J Ther Eng, Vol. 11, No. 4, pp. 949–960, July, 2025

Journal of Thermal Engineering
Web page info: https://jten.yildiz.edu.tr
DOI: 10.14744/thermal.0000955

Research Article

Evaluation of energy efficiencies in a varied steam release domestic pressure cooker

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ARTICLE INFO

Article history
Received: 15 September 2024
Accepted: 18 December 2024

Keywords:
Automated Cooker; Modified Pressure Cooker; Insulated Cooker; Pressure Cooker Efficiency; Zero-Steam Release

ABSTRACT

Despite its efficiency, pressure cooking is characterized by two primary energy losses: direct steam release during whistling and convection heat loss to the surroundings. The study focused on reducing energy losses during pressure cooking. The study experimented to determine the effect of each modification on pressure cooker energy efficiency. Ceramic wool insulation and automation for zero steam release modifications to an ordinary pressure cooker were used interchangeably. The experiment's controls were an ordinary induction-powered pressure cooker and an electric pressure cooker powered with a resistive element. The energy consumption and standby cooking time were measured, and efficiency was calculated. Insulation improved standby cooking time and energy efficiency by 100% and 3.3%, respectively, whereas automation alone increased energy efficiency by 196%. Combining insulation and automation increased energy efficiency by 200%. The insulated automated pressure cooker had an efficiency of 93%, which was close to the electric pressure cooker's 95%; both combined insulation and automation. It was discovered that a combination of insulation and automation eliminates major pressure-cooking losses, including convection and direct steam thermal energy. This reduces the amount of energy consumed while cooking, thereby increasing energy efficiency. This will significantly reduce the cooking carbon footprint, reducing the demand for fuel wood from forests. This will save forests, thereby combating climate change and improving environmental sustainability. The novel aspect of this study is that it investigated each effect of zero-steam release and thermal insulation pressure cooker modification on energy efficiency. This has reduced thermal energy waste and increased energy efficiency, adding to the body of research knowledge in the field of thermal engineering. This study is significant because it will spur efforts to improve energy efficiency in cooking, lowering the carbon footprint.

Cite this article as: Ayub HR, Ambusso WJ, Nyaanga DM. Evaluation of energy efficiencies in a varied steam release domestic pressure cooker. J Ther Eng 2025;11(4):949–960.

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This paper was recommended for publication in revised form by Editor-in-Chief Prof. Ahmet Selim Dalkılıç,

INTRODUCTION

The cooking process of food preparation is energy-dependent. In Sub-Saharan Africa cooking energy accounts for around 70% to 90% of total household energy use. In sub-Saharan Africa, cooking using biomass energy accounts for 80% of total cooking energy [1]. Overreliance on biomass for cooking energy leads to deforestation, which contributes to the three primary global challenges namely; pollution, climate change, and environmental degradation.

Compared to other cooking processes, the boiling method of cooking consumes energy. Simmering is a process after boiling that has continuous steam escape that undergoes phase change and is the basis for high energy use. Pressure cooking overcomes most challenges of boiling by boosting the cooking temperature and pressure. This allows quick cooking with reduced energy usage. Various research studies on the pressure cooker reported pressure cooker temperature and pressure to be in a range of 100°C to 130°C and 130 KPa to 170 KPa, [2-5].

A study on the induction cooker has reported a high efficiency of about 90% This is because the heat is generated on the vessel side, unlike other forms of cooking [6, 7]. This provides the rationale for selecting the induction cooker for powering the modified pressure cooker in this study.

Research has demonstrated that insulation of geothermal fields minimizes steam heat losses to the environment and conserves energy [8, 9]. Insulation reduced energy losses by over 83% and improved efficiency in domestic hot water pipes [10, 11]. The use of palm tree pruning waste to insulate the refrigerated warehouse improved energy efficiency [12].

The integration of insulation into solar-powered cooking brought better heat retention, reduced energy usage, and efficient energy use [13-17]. The use of ceramic liner in water boiling test; retains heat and improves energy consumption resulting in high efficiency [18].

Increased insulation preserved energy and was an efficient cooking technique for overcoming fuel shortage challenges [19]. A literature review on pressure cooker lids emphasized improved design and insulation to bring a reduction in energy use and improved efficiency [20]. Insulated cooking systems were found to have reduced heat loss and particle release while cooking thus improving air quality [21].

An investigation into modern electric cooking systems analyzed and found how higher power and control reduce cooking times and overall energy use compared to traditional fuel-based cooking [22]. In improving the energy efficiency of an induction cooker, it was found that with more power, the food's temperature rises faster, thus taking less time and being more efficient [23].

The cooking of larger amounts of food and water volumes leads to more time spent, higher energy usage, and better energy efficiency [24]. Another study looked into energy in daily food preparation and noted that time and energy increase with food volume [25]. There was more steam production when larger volumes of water were used due to the partial pressure of steam, and water has to be maintained as water volumes rise [26, 27]. As the model of heat and mass transfer research, the more the water, the more steam [2].

Analyzing the current penetration of the Electric Pressure Cooker (EPC), found that families in Tanzania who formerly relied on biomass have started to accept and use EPC, [28]. The use of automatic electric cookers e.g. induction cookers and pressure cookers was found to be fast hence saving time and are more efficient compared to other cook stoves [25, 29]. Analyzing the performance of an automatic cooking system, it was found to have good energy utilization and high efficiency [30]. An automatic pressure cooker was found to be twice as efficient as a slow cooker and uses a quarter energy as a hotplate for the same food cooked [31].

Using insulation in an EPC reduces heat loss and makes it maintain pressure for a long period, reducing energy intake and making it the most efficient cooker [32]. Insulation saves energy by reducing the input energy demand in cooker, [33-35]. Adding insulation to a pressure cooker reduces the energy demand of a pressure cooker [33]. Using a wonder bag in pressure cooking vessels improves standby cooking by reducing heat loss by 30% [36].

