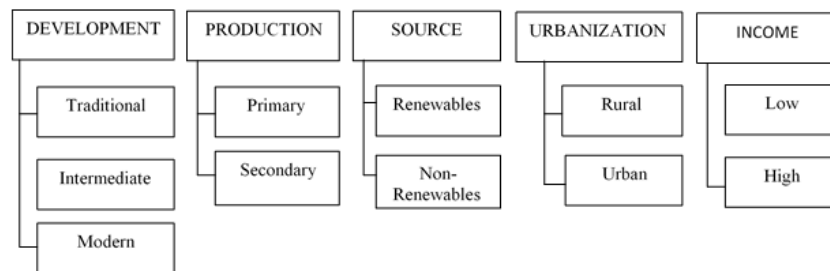

Figure 4. Categories of Household Cooking Energy Types [7, 12].

Figure 5. A Solar parabolic cooker [7, 13].

A small population in rural areas of developing countries uses solar appliances for cooking purposes due to economic difficulties. A solar cooker is an appliance which uses sunlight directly to heat, cook, bake or pasteurize food and drinks. It depends on the sun shine to work and therefore cannot be a stand-alone technology. Solar is a clean source of energy for domestic cooking [7] and institutional cooking [8]. Other researchers have proposed the use of solar induction stoves that are very efficient and option for clean cooking [13]. These new methods of using solar energy directly are more sustainable for cooking. Solar is eco-friendly, clean and cheaper.

3. Cooking Energy and Cleanliness

According to (IEA, 2017) about 2.8 billion people in the world and only 50% of the people in the developing countries have access to clean cooking. The remaining population use biomass and other fossil fuels for cooking. Most of countries especially Sub Sahara Africa, 90% of the households uses wood, charcoal and waste for cooking. Preparing and collecting these fuels require many hours hence affecting women and children. These fuels, when burned, create noxious fumes which affect people as well as premature death.

Most fuels are hydrocarbons which burn to produce CO_2, CO, H_2O, N_2 and traces of NO_2 and SO_2. Carbon dioxide gas is produced by combustion of fossil fuels and biomass which causes ozone layer depletion leading global warming and climate change. About 3 billion people in the world rely on

solid fuels and kerosene for their cooking needs. Exposure to household air pollution from burning these fuels accounts for approximately 3 million premature deaths each year [13-15] and different illnesses such as heart disease, childhood pneumonia, chronic respiratory diseases, eye disease, cardiovascular disease, cancers, burns and cataracts [16-17]. World Health Organisation puts annual premature deaths due to respiratory complications at 7 million annually [18]. This data emphasizes the need to substitute solid fuels with cleaner options. There has thus been a decline in global use of solid fuel and kerosene stoves for daily household energy needs as depicted in Figure 1 above.

Generally, women do most of the cooking in homes and, therefore are disproportionately affected by household air pollution caused by the inefficient burning of solid biomass cooking fuels [18, 19]. Despite several existing efficient and clean cooking energy systems, households generally do not prefer them [18-20]. The reason could be the high initial cost of purchase and reluctance to drop their traditional cooking methods. Charcoal and firewood will remain the main sources of cooking fuel for the next three decades. Corresponding energy policies are needed which set proper priorities and improve the sustainability of the biomass energy sector [21]. The use of efficient cooking stoves can potentially save fuel and reduce the health risks of smoke in the kitchen [22]. The introduction of new biomass technologies such as Improved Cooking Stoves (ICS), despite having a chimney for emptying smoke to outside and avoiding indoor pollution, have a low rate of adoption. The cooking stoves applied in the rural households have been made very simple and their disadvantage is that, they cannot remove biomass smoke during cooking because of their poor design. This cause low thermal efficiency as well as high levels of indoor air [23]. The access to clean cooking fuels and technologies is essential for achieving the Sustainable Development Goals (SDG), particularly in developing countries, to minimize impacts on human health and environment [24].