The research found that Pressure cooking takes about 20% less energy to cook compared to ordinary cooking [37]. Despite the advantages of high efficiency, faster cooking, and lower energy consumption. Pressure cooking still has some losses owing to steam escaping into the atmosphere and convective heat loss into the surroundings. It was found that after the first whistle, the heat loss by external convection was 10% while direct steam loss through valve regulation was 90% [2]. Trying to mitigate the loss of convection and direct steam loss forms the basis of this research, which will analyze the effect of each modification. From experiments, it was found that the efficiency of cooking 1 kg of dry beans in an ordinary pressure cooker releasing steam and a non-steam-releasing insulated box pressure cooker was 33% and 85%, respectively [38-40].

Efforts to minimize convection losses through box insulation after the first whistling in the pressure cooker tried to minimize the losses but still it was not effective because steam in the first whistle had already leaked out, [38]. The research gap exists in the use of total insulation and zero steam release on pressure-cooking soaked beans. The novelty of this study is to determine the individual effect of pressure cooker modification on energy use and efficiency. These results will advance the literature knowledge on pressure cooker thermal energy loss mitigation in the research field of thermal engineering.

MATERIALS AND METHODS

This section of the study provides a complete and detailed overview of the exact materials used in this study, as well as the specific steps and methodologies used during the investigation. The narrative contains a detailed explanation of the sequential steps involved in carrying out the experimental processes. Furthermore, the section describes the numerous data collection methods used, giving a glimpse of the systematic techniques adopted to analyze relevant information.

Pressure Cooker Modification

The automation procedure involved drilling holes in the pressure cooker lid, inserting sensors through them, and finally sealing steam-tightly with rubber and Aphrodite. The DS18B20 temperature sensor and GPT220 pressure sensor were connected to the Arduino-UNO, X-bee, and power relay. The Arduino-UNO was programmed for data collection, control, and recording onto the laptop.

Insulation involved using a 25 mm thick ceramic wall insulation cut and wrapped around the pressure cooker's height and top lid using a binding wire. 25 mm ceramic wool was selected since it was the best maximum thickness available for boiler insulation. The pressure cooker was ready and set for running experiments.

The experiment included five separate pressure cooker settings, each designed to evaluate different alterations and modifications. The traditional ordinary pressure cooker experienced alterations to insulation and steam release, resulting in four distinct case scenarios. These scenarios offered Insulated Automated (IA), Non-Insulated Non-Automated (NI-NA), Insulated Non-Automated (I-NA), and Non-Insulated Automated (NI-A) choices. The addition of EPC brought the total to five situations. It is crucial to highlight that EPC uses resistive element cooker technology, which differs from the induction cookers used in this study.

The comprehensive study examined five different types of pressure cooker vessels designed for a typical 45-minute pressure cooking session. It was rigorously verified that each vessel needed exactly 15 minutes to cook efficiently under the controlled 120-degree steam temperatures throughout this period. The analysis focused on this particular steam cooking technique, which is similar to how fresh beans are cooked for 15 minutes in food processing companies.

Throughout the research process, the energy consumption of these vessels was carefully monitored and examined from numerous angles. The key goals were to assess how each modification i.e. insulation and zero steam release affected cooking time, overall energy consumption, and energy efficiency. One of the most important comparisons addressed in the study was between the EPC and the I-A.

Material Preparation and Experimental Set-Up

1 kg dry yellow beans were soaked in water overnight and the excess water drained after 12 hours, followed by rinsing and draining all the water. The weight of the soaked 1kg dry beans resulted in 2 kg soaked beans. When cooking an extra 2 kg of water is added, bringing the total mass of the contents in the pot to 4 kg. The material prepared was ready for cooking. The basis for selecting a 6L maximum for a domestic pressure cooker with a 10L capacity. The base had a maximum volume of 7L and at this point, water was spilling through the rubber. The experiment used 1kg dry beans a standard for domestic experiments, which

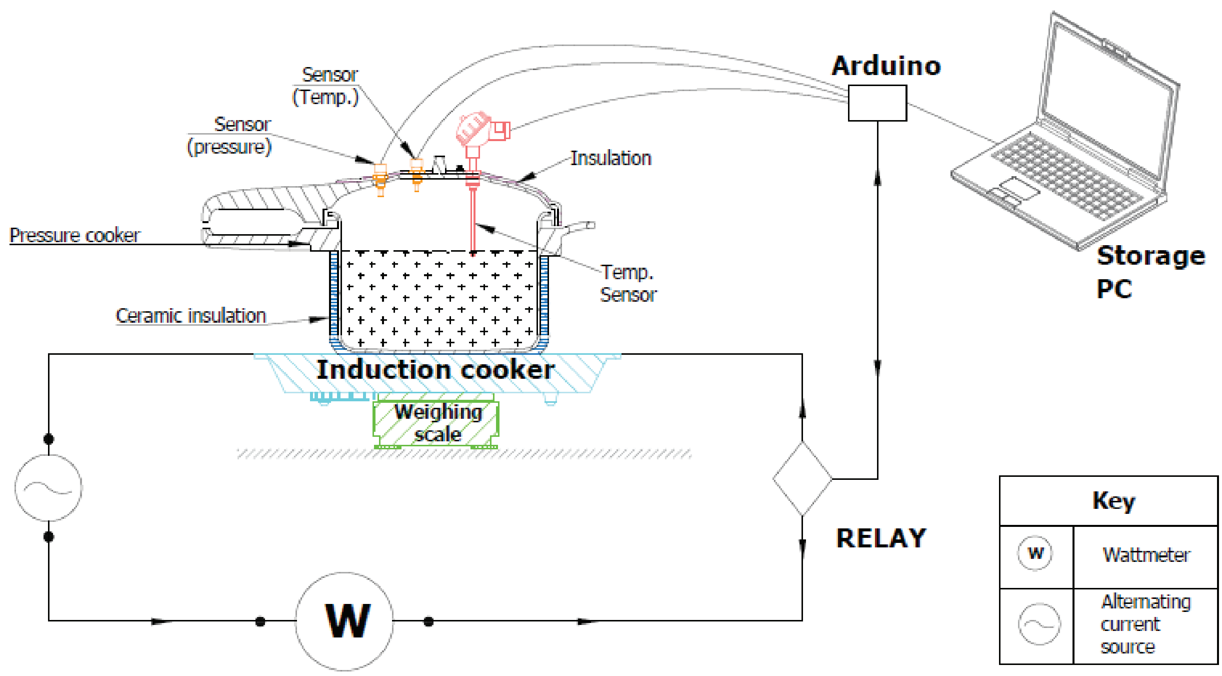

Figure 1. Layout of the experiment for insulated automatic (I-A) case.

when soaked resulted in 2kg, and added 2L water. Where 1L is meant for evaporation and 1L to remain.

The Experimental set-up consisted of; the modified pressure cooker, weighing scale, wattmeter, induction cooker, a relay, data acquisition and storage using wireless transfer, A.C. electrical power, and a 25 mm ceramic wool resistive material, as shown in ƒure 1. The best thermal insulation material available in the market for steam insulation was 25 mm ceramic wool.

Figure 1 comprises an experimental set-up for an I-A pressure cooker with ceramic wool for insulation, an Arduino, and a relay for automation. It shows a cooking setup in which an electrical energy source will power the induction cooker. This will generate heat on the vessel side through induction, causing the contents of the pressure cooker to boil and produce steam. The computer system will capture data and at maximum pressure, the relay will turn off the electricity, allowing standby cooking without the need for external energy.

Experiment Procedure

Procedure 1: The 2 kg soaked beans and 2 kg water were placed into a ceramic wool I-A Pressure cooker as illustrated in the set-up in Figure 1. The pressure cooker was gently closed while all the sensors were in place. The entire mass was recorded, and the induction cooker was adjusted to a power level of 2000 W which had the best possible efficiency. The mass on the weighing scale was recorded, then the induction cooker was powered ON and set to a power level of 2000 W which was the maximum possible for the food to cook. The food was cooked till full pressurization and the relay as seen in Figure 1 put the power at 0.95 bar and there was zero steam release. The heating time, standby cooking time, and amount of energy used were recorded. The energy efficiency was calculated using Equation 1. The same experiment was repeated once and data was recorded and averaged. To get the mass of steam in the pressure cooker efficiency calculation in equation 1, the same experiment was repeated with steam released at the relay power-off point (Maximum pressure possible 0.95 Bar). This was critical since most previous studies overlooked the mass of steam when calculating efficiency. The beans were tested for strength after opening, to reveal if they were fully cooked and if their strength is 1.2 N/M [41].

Figure 2 is NI-A, where the relay unit is controlled by Arduino and will power off the system once maximum pressure has been reached.

Procedure 2: The mass of 4 kg soaked beans and water was repeated but now using a NI-A vessel as in Figure 2. The food was added to the pressure cooker and locked. The induction cooker was powered ON and a selection of 2000 W was selected and food started cooking. At a maximum pressure of 1.35 bar, the relay cut off power and no steam was released. The relay was supposed to power ON at 0.5 bar within the 45 Minute period where the 45 Minute cooking time elapsed before the pressure dropped to 0.5 bar. The vessel was allowed to cool and all time and energy were recorded. The same experiment was repeated and data was recorded and averaged. The experiment was repeated twice while allowing steam to escape to record the mass of steam produced. The beans were tested for strength after opening, and the energy efficiency was calculated with Equation 1.

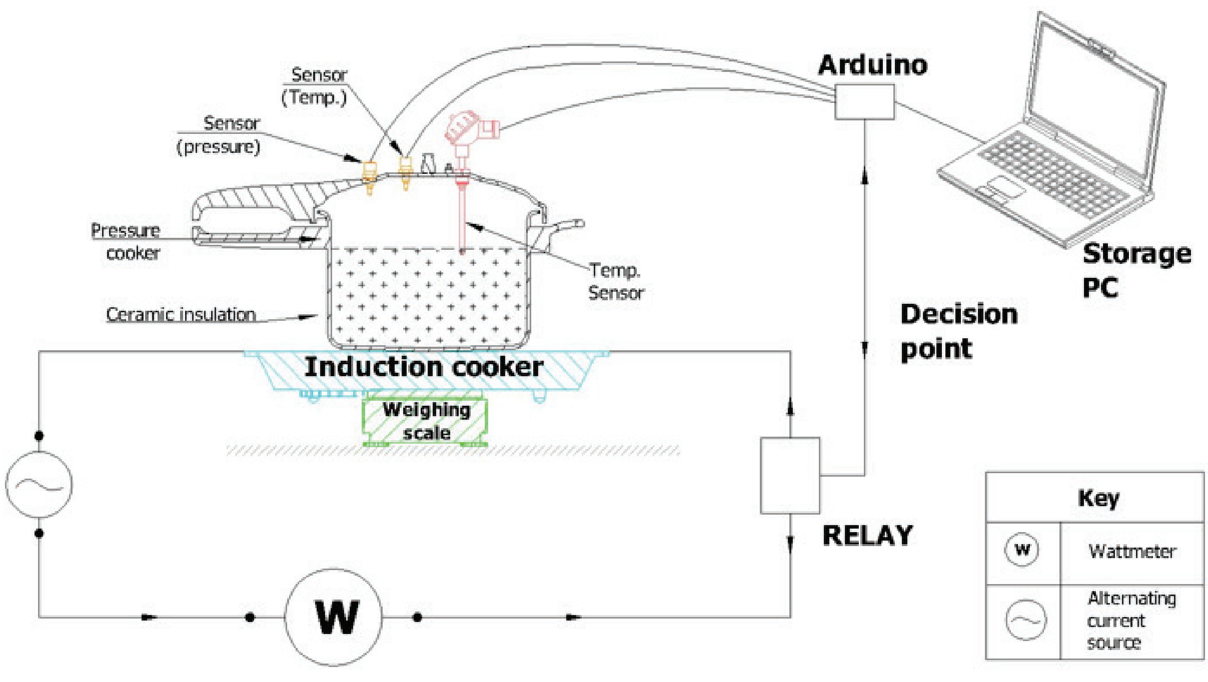

Figure 2. Non-insulated and non-automatic (NI-NA) experimental set-up.