A shift to clean fuel like LPG and other modern gas stoves will bring significant health and environmental benefits, but only with proper and consistent use. Gas cooking is an important source of airborne fine particulate matter indoor because exposure to cooking-derived fine particulate matter will lead to adverse human health impacts on non-smokers, especially in poorly-ventilated residential homes [25]. Sharma and Balasubramanian recommend carbon-free combustion methods of cooking such as solar, electric and hydrogen cooking [26]. Solar cooking has reliability issues while hydrogen cooking is a new concept. Electric cooking is very clean and combustion free. The major challenges to electrical cooking are the high cost of electrical power and low electrification rates in some developing countries. Table 1 shows three categories of cleanliness for fuel as per their effect in indoor pollution. Biomass and fossil fuels undergo incomplete combustion, releasing particulate matter and emissions that are dangerous to life [27]. Hydrogen undergoes clean combustion to release water, while electricity is combustion-less and clean source of cooking energy.

***Table 1.** Cooking Energy in Cleanness Aspect [25, 27].*

Level of Clean Cooking	Forms	Side Effects
Unclean Cooking	Fuel wood, Cow dung, Coal, Peat, Kerosene, Pellets	Most undergo incomplete combustion thus producing fine black carbon, carbon monoxide, carbon dioxide and chlorofluorocarbons that cause respiratory problems.
Clean cooking	Improved cook stoves and charcoal, biogas, Smokeless biomass gasifier and LPG burners	They undergo complete combustion but produce carbon dioxide and carbon aerosols that cause respiratory problems.
Cleanest cooking	Solar, Electrical and Hydrogen cooking.	Hydrogen undergoes combustion but produces water, no carbon compounds. Other sources don't undergo combustion hence no gases emitted.

Efforts have been made to reduce indoor pollution by replacing kerosene lanterns with solar lighting kits. This is a good move but because lighting accounts for only 10% of indoor pollution, the problem of pollution from cooking has to be solved. WHO recommends cooking by combustion of hydrogen or, if carbon sources are used, the flue gases must be expelled from indoor air [27]. Figure 6 shows that people in South Africa use electricity for cooking in about 80% of urban homes and in 60% of rural areas [3]. This is due to high grid connectivity in South Africa and high level of electrification. This shows that electrical cooking is a reality and can be achieved. Other countries in east, west, central and southern African states use biomass for cooking in about 80% of rural and 60% of urban areas [28]. This is because these countries have the lowest electrification rate, and the number of rural population without electricity is high. The major challenges in most of African countries are the low electrification rates, poor grid connection and low power generation.
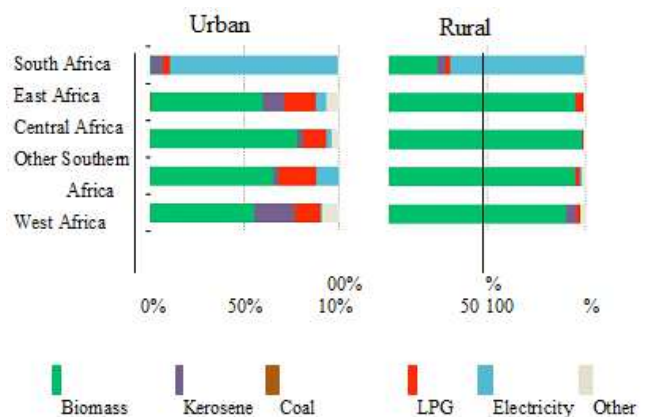

***Figure 6.** Cooking Fuels in Africa [3].*

The annual electrical energy consumption for cooking per household in most developing countries is 3232 kWh which is about 9 kWh per day [3]. With an efficiency improvement on

the vessel side this daily energy use can be supplied by using solar PV [27] and this was supported by Watkins who reported that small food quantities cook well for a family by incorporating insulation to the cookers [29]. The authors recommend that the cooker can be fitted with a gas or battery back-up in non-grid areas to overcome major electrical challenges of cost and availability. Sibiya also proved that solar PV can support an induction cooker which can have a battery back-up for night cooking [30].