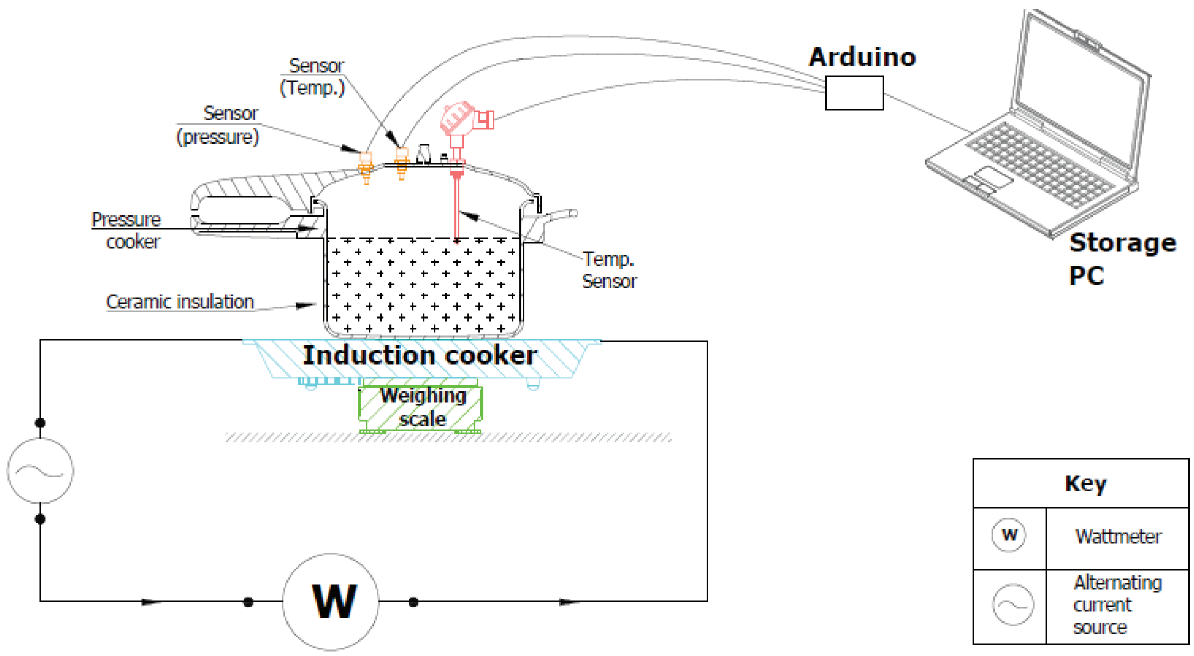

Figure 3. Showing non-insulated automated (NI-A) modified pressure cooker set-up.

Procedure 3: The same set-up used was in Figure 3 where there was no relay for automation. A mass of beans and water mixture weighing 4 Kg was added to an NI-NA vessel and lid locked with data acquisition instruments in place. The mass recorded and induction cooker powered ON at a maximum power of 2000W. The meal was cooked, and at a maximum pressure of 1.35 bar, the vessel released steam before coming to a halt when the pressure reached 1 bar. The vessel pressure fluctuated continuously between 1.35 bar and 1 bar. For the remaining cooking time of 45 minutes, steam was expelled at 1.35 pressure, then stopped at 1 bar before restarting again at 1.35 bar. The time taken to heat and, the mass of steam lost were recorded. The same experiment was repeated and the data was recorded and averaged. The beans strengthened after opening the vessel to see if they were well cooked. The cooking energy efficiency was calculated with Equation 2.

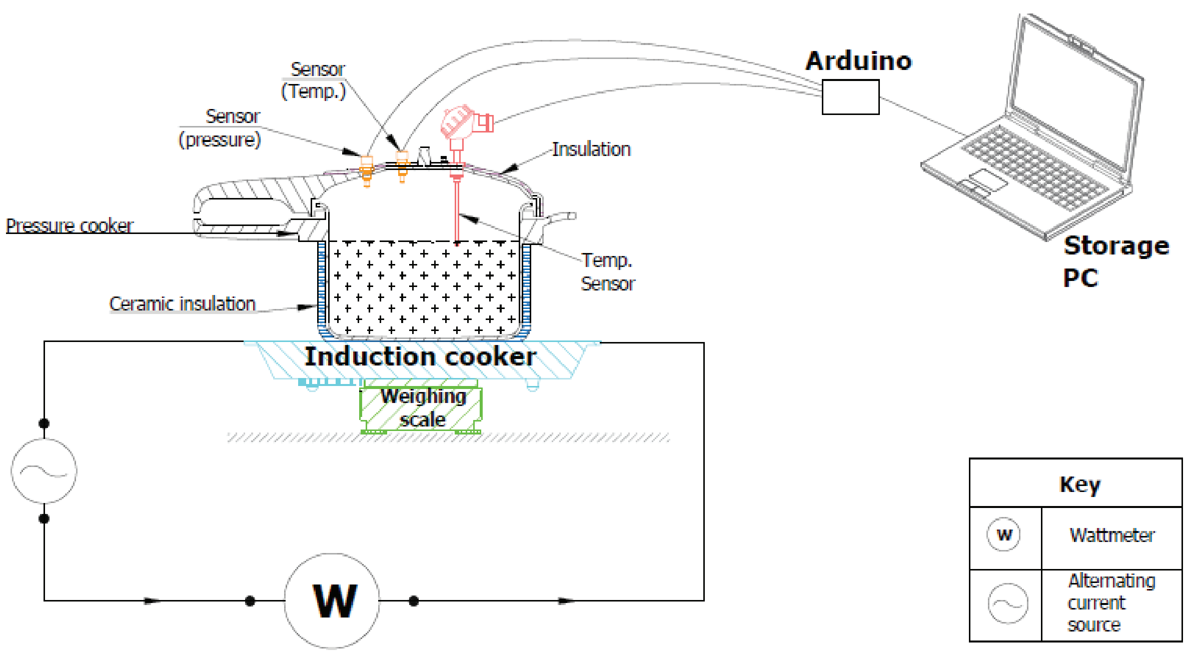

Figure 4. Showing insulated non-automated (I-NA) modified pressure cooker set-up.

Procedure 4: The set-up used was as in Figure 4 where the vessel is an I-NA pressure cooker. The mass of beans and water was weighed and added to the vessel and it was locked with sensors in place. The induction cooker was powered ON and a power of 2000W was selected. The food was cooked to full pressure where steam was released continuously for the remaining time of 45 Minutes cooking period as procedure 3 pressure oscillating between 1.35 bar maximum and 1 bar minimum. The experiment was repeated and the averages of the two experiments thus heating time, energy used, and mass of steam released were recorded. The beans were evaluated for strength, and energy efficiency was calculated with Equation 2.

Procedure 5: A 6L EPC from Power Hive was used and the setup was almost similar to in Figure 1. The only difference is that the EPC has its own insulation and automation circuit for power cut-off by relay at its set-up maximum limit pressure. No extra modification on instrumentation was done on it. Only the energy meter and the mass balance were incorporated into the system. The 4 Kg mass of beans and water was added to the EPC and tightly locked. The EPC was powered ON and it cooked well for 45 minutes, the experiment was repeated and the averages of heating time, and standby cooking time were recorded. The same experiment was repeated twice and at the stop of heating the steam was released and the mass of steam was recorded. The beans were tested for strength after opening to confirm they were well cooked.

Experimental Analysis

To ascertain how insulation affects time, energy consumption, and energy efficiency. The I-A was compared against the NI-A and the I-NA was compared against NI-NA. This grouping of the NA separately and automated separately, it was possible to observe the effect of insulation and NI.

Investigation on how automation affects pressure cooker time, energy usage, and energy efficiency. The NI-NA was compared with NI-A while the I-NA was compared against I-A. This demonstrated the effect of automation, which is zero steam release from pressure cookers.

An EPC was compared to an I-A pressure cooker. This compared the EPC with the insulated automated one cooking the same 4kg soaked beans and water. The EPC never underwent any modification, and the efficiency was calculated with Equation 1.

Pressure Cooker Efficiency Calculation

The efficiencies of five pressure cooker containers that cooked soaked beans and water mixture were computed using Equation 1.

$$\eta = \frac{\{(Mw-Ms)Cpw\Delta T1+(MsHvap)+(MsCps\Delta T2)\}}{(Energy\ consumed * 3600)} x\ 100 \quad (1)$$

$$\eta = \frac{\{(Mw-Ms)Cpw\Delta T1\}}{(Energy\ consumed * 3600)} x\ 100 \quad (2)$$

where; *Mw = Mass of water, Ms = Mass of Steam, Cpw = Specific Heat capacity of water = 4.187kJ/kg K, ΔT1 = Temperature of Water, (117-23) = 94K, Ms = Mass of Steam, Hvap= Heat of vapourisation of Steam = 2257kJ/kg, Cps = Specific Heat capacity of Steam = 1.996kJ/kg K, ΔT2 Temperature change of Steam, (117-93) = 24K* and *Energy consumed in kWh. An assumption on the specific heat capacity of water was used as the specific heat of beans.*

RESULTS AND DISCUSSION

Cooking results of the prepared 2kg soaked beans and 2 kg water in five various pressure cookers are analyzed in this section. A keen comparison of energy usage and efficiency is made.

Effect of Pressure Cooker Modifications on Energy Consumption to Time

From Figure 5, all five pressure cookers were cooked for exactly 45 minutes. Both the NI-NA and I-NA systems received the same energy throughout the 45 minutes and continuously released steam as shown by their purple line overlapping on the black line.

The three pressure cookers; I-A, NI-A, and EPC were only powered till the steam phase, and no extra energy to support steam release was allowed.

The insulated containers boil faster (13.1 minutes) and use less energy (0.43 kWh). The NI pots cook for 13.5 minutes and consume 0.43 kWh. Figure 3 demonstrates that the

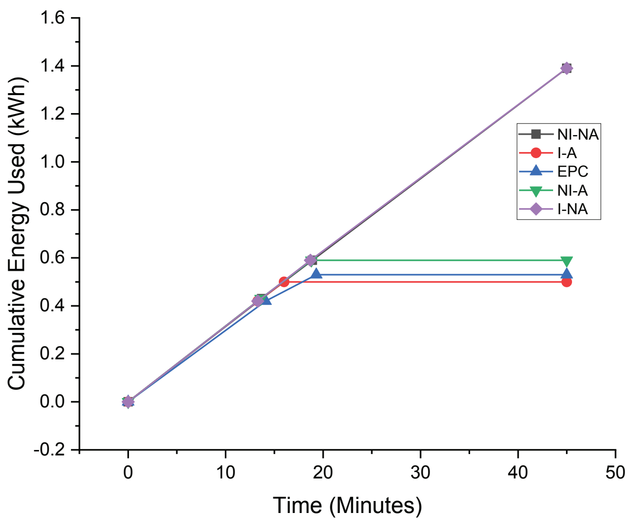

Figure 5. Cumulative energy consumed against time.