4. Cooking System Energy Efficiencies

The efficiency of a cooking system is the ratio of energy output at the cooking vessel to the energy from source at the input side. When the efficiency is low, more energy input is required for the same amount of food to be cooked, compared to a more efficient cooking system. The lower the efficiency the more energy needed. This situation leads to over-exploitation of the available energy resources, and so efficiency improvements are needed for sustainable energy systems. Studies have shown that the efficiencies of cooking systems such as traditional 3-stone fires and improved cook stoves is about 10% and 23-40 respectively [31]. Efficiency for gas cooking is 45-60% and of electrical resistive cooking is about 75%. Efficiency of inductive cooking systems was about 90% [32] and the consumption efficiencies when boiling water were reported as 25%, 46%, 73%, 79%, 66% and 90% for fuel wood, kerosene, gas, electric immersion coil, electric heating coil and electric hot plate, respectively [33]. The electric hot plate with its resistive element is 90% efficient provided that the vessel is larger than the hot plate [32-33]. When they are equal in size, the efficiency reaches about 75%. The induction cooker has a constant efficiency of 90% as it incorporates sensors to determine the size of the cooking vessel and it adjusts the area that it magnetises. Induction cooking is thus widely used for its high efficiency and safety [34]. Although induction cookers heat cook faster than gas [32-35], the major challenges for their adoption in domestic use are initial high cost and the need to replace cooking vessels to ferromagnetic compliant ones.

5. Methods Applied to Improve Cooking Efficiency

Energy can be lost from the cooking systems through various ways. One of these ways is the heat loss to the environment by both the cooking vessel and heat source, through basic heat transfer mechanism of radiation, conversion and conduction resulting to poor heat transmission. Another way is the escape of heated steam in boiling, which will lower the internal energy of the water or food being cooked. Any improvement in cooking efficiency reduces the energy input, thus decreasing demand on energy resources in the world, hence reducing the carbon footprint [36]. The main challenge associated with the present ordinary pressure cookers is the steam release (whistling) hence heat loss to the environment. A well-insulated pressure cooker, made with the ability of not releasing steam during cooking will improve cooking efficiency and as a result save energy.

5.1. Insulation

Insulating materials reduce heat transfer losses from the vessel's or oven's side to the environment. Examples of insulating materials used are air, vacuum in a thermos flask, and rock wool. The fireless cooker is a good example of an almost adiabatic state with almost zero heat loss to the environment. Food can be brought to boiling point and then put in very well-insulated fireless cooker, where it cooks without any extra energy [29]. Solar cooking that utilizes insulation achieves effective energy storage [37]. Employing this insulation technology in an ordinary induction pressure cooker vessel can result in significant energy savings.

5.2. Pressure Cooking

Pressure cooking entails cooking by food in a closed vessel at high temperature with steam at 120°C and therefore a pressure of 1.5 bars will forces steam into the cooking food, hence cooking them faster [38]. There is energy loss from the food when the pressure-valve opens for safety, which escapes with energy [39]. From the review it is concluded that a new approach is needed for the pressure cooker where the cooking is done in a well-insulated pressure cooker powered by an induction cooker without release of steam, with the safety valve in its closed position.

5.3. Automating

The pressure cooker can be automated with the use of a micro-controller which switches an electric cooker off just before steam escapes through the safety valve. Pressure sensors control a relay that switches the heating device on and off, which conserves energy by preventing steam escape. Svosve and Gudukeya have demonstrated an automated stove which prevents the burning of food and powers off when it senses that there is no food to cook [40]. Automation controls energy input resulting in energy economy [41] in smart solar cooking systems [42].

6. Conclusion

This study has successfully explored cooking systems for their cleanliness, efficiencies and sustainability, which was the main aim of the review paper. Electrical cooking was found to be clean, with induction heating giving the fastest and most efficient cooker. Electrical energy for cooking is clean with ease of control and can support other domestic uses. It is necessary to make it more available, affordable, and sourced from renewable energy. The pressure cooker offers energy savings by avoiding steam release, by switching power off and on, using a micro-controller. In this study it proposes research on the possibility of using a system that combines induction cooking technology with an insulated pressure cooker which

is automated with a micro-controller for steam containment. This will prevent most energy losses to the environment, cut indoor pollution and reduce carbon dioxide emissions from combustion. The use of less energy in cooking from electrical renewable resources will help reduce demand for unsustainable energy resources, such as forests residues. This will have a double effect in mitigating climate change, which is one of the Sustainable Development Goals (SDG).

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