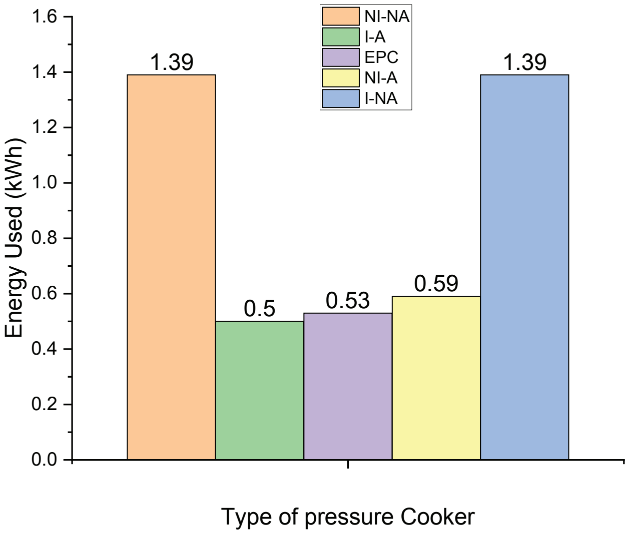

Figure 6. Energy consumed per pressure cooker.

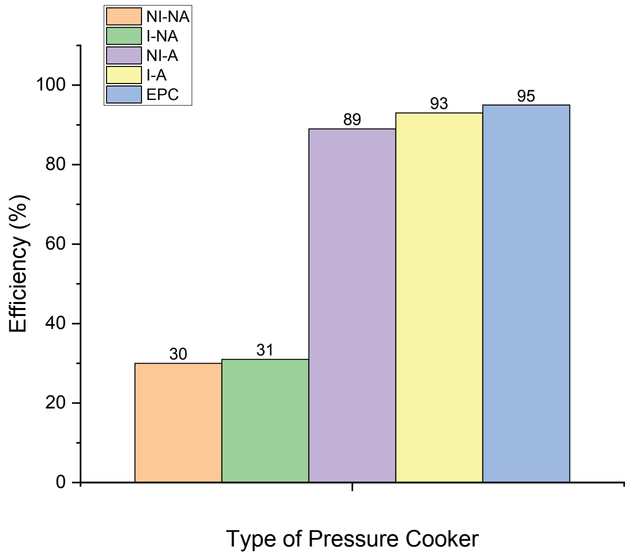

Figure 7. Efficiency per pressure cooker.

automated insulated vessel requires less time and energy to heat (0.42 kWh and 13.1 minutes, respectively) than its NI counterpart (0.43 kWh and 13.5 minutes). The observed small energy consumption disparity can be ascribed to the effect of insulation. Where the lack of insulation lagging in NI vessels creates a thermal temperature difference between the vessel wall and the surrounding environment. This leads to more heat loss to the environment by convection than in insulated cases and restoring the lost heat results in more energy usage as found by [8, 11].

Figure 6 is a bar graph showing the total cumulative energies of each vessel used to cook. Comparing all the five pressure cookers, the insulated automated used 6%, 18%, and 178% less energy when compared to EPC, NI-A, I-NA, and NI-A respectively. This shows that zero-steam had the highest losses than convectional heat loss and it agrees with [2]. The I-NA and NI-NA had the same energy values at 1.39 kWh because the two systems lack the automatic relay power control which cuts power at maximum pressure. This makes the energy source keep supplying energy continuously for 45 minutes of cooking and steam is vented, hence the same energy.

Effect of Pressure Cooker Modifications on Energy Efficiency

The automation effect on the energy efficiency of various pressure cookers is shown in Figure 5.

The NA vessels in Figure 7 had the lowest efficiencies of 31% and 30%, insulated and NI respectively. In contrast, automated ones had the maximum efficiency of 93% and 89% for insulated and NI, respectively. Insulated pressure vessels outperformed their NI counterparts in terms of efficiency. This was attributed to heat loss prevention to the environment by lagging action using ceramic wool insulation material [34, 36]. This contributes greatly to standby cooking activity in automated scenarios because it slows the pace of steam cooling to the environment, giving the meal adequate time to cook without external heat input.

Overall, insulation increases energy efficiency by 1-4%. The insulation findings in this research agree with the insulation findings of geothermal fields [8, 9] and insulated solar electric cooker, [13, 14]. Insulation in the pressure cooker saved energy and reduced energy input which is in agreement with the other researcher's findings [32-36].

Effect of Pressure Cooker Modifications on Energy Utilization

Figure 4 shows that in the case of NI containers, both automated and NA used 0.59 kWh for 18.5 minutes and 1.39 kWh for 45 minutes. For the insulated, the automatic consumed 0.50 kWh in 16 minutes and 1.39 kWh in 45 minutes. The automatic cookers used 160%–170% less energy in both scenarios and it agrees with [28, 30]. This is because automation prevents steam from escaping, maintaining it within the vessel. When steam rejects the heat from the gas-to-liquid phase transition, it becomes an energy source. This heat is responsible for standby cooking without an external heat source.

Figure 8 shows that the energy used for heating is nearly identical in all four scenarios. The EPC and I-A consumed 0.42 kWh, whereas the NI-A and NI-NA used 0.43 kWh each. The NI consumed 2.4% more energy during the heating phase than the insulated. This is due to heat loss to the environment via convection because the NI did not have ceramic wool insulation lagging agreed with [18].

Figure 8 shows that both NI-A and NI-NA systems use the same energy during the heating and steam building-up stages. The observed discrepancy can be attributed to the steam release caused by the purple energy in the NA cases, which is 0.8kWh.

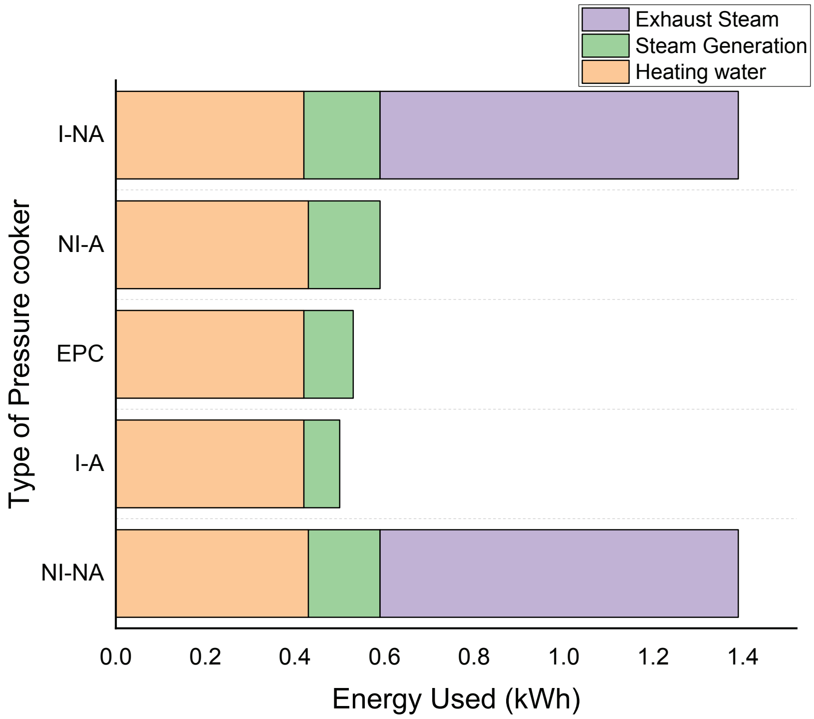

Figure 8. Energy usage analysis.

NA systems waste 160% more energy in the form of steam that could be used to prepare another whole-soaked bean meal, resulting in an excess of 0.8kwh > 0.59 kWh. The steam escaping during pressure cooking is superfluous and completely wasteful. This is the issue that this study attempted to address, and it was successfully proven to be wasteful. The energy consumed in this experiment was consistent with the cooking beans findings in a pressure cooker [2, 39].

According to Figure 7, in NI scenarios, both automated and NA have an energy efficiency of 89% and 30%, respectively, representing a 196% improvement in energy efficiency. Insulated cases exhibit an energy efficiency of 31% for NA and 93% for automated systems. This is a 200% boost in efficiency as a result of zero-steam release which agrees with [2]. As a result, automation that leads to zero steam release improves energy efficiency by 196% to 200%. The zero-steam release in the I-A, NI-A, and EPC models improved energy efficiency. The steam in the vessel releases phase-change energy from steam to water, allowing for standby cooking without additional energy. This saves energy that would otherwise be lost, reducing the energy needed for pressure cooking. The efficiency of an ordinary pressure cooker releasing steam was found to be 30% while the insulated non-steam release was found to be 93% which is in agreement with [39].

Adding insulation to automation delays the rate of cooling which elongates the phase change cooling time. This gives steam more time to interact with the cooking grains. This brings effective heat transfer and energy utilization, achieving cooking with the least energy possible. This re-use of steam agrees with the utilization of escaping steam proposal in a modified pressure cooker [5, 27].

Effect of Pressure Cooker Modifications on Pressure Levels

Pressure cooking's key feature is cooking under pressure, which forces steam heat into the grains. It is aided by the existing thermal gradient between the cooking grains and the outside hot water mixed with steam; it cooks faster. The pressure rising and falling is seen in Figure 9.

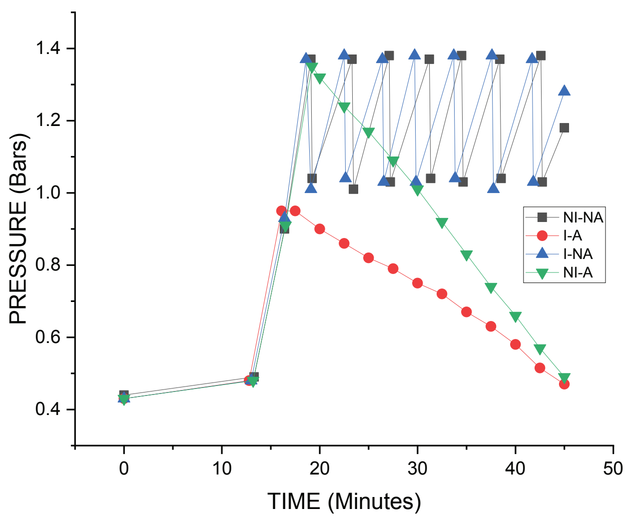

Figure 9. Pressure variation against time during pressure cooking.

As seen in Figure 9, all pressure cooker pressures were measured except EPC, which was not modified to allow pressure capturing. The pressure in the four pressure cooker scenarios starts at 0.43 bars and rises uniformly to 0.5 bars in about 13 minutes at the start of vaporization. From 13 minutes all the vessels rise in pressure uniformly to 0.95 bar, where the I-A pressure cooker stops rising as others proceed. The pressure stop in I-A is due to the cut-off of the supply power by the relay controlled by the Arduino-UNO command. The I-A pressure vessel continues to cool for the remaining 45 minutes in standby cooking mode through the condensing steam energy.

The NI-A continues to rise in pressure due to 1.35, which is the maximum set pressure, and the relay cuts off power thus avoiding any pressure relief through venting steam. This steam cools continuously for the remaining 45-minute cooking time set under standby cooking mode. Although the pressure of the relay was supposed to switch power back at 0.95 bar, this was avoided because the steam present had been assessed to be able to cool at the end of the 45-minute cooking period.

The I-NA and NI-NA pressure rose to 1.35 bar where it was ejected through the non-altered safety valve and pressure decreased from 1.35 bar to 1 bar and stopped. The pressure for the two increased again from 1 bar to 1.35 bar in about 4 minutes and to achieve safety, steam venting occurred and pressure dropped to 1 bar. The trend of rise and fall continued for about 4 minutes in the entirety of the whole cooking time. This resulted in a decrease in the mass of food which was recorded. The I-NA was slightly ahead of NI-NA by about 1 minute and gave slightly more steam by 1.15%, this was due to the presence of insulation that brought faster heating and slightly more steam than the insulated counterpart.

The I-A despite halfway build-up pressure was able to achieve the same cooling time as the NI-A. The difference came as a result of insulation, where insulation doubled the standby-cooking time thereby minimizing energy input and improving energy efficiency and it agrees with [13, 14, 35, 36].

AN ANALYSIS CONTRASTING THE EPC WITH THE I-A

The EPC used 37.5% more energy than the I-A in-building steam phase. But overall, the I-A pressure cooker used 6% less energy than the EPC. These results indicate that this study's modified I-A pressure vessel has better energy utilization despite both being insulated. The induction element in the insulated automated generates heat on the cooking vessel side and has minimal heat loss during heat transfer. The resistive element generates heat slowly and on the element side, again it incurs heat transfer losses to the vessel side. The slowness of resistive elements gives room to environmental heat loss, in addition to heat transfer losses thus resulting in more energy consumption. This result agrees with the induction cooker experiments of other researchers [6, 7, 17, 42].

The EPC has 95% efficiency, while the I-A pressure cooker has 93% despite insulated automation using less energy. This discrepancy is attributed to challenges in achieving total insulation resulting in a 2.1% lower efficiency. Overall, the results of the I-A were in harmony with the results of the EPC cooker. The uncertainty analysis done using root mean square error between the EPC and the I-A was found to be 0.03 and 2 for energy consumption and efficiency, respectively. These errors were below 5, which shows that the two vessels are agreeing in their performance.

Summary Table

Table 1 shows that NI vessels required 3.05% longer heating time than insulated vessels. This is because heat is lost to the environment in NI situations, and heating takes longer to replace the lost heat, requiring more time. The EPC took 7.6% longer to heat than the I-A. This is because the EPC cooker's resistive element takes longer to heat up and needs around a minute before the heat can be transferred to the vessel side. In contrast, an induction element starts up instantaneously and produces heat on the vessel side with very little loss of heat transfer as found by [6, 23, 42].

According to summary Table 1, EPC and NI-A systems take 23.3% and 66.6% longer to steam than insulated automated systems, respectively. The reason is that the I-A is heated to obtain the steam that will condense within 45 minutes of cooking which was in agreement with other researchers' work [39, 40]. This prevents the formation of unnecessary steam that will be wasted. The two NA created steam during the cooking duration, which was 1050% and

Table 1. A summary table of the pressure cooker recorded data

Pressure Cooker Type	Time to boil (M)	Time to steam (M)	Total heat time (M)	Standby cooking time (M)	The mass of steam released (Kg)
1. NI-NA	13.5	31.5	45.0	0.0	0.1305
2. I-NA	13.1	31.9	45.0	0.0	0.132
3. NI-A	13.5	5.0	18.5	27.3	0.0
4. I-A	13.1	3.0	16.1	29.3	0.0
5. EPC	14.5	3.7	18.2	27.1	0.0

1063% higher for insulated and NI, respectively which is wasted.

The total heat time in both NA pressure cookers is 179.5% longer than in the I-A pressure cooker; in NI-A and EPC, it is 14.9% and 12.4% longer, respectively. Due to NA, heating takes longer and wastes a lot of energy. The stand-by cooking time is zero in both the NA pressure cookers while the I-A is the highest at 29.3 minutes which is 7.5% and 6.8% more than for NI-A and EPC vessels respectively. Insulation improves standby cooking by delaying the rate of condensation thus giving grains more time to absorb heat and cook.

The steam released where the NA released most steam. The NI-NA wasted 1.305 Kg while the I-NA released 1.3kg of steam. The NI-A released 0.21 kg of steam. The EPC and the I-A released zero steam. The release of steam into the atmosphere is a waste of energy that this research has tackled through the automation of the pressure cooker so as not to allow any steam to escape.

CONCLUSION

The novelty of this research was to determine the effect of each pressure cooker modification on energy efficiency. It involved cooking soaked beans in a pressure cooker with interchangeable modifications of insulation and zero-steam release on an ordinary pressure cooker. It had controls to compare energy usage and calculate energy efficiency. After carefully assessing the five various pressure cooker scenario cases, it can be inferred that:

- Insulation improves standby cooking time and energy efficiency by 100% and 3.3% respectively.
- Automation alone for non-steam release improves energy efficiency by 196% combining insulation and automation it improves energy efficiency by 200%.

This combination has brought about efficient energy utilization in pressure cooking as seen in this work. The insulated automated pressure cooker had an efficiency of 93%, which was close to the electric pressure cooker's 95%; both combined insulation and automation. This study's novelty identified the individual contribution of insulation and zero-steam release in combating pressure cooker energy losses. Which is very informative to the world of research in thermal engineering and core to energy loss prevention. Applying these results to use will lead to cooking the same food with less energy. It will lead to less fuel wood demand which will slow down the rate at which trees are being cut for cooking fuel. This study was limited to the effect of the modifications on domestic pressure cookers. Future research is highly recommended in the Optimisation and modeling of the cooking energy in domestic and institutional pressure cookers under the modifications of insulation and zero steam release.

ORIGINALITY OF THE ARTICLE

This research is part of PhD work in Renewable Energy Engineering at Kenyatta University, Kenya.

ACKNOWLEDGMENT

The DAAD In-Country Scholarship Reference number 91670866 supported this study and research, which the authors would like to recognize.

AUTHORSHIP CONTRIBUTIONS

Hesborn Ayub is he PhD candidate, Prof. Willis Ambusso and Prof. Daudi Nyaanga are supervisors who looked for funding, supervised the research and helped in reviewing and editing this research article.

CONFLICT OF INTEREST

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

NOMENCLATURE

C_p Specific heat, kJ / kg K
T Temperature

Greek symbols
η Efficiency, Percentage %
Δ Change

Subscripts
w Refers to water
s Refers to steam

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